UNITED STATES OF AMERICA

Before the

FEDERAL POWER COMMISSION

APPLICATION OF
ALCAN PIPELINE COMPANY
AT DOCKET NO. CP76-
FOR
CERTIFICATE OF PUBLIC CONVENIENCE
AND NECESSITY

EXHIBIT Z2
SUPPLEMENTARY DETAILS

PURSUANT TO SECTION 7 (c) OF THE
NATURAL GAS ACT

AUTHORIZING THE TRANSPORTATION
OF NATURAL GAS IN INTERSTATE
COMMERCE

Alcan Pipeline Company
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SUPPLEMENTARY DETAILS

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STRIP MAPS

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SYSTEM DESIGN INDEX

FRANKLIN BLUFFS CAMP
COMPRESSOR #1
HAPPY VALLEY CAMP
COMPRESSOR #2
TOOLIK CAMP
GALBRAITH CAMP
ATIGUN CAMP
CHANDALAR CAMP
DIETRICH CAMP
COLDFOOT CAMP
PROSPECT CAMP
OLD MAN CAMP
COMPRESSOR #7
FIVE MILE CAMP
FORT WAINWRIGHT CAMP
BIG DELTA CAMP
NORTHWAY CAMP
COMPRESSOR #14
YUKON
ALASKA
GULF INTERSTATE ENGINEERING COMPANY
Alcan Pipeline Company
42" GAS LINE ROUTE
M P 0.00 to M P 731.4
DRWN
SCALE 1:25 MILES
DATE
APPRVD.
DRAW. NO. APC-R9-1
REV.NO.

Geotechnical Description	COASTAL PLAIN THIN BEDDED TO MASSIVE, ORGANIC-RICH, SILTY SAND AND SANDY SILT OVERLYING SANDY GRAVEL AND GRAVELLY SAND.	ALLUVIAL TERRACES AND FLOODPLAIN. COARSE SANDY GRAVEL AND SAND WITH MINOR AMOUNTS OF SILT. GRAVEL CLASTS SUB-ROUNDED TO ROUNDED. GENERALLY POORLY STRATIFIED WITH LOCAL BEDS AND LENSES OF SAND COMMONLY MANTLED BY ½ TO 6 FEET OF ORGANIC RICH SILTY SAND AND SILT.
Terrain	FLAT TERRAIN SURROUNDED BY SUBDUED SCARPS (FORMER SHORELINES). TUNDRA VEGETATION. PERMAFROST GENERALLY PRESENT WITHIN 2 FEET OF THE SURFACE AND GENERALLY EXTREMELY ICE RICH. ICE WEDGES COMMON AND CLOSED SYSTEM PINGOS PRESENT LOCALLY.	SERIES OF FLAT TOPPED TERRACES SEPARATED FROM ONE ANOTHER AND FROM THE FLOODPLAIN BY SMALL SCARPS. TUNDRA VEGETATION PERMAFROST GENERALLY PRESENT WITHIN TWO FEET OF THE SURFACE. ICE COATS PARTICLES AND FILLS VOIDS IN GRAVEL. ICE WEDGES AND MASSES PRESENT LOCALLY, ESPECIALLY WELL DEVELOPED IN TERRACES AWAY FROM THE ACTIVE FLOODPLAIN.

LEGEND
- ALYESKA/STATE HAUL ROAD
- ALYESKA OIL PIPELINE
- ALCAN PIPELINE
- GAS FUEL LINE
- BORROW PIT

ALCAN PIPELINE COMPANY
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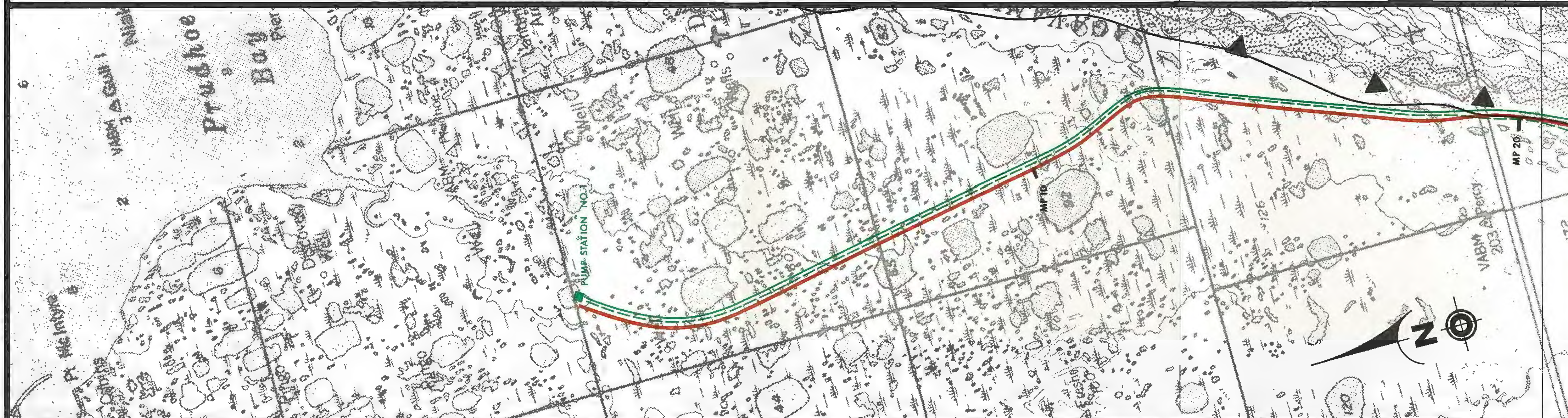
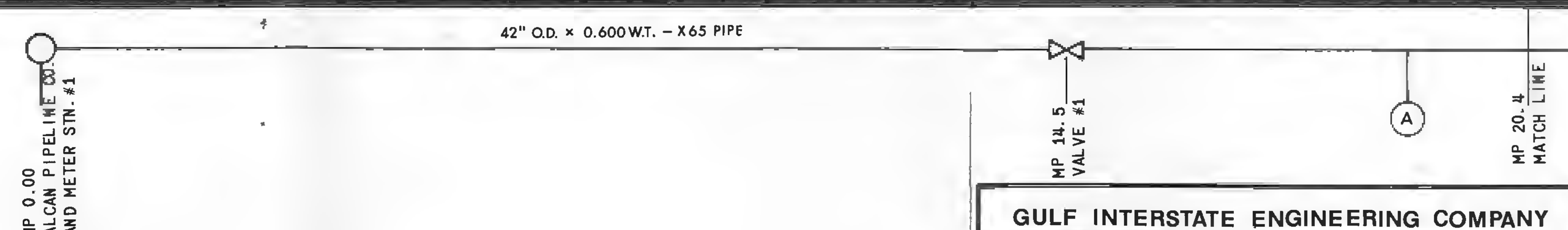


Pipeline Schematic



Notes

A. MP 19.0 ROAD CROSSING R
42"O.D. x 0.675 W.T. –X65 PIPE

GULF INTERSTATE ENGINEERING COMPANY

Alcan Pipeline Company

42" GAS LINE ROUTE
MP 00.0 TO MP 20.4

DRWN.	SCALE 1" = 2 Miles	DATE June 20/76
APPRVD.	DRWG. NO. APC-B9-1	REV. NO.

Geotechnical Description

ALLUVIAL TERRACES AND FLOODPLAIN COARSE, SANDY GRAVEL AND SAND WITH MINOR AMOUNTS OF SILT. GRAVEL CLASTS SUB-ROUNDED TO ROUNDED. GENERALLY POORLY STRATIFIED WITH LOCAL BEDS AND LENSES OF SAND. COMMONLY MANTLED BY ½ TO 6 FEET OF ORGANIC-RICH SILTY SAND AND SILT. ALLUVIAL DEPOSITS INCREASE IN DEPTH TO NORTH WITHIN FLOODPLAIN. BEDROCK CONSISTING OF CRETACEOUS SEDIMENT (SANDSTONE, SHALE AND CONGLOMERATES) GENERALLY WITHIN 20 TO 40 FEET OF SURFACE.

Terrain

SERIES OF FLAT-TOPPED TERRACES SEPARATED FROM ONE ANOTHER AND FROM THE ACTIVE FLOOD PLAIN BY SMALL SCARPS. TUNDRA VEGETATION; LOCALLY ON UPPER REACHES OF SAGAVANIRKTOK RIVER, LOW BRUSH. PERMAFROST GENERALLY PRESENT WITHIN 2 FEET OF THE SURFACE. ICE COATS PARTICLES AND FILLS VOIDS IN GRAVEL. ICE WEDGES PRESENT LOCALLY, ESPECIALLY WELL DEVELOPED IN TERRACES AWAY FROM ACTIVE FLOOD PLAIN.

LEGEND

- ALYESKA/STATE HAUL ROAD
- ALYESKA OIL PIPELINE
- ALCAN PIPELINE
- GAS FUEL LINE
- BORROW PIT

ALCAN PIPELINE COMPANY
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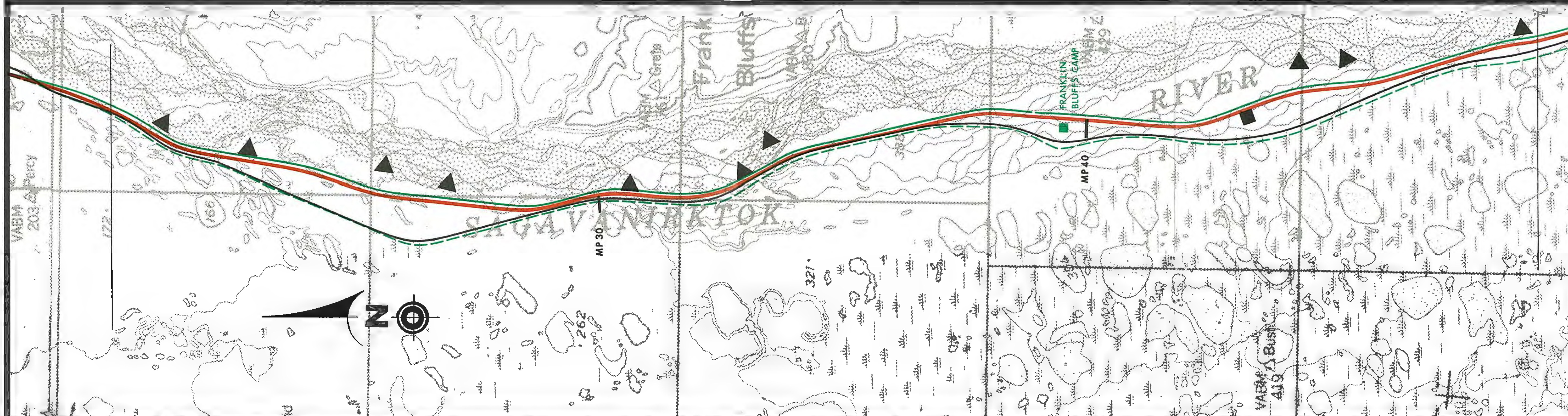

Pipeline Schematic

42" O.D. × 0.600 W.T. -X65 PIPE

MP 20.4 MATCH LINE
MP 29.0 VALVE #2
MP 39.3 FRANKLIN BLUFFS CAMP
MP 43.5 COMPRESSOR STN. #1
MP 49.5 MATCH LINE

Notes

GULF INTERSTATE ENGINEERING COMPANY

Alcan Pipeline Company

42" GAS LINE ROUTE
MP 20.4 TO MP 49.5

DRWN.	SCALE 1" = 2 Miles	DATE June 20/76
APPRVD.	DRWG. NO. APC-B9-2	REV. NO.

Geotechnical Description

ALLUVIAL TERRACE AND FLOODPLAIN COARSE, SANDY GRAVEL AND SAND WITH MINOR AMOUNTS OF SILT. GRAVEL CLASTS SUB-ROUNDED TO ROUNDED. GENERALLY POORLY STRATIFIED WITH LOCAL BEDS AND LENSES OF SAND. COMMONLY MANTLED BY ½ TO 3 FEET OF ORGANIC-RICH SILTY SAND. ALONG THE SAGAVANIRKTOK RIVER, GRAVEL BECOMES PROGRESSIVELY COARSER UPSTREAM. OLDER TERRACES COMMONLY MANTLED BY 2 TO 10 FEET OF ORGANIC-RICH SILTY SAND. BEDROCK LOCALLY CAN BE CLOSE TO THE SURFACE. CONSISTS OF CRETACEOUS SEDIMENTS.

Terrain

SERIES OF FLAT-TOPPED TERRACES SEPARATED FROM ONE ANOTHER AND FROM THE ACTIVE FLOOD PLAIN BY SMALL SCARPS. TUNDRA VEGETATION; LOCALLY ON UPPER REACHES OF SAGAVANIRKTOK RIVER, LOW BRUSH. PERMAFROST GENERALLY PRESENT WITHIN 2 FEET OF THE SURFACE. ICE COATS PARTICLES AND FILLS VOIDS IN GRAVEL. ICE WEDGES AND MASSES PRESENT LOCALLY, ESPECIALLY WELL DEVELOPED IN TERRACES AWAY FROM ACTIVE FLOOD PLAIN. PERMAFROST GENERALLY ABSENT IN PROXIMITY TO MAIN CHANNELS OF RIVERS; POSSIBLY PRESENT AT DEPTH. THE ACTIVE FLOOD PLAIN CONSISTS OF A NETWORK OF BRAIDED CHANNELS WITH LOCAL RELIEF OF 2 TO 10 FEET. GENERALLY BARE OF VEGETATION.

LEGEND

- ALYESKA/STATE HAUL ROAD
- ALYESKA OIL PIPELINE
- ALCAN PIPELINE
- GAS FUEL LINE
- ▲ BORROW PIT

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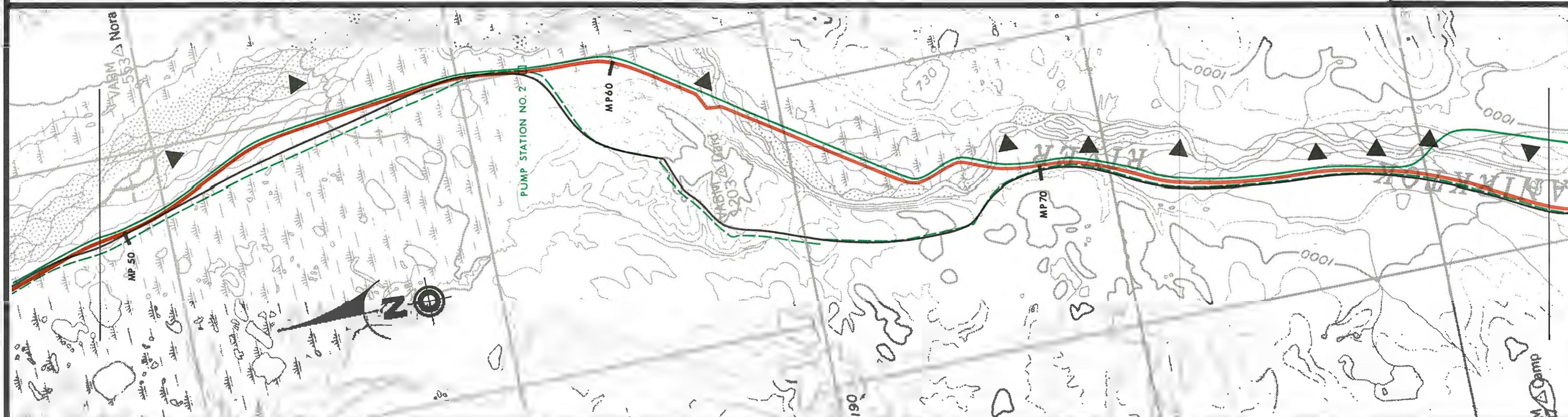

Pipeline Schematic

42" O.D. × 0.600 W.T. -X65 — 42" O.D. × 0.675 W.T. -X65

MP 49.5 MATCH LINE — MP 58.8 ALYESKA PUMP STN #2 — (1) — MP 63.5 VALVE #3 — (2) — MP 77.1 — MP 80.0 MATCH LINE

Notes

1. SAGAVANIRKTOK RIVER CROSSING - MP 62.4
2. SAGAVANIRKTOK RIVER CROSSING - MP 69.1

GULF INTERSTATE ENGINEERING COMPANY		
Alcan Pipeline Company		
42" GAS LINE ROUTE MP 49.5 TO MP 80.0		
DRWN.	SCALE 1" = 2 Miles	DATE June 20/76
APPRVD.	DRWG. NO. APC-B9-3	REV. NO.

Geotechnical Description	GLACIAL TILL ORGANICS AND ORGANIC SILT TO SANDY SILT WITH MASSIVE ICE, INTERBEDDED WITH SILT, SAND AND GRAVEL. MAY CONTAIN LOCALIZED OCCURENCES OF TERRACE GRAVELS, AND FLUVIAL DEPOSITS. ALSO SOME CRETACEOUS SEDIMENTS.	SERIES OF ALLUVIAL TERRACES. COARSE, SANDY GRAVEL AND SAND WITH MINOR AMOUNTS OF SILT. GRAVEL CLASTS SUB-ROUNDED TO ROUNDED. GENERALLY POORLY STRATIFIED WITH LOCAL BEDS AND LENSES OF SAND. COMMONLY MANTLED BY ORGANIC-RICH SAND, ½ TO 3 FEET THICK IN YOUNG TERRACES AND 2 TO 10 FEET THICK IN OLD TERRACES.
Terrain	GENERALLY MODERATE SLOPES, BUT LOCALLY STEEP. TUNDRA VEGETATION. PERMAFROST GENERALLY PRESENT WITHIN 2 FEET OF SURFACE. MASSIVE ICE DEPOSITS FREQUENT IN UPPER 50 FEET OF SEDIMENTS AND AS LENSES WITHIN SILTS AND ORGANIC SILTS. LOCALLY DEVELOPED ICE WEDGES.	SERIES OF FLAT-TOPPED TERRACES SEPARATED FROM ONE ANOTHER AND FROM THE ACTIVE FLOOD PLAIN BY SMALL SCARPS. TUNDRA VEGETATION; LOCALLY ON UPPER REACHES OF SAGAVANIRKTOK RIVER, LOW BRUSH. PERMAFROST GENERALLY PRESENT WITHIN 2 FEET OF THE SURFACE. ICE COATS PARTICLES AND FILLS VOIDS IN GRAVEL. ICE WEDGES PRESENT LOCALLY, ESPECIALLY WELL DEVELOPED IN TERRACES AWAY FROM ACTIVE FLOOD PLAIN.

LEGEND

- ALYESKA/STATE HAUL ROAD
- ALYESKA OIL PIPELINE
- ALCAN PIPELINE
- GAS FUEL LINE
- BORROW PIT

BEDROCK IN THIS AREA CONSISTS OF CRETACEOUS SANDSTONES, SHALES AND CONGLOMERATES.

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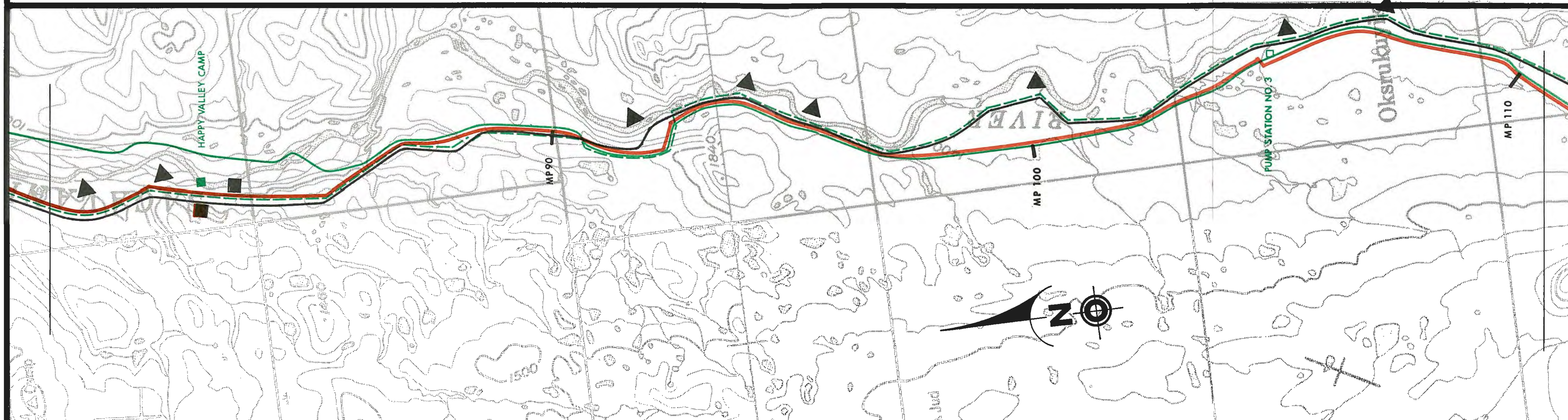

Pipeline Schematic

42" O.D. × 0.675 W.T. - X65 — 42" O.D. × 0.600 W.T. - X65 — 42" O.D × 0.600 W.T. - X65

MP 80.0 MATCH LINE
MP 83.0 HAPPY VALLEY CAMP
MP 83.7 COMPRESSOR STN. #2
HAPPY VALLEY O&M DISTRICT BASE
MP 87.2
MP 90.5 NOTE A
3
MP 101.2 VALVE #4
4
MP 105.1 ALYESKA PUMP STN #3
MP 110.7 MATCH LINE

Notes

A. 42 O.D. x 0.675 W.T. - X65 PIPE

3. UNNAMED CREEK CROSSING - MP 100.2
4. UNNAMED CREEK CROSSING - MP 103.3

GULF INTERSTATE ENGINEERING COMPANY		
Alcan Pipeline Company		
42" GAS LINE ROUTE MP 80.0 TO MP 110.7		
DRWN.	SCALE 1" = 2 Miles	DATE June 20/76
APPRVD.	DRWG. NO. APC-89-4	REV. NO.

Geotechnical Description	YOUNG GLACIAL MORAINE, ICE, SILTY ICE AND ORGANIC SILT WITH TRACE OF GRAVEL UNDERLAIN BY GRAVEL AND SANDY GRAVEL WITH SCATTERED COBBLES.	GLACIAL TILL, ORGANICS TO SILT WITH SOME SAND AND ORGANICS; SANDY GRAVEL WITH SOME SILT INTERBEDDED WITH GRAVEL, SAND, SILT COBBLES AND AND BOULDERS. KAPACUK RIVER FLOODPLAIN CONTAINS SAND AND GRAVEL LOCALLY OVERLAIN BY SILT AND SAND.	COLLUVIUM ORGANICS, ORGANIC SILT TO SANDY SILT, GRAVEL TO SANDY GRAVEL WITH SOME SILT AND SCATTERED COBBLES.
Terrain	MODERATE TO MODERATELY STEEP SLOPES OF PARTIALLY SUBDUED HUMMOCKY TERRAIN. TUNDRA VEGETATION. PERMAFROST GENERALLY PRESENT WITHIN 2 FEET OF SURFACE AND LOCALLY ICE-RICH. CONSPICUOUS ICE WEDGES PRESENT LOCALLY IN DEPRESSIONS.	MODERATE TO MODERATELY STEEP MOUNTAINOUS SLOPES. GENERALLY BARE OF VEGETATION. PERMAFROST GENERALLY PRESENT WITHIN TWO FEET OF SURFACE AND LOCALLY ICE-RICH. CONSPICIOUS ICE WEDGES PRESENT LOCALLY IN DEPRESSIONS.	

LEGEND

- ALYESKA/STATE HAUL ROAD
- ALYESKA OIL PIPELINE
- ALCAN PIPELINE
- GAS FUEL LINE
- BORROW PIT

ADJACENT RIDGES CONSIST OF CRETACEOUS AND JURASSIC SANDSTONES, SHALES AND CONGLOMERATES.

ADJACENT RIDGES CONSIST OF CRETACEOUS AND JURASSIC SANDSTONES, SHALES AND CONGLOMERATES.

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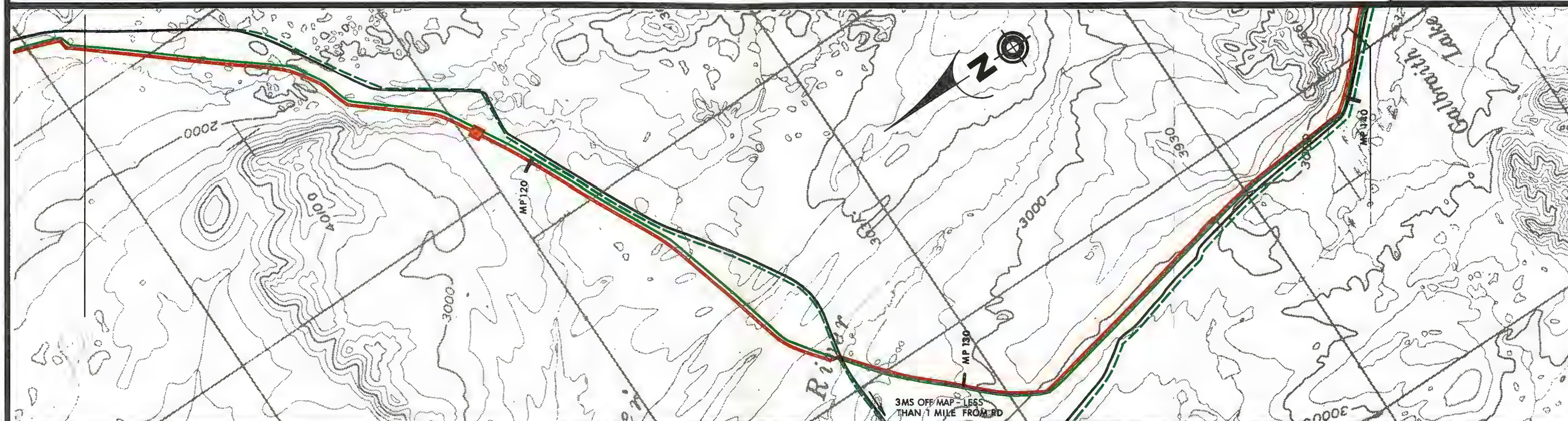
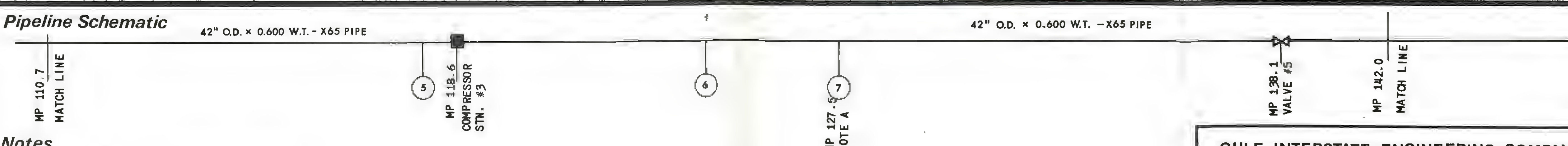


Pipeline Schematic



Notes

A. 42 O.D. × 0.675 W.T. -X65 PIPE

5. UNNAMED CREEK CROSSING - MP 118.0
6. TOOLIK RIVER CROSSING - MP 125.0
7. KUPARUK RIVER CROSSING - MP 127.5

GULF INTERSTATE ENGINEERING COMPANY		
Alcan Pipeline Company		
42" GAS LINE ROUTE MP 110.7 TO MP 142.0		
DRWN.	SCALE 1" = 2 Miles	DATE June 20/76
APPRVD.	DRWG. NO. APC-B9-5	REV. NO.

Geotechnical Description	COLLUVIUM AND FINE ALLUVIUM. COLLUVIUM IS POORLY SORTED GRAVELLY SANDY SILT WITH NUMEROUS ROCK FRAGMENTS. ALLUVIUM IS SILTY SAND WITH ORGANICS. BEDROCK AT VARIABLE DEPTH.	ACTIVE FLOODPLAIN, ALLUVIAL FANS, COLLUVIUM AND ALLUVIAL TERRACES. GENERALLY COARSE SANDY GRAVEL WITH MINOR AMOUNTS OF SILT IN THE ALLUVIUM. COLLUVIUM IS POORLY SORTED GRAVELLY SANDY SILT. CONTAINS NUMEROUS ANGULAR ROCK FRAGMENTS.	PALEOZOIC SEDIMENTS AND METASEDIMENTS, AT DIVIDE. COLLUVIUM AND ALLUVIAL FAN IN SOUTH DRAINAGE. MAINLY ANGULAR ROCK RUBBLE.
Terrain	MODERATELY STEEP TO GENTLY SLOPING TERRAIN. TUNDRA VEGETATION. PERMAFROST GENERALLY IS WITHIN 2 FEET OF THE SURFACE AND GENERALLY ICE RICH. ICE WEDGES AND ICE LENSES COMMON.	GENTLE TO MODERATELY STEEP SLOPES. ROUTE SLOPE GENERALLY APPROXIMATES GRADIENT OF STREAM. LOW BRUSH AND TUNDRA VEGETATION. PERMAFROST GENERALLY PRESENT WITHIN 2 FEET OF THE SURFACE. ICE COMMONLY COATS PARTICLES AND FILLS VOIDS. GENERALLY ABSENT IN PROXIMITY TO MAIN CHANNELS OF RIVERS; POSSIBLY PRESENT AT DEPTH.	VERY STEEP TO MODERATELY STEEP SLOPES. GENERALLY BARE OF VEGETATION. PERMAFROST GENERALLY PRESENT WITHIN 2 FEET OF THE SURFACE.

LEGEND

- ALYESKA/STATE HAUL ROAD
- ALYESKA OIL PIPELINE
- ALCAN PIPELINE
- GAS FUEL LINE
- BORROW PIT

BEDROCK IN THE AREA CONSISTS OF PALEOZOIC SEDIMENTS AND METASEDIMENTS. THESE OCCUR FAIRLY NEAR THE SURFACE OF THE FLOODPLAIN.

BEDROCK HAS BEEN FAULTED AND FOLDED. STRUCTURAL TRENDS ARE GENERALLY ALIGNED EAST-WEST. NO EVIDENCE OF FAULT MOVEMENT DURING HOLOCENE TIME.

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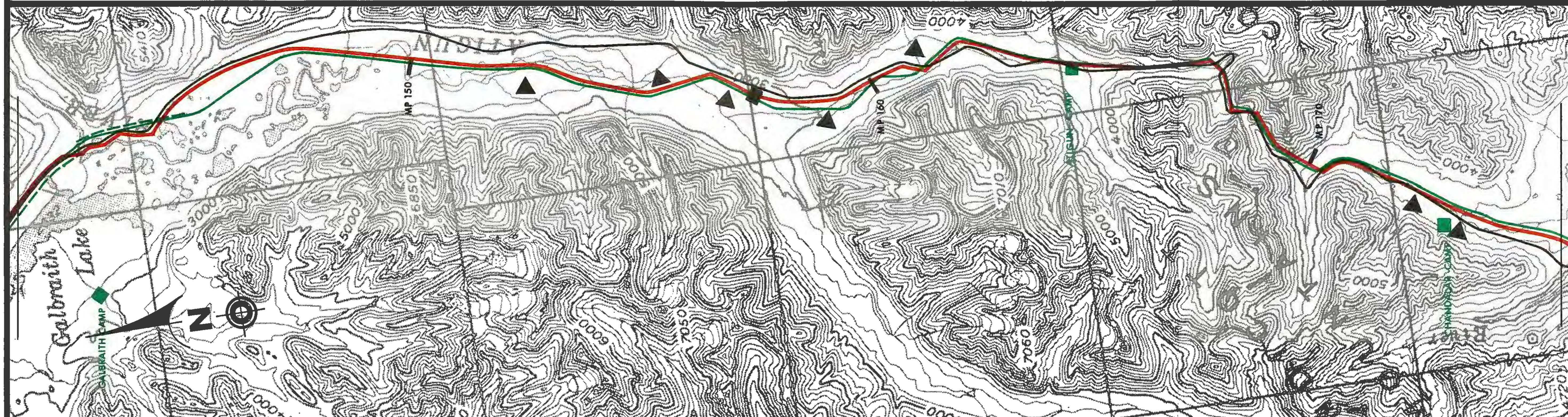
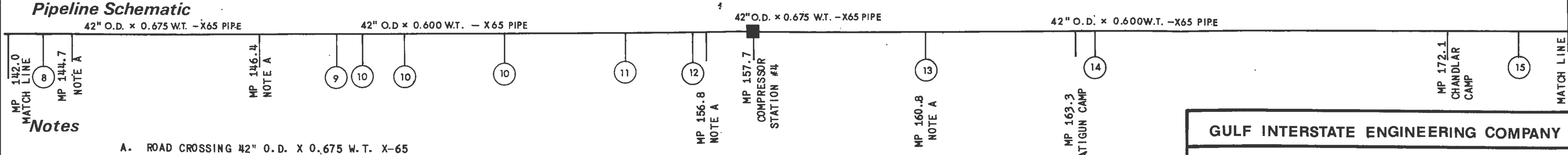


Pipeline Schematic



Notes

A. ROAD CROSSING 42" O.D. X 0.675 W.T. X-65

8. ATIGUN RIVER CROSSING MP 143.6
9. UNNAMED CREEK CROSSING MP 148.7
10. ATIGUN RIVER CROSSING MP 149.3, MP 150.0, MP 154.4
11. UNNAMED CREEK CROSSING MP 154.4
12. ATIGUN RIVER CROSSING MP 156.2
13. UNNAMED CREEK CROSSING MP 160.8
14. ATIGUN RIVER CROSSING MP 163.5
15. DIETRICH RIVER CROSSING MP 174.2

GULF INTERSTATE ENGINEERING COMPANY

Alcan Pipeline Company

42" GAS LINE ROUTE
MP 142.0 TO MP 175.2

DRWN.	SCALE 1" = 2 Miles	DATE June 20/76
APPRVD.	DRWG. NO. APC-B9-6	REV. NO.

Geotechnical Description

MODERN ALLUVIUM, ALLUVIAL FANS, ALLUVIAL TERRACES AND COLLUVIUM. MODERN ALLUVIUM CONSISTS OF SILTY SANDY GRAVEL WITH SCATTERED BOULDERS. FAN DEPOSITS CONSIST OF A HETEROGENEOUS MIXTURE OF SILT, SAND & ANGULAR TO SUBROUNDED GRAVEL. COLUVIUM CONSISTS OF HETEROGENEOUS MIXTURE OF SILT SAND & ROCK FRAGMENTS. USUALLY FINE GRAINED ON GENTLE SLOPES AND COARSE ON STEEP SLOPES. SHALLOW BEDROCK WITH OCCASIONAL OUTCROPS.

Terrain

SLOPE OF THE LINE GENERALLY APPROXIMATES GRADIENT OF DIETRICH RIVER. SPARSE OR NO VEGETATION.

PERMAFROST GENERALLY PRESENT, BUT MAY BE DEEP UNDER ACTIVE RIVER CHANNELS WHERE COMPLETE SEASONAL FREEZE-UP DOES NOT OCCUR. PERMAFROST GENERALLY LOW IN ICE-CONTENT.

LEGEND

- ALYESKA/STATE HAUL ROAD
- ALYESKA OIL PIPELINE
- ALCAN PIPELINE
- GAS FUEL LINE
- BORROW PIT

SEISMICITY - THRUST FAULTS ARE COMMON IN THE AREA. THESE ARE ALIGNED GENERALLY EAST-WEST PARALLEL AND SUBPARALLEL TO BEDROCK STRUCTURES.

FAULT TRACES CONCEALED BENEATH ALLUVIUM IN STREAM VALLEYS. AREA REPORTEDLY SUBJECT TO MAXIMUM PROBABLE EARTHQUAKE MAGNITUDE OF 5.5, HOWEVER THERE IS NO EVIDENCE OF RECENT FAULT MOVEMENT.

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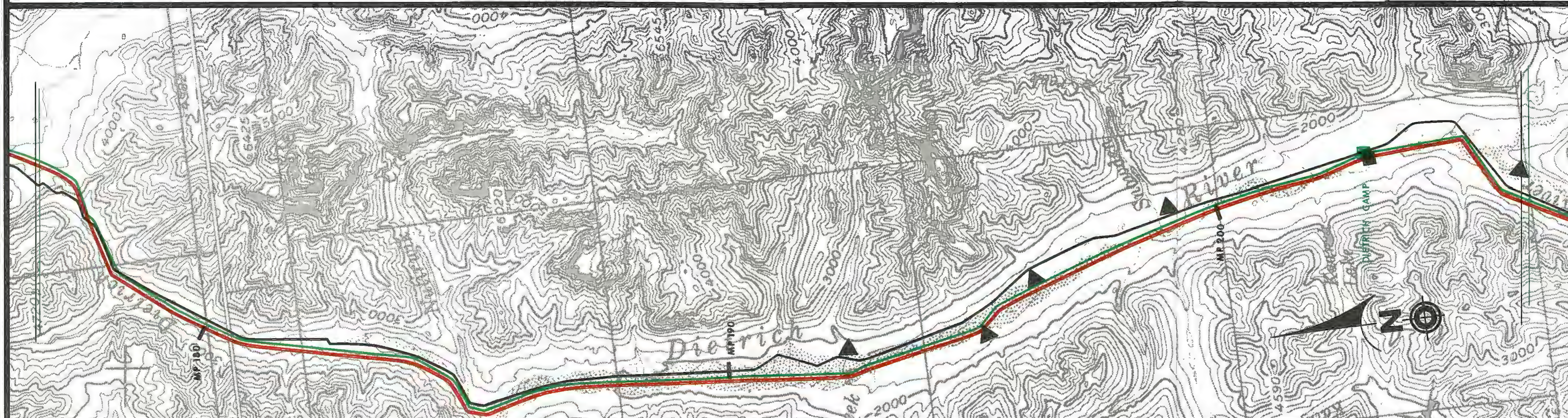
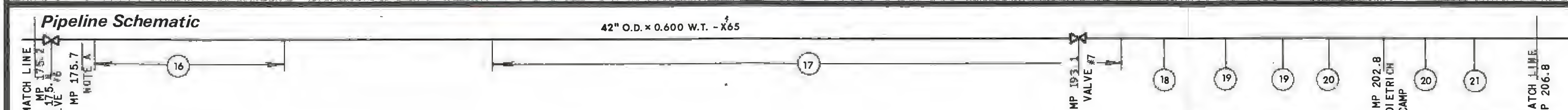


Pipeline Schematic



Notes

A. ROAD CROSSING 42" O.D. X 0.675 W.T.-X65

16. DIETRICH RIVER FLOODPLAIN MP 176.8 TP MP 181.4
17. DIETRICH RIVER FLOODPLAIN MP 185.1 TO MP 198.0
18. SNOWDEN CREEK CROSSING MP 198.8
19. DIETRICH RIVER CROSSING MP 199.8, MP 201.0
20. UNNAMED CREEK CROSSING MP 201.9, MP 204.2
21. DIETRICH RIVER CROSSING MP 205.3

GULF INTERSTATE ENGINEERING COMPANY		
Alcan Pipeline Company		
42" GAS LINE ROUTE MP 175.2 TO MP 206.8		
DRWN.	SCALE 1" = 2 Miles	DATE June 20/76
APPRVD.	DRWG. NO. APC-B9-7	REV. NO.

Geotechnical Description

MODERN ALLUVIUM, TERRACE GRAVELS, OLDER ALLUVIUM, AND ALLUVIAL FANS. MODERN ALLUVIUM CONSISTS OF SILT, SAND, & SUBANGULAR TO SUBROUNDED GRAVEL; WITH COBBLES. OLDER ALLUVIUM IS SILT, SAND & SUBANGULAR TO SUBROUNDED GRAVEL. TERRACE GRAVELS CONSIST OF CLEAN GRAVEL AND SAND WITH MINOR AMOUNTS OF SILT. ALLUVIAL FANS CONSIST OF HETEROGENEOUS MIXTURE OF SILT, SAND AND SUBANGULAR GRAVEL. APEX OF FAN COMPOSED CHIEFLY OF COARSE MATERIAL, WHILE FINE GRAINED MATERIALS OCCUR ON LOWER SLOPES.

Terrain

MODERATE TO GENTLE SLOPES. ROUGHLY APPROXIMATING GRADIENT OF RIVER. MODERN ALLUVIUM IS GENERALLY BARE OF VEGETATION.

SOME SPRUCE AND SHRUBS ON OTHER DEPOSITS.

PERMAFROST GENERALLY WITHIN 2 FEET OF SURFACE EXCEPT UNDER MODERN CHANNELS WHERE A THAW BULB OCCURS.

LEGEND

- ALYESKA/STATE HAUL ROAD
- ALYESKA OIL PIPELINE
- ALCAN PIPELINE
- GAS FUEL LINE
- BORROW PIT

SEISMICITY – NORMAL AND THRUST FAULTS COMMON IN THE AREA. THESE ARE ALIGNED GENERALLY EAST-WEST. AREA REPORTEDLY SUBJECT TO MAXIMUM PROBABLE EARTHQUAKE MAGNITUDE OF 5.5 HOWEVER THERE IS NO EVIDENCE OF RECENT FAULT MOVEMENT.

SURROUNDING BEDROCK CONSISTS OF DEVONIAN SEDIMENTS AND METASEDIMENTS, PREDOMINANTLY SILT STONES WITH SOME LIMESTONES, SLATES, PHYLLITES, GREENSTONES AND QUARTZ-MICA SCHIST.

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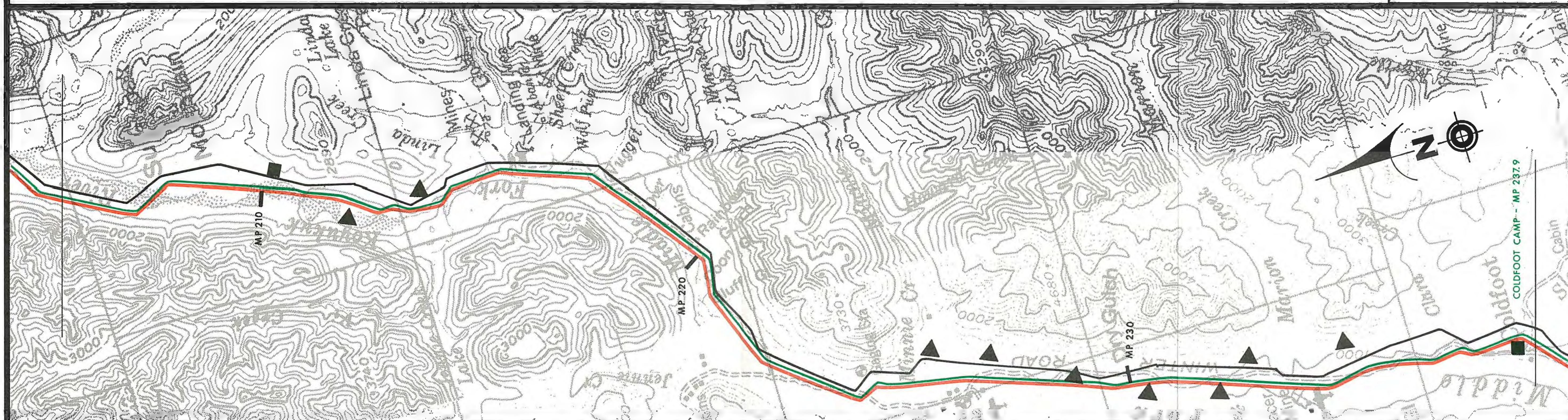
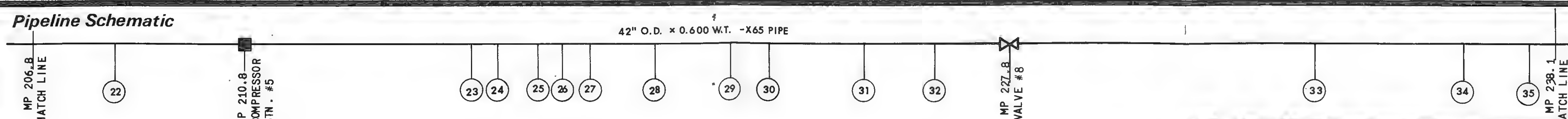


Pipeline Schematic



Notes

22. MID FK KOYUKUK RIVER CROSSING – MP 208.6
23. LINDA CREEK CROSSING – MP 215.3
24. GOLD CREEK CROSSING – MP 215.7
25. SHEEP CREEK CROSSING – MP 216.6
26. WOLF PUP CREEK CROSSING – MP 216.9
27. NUGGET CREEK CROSSING – MP 217.3
28. OVER CREEK CROSSING – MP 218.8
29. MID. FK. KOYUKUK RIVER CROSSING – MP 221.9
30. HAMMOND RIVER CROSSING – MP 222.2
31. MID. FK. KOYUKUK RIVER CROSSING – MP 224.8
32. MINNIE CREEK CROSSING – MP 225.5
33. MARION CREEK CROSSING – MP 233.5
34. CLARA CREEK CROSSING – MP 236.4
35. SLATE CREEK CROSSING – MP 237.8

GULF INTERSTATE ENGINEERING COMPANY

Alcan Pipeline Company

42" GAS LINE ROUTE

MP 206.8 TO MP 238.1

DRWN.	SCALE 1" = 2 Miles	DATE June 20/76
APPRVD.	DRWG. NO. APC-B9-8	REV. NO.

Geotechnical Description	MODERN ALLUVIUM AND OLDER ALLUVIUM. SILT, SAND, & SUBANGULAR TO SUBROUNDED GRAVEL WITH COBBLES.	GROUND MORAINE CONSISTING OF SAND & GRAVEL MANTLED BY SILT WITH NUMEROUS CLOSED DEPRESSIONS GENERALLY CONTAINING WATER.	MODERN ALLUVIAL GRAVELS, TERRACE GRAVELS, ALLUVIAL FANS, & COLLUVIUM. MODERN ALLUVIUM AND TERRACE GRAVELS CONSIST OF SILT, SAND & SUBROUNDED GRAVEL. ALLUVIAL FANS CONSIST OF HETEROGENEOUS MIXTURE OF SILT, SAND AND ANGULAR TO SUBROUNDED GRAVEL. COLLUVIUM IS A HETEROGENEOUS MIXTURE OF SILT, SAND & ROCK FRAGMENTS.
Terrain	GENTLE SLOPES WITH SPRUCE AND SHRUBS ON OLDER ALLUVIUM. PERMAFROST GENERALLY WITHIN 2 FEET OF SURFACE EXCEPT UNDER MODERN STREAM CHANNELS.	FLAT TO GENTLE SLOPE WITH NUMEROUS CLOSED DEPRESSIONS. SPARSE SPRUCE AND SHRUB VEGETATION. PERMAFROST GENERALLY WITHIN THREE FEET OF SURFACE. FORMS VOID FILLINGS AND COATINGS ON GRAVELS MAY FORM MASSIVE ICE. ICE WEDGES AND LENSES IN THE FINER GRAINED SEDIMENTS.	GENTLE TO MODERATE SLOPES. SPARSE TO FAIRLY DENSE BRUSH AND SPRUCE TREES. PERMAFROST GENERALLY WITHIN 3 FEET OF SURFACE EXCEPT WHERE MODERN STREAM CHANNELS HAVE CREATED THAW BULBS. CONTAINS SOME ICE LENSES, WEDGES, AND MASSIVE ICE.

LEGEND

- ALYESKA/STATE HAUL ROAD
- ALYESKA OIL PIPELINE
- ALCAN PIPELINE
- GAS FUEL LINE
- BORROW PIT

SEISMICITY – ISOLATED NORMAL AND THRUST FAULTS IN THE AREA. GENERALLY TREND EAST-WEST. AREA REPORTEDLY SUBJECT TO MAXIMUM PROBABLE EARTHQUAKE MAGNITUDE OF 5.5 TO 7.5.

SURROUNDING BEDROCK CONSISTS OF MESOZOIC CONGLOMERATES AND SANDSTONES, PLUS GRANITIC, MAFIC, AND ULTRAMAFIC IGNEOUS ROCKS.

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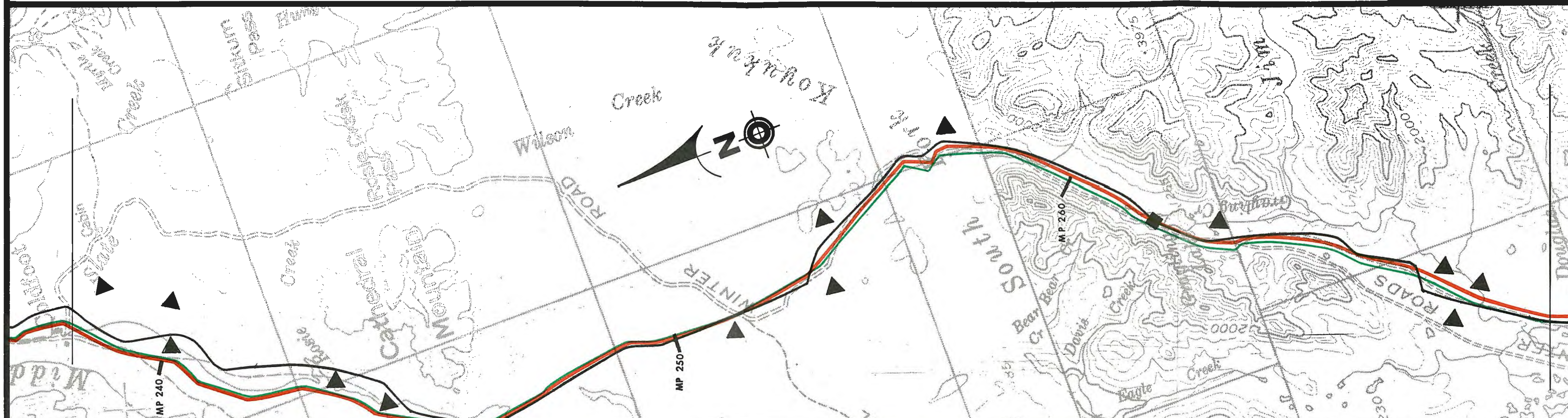
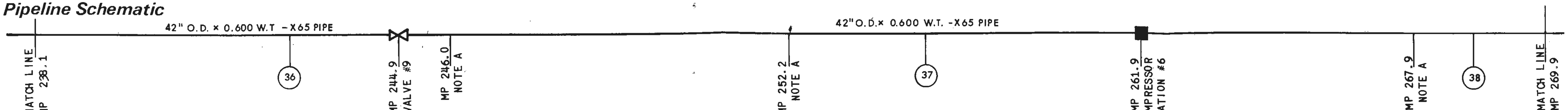


Pipeline Schematic



Notes

A. ROAD CROSSING 42" O.D. X 0.675 W.T.–X65 PIPE
36. ROSIE CREEK CROSSING MP 243.4
37. SFK KOYUKUK RIVER CROSSING MP 256.7
38. JIM RIVER CROSSING MP 268.6

GULF INTERSTATE ENGINEERING COMPANY

Alcan Pipeline Company

42" GAS LINE ROUTE
MP 238.1 TO MP 269.9

DRWN.	SCALE 1" = 2 Miles	DATE June 20/76
APPRVD.	DRWG. NO. APC- B9-9	REV. NO.

Geotechnical Description	SAND & CLEAN GRAVEL OFTEN COVERED BY A THIN LAYER OF WINDBLOWN SILT.	AREA OF NUMEROUS BEDROCK OUTCROPS WITH LOCAL AREAS MANTLED BY COLLUVIUM AND MODERN ALLUVIUM. BEDROCK CONSISTS OF SCHIST, PHYLLITE, GREENSTONE, HORNFELS, GABBRO, DIABASE, BASALT, QUARTZ MONZONITE, GRANODIORITE, SYENITE, MONZONITE AND TUFF. ALLUVIUM IN STREAM VALLEYS CONSISTS OF SILT, SAND, & SUBANGULAR TO ROUNDED GRAVELS. COLLUVIUM IN LOCAL AREAS IN COMPRISED OF A HETEROGENEOUS MIXTURE OF SILT, SAND AND ROCK FRAGMENTS; LOCALLY EXHIBITS SOLIFLUCTION LOBES.
Terrain	FLAT TO GENTLE SLOPES WITH LOCAL CLOSED DEPRESSIONS - CONTAINS NUMEROUS SMALL LAKES. SMALL SPRUCE TREES. PERMAFROST GENERALLY WITHIN 3 FEET OF SURFACE.	MODERATE TO STEEP TOPOGRAPHY. GENERALLY SPARSE VEGETATION, WITH LOCAL AREAS COVERED WITH SPRUCE AND SHRUBS. PERMAFROST GENERALLY WITHIN 10 FEET OF SURFACE IN BEDROCK AREA. WITHIN 2 FEET OF SURFACE IN LOCAL AREAS OF COLLUVIUM. PERMAFROST GENERALLY DEEP UNDER THAW BULBS OF STREAM CHANNELS.

LEGEND
- ALYESKA/STATE HAUL ROAD
- ALYESKA OIL PIPELINE
- ALCAN PIPELINE
- GAS FUEL LINE
- BORROW PIT

SEISMICITY - ISOLATED NORMAL FAULTS, CONCEALED BENEATH RECENT SEDIMENTS, TREND NORTHWESTERLY AND SOUTHWESTERLY. AREA REPORTEDLY SUBJECT TO MAXIMUM PROBABLE EARTHQUAKE MAGNITUDE OF 7.5.

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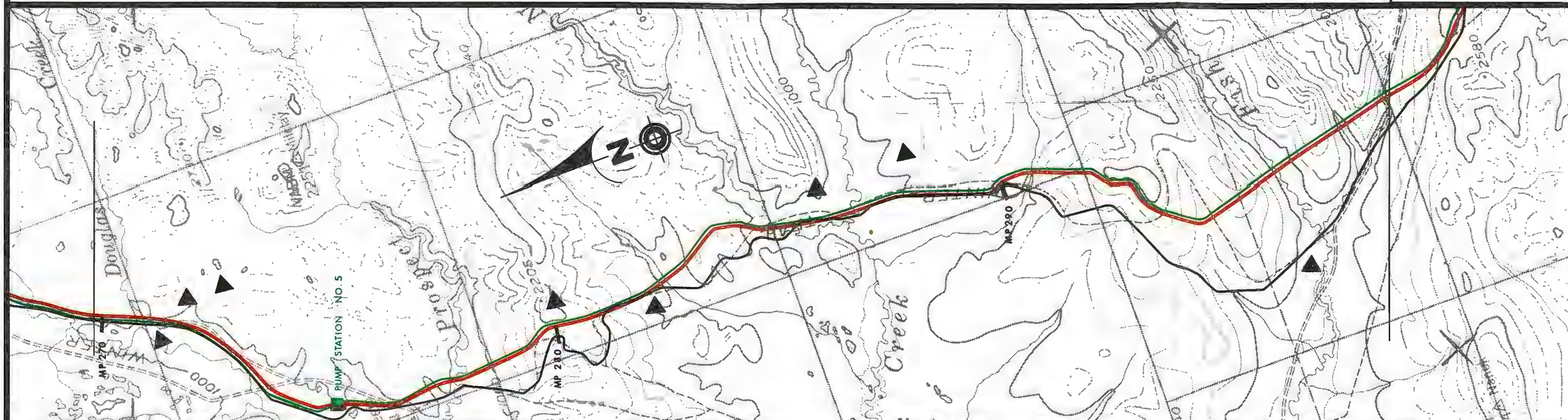
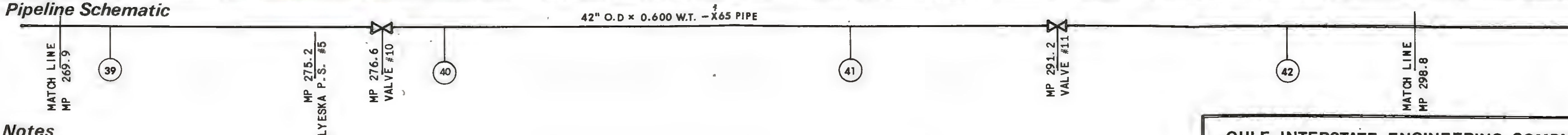


Pipeline Schematic



Notes

39. DOUGLAS CREEK CROSSING MP 270.8
40. PROSPECT CREEK CROSSING MP 277.9
41. BONANZA CREEK CROSSING MP 287.1
42. FISH CREEK CROSSING MP 296.1

GULF INTERSTATE ENGINEERING COMPANY

Alcan Pipeline Company

42" GAS LINE ROUTE
MP 269.9 TO MP 298.8

DRWN.	SCALE 1" = 2 Miles	DATE June 20/76
APPRVD.	DRWG. NO. APC-B9-10	REV. NO.

Geotechnical Description

BEDROCK THROUGHOUT A MAJOR PORTION OF THIS AREA IS MASKED BY COLLUVIUM, ALDER ALLUVIUM AND RANDOM OCCURENCES OF TERRACE SANDS AND GRAVELS. THE BEDROCK CONSISTS OF QUARTZ MONZONITE, GRANODIORITE, SYENITE, MONZONITE, GABBRO, DIABASE, BASALT, CHERT, SCHIST, PHYLLITE, GREENSTONE, AND HORNFELS. THE OVERLYING COLLUVIUM CONSISTS OF A HETEROGENEOUS MIXTURE OF SILT, SAND & ROCK FRAGMENTS; LOCALLY CONTAINS SOLIFLUCTION LOBES; IN LOW LYING AREAS IT IS CHIEFLY SILT. RIVER AND STREAM CHANNELS COMPOSED OF SILT, SAND AND GRAVEL WITH COBBLES.

Terrain

MODERATE TO STEEP SLOPES WITH SOME GENTLE SLOPES IN LOCAL AREAS OF COLLUVIUM. VEGETATION SPARSE TO MODERATE. VEGETATION BECOMING MORE DENSE IN SOUTHERN PART OF THE SECTION.

PERMAFROST IS GENERALLY PRESENT WITHIN 2 FEET OF THE SURFACE. IN AREAS OF BEDROCK OUTCROP THE DEPTH TO PERMAFROST MAY APPROACH 10 FEET. DEEP THAW BULBS MAY BE EXPECTED BELOW PRESENT STREAM CHANNELS.

LEGEND

- ALYESKA/STATE HAUL ROAD
- ALYESKA OIL PIPELINE
- ALCAN PIPELINE
- GAS FUEL LINE
- BORROW PIT

SEISMICITY – SOME LOCALIZED FAULTING IN PRECAMBRIAN, PALEOZOIC AND MESOZOIC ROCKS. NO EVIDENCE OF RECENT MOVEMENT. REPORTED MAXIMUM PROBABLE EARTHQUAKE MAGNITUDE OF 7.5.

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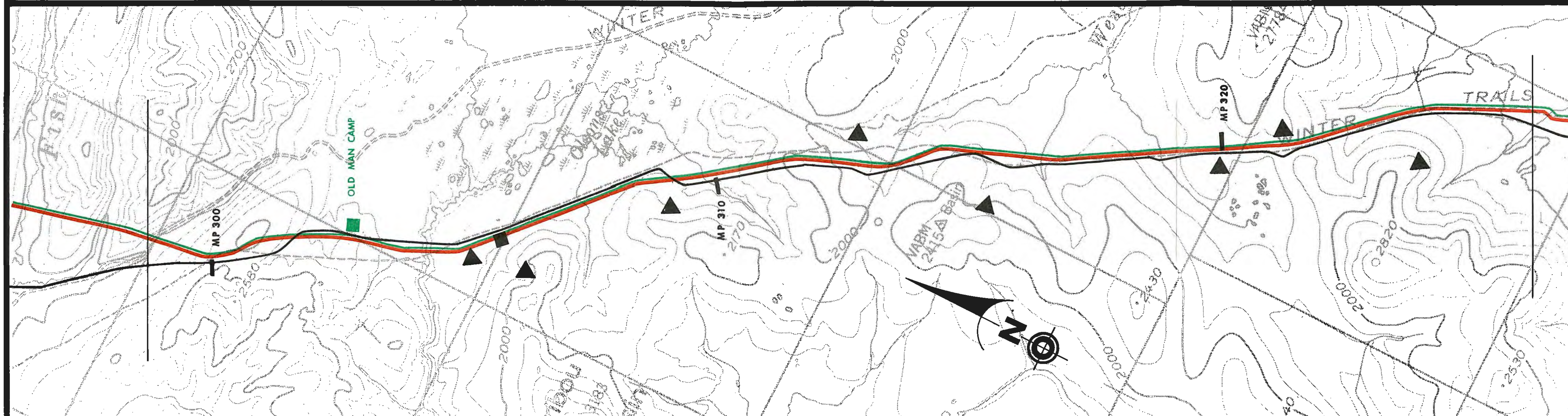
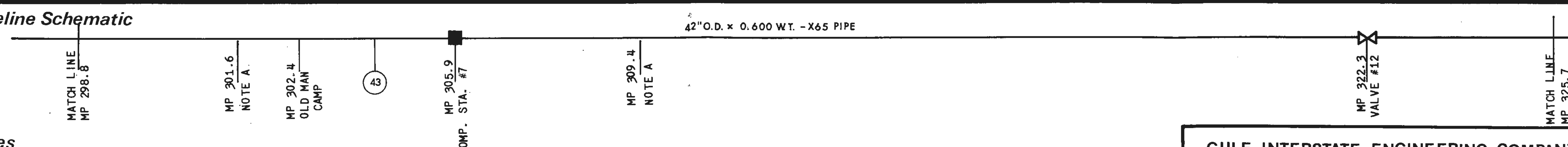


Pipeline Schematic



Notes

A. ROAD CROSSING 42" O.D. X 0.675 W.T. X-65 PIPE
43. KANUTI RIVER CROSSING MP 304.1

GULF INTERSTATE ENGINEERING COMPANY

Alcan Pipeline Company

42" GAS LINE ROUTE
MP 298.8 TO MP 325.7

DRWN.	SCALE 1" = 2 Miles	DATE June 20/76
APPRVD.	DRWG. NO. APC-B9-11	REV. NO.

Geotechnical Description

FORT HAMLIN HILLS SECTION CONSISTS OF COLLUVIUM, WIND BLOWN SILT (LOESS), HIGH LEVEL GRAVELS, MODERN STREAM ALLUVIUM IN THE RAY RIVER, AND LOCAL OUTCROPS OF METAMORPHIC AND IGNEOUS BEDROCK. COLLUVIUM IS A HETEROGENEOUS MIXTURE OF SILT, SAND, AND ROCK FRAGMENTS; CHIEFLY SILTS IN LOW-LYING AREAS. THE HIGH LEVEL GRAVELS ARE CLEAN WELL-SORTED AND UP TO 2 INCHES IN DIAMETER. THE WINDBLOWN SILTS ARE TYPICAL THICK EOLIAN DEPOSITS.

YUKON RIVER AREA. GENERALLY CONSISTS OF WINDBLOWN SILT WITH SMALL OUTCROPS OF BEDROCK. HIGH SILT BANKS ON YUKON RIVER.

Terrain

STEEP SLOPES IN THE FORT HAMLIN HILLS AREA. MODERATE TO GENTLE SLOPES IN AREAS OF COLLUVIUM AND WINDBLOWN SILT NORTH AND SOUTH OF FORT HAMLIN HILLS. HEAVILY COVERED BY VEGETATION.

PERMAFROST IS GENERALLY PRESENT WITHIN 2 TO 3 FEET OF THE SURFACE.

GENTLE TO STEEP SLOPES HEAVILY MANTLED BY SPRUCE BIRCH & OTHER VEGETATION.

PERMAFROST PRESENT WITHIN 2 TO 3 FEET OF SURFACE. MAY CONTAIN LOCAL ICE LENSES AND MASSES.

LEGEND

- ALYESKA/STATE HAUL ROAD
- ALYESKA OIL PIPELINE
- ALCAN PIPELINE
- GAS FUEL LINE
- BORROW PIT

SEISMICITY – MAY BE SOME FAULTING IN BEDROCK UNITS. NO EVIDENCE OF RECENT MOVEMENT. REPORTED MAXIMUM PROBABLE EARTHQUAKE MAGNITUDE OF 7.5.

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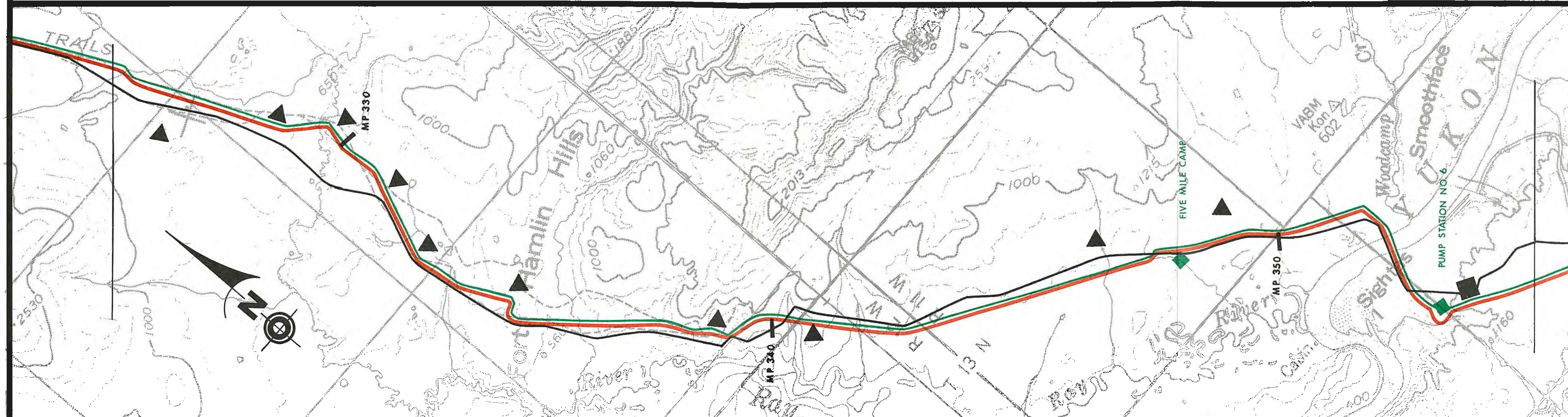
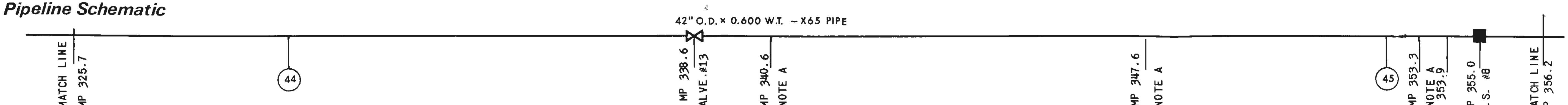


Pipeline Schematic



Notes

A. ROAD CROSSING 42" O.D. X 0.675 W.T.-X65 PIPE

44. UNNAMED CREEK CROSSING MP 329.5
45. YUKON RIVER CROSSING MP 352.6

GULF INTERSTATE ENGINEERING COMPANY

Alcan Pipeline Company

42" GAS LINE ROUTE

MP 325.7 TO MP 356.2

DRWN.	SCALE 1" = 2 Miles	DATE June 20/76
APPRVD.	DRWG. NO. APC-B9-12	REV. NO.

Geotechnical Description

MAINLY WIND DEPOSITED SILT (LOESS) WITH MINOR AREAS OF SILT OF UNDETERMINED ORIGIN. ALSO CONTAINS LOCALIZED AREAS OF COLLUVIUM. BEDROCK OUTCROPS IN LOCAL AREAS. STREAM CHANNELS CONTAIN ALLUVIUM CONSISTING OF SILT, SAND, AND SUBANGULAR TO ROUNDED GRAVEL; MATERIAL FINE-GRAINED IN CREEKS AT LOW ELEVATIONS; RELATIVELY COARSE GRAINED IN FAST-FLOWING CREEKS ON STEEP SLOPES. OUTCROPPING BEDROCK CONSISTS OF BASALT, SLATY SHALE, ARGILLITE, CHERT, DIORITE, DIABASE, GABBRO AND MINOR AMOUNTS OF SANDY LIMESTONE.

Terrain

ROLLING HILLS WITH GENTLE TO MODERATE SLOPES. SOME LOW-LYING FLAT AREAS. HEAVILY MANTLED BY SPRUCE, BIRCH, ALDER, AND OTHER VEGETATION. PERMAFROST GENERALLY PRESENT WITHIN 2 TO 3 FEET OF SURFACE. MAY BE DEEPER ON SOUTH-FACING SLOPES. MAY BE ABSENT BENEATH LARGER STREAMS.

LEGEND
- ALYESKA/STATE HAUL ROAD
- ALYESKA OIL PIPELINE
- ALCAN PIPELINE
- GAS FUEL LINE
- BORROW PIT

SEISMICITY – POSSIBLE MINOR FAULTING IN BEDROCK UNITS, HOWEVER ARE CONCEALED BY RECENT DEPOSITS. TREADS PROBABLY EAST-WEST TO SOUTHWESTERLY. REPORTED MAXIMUM PROBABLE EARTHQUAKE MAGNITUDE OF 7.5.

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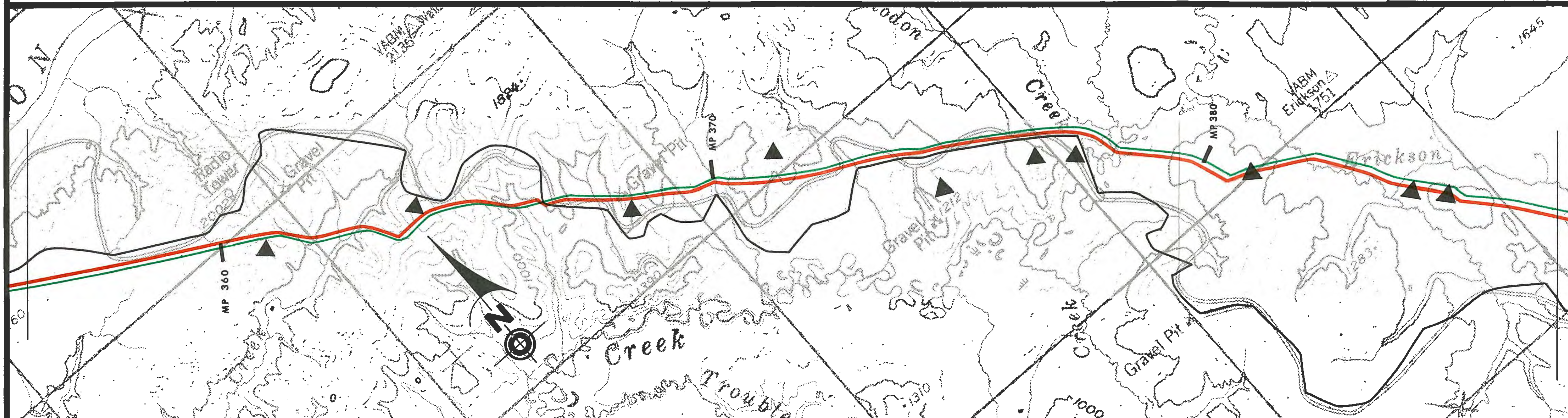

Pipeline Schematic

42" O.D. × 0.600 W.T. – X65 PIPE

MATCH LINE MP 356.2 | 46 | MP 366.8 NOTE A | MP 370.2 VALVE #14 | 47 | 48 | MP 385.5 VALVE #15 | MATCH LINE MP 386.7

Notes

A. ROAD CROSSING 42" O.D. X 0.675 W.T. -X65 PIPE

46. ISOM CREEK CROSSING MP 362.6
47. HESS CREEK CROSSING MP 377.9
48. ERICKSON CREEK CROSSING MP 384.0

GULF INTERSTATE ENGINEERING COMPANY

Alcan Pipeline Company

42" GAS LINE ROUTE
MP 356.2 TO MP 386.7

DRWN.	SCALE 1" = 2 Miles	DATE June 20/76
APPRVD.	DRWG. NO. APC-B9-13	REV. NO.

Geotechnical Description

SOILS CONSIST MAINLY OF COLLUVIUM, WIND-DEPOSITED SILTS, AND SILTS OF UNDIFFERENTIATED ORIGIN. ALSO PRESENT ARE ALLUVIAL FAN MATERIALS AND RECENT ALLUVIAL SOILS IN PRESENT DAY STREAM CHANNELS. COLLUVIUM, WHICH IS THE PREDOMINANT SOIL TYPE, CONSISTS OF A HETEROGENEOUS MIXTURE OF SILT, SAND, & ROCK FRAGMENTS. THIS SECTION HAS NUMEROUS BEDROCK OUTCROPS. BEDROCK TYPES INCLUDE CHERT, SHALE, SILTSTONE, DOLOMITE, LIMESTONE, GRAYWACKE, SHALE & CONGLOMERATE.

Terrain

TOPOGRAPHY CONSISTS OF ROUNDED HILLS WITH GENTLE TO STEEP SLOPES. ALSO CONTAINS LOW-LYING FLAT AREAS. COVERED BY MIXED INTERIOR FOREST OF SPRUCE, BIRCH AND BALSAM POPLAR. PERMAFROST GENERALLY PRESENT WITHIN 1½ TO 2 FEET OF SURFACE. DEPTH MAY BE 6 FEET OR MORE ON SOUTH-FACING SLOPES.

LEGEND

- ALYESKA/STATE HAUL ROAD
- ALYESKA OIL PIPELINE
- ALCAN PIPELINE
- GAS FUEL LINE
- BORROW PIT

SEISMICITY – LOCALIZED FAULTING INCLUDING THRUST FAULTING IN BEDROCK UNITS. FAULTS GENERALLY TREND SOUTHWESTERLY AND ARE CONCEALED BY RECENT SEDIMENTS. REPORTED MAXIMUM PROBABLE EARTHQUAKE MAGNITUDE OF 7.5.

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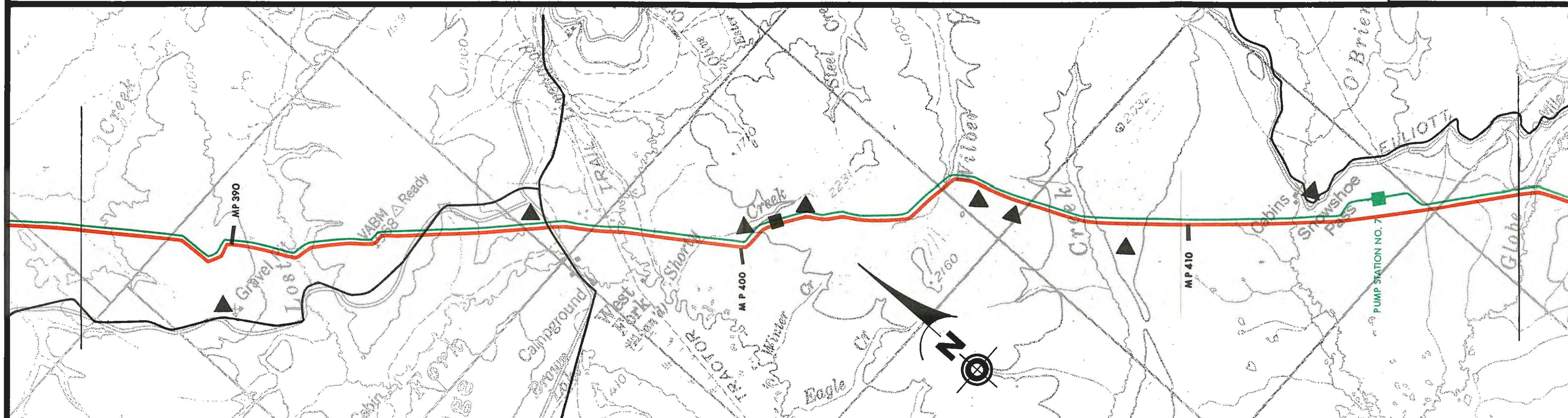
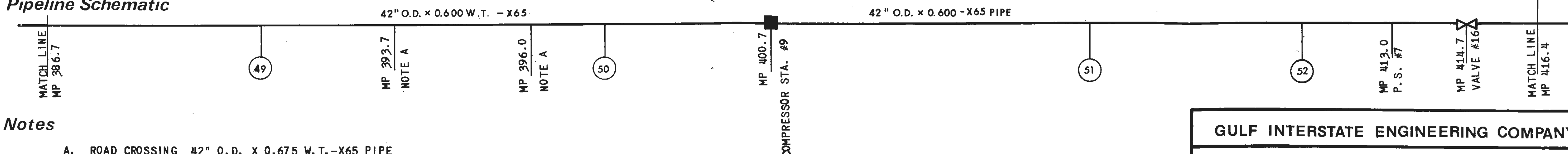


Pipeline Schematic



Notes

A. ROAD CROSSING 42" O.D. X 0.675 W.T.-X65 PIPE
49. LOST CREEK CROSSING MP 391.1
50. TOLOVANA RIVER CROSSING MP 397.5
51. SLATE CREEK CROSSING MP 407.9
52. TATALINA RIVER CROSSING MP 412.1

GULF INTERSTATE ENGINEERING COMPANY		
Alcan Pipeline Company		
42" GAS LINE ROUTE MP 386.7 TO MP 416.4		
DRWN.	SCALE 1" = 2 Miles	DATE June 20/76
APPRVD.	DRWG. NO. APC-B9-14	REV. NO.

Geotechnical Description

SOILS CONSIST MAINLY OF WIND-DEPOSITED SILT (LOESS) AND CALLUVIUM WITH NUMEROUS BEDROCK OUTCROPS IN THE WICKERSHAM DOME AREA. FLOODPLAIN DEPOSITS IN THE CHATANIKA RIVER VALLEY CONSIST OF SILT AND SAND FROM OVERBANK DEPOSITION; GENERALLY UNDERLAIN BY STREAM GRAVELS. THE FLOODPLAINS OF GOLDSTREAM CREEK AND ENGINEER CREEK CONTAIN PLACER MINE DREDGE TAILINGS (REWORKED GRAVELS). BEDROCK OUTCROPS CONSIST OF ARGILLITE, SLATE, LIMESTONE, QUARTZITE, AND SCHIST.

Terrain

GENTLE TO STEEP SLOPES IN WICKERSHAM DOME AREA. GENTLY ROLLING AND LOW ROUNDED HILLS SOUTH OF WICKERSHAM DOME. SPARSE VEGETATION IN WICKERSHAM DOME AREA. VEGETATION HEAVIER SOUTH OF WICKERSHAM DOME.

PERMAFROST GENERALLY ABSENT ON HILL TOPS AND WELL-DRAINED SOUTH-FACING SLOPES. SPORADIC PERMAFROST AT DEPTHS OF 2 TO 4 FEET IN FLOODPLAINS. SOME ICE LENSES AND MASSES PRESENT LOCALLY.

LEGEND

- ALYESKA/STATE HAUL ROAD
- ALYESKA OIL PIPELINE
- ALCAN PIPELINE
- GAS FUEL LINE
- BORROW PIT

SEISMICITY – REPORTED MAXIMUM PROBABLE EARTHQUAKE MAGNITUDE OF 7.5.

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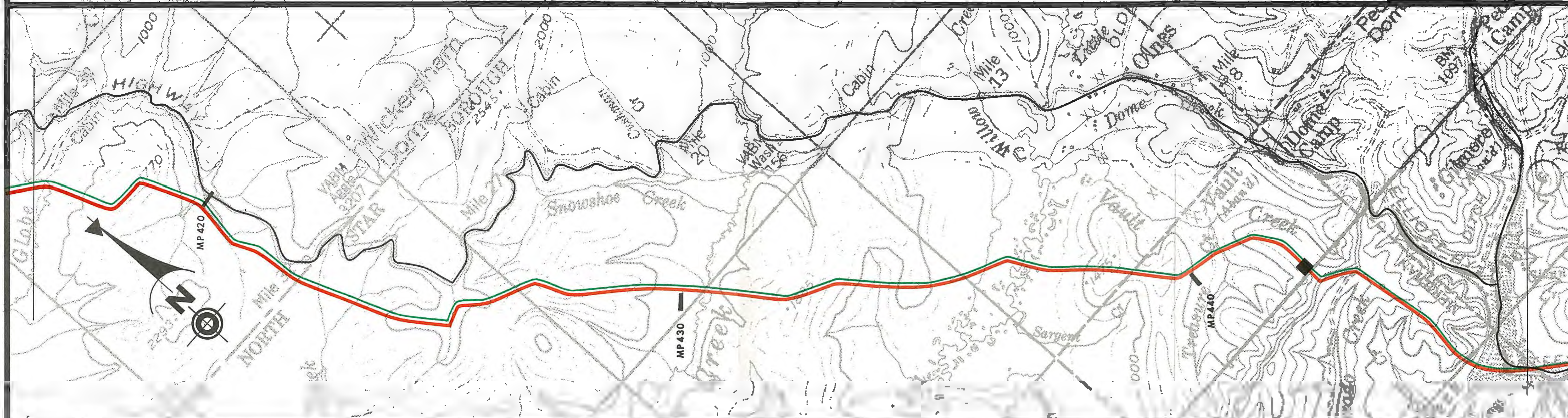
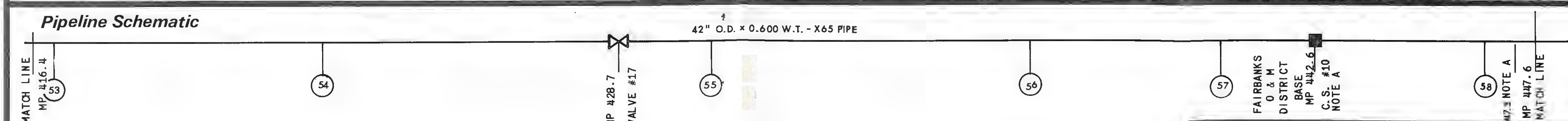


Pipeline Schematic



Notes

A. ROAD CROSSING 42" O.D. X 0.675 W.T.-X65 PIPE

53. GLOBE CREEK CROSSING MP 416.7
54. AGGIE CREEK CROSSING MP 422.9
55. WASHINGTON CREEK CROSSING MP 430.7
56. CHATANIKA RIVER CROSSING MP 436.7
57. TREASURE CREEK CROSSING MP 440.8
58. GOLDSTREAM CREEK CROSSING MP 446.7

GULF INTERSTATE ENGINEERING COMPANY

Alcan Pipeline Company

42" GAS LINE ROUTE

MP 416.4 TO MP 447.6

DRWN.	SCALE 1" = 2 Miles	DATE June 20/76
APPRVD.	DRWG. NO. APC-B9-15	REV. NO.

Geotechnical Description	SOILS INCLUDE REWORKED CREEK GRAVELS (DREDGE TAILINGS) WIND DEPOSITED SILT, COLLUVIUM, PERENNIALLY FROZEN SILT, FINE AND COARSE ALLUVIUM AND MINOR PEAT BOGS. BEDROCK CONSISTS OF METAMORPHIC ROCKS.	SOILS CONSIST OF CHENA RIVER FLOODPLAIN DEPOSITS INCLUDING SILTS, SANDY SILTS AND SILTY SANDS WITH GRAVELS AND SANDY GRAVELS IN STREAM CHANNELS.
Terrain	GENTLY ROLLING AND LOW ROUNDED HILLS. MIXED INTERIOR FOREST VEGETATION OF SPRUCE, BIRCH, BALSAM POPLAR AND SHRUBS.	LOW RELIEF WITH GENTLE SLOPES AND MEANDERING STREAMS. MIXED INTERIOR FOREST VEGETATION OF SPRUCE, BIRCH, BALSAM POPLAR AND SHRUBS. PERMAFROST PRESENT AT DEPTH OF 1 TO 4 FEET IN THE FINE ALLUVIUM; AT 2 TO 3 FEET IN COLLUVIUM ON NORTH SLOPES AND MORE THAN 6 FEET ON SOUTH SLOPES, AT 2 TO 4 FEET IN OLDER PARTS OF THE CHENA RIVER FLOODPLAIN; AT 1 TO 20 FEET IN PERENNIALLY FROZEN SILT. GENERALLY ABSENT BENEATH LARGER STREAMS.

LEGEND

- ALYESKA/STATE HAUL ROAD
- ALYESKA OIL PIPELINE
- ALCAN PIPELINE
- GAS FUEL LINE
- BORROW PIT

SEISMICITY – REPORTED MAXIMUM PROBABLE EARTHQUAKE MAGNITUDE OF 7.5.

SCATTERED METAMORPHIC BEDROCK OUTCROPS NEAR MOOSE CREEK AND EIELSON AIR FORCE BASE.

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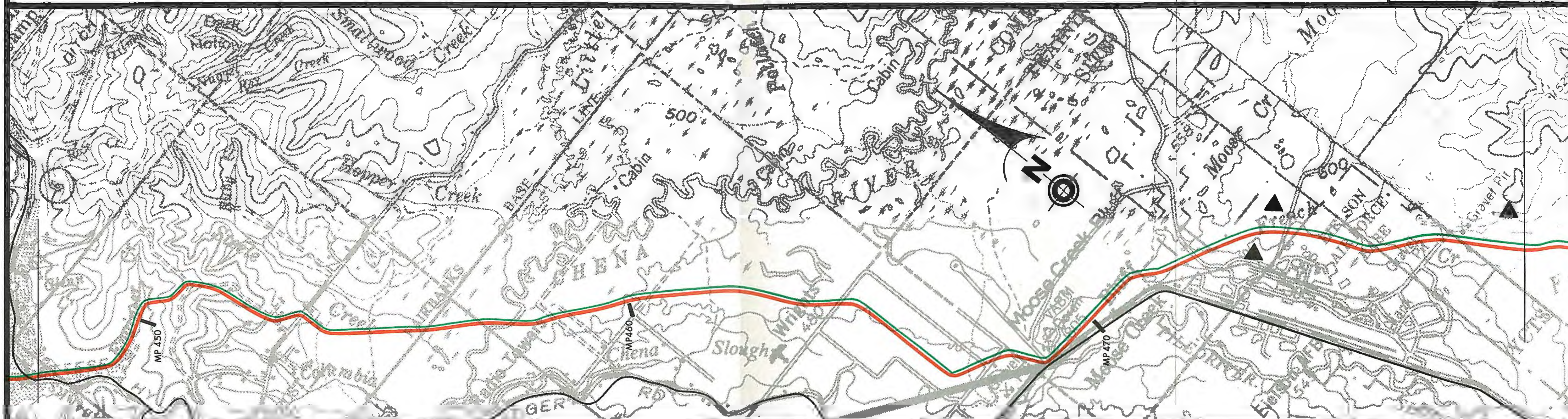
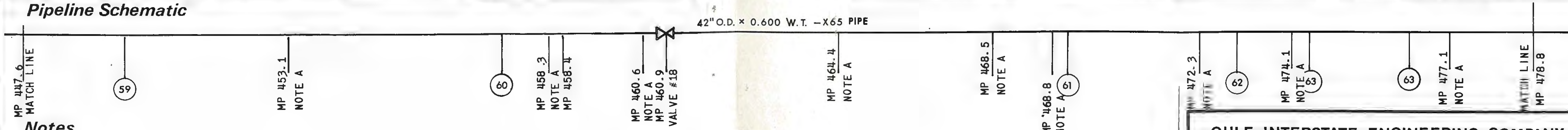


Pipeline Schematic



Notes

A. ROAD CROSSING 42" O.D. X 0.675 W.T.-X65 PIPE
59. ENGINEER CREEK CROSSING MP 449.6
60. CHENA (AVER) RIVER CROSSING MP 457.5
61. MOOSE CREEK CROSSING MP 468.9
62. FRENCH CREEK CROSSING MP 472.6
63. FRENCH CREEK CROSSING MP 474.2
FRENCH CREEK CROSSING MP 476.5

GULF INTERSTATE ENGINEERING COMPANY

Alcan Pipeline Company

42" GAS LINE ROUTE
MP 447.6 TO MP 478.8

DRWN.	SCALE 1" = 2 Miles	DATE June 20/76
APPRVD.	DRWG. NO. APC-B9-16	REV. NO.

Geotechnical Description	SOILS ALMOST WHOLLY CONSIST OF PERENNIALLY FROZEN SILT. THE LINE CROSSES A SMALL AREA OF WIND-DEPOSITED SILT AND TWO NARROW STRIPS OF STREAM ALLUVIUM IN FRENCH CREEK AND THE LITTLE SALCHA RIVER. BEDROCK OCCURS AT SHALLOW DEPTH IN SMALL STREAM VALLEYS.	BEDROCK IS PRESENT AT HIGHER ELEVATIONS WITH PERENNIALLY FROZEN SILTS IN THE LOWER ELEVATIONS. ALSO OCCURRING IS A LOCALIZED AREA OF WIND-DEPOSITED SILT. COARSE GRAVELLY ALLUVIUM OCCURS IN THE FLOOD PLAIN OF THE SALCHA RIVER, WHILE FINE ALLUVIUM IS FOUND IN REDMOND CREEK.
Terrain	GENTLY SLOPING ALLUVIAL FANS & COLLUVIAL SLOPES. BIRCH & SPRUCE TIMBER. PERMAFROST DEPTH FROM 1 TO 4 FEET GENERALLY, BUT CAN BE AS DEEP AS 20 FEET. SOME OCCURENCES OF ICE LENSES AND MASSES.	MODERATE TO STEEP SLOPES IN BEDROCK AREAS AND GENTLE SLOPES IN THE SILT-COVERED LOWLANDS. SPRUCE & BIRCH VEGETATION. PERMAFROST THROUGHOUT MOST OF AREA AT DEPTHS OF 2 TO 4 FEET. ABSENT UNDER BED OF SALCHA RIVER.

LEGEND

- ALYESKA/STATE HAUL ROAD
- ALYESKA OIL PIPELINE
- ALCAN PIPELINE
- GAS FUEL LINE
- ▲ BORROW PIT

SEISMICITY – REPORTED MAXIMUM PROBABLE EARTHQUAKE MAGNITUDE OF 7.5.

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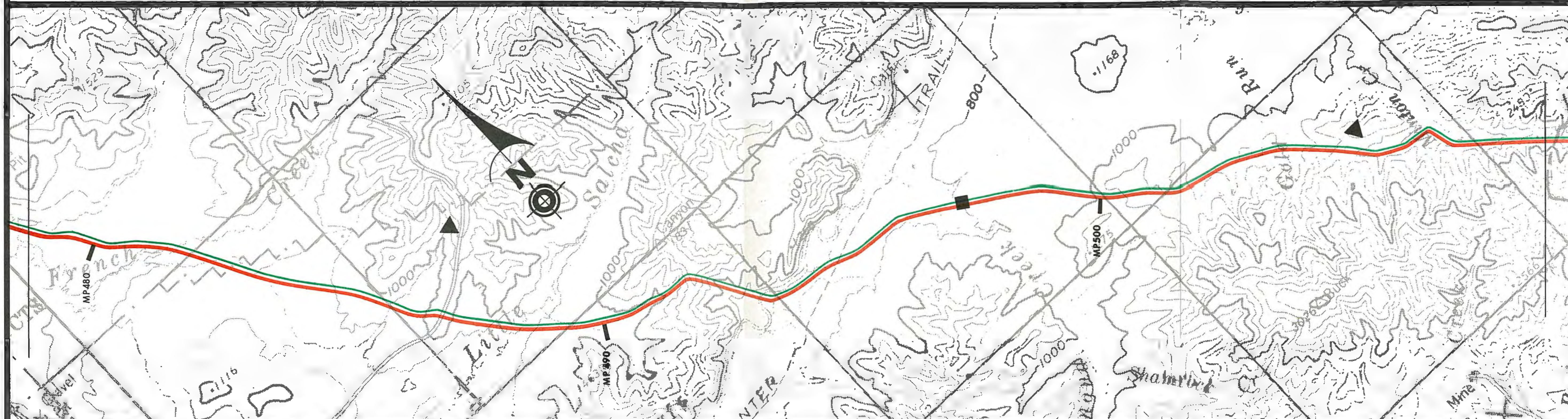

Pipeline Schematic

42" O.D. × 0.600 W.T. -X65 PIPE

MATCH LINE MP 478.8 — MP 479.1 VALVE #19 — 63 — MP 486.9 NOTE A — 64 — 65 — 66 — MP 497.4 COMP. STA. #11 — 67 — MATCH LINE MP 509.3

Notes

A. ROAD CROSSING 42" O.D. X 0.675 W.T.-X65 PIPE

63. FRENCH CREEK CROSSING MP 481.6
64. LITTLE SALCHA RIVER CROSSING MP 488.4
65. SALCHA RIVER CROSSING MP 493.3
66. REDMOND CREEK CROSSING MP 497.1
67. GOLD RUN CREEK CROSSING MP 503.8

GULF INTERSTATE ENGINEERING COMPANY

Alcan Pipeline Company

42" GAS LINE ROUTE

MP 478.8 TO MP 509.3

DRWN.	SCALE 1" = 2 Miles	DATE June 20/76
APPRVD.	DRWG. NO. APC-B9-17	REV. NO.

Geotechnical Description	THIS IS A SECTION OF FINE GRAINED, POORLY DRAINED SOILS. SOIL UNITS UNDERLYING THE LINE CONSIST OF PERENNIALLY FROZEN SILT, WIND DEPOSITED SILT AND DUNE SAND. THESE IN TURN ARE UNDERLAIN BY SANDY GRAVELS AND GRAVELS.
Terrain	GENTLY SLOPING TO FLAT TERRAIN. EXTENSIVE SWAMPY TERRAIN IN THE SHAW CREEK FLATS AREA. PERMAFROST PREVALENT BUT DISCONTINUOUS IN THIS AREA; OCCURS AT DEPTHS OF 2 TO 4 FEET IN MUCH OF THE AREA.

LEGEND
- ALYESKA/STATE HAUL ROAD
- ALYESKA OIL PIPELINE
- ALCAN PIPELINE
- GAS FUEL LINE
- BORROW PIT

SEISMICITY – REPORTED MAXIMUM PROBABLE EARTHQUAKE MAGNITUDE OF 7.5. CLEARWATER LAKE FAULT ZONE IMMEDIATLY SOUTH OF BIG DELTA HAS NORTHWESTERLY TREND.

BEDROCK CONSISTING OF QUARTZ-FELDSPAR-BIOTITE GNEISS OUTCROPS ON THE NORTH BANK OF THE TANANA RIVER.

ALCAN PIPELINE COMPANY
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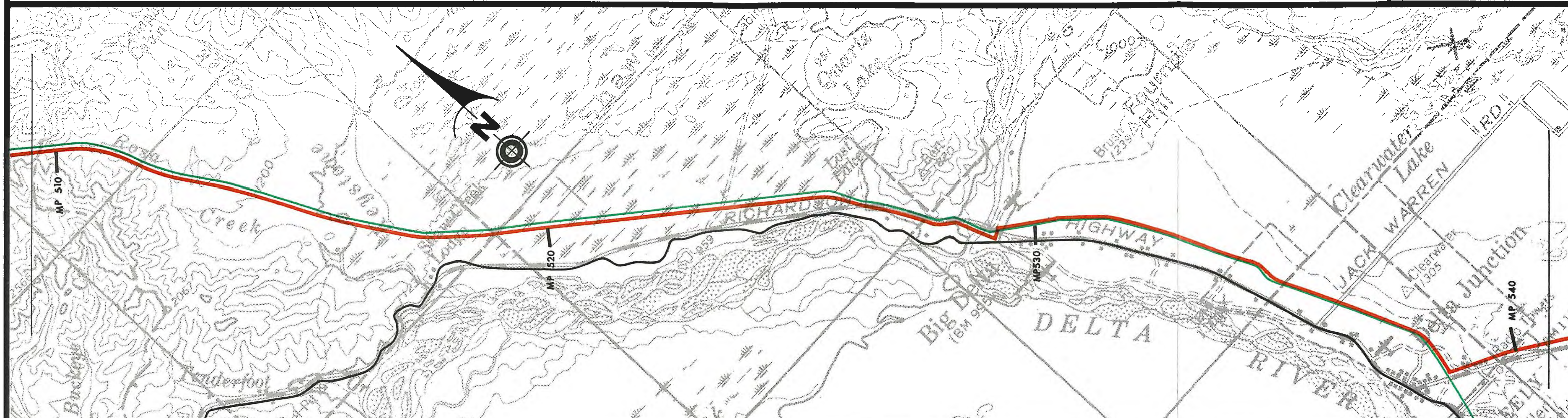

Pipeline Schematic

42" O.D. × 0.600 W.T. - X65 PIPE

MATCH LINE MP 509.3 — MP 512.8 VALVE #20 — (68) — MP 526.7 NOTE A — MP 528.2 VALVE #21 — (69) — MP 529.5 NOTE A — MP 538.8 — HAINES PIPE LINE R.O.W. — MATCH LINE MP 540.7

Notes

A. ROAD CROSSING 42" O.D. X 0.675 W.T.-X65 PIPE

68. SHAW CREEK CROSSING MP 517.7
69. TANANA RIVER CROSSING MP 528.8

GULF INTERSTATE ENGINEERING COMPANY

Alcan Pipeline Company

42" GAS LINE ROUTE
MP 509.3 TO MP 540.7

DRWN.	SCALE 1" = 2 Miles	DATE June 20/76
APPRVD.	DRWG. NO. APC-B9-18	REV. NO.

Geotechnical Description	SOILS CONSIST MAINLY OF WELL DRAINED GLACIO-FLUVIAL GRAVELS AND MORAINE DEPOSITS. MAY CONTAIN SHALLOW PEAT AND SILT BOGS IN ABANDONED DRAINAGE CHANNELS.	FAN APRON CONSISTS OF POORLY STRATIFIED PEBBLE TO BOULDER GRAVELS, DEVELOPED BY COALESCING ADJACENT ALLUVIAL FANS FROM ADJACENT UPLANDS. A THIN SILT OR SAND MANTLE MAY OCCUR OVER THE GRAVELS.	GLACIO FLUVIAL DEPOSITS AND STREAM TERRACE DEPOSITS. MAINLY GRAVEL AND SAND.
Terrain	GENTLY SLOPING TERRAIN CHARACTERISTIC OF AN OUTWASH APRON. BIRCH AND SPRUCE TIMBER.	GENTLY SLOPING TOPOGRAPHY. BIRCH AND SPRUCE VEGETATION. DISCONTINUOUS PERMAFROST AREA. PERMAFROST GENERALLY AT A DEPTH OF 20 FEET, EXCEPT IN BOGS WHERE SILT COVER IS THICK. LOW GROUND ICE.	GENTLY SLOPING BIRCH AND SPRUCE FOREST. SPORADIC PERMAFROST.

LEGEND
- ALYESKA/STATE HAUL ROAD
- ALYESKA OIL PIPELINE
- ALCAN PIPELINE
- GAS FUEL LINE
- BORROW PIT

SEISMICITY – REPORTED MAXIMUM PROBABLE EARTHQUAKE MAGNITUDE OF 7.5.

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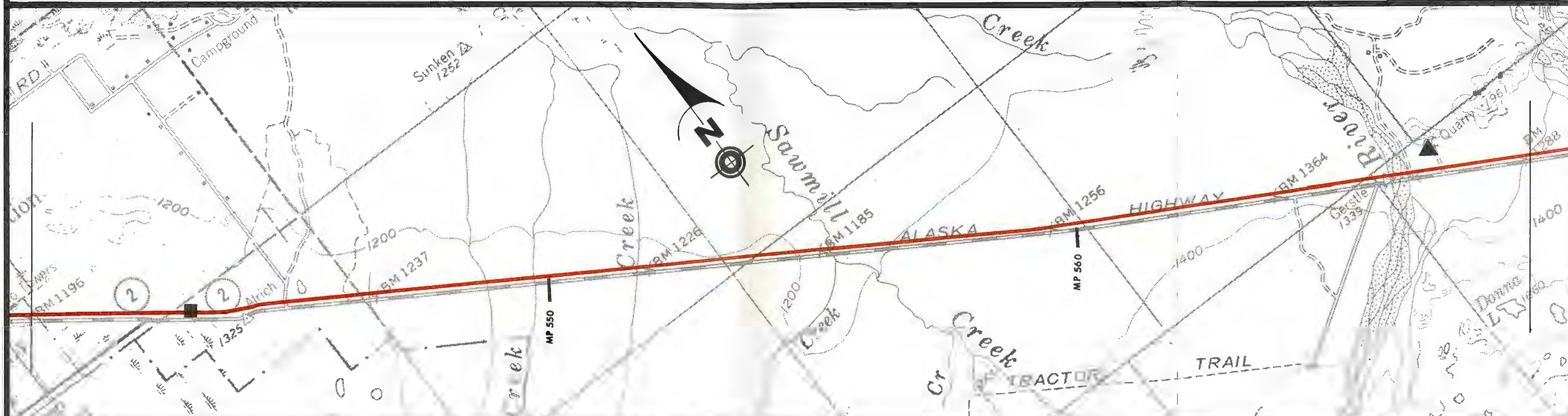
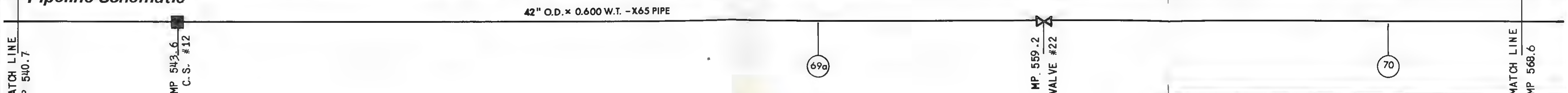


Pipeline Schematic



Notes

69a. SAWMILL CREEK CROSSING MP 555.2
70. GERSTLE RIVER CROSSING MP 566.0

GULF INTERSTATE ENGINEERING COMPANY		
Alcan Pipeline Company		
42" GAS LINE ROUTE MP 540.7 TO MP 568.6		
DRWN.	SCALE 1" = 2 Miles	DATE June 20/76
APPRVD.	DRWG. NO. APC-B9-19	REV. NO.

Geotechnical Description	GLACIO-FLUVIAL DEPOSITS AND STREAM-TERRACE DEPOSITS. MAINLY GRAVEL AND SAND.	MORAINE DEPOSITS HETEROGENEOUS MIXTURE OF BOULDERS, GRAVEL, SAND AND SILT-LOCALLY CONTAINS CLEAN GRAVEL.	MAINLY CLEAN GRAVELS OF GLACIO FLUVIAL AND ALLUVIAL FAN ORIGIN. GENERALLY GOOD SURFACE AND SUBSURFACE DRAINAGE. BED OF JOHNSON RIVER IS COMPRISED OF GRAVEL AND SAND, ALSO, LOCALIZED PEAT DEPOSIT WEST OF SCARS CREEK.	SILT AND PEAT DEPOSITS IN CONTACT WITH GRANITE BEDROCK OUTCROP.	CLEAN, WELL-DRAINED ALLUVIAL GRAVELS.
Terrain	GENTLY SLOPING. FORESTED WITH BIRCH AND SPRUCE. SPORADIC PERMAFROST.	UNDULATING KNOB AND KETTLE TOPOGRAPHY. BIRCH AND SPRUCE TIMBER. SPORADIC PERMAFROST.	GENTLY SLOPING TERRAIN. MODERATE TO HEAVY MIXED BIRCH, SPRUCE AND BALSAM POPLAR TIMBER. DISCONTINUOUS PERMAFROST. ACTIVE LAYER OF 8 TO 10 FEET. GENERALLY LOW IN GROUND ICE.	MODERATE TO STEEP SLOPES IN BEDROCK NOSE. PERMAFROST WITHIN 8 FEET IN PEAT BAG.	FLAT TO GENTLY SLOPING. HEAVY BIRCH AND SPRUCE TIMBER. DISCONTINUOUS THAW-STABLE PERMAFROST.

LEGEND

- ALYESKA/STATE HAUL ROAD
- ALYESKA OIL PIPELINE
- ALCAN PIPELINE
- GAS FUEL LINE
- ▲ BORROW PIT

SEISMICITY — REPORTED MAXIMUM PROBABLE EARTHQUAKE MAGNITUDE OF 7.5.

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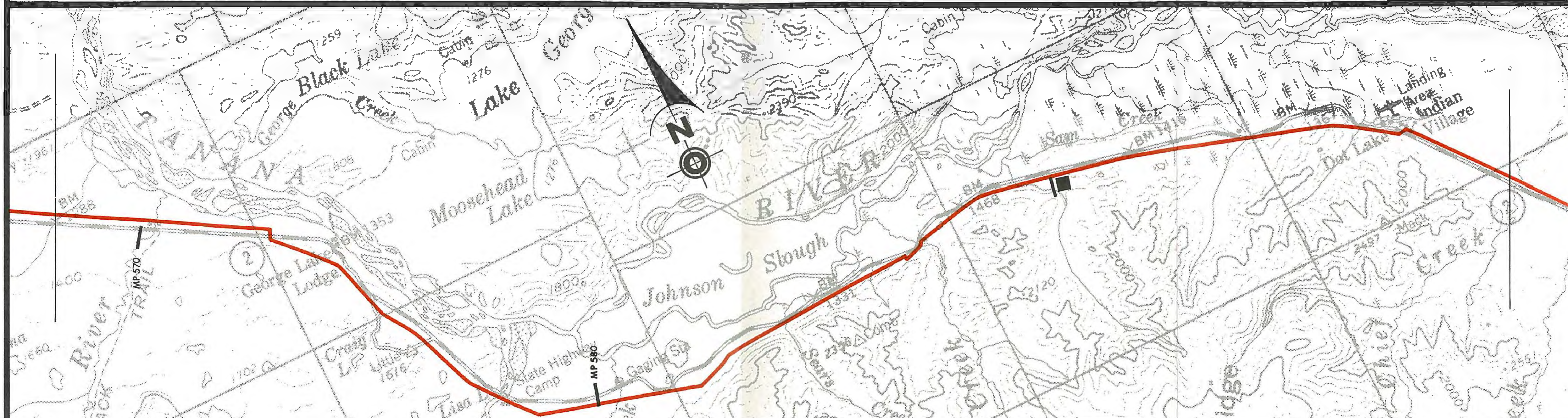

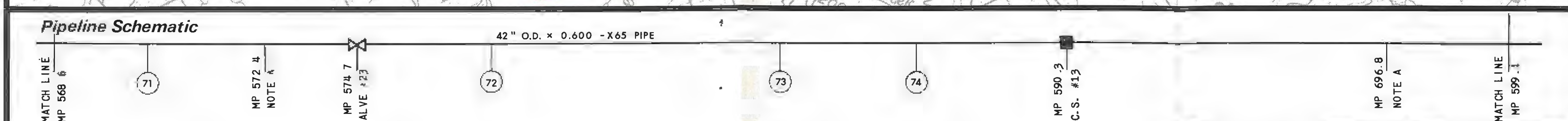

Notes

A. ROAD CROSSING 42" O.D. X 0.675-X65 PIPE

71 LITTLE GERSTLE RIVER CROSSING MP 570.2
72. JOHNSON RIVER CROSSING MP 578.0
73. SEARS CREEK CROSSING MP 584.1
74. BERRY CREEK CROSSING MP 587.2

GULF INTERSTATE ENGINEERING COMPANY

Alcan Pipeline Company

42" GAS LINE ROUTE
MP 568.6 TO MP 599.1

DRWN.	SCALE 1" = 2 Miles	DATE June 20/76
APPRVD.	DRWG. NO. APC-B9-20	REV. NO.

Geotechnical Description	CLEAN OUTWASH GRAVELS. GOOD SURFACE AND SUBSURFACE DRAINAGE. NARROW SILT AND PEAT CHANNEL AT BM 1585.	PREDOMINANTLY MORAINE DEPOSITS OF DONNELLY & DELTA GLACIATIONS. MIXTURE OF BOULDERS, GRAVEL, SAND AND SILT. MINOR SILT AND PEAT IN CLOSED DEPRESSIONS.	THIS PORTION OF THE LINE CONSISTS PREDOMINANTLY OF FREE DRAINING ALLUVIAL FAN GRAVELS. GENERALLY EXCELLENT FOUNDATION SOILS. THE LINE CROSSES A SMALL SECTION OF GLACIOFLUVIAL DEPOSITS (BOULDERS, GRAVEL, SAND & SILT) EAST OF YERRICK CREEK. IMMEDIATLY WEST OF MOON LAKE THE LINE CROSSES SILT AND PEAT.
Terrain	GENTLY SLOPING TERRAIN INTERRUPTED BY MINOR DRAINAGES. DISCONTINUOUS PERMAFROST - THAW STABLE.	IRREGULAR KNOB & KETTLE TOPOGRAPHY MODIFIED BY POST-GLACIAL EROSION. DISCONTINUOUS PERMAFROST. MAY CONTAIN ICE SEGREGATIONS.	GENTLY SLOPING TERRAIN WHICH IS INTERRUPTED BY MANY DRAINAGE CHANNELS FLOWING TO THE TANANA RIVER. MIXED BIRCH AND SPRUCE TIMBER. DISCONTINUOUS PERMAFROST. MATERIAL IS THAW-STABLE WITH LOW GROUND ICE.

LEGEND

- ALYESKA/STATE HAUL ROAD
- ALYESKA OIL PIPELINE
- ALCAN PIPELINE
- GAS FUEL LINE
- ▲ BORROW PIT

SEISMICITY - FAULT TRENDING NORTHEASTERLY IN THE VICINITY OF CATHEDRAL BLUFFS, IS CONCEALED BENEATH GLACIAL AND POST GLACIAL DEPOSITS. MAXIMUM REPORTED PROBABLE EARTHQUAKE MAGNITUDE OF 7.5.

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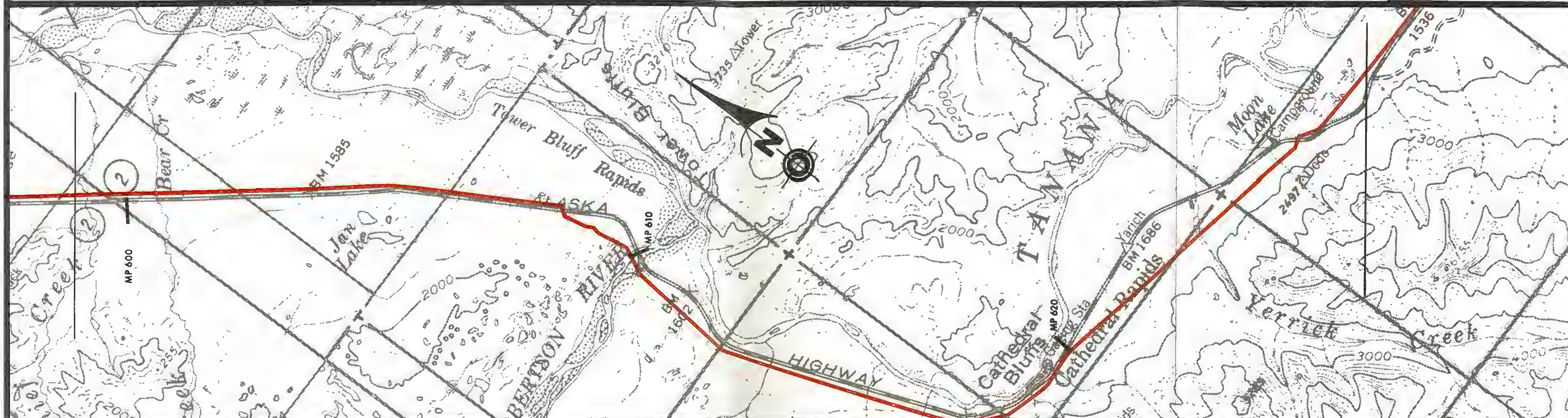
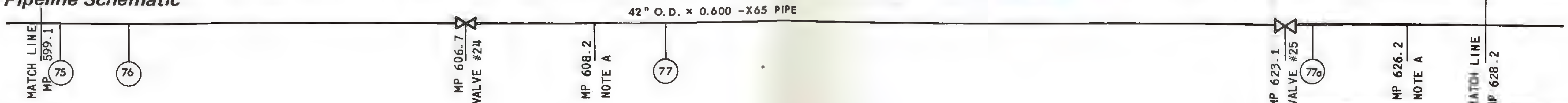


Pipeline Schematic



Notes

A. ROAD CROSSING 42" O.D. X 0.675 W.T.-X65

75. CHIEF CREEK CROSSING MP 599.2
76. BEAR CREEK CROSSING MP 600.6
77. ROBERTSON RIVER MP 610.0
77a. YERRICK CREEK CROSSING MP 623.4

GULF INTERSTATE ENGINEERING COMPANY

Alcan Pipeline Company

42" GAS LINE ROUTE
MP 599.1 TO MP 628.2

DRWN.	SCALE 1" = 2 Miles	DATE June 20/76
APPRVD.	DRWG. NO. APC-B9-21	REV. NO.

Geotechnical Description

SOILS IN THIS SECTION CONSIST PREDOMINANTLY OF CLEAN ALLUVIAL FAN GRAVELS. THESE ARE EXCELLENT FOUNDATION SOILS WITH GOOD SURFACE AND INTERNAL DRAINAGE. THE LINE CROSSES APPROXIMATELY 2 MILES OF SILT AND PEAT SOILS WEST OF TANACROSS.

Terrain

GENTLY SLOPING ALLUVIAL OR FAN APRON TERRAIN. TOPOGRAPHY INTERRUPTED BY SCATTERED STREAMS FLOWING NORTHERLY INTO THE TANANA RIVER. MIXED BIRCH AND SPRUCE TIMBER. WELL DRAINED.

DISCONTINUOUS PERMAFROST ZONE. MATERIAL IS THAW STABLE AND CONTAINS LITTLE GROUND ICE.

LEGEND

- ALYESKA/STATE HAUL ROAD
- ALYESKA OIL PIPELINE
- ALCAN PIPELINE
- GAS FUEL LINE
- ▲ BORROW PIT

SEISMICITY – NO REPORTED FAULTS. EARTHQUAKES OF MAGNITUDE 6 OR GREATER HAVE NOT BEEN RECORDED IN THIS AREA, ALTHOUGH SOME SMALLER SHOCKS HAVE OCCURED.

ALCAN PIPELINE COMPANY
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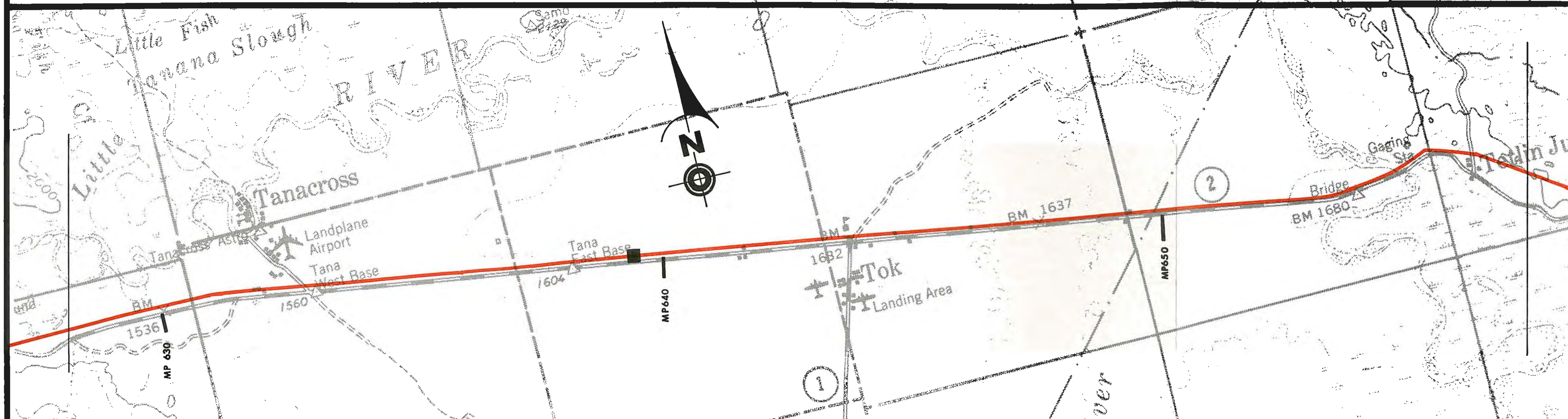
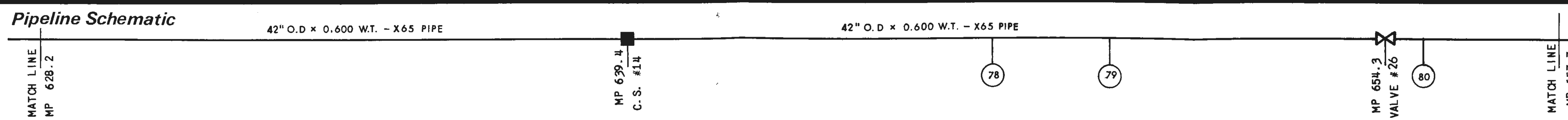


Pipeline Schematic



Notes

78. CREEK CROSSING MP 646.5
79. TOK RIVER CROSSING MP 648.6
80. TANANA RIVER CROSSING MP 654.7

GULF INTERSTATE ENGINEERING COMPANY		
Alcan Pipeline Company		
42" GAS LINE ROUTE MP 628.2 TO MP 657.7		
DRWN.	SCALE 1" = 2 Miles	DATE June 20/76
APPRVD.	DRWG. NO. APC-B9-22	REV. NO.

Geotechnical Description	WIND-DEPOSITED MEDIUM TO FINE-GRAINED SAND IN STABILIZED DUNES.	THIS SECTION OF LINE CROSSES AN AREA OF IGNEOUS & METAMORPHIC BEDROCK. SAND DUNES OCCUR ON TOP OF THE BEDROCK ALONG ABOUT 75% OF THE ROUTE. THE BEDROCK CONSISTS OF GRANODIORITE, SCHIST AND QUARTZITE. THE SAND DUNES, MOSTLY STABILIZED, CONSIST OF MEDIUM TO FINE-GRAINED SAND.
Terrain	GENTLY UNDULATING SAND DUNE TERRAIN. LIGHT TO MEDIUM VEGETATION-DISCONTINUOUS PERMAFROST-6' TO 8' DEEP.	GENTLY SLOPING TERRAIN. BIRCH AND SPRUCE TIMBER. DISCONTINUOUS PERMAFROST ZONE. LOW ICE-CONTENT SOILS. THAW STABLE. SEISMICITY - THREE PARALLEL SOUTHEASTERLY TRENDING FAULTS REPORTED NORTH OF MIDWAY LAKE. TWO SMALL FAULTS ROUGHLY PARALLEL AND NORTH OF THE HIGHWAY, BETWEEN BITTERS CREEK AND BEAVER CREEK. NO RECORDED EARTHQUAKES MAGNITUDE 6 OR ABOVE HAVE BEEN REPORTED ALTHOUGH SOME SMALLER SHOCKS HAVE OCCURED.

LEGEND

- ALYESKA/STATE HAUL ROAD
- ALYESKA OIL PIPELINE
- ALCAN PIPELINE
- GAS FUEL LINE
- BORROW PIT

ALCAN PIPELINE COMPANY
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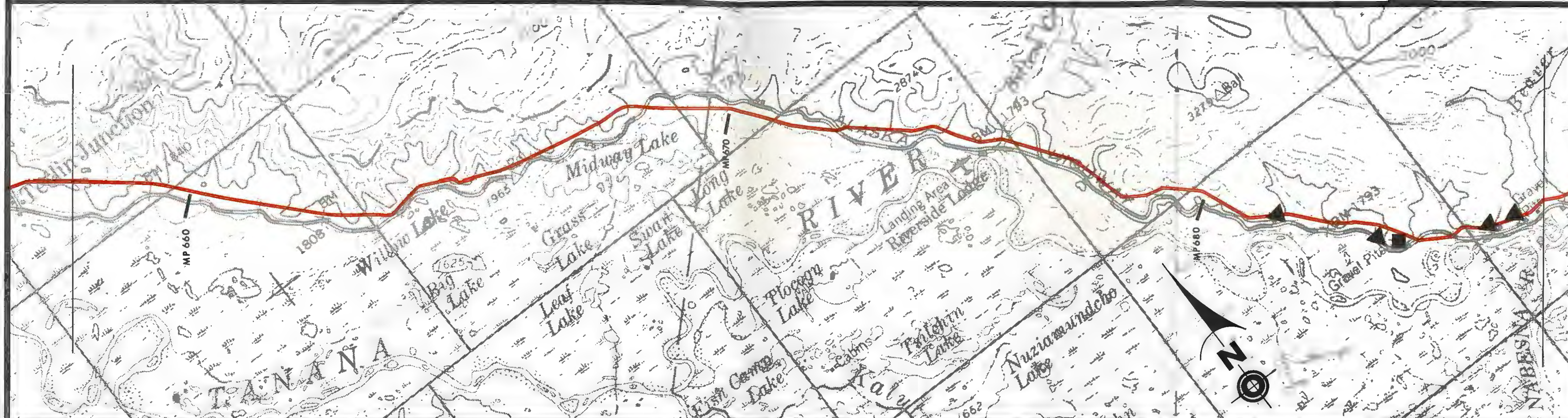

Pipeline Schematic

42" O.D. × 0.600 W.T. -X65 PIPE

42" O.D × 0.600 W.T. - X65 PIPE

MATCH LINE MP 657.7

MP 668.4 NOTE A

MP 669.2 VALVE #27

MP 672.3 NOTE A

81

C.S. #15 MP 684.1

MP 684.5 NOTE A

MP 685.1 NOTE A

MATCH LINE MP 687.2

Notes

A. ROAD CROSSING 42" O.D. X 0.675 W.T.-X65 PIPE

81. BITTERS CREEK CROSSING MP 675.7

GULF INTERSTATE ENGINEERING COMPANY		
Alcan Pipeline Company		
42" GAS LINE ROUTE MP 657.7 TO MP 687.2		
DRWN.	SCALE 1" = 2 Miles	DATE June 20/76
APPRVD.	DRWG. NO. APC-B9-23	REV. NO.

Geotechnical Description

THIS SECTION OF THE LINE HAS NUMEROUS BEDROCK OUTCROPS WITH ALLUVIUM AND COLLUVIUM IN SMALL STREAM VALLEYS AND COLLUVIAL APRONS. ALLUVIUM AND COLLUVIUM CONSIST OF GRAVEL, SAND, SILT AND ROCK RUBBLE. BEDROCK CONSISTS PRIMARILY OF GRANITIC ROCKS, MOSTLY GRANODIORITE.

Terrain

MODERATE TO GENTLE SLOPES. HEAVILY FORESTED WITH BIRCH, SPRUCE AND BALSAM POPLAR.

DISCONTINUOUS PERMAFROST ZONE. SHALLOW DEPTH TO PERMAFROST TABLE ON NORTH-FACING SLOPES. SEASONAL FROST PENETRATION TO 16 FEET.

SEISMICITY - NO RECORDED EARTHQUAKES OF MAGNITUDE 6 OR ABOVE HAVE BEEN REPORTED ALTHOUGH SOME SMALLER SHOCKS HAVE OCCURED.

LEGEND

- ALYESKA/STATE HAUL ROAD
- ALYESKA OIL PIPELINE
- ALCAN PIPELINE
- GAS FUEL LINE
- BORROW PIT

ALCAN PIPELINE COMPANY	
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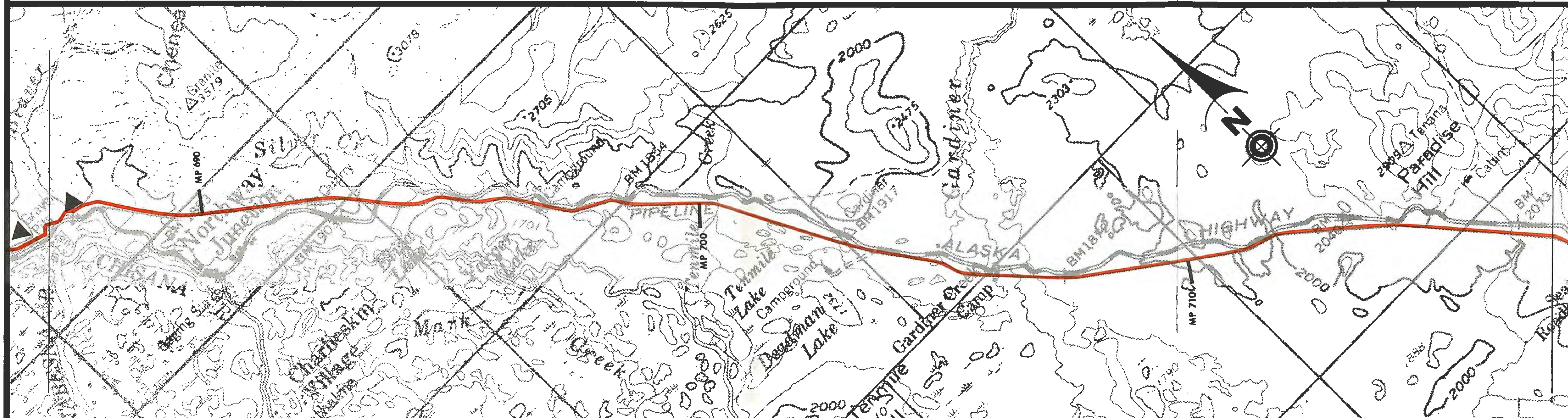
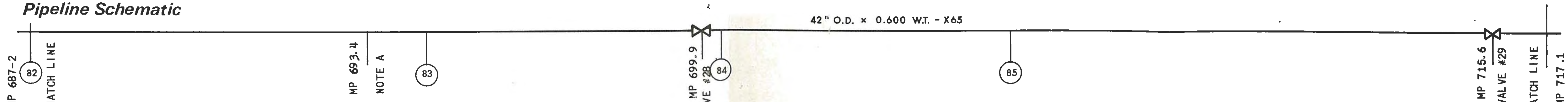


Pipeline Schematic



Notes

NOTE A. ROAD CROSSING 42"O.D. X 0.675 W.T.-X65

82. BEAVER CREEK CROSSING MP 687.2
83. SILVER CREEK CROSSING MP 694.7
84. TENMILE CREEK CROSSING MP 700.4
85. GARDNER CREEK CROSSING MP 715.6

GULF INTERSTATE ENGINEERING COMPANY		
Alcan Pipeline Company		
42" GAS LINE ROUTE MP 687.2 TO MP 717.1		
DRWN.	SCALE 1" = 2 Miles	DATE June 20/76
APPRVD.	DRWG. NO. APC-B9-24	REV. NO.

Geotechnical Description	BEDROCK OUTCROPS, COLLUVIUM AND STREAM ALLUVIUM. DEEP ALLUVIAL SOILS IN DESPER CREEK AND SCOTTIE CREEK AREAS. BEDROCK IS MAINLY GRANODIORITE.
Terrain	MODERATE SLOPES ON BEDROCK HILLS WITH FLAT LOW-LYING AREAS BETWEEN THEM. DISCONTINUOUS PERMAFROST ZONE. PERMAFROST SHALLOW ON NORTH-FACING SLOPES. SEISMICITY - NO RECORDED EARTHQUAKES OF MAGNITUDE 6 OR ABOVE HAVE BEEN REPORTED ALTHOUGH SOME SMALLER SHOCKS HAVE OCCURED.

LEGEND

- ALYESKA/STATE HAUL ROAD
- ALYESKA OIL PIPELINE
- ALCAN PIPELINE
- GAS FUEL LINE
- BORROW PIT

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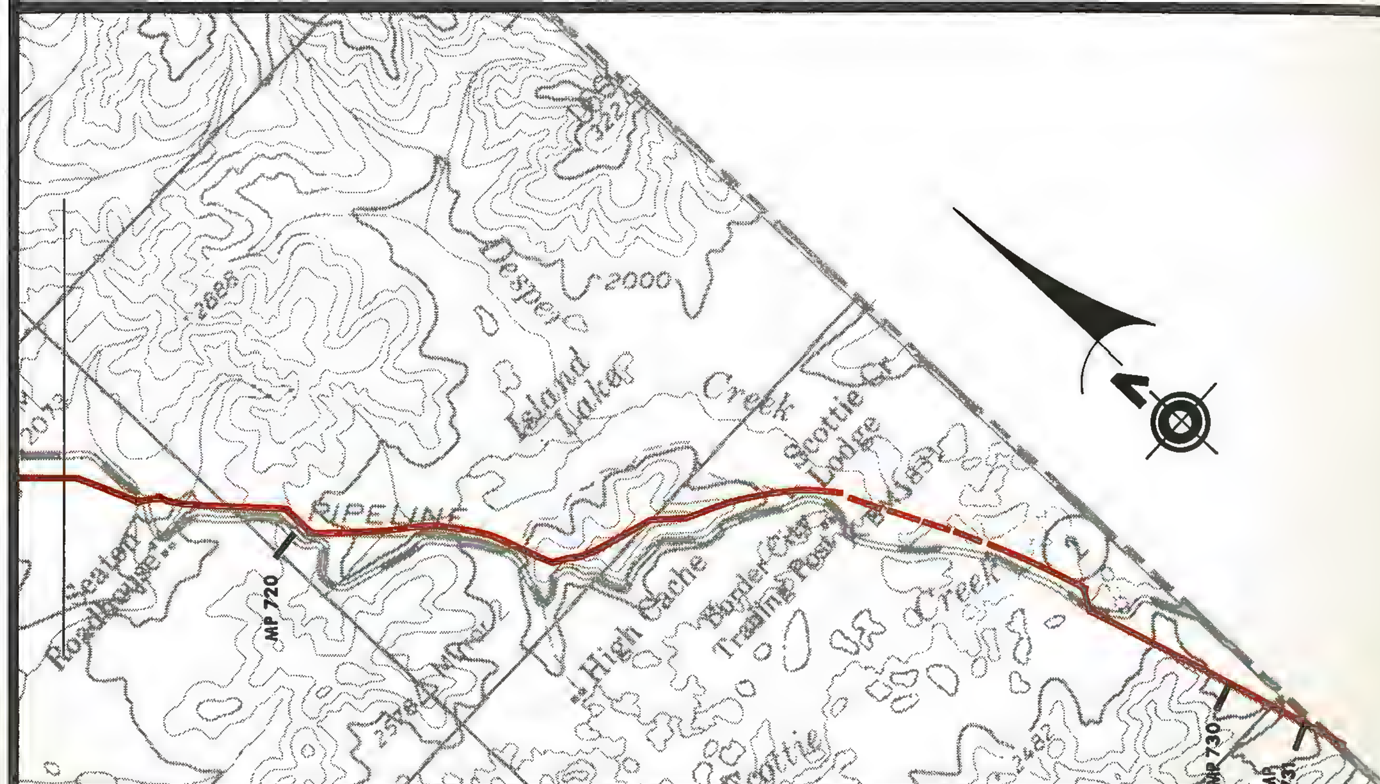
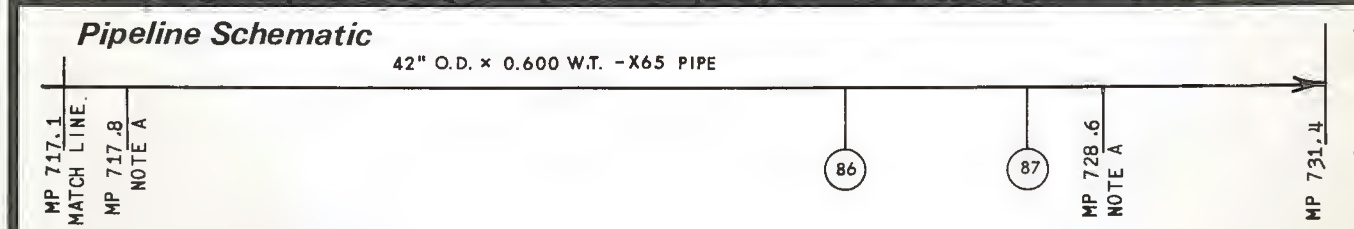


Pipeline Schematic



Notes

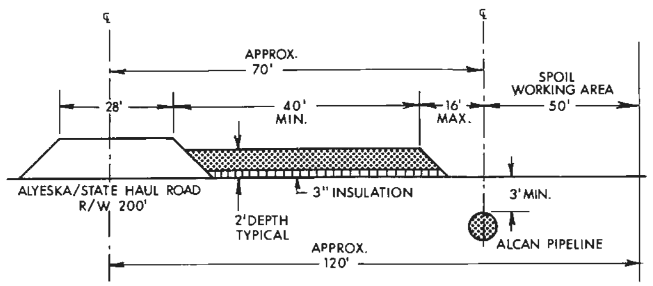
A. ROAD CROSSING 42" O.D. X 0.675 W.T.-X65 PIPE

86. DESPER CREEK CROSSING MP 725.9

87. SCOTTIE CREEK CROSSING MP 727.8

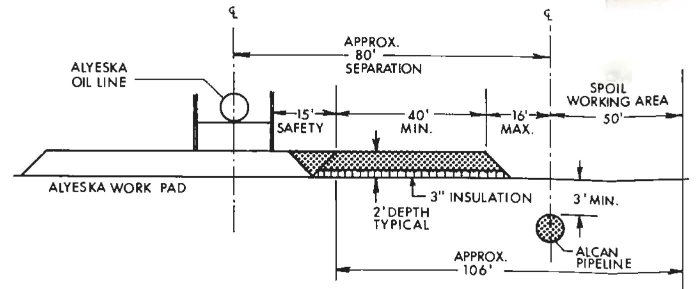
GULF INTERSTATE ENGINEERING COMPANY		
Alcan Pipeline Company		
42" GAS LINE ROUTE MP 717.1 TO MP 731.4		
DRWN.	SCALE 1" = 2 Miles	DATE June 20/76
APPRVD.	DRWG. NO. APC-B9-25	REV. NO.

MODE OF CONSTRUCTION : M1



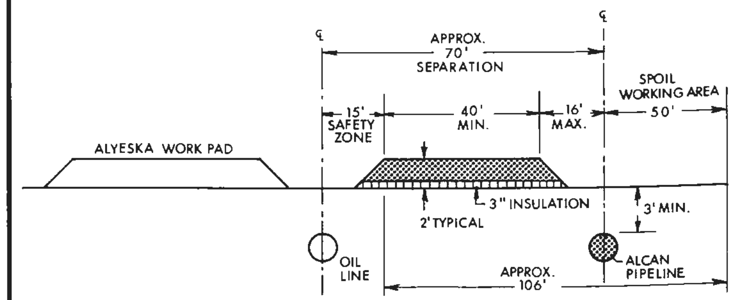
M1: INSULATED WORK PAD ADJACENT TO ALYESKA/STATE HAUL ROAD – NORTH OF THE BROOKS RANGE.

MODE OF CONSTRUCTION : M5



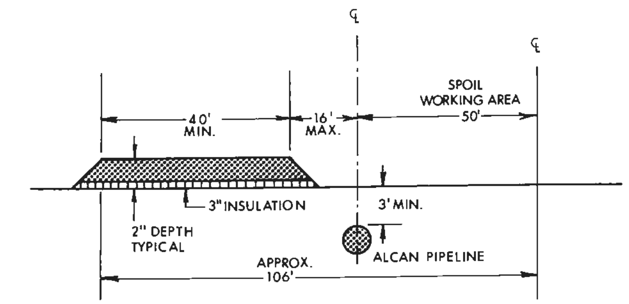
M5: INSULATED WORK PAD ADJACENT TO ELEVATED ALYESKA OIL LINE NORTH OF BROOKS RANGE – SAME SIDE OF WORK PAD AS OIL LINE

MODE OF CONSTRUCTION: M9



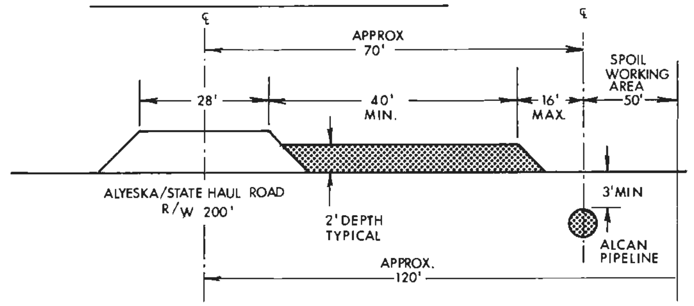
M9: INSULATED WORK PAD ADJACENT TO BURIED OIL LINE, NORTH OF BROOKS RANGE – SAME SIDE OF WORK PAD AS OIL LINE

MODE OF CONSTRUCTION : M11



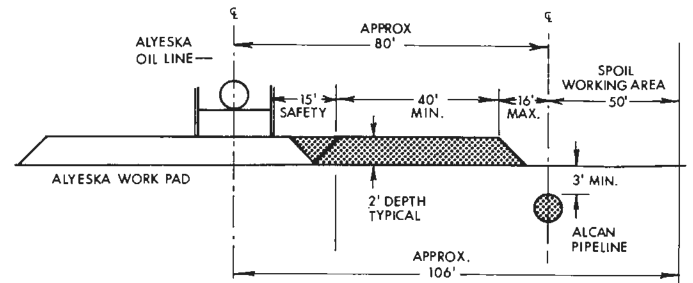
M 11: INSULATED WORK PAD FOR CONSTRUCTION SEPARATE FROM HAUL ROAD AND OIL LINE

MODE OF CONSTRUCTION : M2



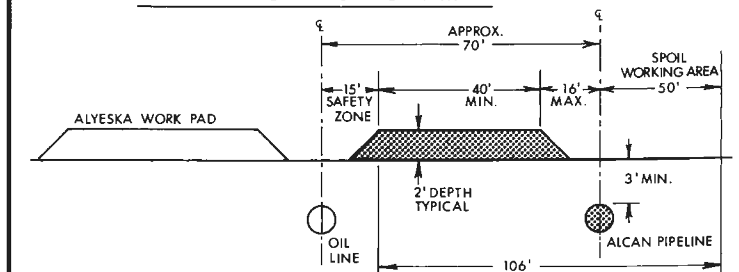
M2: NON – INSULATED WORK PAD ADJACENT TO ALYESKA/STATE HAUL ROAD– SOUTH OF THE BROOKS RANGE

MODE OF CONSTRUCTION : M6



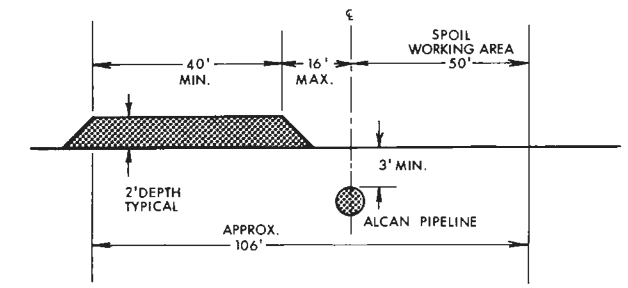
M6: NON-INSULATED WORK PAD ADJACENT TO ELEVATED ALYESKA OIL LINE SOUTH OF BROOKS RANGE – SAME SIDE OF WORK PAD AS OIL LINE

MODE OF CONSTRUCTION : M10



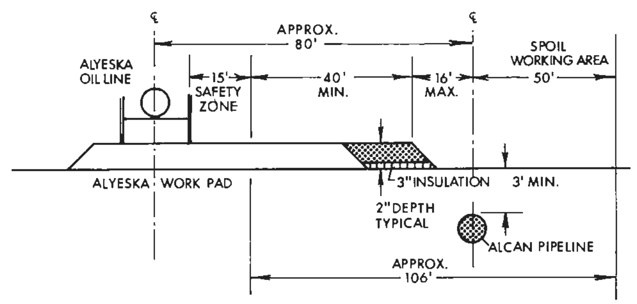
M 10: NON-INSULATED WORK PAD ADJACENT TO BURIED OIL LINE, SOUTH OF BROOKS RANGE – SAME SIDE OF WORK PAD AS OIL LINE

MODE OF CONSTRUCTION : M12



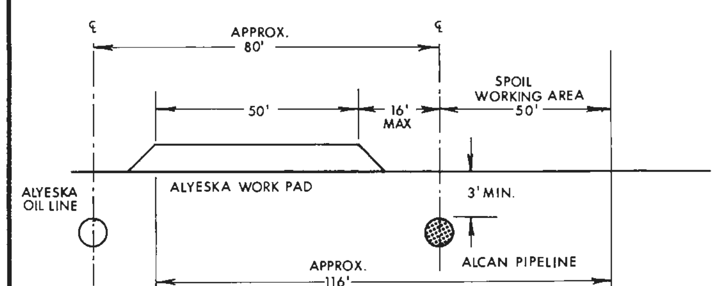
M11 : NON-INSULATED WORK PAD FOR CONSTRUCTION SEPARATE FROM HAUL ROAD AND OIL LINE

MODE OF CONSTRUCTION : M3



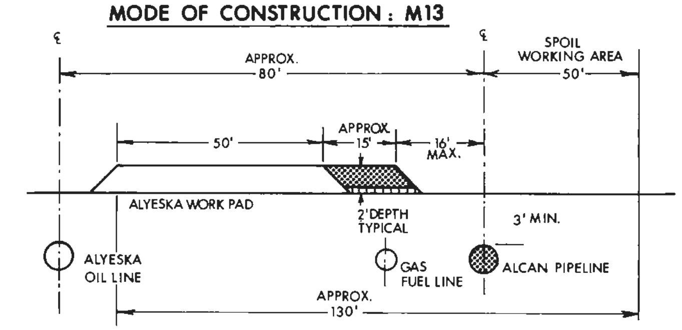
M3: INSULATED WORK PAD ADJACENT TO ELEVATED ALYESKA OIL LINE; NORTH OF BROOKS RANGE – OPPOSITE SIDE OF WORK PAD FROM OIL LINE

MODE OF CONSTRUCTION : M7



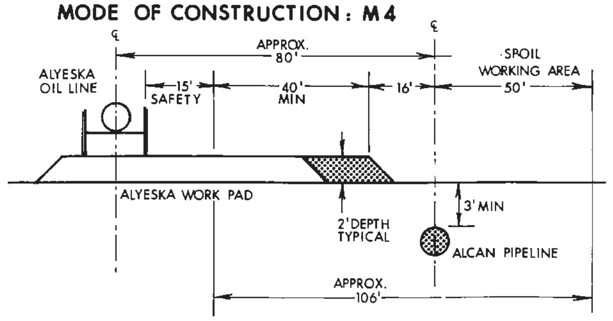
M7: USE OF EXISTING WORK PAD ADJACENT TO THE BURIED POSITIONS OF THE ALYESKA OIL LINE, OPPOSITE SIDE OF ALYESKA PAD

MODE OF CONSTRUCTION : M13



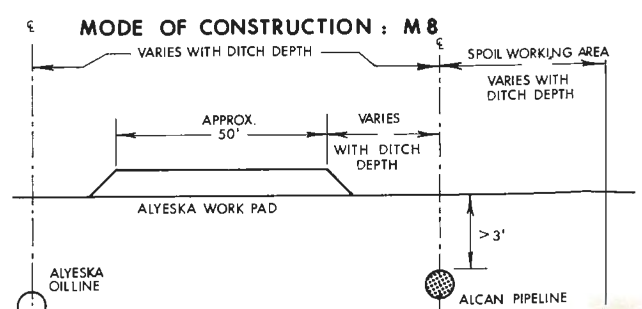
M13: EXISTING WORK PAD ADJACENT TO THE BURIED ALYESKA OIL LINE

MODE OF CONSTRUCTION : M4



M4: NON-INSULATED WORK PAD ADJACENT TO ELEVATED ALYESKA OIL LINE – SOUTH OF BROOKS RANGE OPPOSITE SIDE OF WORK PAD FROM OIL LINE

MODE OF CONSTRUCTION : M8



M8: USE OF EXISTING WORKING PAD ADJACENT TO DEEP- BURIED PORTION OF THE ALYESKA OIL LINE

CONSTRUCTION MODE	PAD REQUIREMENTS YD3/ MILE			
M 1	13,700			
M 2	15,000			
M 3	5,000			
M 4	5,700			
M5	16,900			
M6	19,400			
M7	—			
M8	—			
M9	13,700			
M10	15,600			
M11	13,700			
M12	15,600			
M13	5,100			

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WORK PAD REQUIREMENTS & CONSTRUCTION MODES

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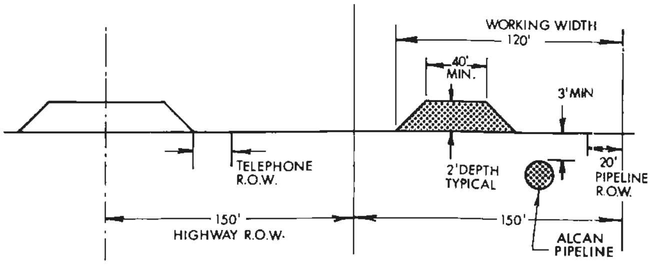
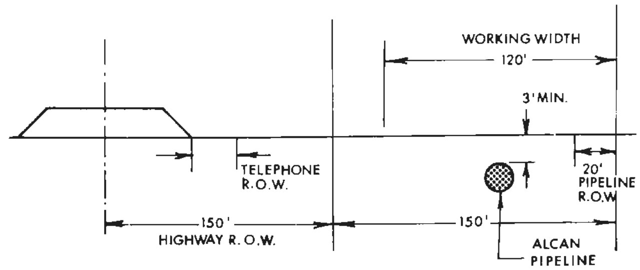
MODE OF CONSTRUCTION: M14



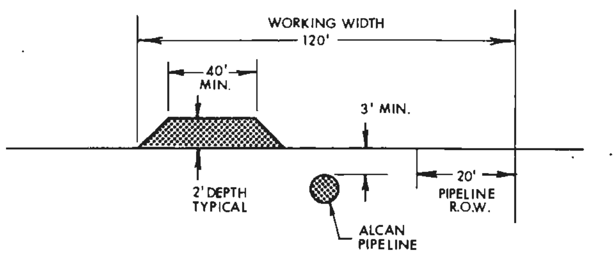
M-14: NON-INSULATED WORK PAD FOR CONSTRUCTION ALONG THE ALCAN HIGHWAY AND HAINES PIPELINE R.O.W.

MODE OF CONSTRUCTION: M15



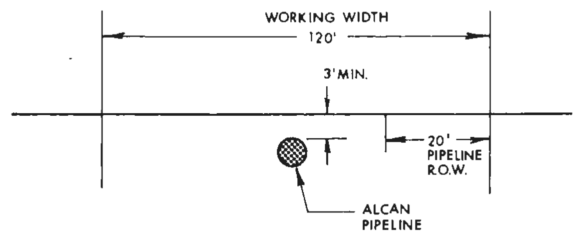
M15: NO WORK PAD FOR CONSTRUCTION ALONG THE ALCAN HIGHWAY AND HAINES PIPELINE R.O.W.

MODE OF CONSTRUCTION: M16



M-16: NON-INSULATED WORK PAD FOR CONSTRUCTION ALONG THE HAINES PIPELINE R.O.W.

MODE OF CONSTRUCTION: M17



M-17: NO WORK PAD FOR CONSTRUCTION ALONG THE HAINES PIPELINE R.O.W.

CONSTRUCTION MODE	PAD REQUIREMENTS YD³/ MILE			
M 14	15,600			
M 15	—			
M 16	15,600			
M 17	—			

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WORK PAD REQUIREMENTS & CONSTRUCTION MODES P-2		
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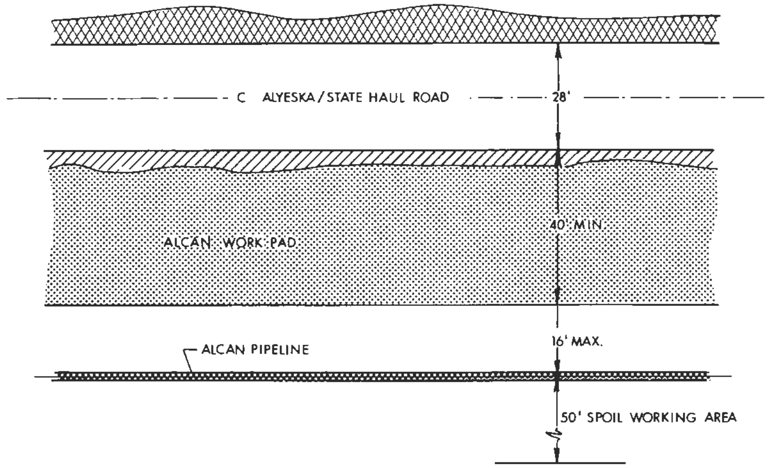
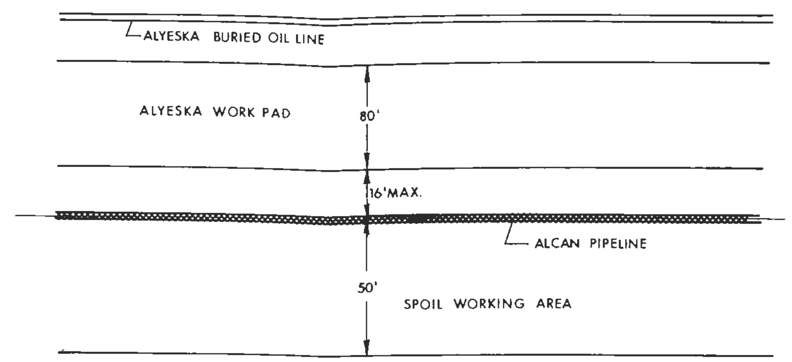
APPRVD.	DRWG NO. APC-59-11	REV. NO.

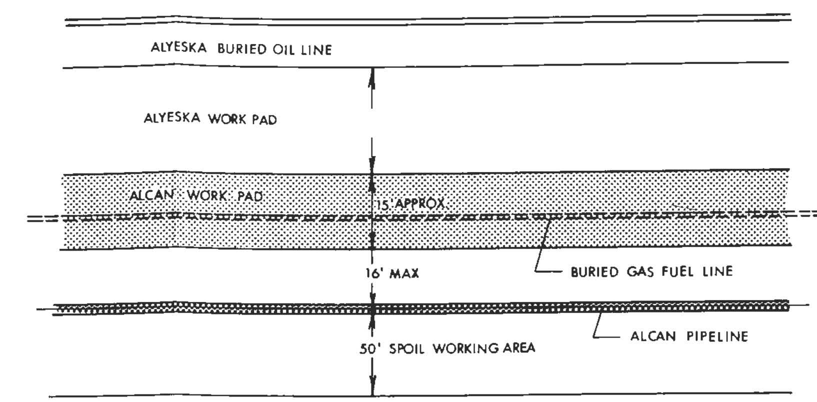
MODE OF CONSTRUCTION M1 & M2
ALCAN PIPELINE PARALLELING HAUL ROAD



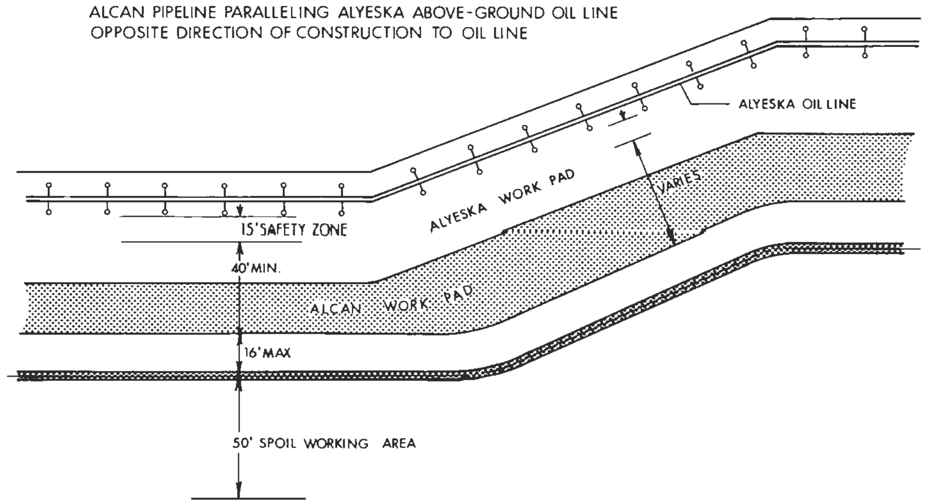
MODE OF CONSTRUCTION M7
USE OF EXISTING ALYESKA WORK PAD ADJACENT TO BURIED OIL LINE – OPPOSITE DIRECTION OF CONSTRUCTION TO OIL LINE



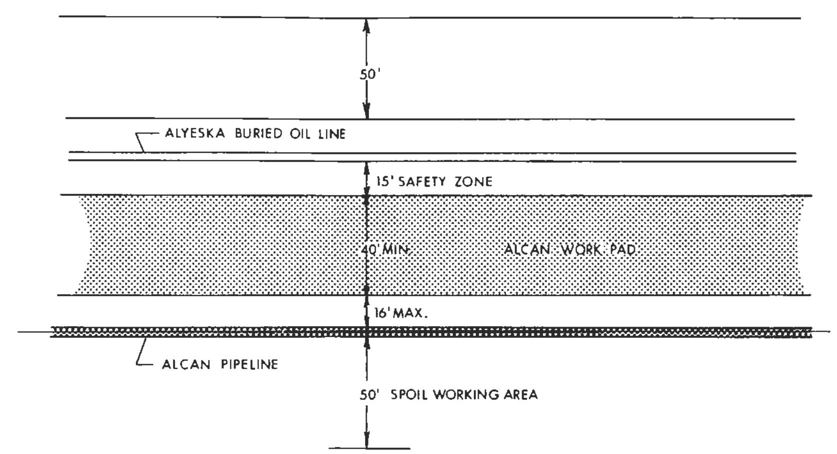
MODE OF CONSTRUCTION M13
USE OF EXISTING ALYESKA WORK PAD ADJACENT TO BURIED OIL LINE ON SAME SIDE OF PAD AS FUEL GAS LINE – OPPOSITE DIRECTION OF CONSTRUCTION TO OIL LINE



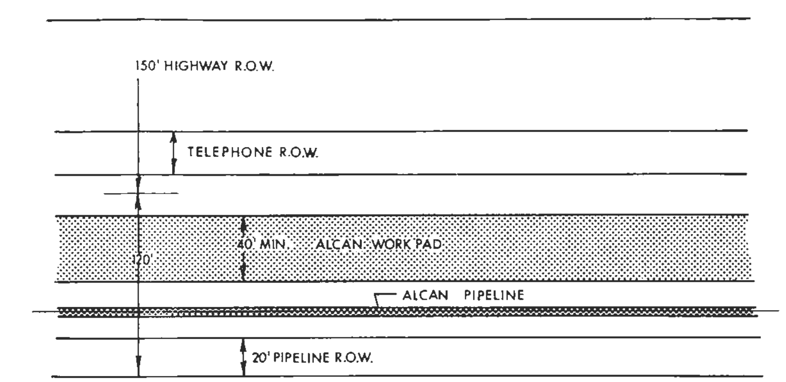
MODE OF CONSTRUCTION M3 & M4
ALCAN PIPELINE PARALLELING ALYESKA ABOVE-GROUND OIL LINE
OPPOSITE DIRECTION OF CONSTRUCTION TO OIL LINE



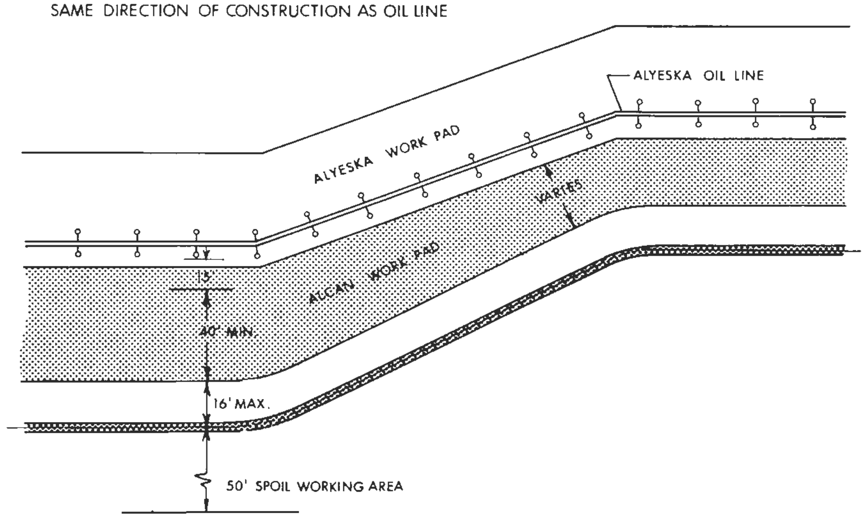
MODE OF CONSTRUCTION M9 & M10
WORK PAD ADJACENT TO BURIED OIL LINE
SAME DIRECTION OF CONSTRUCTION AS OIL LINE



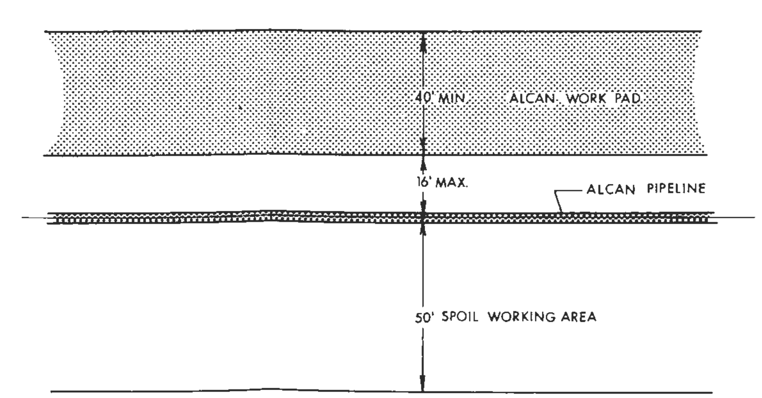
MODE OF CONSTRUCTION M14



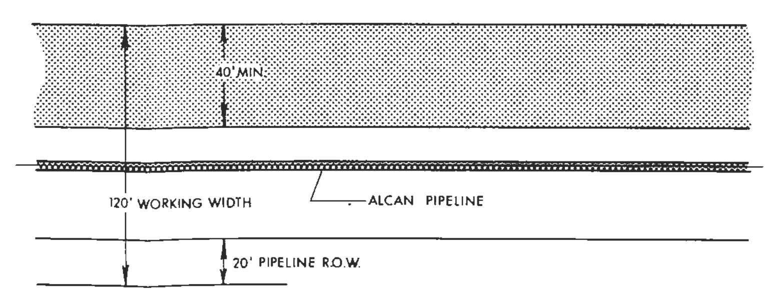
MODE OF CONSTRUCTION M5 & M6
ALCAN PIPELINE PARALLELING ALYESKA ABOVE-GROUND OIL LINE
SAME DIRECTION OF CONSTRUCTION AS OIL LINE



MODE OF CONSTRUCTION M11 & M12
CONSTRUCTION SEPARATE FROM WORK PAD



MODE OF CONSTRUCTION M16



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APPRVD.	DRWG. NO. APC-S9-12	REV. NO.

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Exhibit Z2-2

SYSTEM DESIGN

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SYSTEM DESIGN
INDEX

2.1 SYSTEM DESIGN FORMULAE

The Foothills Pipe Lines Limited computer program was used for the solution of the formulae used in calculation of temperature, pressure and velocity conditions in the pipeline. These formulae in differential form are presented below.

(a) Energy Equation

$$(\partial H/\partial P)_T dP/dx + (\partial H/\partial T)_P dT/dx + (u/g_c) du/dx + (g/g_c) dZ/dx = dQ/dx - dw/dx$$

WHERE:

- Q = heat in or out of the system
- w = work done by the system
- H = enthalpy
- u = average flow velocity in pipe
- Z = elevation above datum
- g = acceleration due to gravity
- g_c = conversion factor
- P = absolute pressure
- T = gas temperature
- x = independent variable (position along pipe in direction of flow)

(b) Momentum Equation

$$(1/\rho)\ dp/dx + (u/g_c)\ du/dx + [2(fu^2)/g_c Di] + (g/g_c)\ \mathrm{SIN}\Theta = 0$$

WHERE:

$$\mathrm{Sin}\ \Theta = (Z_1 - Z_2)/(X_1 - X_2)$$

- Θ = angle subtended between the pipe and a horizontal datum
- X_1 = upstream length with respect to some reference
- X_2 = downstream length with respect to some reference
- Z_1 = upstream elevation
- Z_2 = downstream elevation
- D_i = pipe internal diameter
- X = some point along the pipe
- ρ = density of gas
- f = fanning friction factor

(c) Continuity Equation

$$\partial(\rho u)/\partial x = 0$$

The following assumptions have been made in the derivation of the energy, momentum and continuity equations:

(a) Conservation of energy, momentum, and mass;

(b) Steady state flow conditions;

(c) Flow is uni-directional, thereby implying that the flowing velocity is accurately characterized by the apparent bulk average velocity, and that the thermodynamic properties are constant for the flow cross-sections;

(d) The Fanning friction factor relationship models viscous losses;

(e) The elevation gradient between points is constant.

2.1.1 METHOD OF SOLUTION

The pipeline is divided into a number of segments each of length Δx, being always less than 4 miles.

(a) Solving the energy equation, momentum equation, and continuity equation simultaneously for $\partial u/\partial x$, $\partial P/\partial x$, and $\partial T/\partial x$ at some step yields,

$$\partial u/\partial x = [(a_{12}a_{31}/a_{11}-a_{32})b_2/a_{22}-b_1a_{31}/a_{11}] \,/\, [(a_{12}a_{31}/a_{11}-a_{32})a_{23}/a_{22}-(a_{13}a_{31}/a_{11}-1.0)]$$

$$\partial P/\partial x = b_2/a_{22}-(a_{23}/a_{22})\partial u/\partial x$$

$$\partial T/\partial x = b_1/a_{11}-(a_{12}/a_{11})\partial P/\partial x-(a_{13}/a_{11})\partial u/\partial x$$

WHERE

$$a_{11} = (\partial H/\partial T)_P$$

$$a_{12} = (\partial H/\partial P)_T$$

$$a_{13} = u/g_c$$

$$a_{22} = 1/\rho$$

$$a_{23} = a_{13}$$

$$a_{31} = -m[1/P+(\partial Z/\partial T)_P/Z]/(\rho A)$$

$$a_{32} = m[1/P-(\partial Z/\partial P)_T]/(\rho A)$$

$$b_1 = -\partial Q/\partial x - S$$

$$b_2 = -2fu^2/(g_c Di) - S$$

WHERE

m is the mass flow rate
A is the cross sectional area of the pipe
Z is the gas supercompressibility
S is the elevation gradient

and $(\partial H/\partial T)_P$, $(\partial H/\partial P)_T$, $(\partial Z/\partial P)_T$, $(\partial Z/\partial T)_P$ and $\partial Q/\partial x$ are as calculated respectively in 2.1.7, 2.1.6 and 2.1.12.

The values of $\partial u/\partial x$, $\partial P/\partial x$ and $\partial T/\partial x$ have thus been evaluated at the inlet conditions of the segment pipe and are denoted as

$$(\partial u/\partial x)_1,\ (\partial P/\partial x)_1 \text{ and } (\partial T/\partial x)_1$$

(b) Evaluate new values T, P and u as follows:

$$T_1 = T_i + (\Delta x/2)\ (\partial T/\partial x)_1$$

$$P_1 = P_i + (\Delta x/2)\ (\partial P/\partial x)_1$$

$$u_1 = u_i + (\Delta x/2)\ (\partial u/\partial x)_1$$

Where subscript i refers to the inlet values of the variables and Δx is the integration increment.

(c) Use T_1, P_1 and u_1 to evaluate the a's and b's. Then solve for the second estimate of the derivatives which are denoted as:

$$(\partial u/\partial x)_2,\quad (\partial P/\partial x)_2 \quad\text{and}\quad (\partial T/\partial x)_2$$

(d) Evaluate new values of T, P and u as follows:

$$T_2 = T_i + (\Delta x/2)\ (\partial T/\partial x)_2$$

$$P_2 = P_i + (\Delta x/2)\ (\partial P/\partial x)_2$$

$$u_2 = u_i + (\Delta x/2)\ (\partial u/\partial x)_2$$

(e) Use T_2, P_2 and u_2 to evaluate the a's and b's. Then solve for the third estimate of the derivatives which are denoted as:

$$(\partial u/\partial x)_3,\ (\partial P/\partial x)_3 \text{ and } (\partial T/\partial x)_3$$

(f) Evaluate new values of T, P and u as follows:

$$T_3 = T_i + (\Delta x)\ (\partial T/\partial x)_3$$

$$P_3 = P_i + (\Delta x)\ (\partial P/\partial x)_3$$

$$u_3 = u_i + (\Delta x)\ (\partial u/\partial x)_3$$

(g) Use T_3, P_3 and u_3 to evaluate the a's and b's. Then solve for the fourth estimate of the derivatives which are denoted as:

$$(\partial u/\partial x)_4,\ (\partial P/\partial x)_4 \text{ and } (\partial T/\partial x)_4$$

(h) By fourth-order Runge-Kutta integration, the values of temperature, pressure and velocity at the end of the increment are:

$$T_{i+1} = T_i + (\Delta x/6)[(\partial T/\partial x)_1 + 2(\partial T/\partial x)_2 + 2(\partial T/\partial x)_3 + (\partial T/\partial x)_4]$$

$$P_{i+1} = P_i + (\Delta x/6)[(\partial P/\partial x)_1 + 2(\partial P/\partial x)_2 + 2(\partial P/\partial x)_3 + (\partial P/\partial x)_4]$$

$$u_{i+1} = u_i + (\Delta x/6)[(\partial u/\partial x)_1 + 2(\partial u/\partial x)_2 + 2(\partial u/\partial x)_3 + (\partial u/\partial x)_4]$$

Where i+1 denotes the value at the end of the increment. It should be noted that each time a derivative re-evaluated it is necessary to have current thermodynamic variables for the a's and b's. This requires that the calculations in 2.1.4 to 2.1.7 must be repeated.

The values of T, P and u at the end of the increment are assigned to the values of T, P and u at the inlet of the next increment. Steps a through h are repeated. This procedure continues until the end of the pipe is reached.

2.1.2 <u>TRANSMISSION FACTORS</u>

(a) Fully Turbulent Fanning Transmission Factor

$$\sqrt{1/f} = 4 \log_{10}(3.7D_i/E)$$

Where D_i = Pipe inside diameter (in)

E = Effective roughness (micro-in)

(b) Partially Turbulent Fanning Transmission Factor

$$\sqrt{1/f} = \text{Drag Factor } (4 \log_{10} (\text{Reynolds Number } \sqrt{f}) - .6)$$

This implicit equation is evaluated in an iterative manner. The two transmission factors are compared and the lesser value is used.

2.1.3 GAS PROPERTIES

(a) Molecular Weight

$$\text{Molecular Weight} = \sum_{j=1}^{11} \text{Molecular weight } j \times \text{ Mole Fraction } j$$

j = Pure component index

j	Component
1	Nitrogen
2	Hydrogen Sulfide
3	Carbon Dioxide
4	Methane
5	Ethane
6	N-Propane
7	N-Butane
8	I-Butane
9	N-Pentane
10	I-Pentane
11	Hexane^{+}

2.1.4 MOLAR DENSITY

The Starling and Han equation of state is used to calculate the molar density.

$$P=\rho RT+(B_0RT-A_0-C_0/T^2+D_0/T^3-E_0/T^4)\rho^2+ (bRT-a-d/T)\rho^3+ \alpha(a+d/T)\rho^6+c\rho^3/T^2(1+\gamma\rho^2)\exp(-\gamma\rho^2)$$

Where A_0, B_0, C_0, D_0, E_0, a, b, c, d, γ, α, are parameters for the gas mixture. The equation is solved iteratively using the Newton-Raphson Technique.

2.1.5 EQUATION OF STATE PARAMETERS

Individual component parameters for the equation of state:

$\rho_{cj}B_{oj}=A_1+B_1\omega_j$

$\rho_{cj}A_{oj}/(RT_{cj})=A_2+B_2\omega_i$

$\rho_{cj}C_{cj}/(RT^3_{oj})=A_3+B_3\omega_j$

$\rho^2_{cj}\gamma_j=A_4+B_4\omega_j$

$\rho^2_{cj}b_j=A_5+B_5\omega_j$

$\rho^2_{cj}a_j/(RT_{cj})=A_6+B_6\omega_j$

$\rho^3_{cj}\alpha_j=A_7+B_7\omega_j$

$\rho^2_{cj}C_j/(RT^3_{cj})=A_8+B_8\omega_j$

$\rho_{cj}D_{oj}/(RT^4_{cj})=A_9+B_9\omega_j$

$\rho^2_{cj}d_j/(RT^2_{cj})=A_{10}+B_{10}\omega_j$

$\rho_{cj}E_{oj}/(RT^5_{cj})=A_{11}+B_{11}\omega_j\exp(-3.8\omega_j)$

Where the constants A & B are:

- Values of parameters A_k and B_k, for use with generalized equation of state

Parameter subscript (k)	Parameter value	
	A_K	B_K
1.	0.4436900	0.115449
2.	1.2843800	-0.920731
3.	0.3563060	1.708710
4.	0.5449790	-0.270896
5.	0.5286290	0.349261
6.	0.4840110	0.754130
7.	0.0705233	-0.044448
8.	0.5040870	1.322450
9.	0.0307452	0.179433
10.	0.0732828	0.463492
11.	0.0064500	-0.022143

And ω, T_c and ρ_c are:

Physical properties of pure materials

used with generalized equation of state

	T_c Critical Temp., °F	ρ_c Critical Density lb. mole / cu. ft.	MWT Molecular Weight	ω Acentric Factor
Methane	-116.43	0.6274	16.042	0.0130
Ethane	90.03	0.4218	30.068	0.1018
Propane	206.13	0.3121	44.094	0.1570
i - Butane.	274.96	0.2373	58.120	0.1830
n - Butane	305.67	0.2448	-58.120	0.1970
i - Pentane	369.00	0.2027	72.146	0.2260
n - Pentane.	385.42	0.2007	72.146	0.2520
n - Hexane	453.45	0.1696	86.172	0.3020
n - Heptane	512.85	0.1465	100.198	0.3530
n - Octane	563.79	0.1284	114.224	0.4120
n - Nonane.	610.50	0.1150	128.250	0.4750
n - Decane	651.90	0.1037	142.276	0.5400
n - Undecane.	692.31	0.0946	156.300	0.6000
Ethylene	49.82	0.5035	28.050	0.1010
Propylene	197.40	0.3449	42.080	0.1500
Nitrogen	-232.60	0.6929	28.016	0.0350
Carbon Dioxide	87.80	0.6641	44.010	0.2100
Hydrogen Sulfide	212.70	0.6571	34.076	0.1050
Cyclohexane.	535.60	0.2027	84.156	0.2100
Benzene	552.00	0.2401	78.108	0.2150
Nitrous Oxide	97.77	0.6483	44.020	0.1550
Nitric Oxide	-135.69	1.0764	30.010	0.6000
Toluene	605.50	0.1924	92.134	0.2600

The mixture parameters are calculated using the individual component parameters and the following mixing rules

$$B_0 = \sum_i x_i B_{0i}$$

$$A_0 = \sum_{ij}\sum x_i x_j A_{0i}^{1/2} A_{0j}^{1/2}(1-k_{ij})$$

$$C_0 = \sum_{ij}\sum x_i x_j C_{0i}^{1/2} C_{0j}^{1/2}(1-k_{ij})^3$$

$$\gamma = [\sum_i x_i \gamma_i^{1/2}]^2$$

$$b = [\sum_i x_i b_i^{1/3}]^3$$

$$a = [\sum_i x_i a_i^{1/3}]^3$$

$$\alpha = [\sum_i x_i \alpha_i^{1/3}]^3$$

$$c = [\sum_i x_i c_i^{1/3}]^3$$

$$D_0 = \sum_{ij}\sum x_i x_j D_{0i}^{1/2} D_{0j}^{1/2} (1-k_{ij})^4$$

$$d = [\sum_i x_i d_i^{1/3}]^3$$

$$E_0 = \sum_{ij}\sum x_i x_j E_{0i}^{1/2} E_{0j}^{1/2} (1-k_{ij})^5$$

Where:

i, j = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, and 11.

x_i = Mole fraction of the i^{th} component.

k_{ij} = The interaction parameter, is a measure of deviations from ideal solution behavior and is given for the i^{th} and j^{th} component below,

Values of interaction parameters k_{ij} for use in generalized correlation

(k_{ij} x 100)

Methane	Ethylene	Ethane	Propylene	Propane	i-Butane	n-Butane	i-Pentane	n-Pentane	Hexane	Heptane	Octane	Nonane	Decane	Undecane	Nitrogen	Carbon Dioxide	Hydrogen Sulfide	
0.0	1.0	1.0	2.1	2.30	2.75	3.10	3.60	4.10	5.00	6.00	7.0	8.1	9.2	10.1	2.5	5.0	5.0	Methane
	0.0	0.0	0.3	0.31	0.40	0.45	0.50	0.60	0.70	0.85	1.0	1.2	1.3	1.5	7.0	4.8	4.5	Ethylene
		0.0	0.3	0.31	0.40	0.45	0.50	0.60	0.70	0.85	1.0	1.2	1.3	1.5	7.0	4.8	4.5	Ethane
			0.0	0.00	0.30	0.35	0.10	0.45	0.50	0.65	0.8	1.0	1.1	1.3	10.0	4.5	4.0	Propylene
				0.00	0.30	0.35	0.10	0.45	0.50	0.65	0.8	1.0	1.1	1.3	10.0	4.5	4.0	Propane
					0.00	0.00	0.08	0.10	0.15	0.18	0.2	0.25	0.3	0.3	11.0	5.0	3.6	i-Butane
						0.00	0.08	0.10	0.15	0.18	0.2	0.25	0.3	0.3	12.0	5.0	3.4	n-Butane
							0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	13.4	5.0	2.8	i-Pentane
								0.00	0.00	0.00	0.0	0.0	0.0	0.0	14.8	5.0	2.0	n-Pentane
									0.00	0.00	0.0	0.0	0.0	0.0	17.2	5.0	0.0	Hexane
										0.00	0.0	0.0	0.0	0.0	20.0	5.0	0.0	Heptane
											0.0	0.0	0.0	0.0	22.8	5.0	0.0	Octane
												0.0	0.0	0.0	26.4	5.0	0.0	Nonane
													0.0	0.0	29.4	5.0	0.0	Decane
														0.0	32.2	5.0	0.0	Undecane
															0.0	0.0	0.0	Nitrogen
																0.0	3.5	Carbon Dioxide
																	0.0	Hydrogen Sulfide

This specifies all the constants required in the equation of state for a given composition

2.1.6 COMPRESSIBILITY

Using the molar density, compressibility (Z) is calculated:

$$Z = P/(\rho RT)$$

Where:

R is defined here as the ideal gas constant.

Calculation of $(\partial Z/\partial P)_T$ and $(\partial Z/\partial T)_P$

Holding temperature constant, a three-point finite difference method is used to calculate $(\partial Z/\partial P)_T$.

$(\partial Z/\partial T)_P$ is calculated in a similar manner.

2.1.7 ENTHALPY AND HEAT CAPACITY

Ideal enthalpy (H^0) is calculated using the following equation and table:

Ideal Gas Enthalpy Polynomial Parameters Used for Thermodynamic Property Tables and Mollier Diagrams

	$H^0 = A_0 + A_1T + A_2T^2 + A_3T^3 + A_4T^4 + A_5T^5$ (H^0 in Btu / lb. T in °R)						
	Temp. Range. °R	A_0	$A_1 \times 10^2$	$A_2 \times 10^4$	$A_3 \times 10^7$	$A_4 \times 10^{10}$	$A_5 \times 10^{13}$
Methane	160-1060	-1798.1600	53.978	-1.345	0.676	1.966	-1.037
Ethane	210-860	-993.3200	30.668	-1.427	4.203	-1.567	0.000
Propane	210-860	-801.8100	25.177	-1.602	5.160	-2.110	0.000
n-Butane	210-960	-739.7700	22.389	-0.601	3.930	-1.594	0.000
n-Pentane	210-1260	-688.0900	22.267	-0.890	5.018	-3.048	0.611
n-Hexane	460-1460	-618.3800	0.210	1.118	-0.614	0.000	0.000
n-Heptane	160-1160	-596.1000	0.519	3.989	-0.587	0.000	0.000
n-Octane	160-1160	-577.5900	0.612	1.091	-0.605	0.000	0.000
Isobutane	360-960	-776.1100	6.872	3.071	0.000	0.000	0.000
Isopentane	360-1160	-709.2800	7.182	2.515	0.857	-0.161	0.000
Ethylene	180-1080	928.2500	32.919	-2.177	1.768	-1.711	0.000
Propylene	537-1110	376.8600	9.868	2.317	0.295	-0.196	0.000
Nitrogen	180-1110	-0.3391	21.902	0.011	-0.095	0.414	-0.029
Carbon Dioxide	180-1440	-3839.0800	11.951	0.897	0.161	0.000	0.000
Hydrogen Sulfide	180-1440	-217.9200	23.997	-0.300	0.172	-0.157	0.017

The enthalpy departure is thus calculated using the following equation:

$$(H-H^0) = (B_0RT-2A_0-4C_0/T^2+5D_0/T^3-6E_0/T^4)\rho$$

$$+ (2bRT-3a-4d/T)\rho^2/2+\alpha(6a+7d/T)\rho^5/5$$

$$+ c/(\gamma T^2)[3-(3+\gamma\rho^2/2-\gamma^2\rho^4) \exp(-\gamma\rho^2)]$$

WHERE:

H = Enthalpy, Btu/lb.

$(H-H^0)$ = Enthalpy for the real gas less the enthalpy for the ideal gas at the same temperature, Btu/lb.

H^0 = Enthalpy of ideal gas, Btu/lb.

M = Molecular weight

P = Absolute pressure, psia

R = Gas constant, 10.73 psia cu.ft./(lbm. mole ^{0}R)

T = Temperature, ^{0}R

T_c = Critical Temperature, ^{0}R

B_0, A_0, C_0, D_0, E_0, b, a, c, d, α and γ = Equation of state parameters

ij = Interaction between i and j components
k = Interaction parameter
n = Total number of components
x_i = Mole fraction of the i^{th} component
ω = Acentric factor
ρ = Molar density, lb.-moles/cu.ft.
ρ_c = Molar critical density lb.-moles/cu.ft.

Now using the three point finite difference method,

$(\partial H/\partial P)_T = C_P$ and $(\partial H/\partial T)_P$ are calculated.

2.1.8 VISCOSITY

The viscosity μ is calculated using the Lee-Starling-Dolan-Ellington Generalized viscosity correlation:

$$\mu = K\ (T,\ M)\ \exp\left[\ X(T,\ M)\rho\ Y(T,\ M)\right]$$

Wherein:

$$K(T,\ M) = (7.77 + 0.0063M)\ T^{1.5} / \ (122.4 + 12.9M + T)$$

$$X(T,\ M) = 2.57 + 1914.5\ /\ T + 0.0095M$$

$$Y(T,\ M) = 1.11 + 0.04X\ (T,\ M)$$

Where ρ is the gas density, M is the molecular weight.

2.1.9 SPECIFIC GRAVITY

Specific Gravity = Mixture molecular weight / Molecular weight of air

2.1.10 JOULE-THOMSON COEFFICIENT

Joule-Thomson coefficient = $T^2R\ (\ \partial Z/\partial T\ )_P / \ (\ M\ (\partial H/\partial T\ )_P P)$

Where P is the pressure and $(\partial Z/\partial T)_P$ and $(\partial H/\partial T)_P$ are as calculated in 2.1.6 and 2.1.7 respectively.

2.1.11 ISENTROPIC EXPONENT

The isentropic exponent (N) used in the determination of temperature change across the compressor is calculated at suction conditions:

$$N = R\ (\ Z + T\ (\ \partial Z\ /\ \partial T\ )_P)\ /\ (\ M\ (\ \partial H\ /\ \partial T\ )_P)$$

Where Z is the supercompressibility and the other variables are as given in 2.1.10.

2.1.12 HEAT TRANSFER

The following formula was used in the determination of the heat transfer between the pipeline gas and the surrounding soil:

$$dQ / dx = \Delta T / (m \sum_j R_j)$$

WHERE:

Q = heat transfer per unit mass between gas and soil at position x

$\Delta T = T - T_g$

T_g = effective soil temperature at pipe depth

$\sum_j R = R_s + R_i + R_p + R_{FF}$

R_s = soil resistance to heat transfer

R_i = insulation resistance to heat transfer

R_p = pipe resistance to heat transfer

R_{FF} = gas film resistance to heat transfer

Introducing expressions for the resistance,

$$dQ/dx = (T-T_g) / [\ln(2h_i / D_s + (4h_i^2 / D_s^2 - 1)^{\frac{1}{2}}]/(2\pi K_s) + \ln(D_s/D_o) / (2\pi K_i) + \ln(D_o/D_i) / (2\pi K_p) + 1 / (\pi h D_i)] / m$$

WHERE:

K_s = soil thermal conductivity

K_i = insulation thermal conductivity

K_p = pipe thermal conductivity

h = gas film coefficient

D_s = diameter of pipe plus insulation

D_o = pipe O.D.

h_i = depth of burial of pipe to centerline

The following basic assumptions were made in the development of the Heat Transfer equation:

(a) Steady state conditions;

(b) The Kennelly equation represents the heat transfer from the pipe to the soil;

(c) The ground surface temperature is constant;

(d) The ground temperature is uniform;

(e) The ground thermal conductivity is constant;

(f) The gas film coefficient is constant for the length of the pipe;

(g) The latent heat effect of ground moisture content is ignored.

2.1.13 HYDRAULIC HORSEPOWER

The Joule-Thomson effect as a result of the suction loss is accounted for by:

$$T_s = T_i - J(P_i - P_s)$$

where J is the Joule-Thomson coefficient and the subscript i refers to the station inlet and s refers to the suction of the compressor.

The discharge pressure is calculated taking into account the discharge loss and any chiller losses. Knowing the compression ratio, the approximate discharge temperature is calculated using the value of N calculated for the suction conditions:

$$T_{d\ approx} = T_s (P_d/P_s)^N$$

Knowing the discharge temperature and pressure, Z and N are calculated for the discharge conditions. An average value for Z and N are then calculated. The horsepower required is then calculated.

$$HP = \frac{0.08584\ Ts\ Zavg}{E\ Navg} \left[(P_D/P_S)^{Navg} - 1 \right] QB$$

WHERE

E is the compression efficiency.
T_s is the suction temperature, ^0R.
P_d is the compressor discharge pressure, psia
P_s is the compressor suction pressure, psia
QB is the flow at base conditions, MMCFD
HP is the horsepower
N_{avg} is the average isentropic temperature change exponent

The Compression Horsepower equation is a standard equation with the following basic assumptions:

(a) Changes in Kinetic Energy between the suction and discharge conditions are negligible;

(b) The isentropic temperature change exponent and the gas compressibility are both average values, selected at the mid-point of compression to typify the cycle.

The fuel used is calculated and the new flow is determined.

New Flow = QB - fuel

The horsepower is recalculated using the new flow. This procedure is repeated until the flow imbalance is within a specified tolerance.

2.1.14 ACTUAL COMPRESSOR DISCHARGE TEMPERATURE

The actual discharge temperature is calculated:

$$T_{d\ actual} = T_s(P_d/P_s)^{N_{avg}} + 2545(1-E)HP / (mC_{pd})$$

Where m is the mass flow of gas and $C_{pd} = [(\partial H/\partial T)_p]_d$ is evaluated at discharge condition. The first term on the right represents the isentropic temperature rise and second term accounts for the temperature rise due to compression inefficiency. The following basic assumptions are made:

(a) Heat conductivity in the direction of flow is negligible;

(b) Effect of Heat flux thru the Compressor Wall can be ignored.

2.1.15 CHILLING LOAD

The chilling load is calculated by:

$$\text{Load} = mC_{p\ avg}\ [(T_d - T_o) - J_{avg}\ (P_d - P_o)]$$

WHERE:

C_{pavg} is the average value of $(\partial H/\partial T)_p$ between compressor discharge and chiller discharge

T_d is the compressor discharge temperature

T_o is the temperature at the chiller exit

J_{avg} is the average value of the Joule-Thomson coefficient between compressor discharge and chiller discharge

P_d is the compressor discharge pressure

P_o is the chiller discharge pressure

2.2 DESIGN CRITERIA

2.2.1 Gas Composition

The following gas composition is representative of the gas to be received from producers metering facilities at Prudhoe Bay.

Component	Mol%
N_2	0.772
CO_2	1.000
C_1	86.440
C_2	7.390
C_3	3.430
iC_4	0.370
nC_4	0.492
iC_5	0.060
nC_5	0.041
C_6	0.005
C_7+	---
	100.00

S. G. = 0.6503
H. V. = 1122 gross dry

where S. G. = specific gravity Air = 1.0 and H. V. = gross dry heating valve in Btu per SCF

2.2.2 Hydrocarbon Dewpoint

The hydrocarbon dewpoint curve shown in Figure 2.2.1 is representative of the pipeline gas composition given in 2.2.1. At 1000 psia, the hydrocarbon dewpoint of the pipeline gas is -10^{o}F.

2.2.3 Pipe Data

Calculation of the transmission factor as outlined in Section 2.1.2 includes an effective roughness (E), based on internally coated pipe, of 250 micro-inches. The drag factor as used in Section 2.1.2 was set at a value of 0.96.

Mainline pipe used in the flow studies is 42 inch outside diameter, 0.600 inch wall thickness, API5LX - X-65 grade. Maximum operating pressure for this material at 72% SMYS is 1337 psig.

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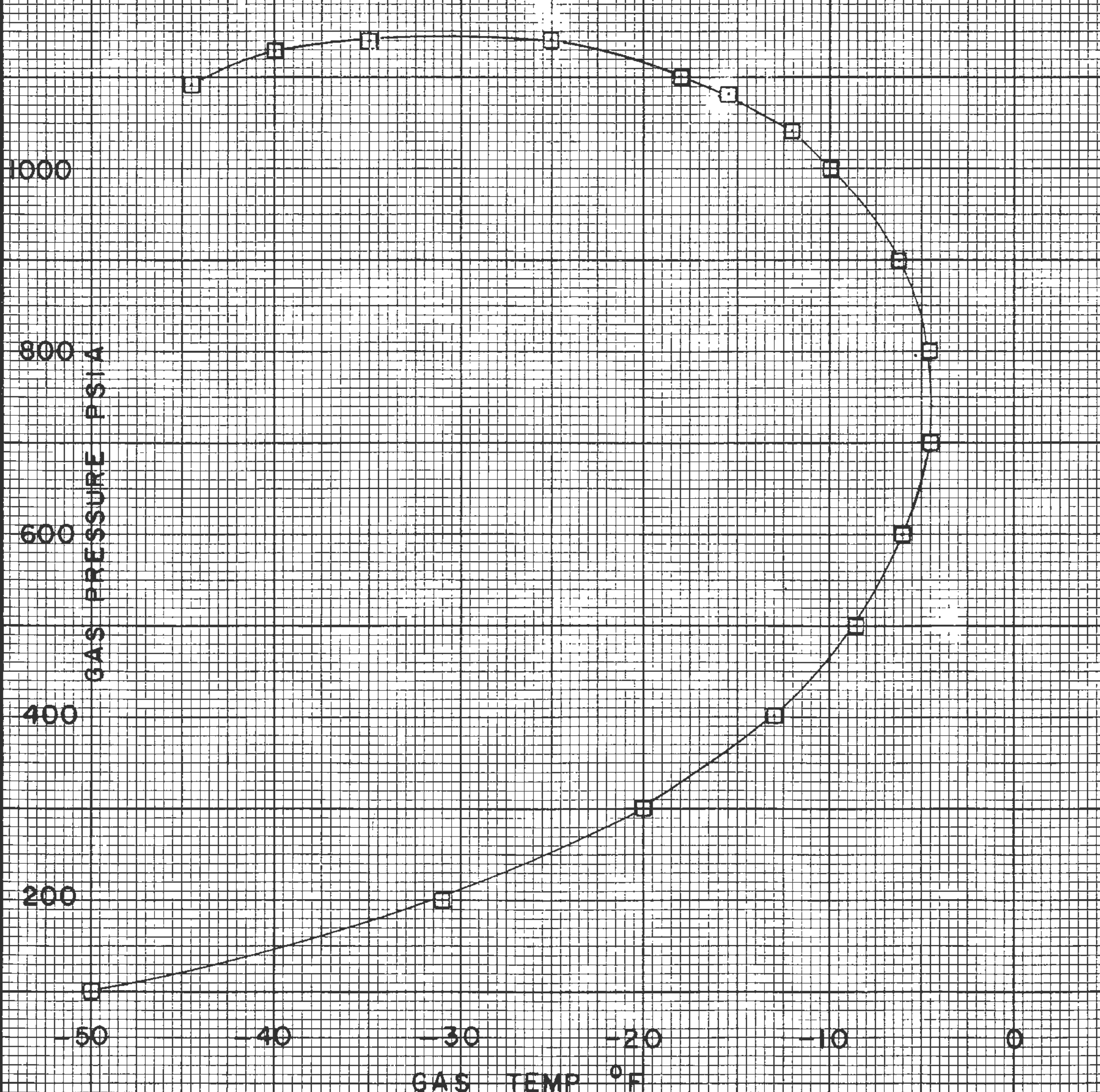

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FIGURE 2.2.1

2.2.4 Receipt Volumes

The following volumes, measured at 14.73 psia and 60° F base conditions, are received into the pipeline system at Prudhoe Bay. Each receipt is based on average day volumes.

Year	Volume MMSCFD
1981	1200
1982	1600
1983	2400

2.2.5 Fairbanks Deliveries

The following volumes, measured at 14.73 psia and 60° F base conditions, are delivered to the Fairbank vicinity. Each delivery is based on average day volumes.

Year	Volume MMSCFD
1981	22.50
1982	30.00
1983	45.00

2.2.6 Station Locations, Elevations and Ambient Temperatures

See Table 2.2.1 for station locations, elevations and ambient temperatures.

Summer ambient temperatures are based on averages of the daily maximum and minimum temperatures for the month of July.

Winter ambient temperatures are based on averages of the daily maximum and minimum temperatures for the month of January.

For the purpose of site rating the pipeline compressors, ambient air inlet temperatures for both summer and winter are taken as 60° F. Preheating of inlet air will be accomplished by bleeding power turbine exhaust gases into the inlet plenum. For the purpose of refrigeration condensing temperatures, the summer ambients shown above are used. Under winter conditions, an ambient temperature of 30° F is used. This heated air will be obtained by utilizing recirculation louvers on the condensing units. Condenser approach temperature is taken as 30° F.

TABLE 2.2.1

Sta No.	Mile Post	Elevation Ft.	Summer Ambient °F	Winter Ambient °F
1	43.5	410	40.5	-14.0
2	83.7	1050	48.0	-10.5
3	118.6	2575	49.0	-10.0
4	157.7	2955	54.0	-10.0
5	210.8	1405	57.5	-10.5
6	261.9	1360	59.5	-12.0
7	305.9	1371	59.5	-11.0
8	355.0	1000	59.5	-9.0
9	400.7	960	60.0	-8.0
10	442.6	1360	60.0	-8.0
11	497.4	806	58.5	-8.0
12	543.6	1223	58.5	-5.0
13	590.3	1598	59.0	-6.5
14	639.4	1649	59.0	-11.0
15	684.1	2225	59.5	-14.0

2.2.7 Gas Flowing Temperatures

Flowing temperatures are as presented on the flow diagrams at stations and chilling units.

2.2.8 Ground Temperatures and Soil Thermal Conductivities

The following ground temperatures and thermal conductivities were used for flow study purposes.

Mile Post	Summer Ground Temp. °F	Winter Ground Temp. °F	K (soil) Frozen Btu/hr ft^2 °F
0-100	31.0	1.0	1.25
100-125	34.0	3.0	1.50
125-131.7	36.0	5.5	1.70
131.7-140	36.0	6.5	1.25
140-157.7	37.0	8.5	1.50
157.7-170.5	38.0	11.0	1.70
170-202	39.0	14.5	2.10
202-217	41.0	18.0	1.70
217-228	41.0	20.5	2.10
228-252.3	45.0	23.0	1.25
252.3-269.2	45.0	25.0	1.25
269.2-315.2	45.0	26.0	1.25
315.2-341.9	45.0	27.0	1.25
341.9-415.2	48.0	29.0	1.50
415.2-455.0	50.0	30.5	1.25
455-475	48.0	30.5	1.00
475-525	48.0	30.0	1.00
525-601.4	44.0	30.0	1.50
601.4-639.4	40.0	29.5	1.70
639.4-670.9	42.0	29.5	2.10
670.9-731.4	42.0	28.5	1.70

Summer ground temperatures are taken as an average of minimum and maximum ground temperatures for July.

Winter ground temperatures are based on averages of minimum and maximum ground temperatures for January.

Data are based on measured ground temperatures at Barrow, Fort Yukon, Fairbanks, Big Delta and Northway measuring stations.

2.2.9 Refrigeration Formulae

The chilling system considered uses propane as the refrigerant gas with two stage compression and an economizer cycle. A thermodymanic description of the cycle is shown in Figure 2.2.2. In the diagram, W_n represents the mass flow rate of regrigerant through the system at point n. Figure 2.2.3 shows the physical description of the system shown in Figure 2.2.2.

(a) Because the step 10 → 1 lies within the vapor-liquid envelope in Figure 2.2.2 the temperature as well as the pressure of the refrigerant is constant in this section.

This chiller temperature is both a function of approach temperature and mainline outlet gas temperature.

$$T_C = T_{Gas} - T_{Approach}$$

WHERE: $T_{Approach}$ is an independent variable

T_C is the temperature of the propane in the chiller

T_{Gas}, the mainline gas temperature at the chiller discharge, is an independant variable as well.

(b) When the chiller temperature, T_C, has been determined the corresponding pressure can be determined using a polynomial curve fit relating temperature and pressure in the vapor liquid envelope:

$$P = 40.0 + .737\ (T_C) + .00557\ (T_C^{\ 2}) +$$

$$.00001689\ (T_C^{\ 3}) + 2.069 \times 10^{-7}\ (T_C^{\ 4})$$

Where T_c is in ^oF.

(c) The back pressure valve between 1 and 2 causes a small pressure drop (and hence a small drop in temperature of the refrigerant). The inlet conditions for the 1st stage of compression then are:

P suction = P chiller - Valve and pipe losses
T suction = T chiller - Jx (valve and pipe losses)
Where J represents the Joule Thompson coefficient.

(d) Before the compression calculations can be performed it is necessary to know the condensing temperature. This temperature is both a function of ambient air temperature and the approach temperature.

T condenser = T ambient + T approach

WHERE: (1) T abmient = T ambient for air temperatures > 30°F

(2) T ambient = 30° for air temperatures < 30°F and T approach is again an independent variable.

The second note (2) indicates that in cold ambient temperatures (below 30°F) the louvers on the condenser would be closed to maintain the circulation air at approximately 30°F

(e) The condensing pressure is calculated using the same equation given in (b). The pressure at the discharge of the 2nd stage of compression is calculated by:

$$P_{Discharge} = P_{condenser} + \text{(Discharge Piping Loss)}$$

(f) Knowing the pressure at the discharge of the 2nd stage of compression allows the interstage pressure to be calculated. In an attempt to equalize the load between the two stages the following relationship is used:

$$P_{Interstage} = \sqrt[2]{(P\ \text{suction}) \times (P\ \text{discharge})}$$

(g) Once the interstage pressure has been calculated it is possible to calculate the economizer temperature. A polynomial approximation is used to relate the temperature and the pressure:

$$T\ \text{economizer} = -81.0 + 3.0787\ (P) - .0335\ (P^2) + .00024787\ (P^3) - .109 \times 10^{-5}\ (P^4) + .2749 \times 10^{-8}\ (P^5) - .3665 \times 10^{-11}\ (P^6)$$

(h) Before proceeding with the horsepower calculation it is necessary to know the mass flow rate of refrigerant through the chiller (and hence through the 1st stage of compression). Using the chilling load calculated in section 2.1.15 and equating this to the heat of vaporization of the propane yields:

Load = (mass flow of refrigerant through chiller) x (change in enthalpy) or in terms of Figure 2.2.2:

Load = W_1 (H_1 - H_{10}) or W_1 = Load/(H_1 - H_{10})

Where H is the enthalpy at the stated point

Since the flashing process in the chiller is isenthalpic, the enthalpy of the liquid - vapor mixture at 10 is the same as the enthalpy of the liquid leaving the economizer at 9, which is saturated liquid. Enthalpy of saturated liquid is approximated by:

$$H_{LIQ} = -857.0 + .562(T) + .2339 \times 10^{-3}(T^2) + .5986 \times 10^{-6}(T^3) + .4209 \times 10^{-7}(T^4) - .4234 \times 10^{-9}(T^5) + .14156 \times 10^{-11}(T^6)$$

Where T is as calculated in (g)

Since the vapor is drawn off the top of the chiller, the enthalpy at 1 is calculated for saturated vapor by:

$$H_{VAP} = -686.9 + .269(T) - .1335 \times 10^{-3}(T^2) - .649 \times 10^{-6}(T^3) - .1746 \times 10^{-7}(T^4) + .1907 \times 10^{-9}(T^5) - .7475 \times 10^{-12}(T^6)$$

Where T is the chiller temperature

Thus: W_1 = Load/(H_1 - H_9)

(i) It is now possible to calculate the horsepower required for the 1st stage of compression.

(1) Calculate the temperature at the discharge of the 1st stage using 100% efficiency, i.e. an isentropic process:

$$T_{\substack{\text{discharge} \\ \text{ideal}}} = (T_{\text{suction}})(P\ \text{interstage}/P\ \text{suction})^{EXP.}$$

Where EXP is the compression exponent calculated using the same general approach as used in the mainline compressor calculation.

(2) Knowing (P interstage) and (T discharge ideal) the enthalpy at this point, H_3 ideal is calculated using a computer look-up of propane pressure--enthalpy table generated by Starling and Han equation of state. Because H_1=H_2 the change in enthalpy for the ideal or isentropic compression can be calculated:

H ideal $= H_{3A\ \text{ideal}} - H_2$

The actual change in enthalpy is:
ΔH actual $= \Delta H$ ideal/isentropic efficiency

Since ΔH actual $= H_3$ actual $- H_2$

$H_{3\ \text{actual}} = \Delta H$ ideal/isentropic efficiency $+ H_2$

(3) Thus the 1st stage horsepower is given by:

$Hp_1 = W_1$ (ΔH actual)/2545

(j) The flow from the economizer is merged with the flow from the 1st stage of compression. From the continuity equation:

$$W_2 = W_1 + W_3 \quad \text{or} \quad W_3 = W_2 - W_1$$

The enthalpy at the suction of the 2nd stage of compression, H_{3B}, is determined by:

$$W_2 \times H_{3B} = W_1 \times H_3 \text{ actual} + W_3 \times H_8$$

or substituting for W_3:

$$H_{3B} = H_8 + W_1/W_2\ [H_{3\ \text{actual}} - H_8]$$

From: Fig. 2.2.2 , $W1/W2 = H_8 - H_7/H_8 - H_9$

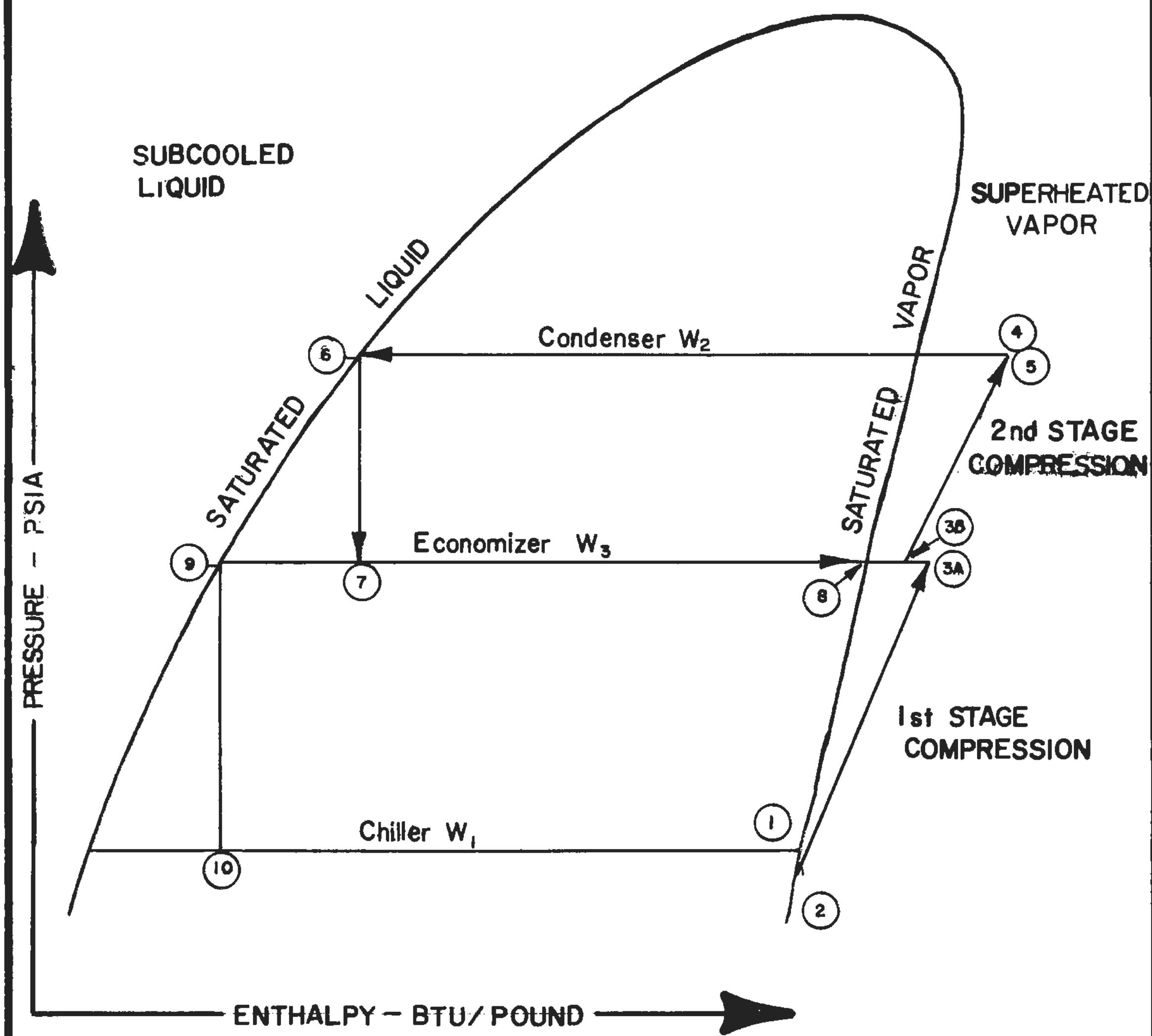
Substituting in the previous equation:

$$H_{3B} = [H_8(H_7 - H_9) + (H_8 - H_7)(H_{3\text{actual}})]/(H_8 - H_9)$$

(k) Knowing the pressure, P interstage, and the enthalpy, H_{3B}, at the suction of the 2nd stage, the temperature, T_{3B}, can be found using a backwards computer look-up of propane pressure--temperature enthalpy data. From this point a new value of EXP can be calculated. The procedure for calculating the 2nd stage horsepower is then similar to the first stage calculation

(l) The total chilling horsepower requirements are then:

$$HP_{\text{Total}} = HP_{\text{Stage 1}} + HP_{\text{Stage 2}}$$



PRESSURE vs ENTHALPY FOR PROPANE

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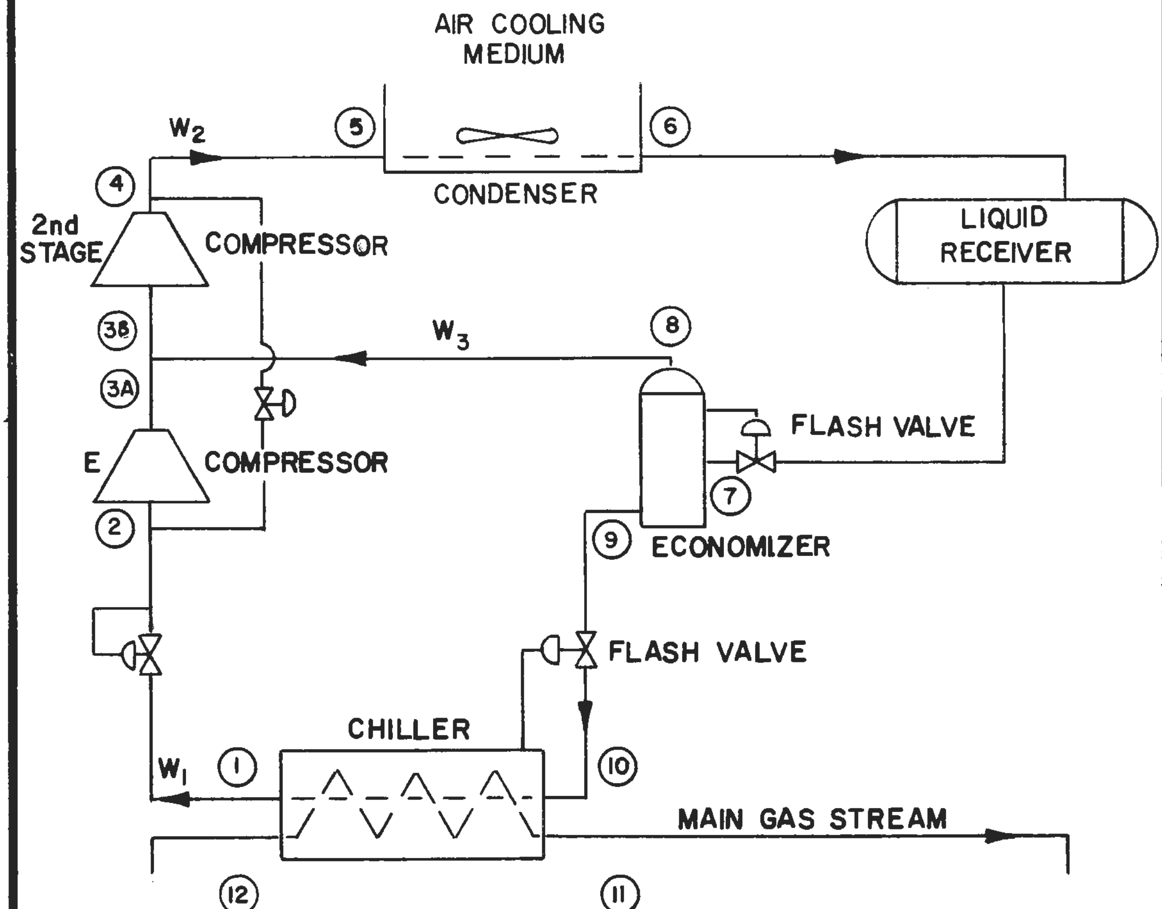
FIGURE 2.2.2



PROPANE CHILLING SYSTEM

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FIGURE 2.2.3.

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Exhibit Z2-3

PIPELINE DESIGN

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3.1 GEOTHERMAL MODEL

The report on the following pages, entitled the Geothermal Model, describes the organization and use of the model which will be applied for the analysis of geothermal problems encountered by the applicant.

THE GEOTHERMAL MODEL

Submitted To

ENERGY SYSTEMS ENGINEERING LTD.

EBA ENGINEERING CONSULTANTS LTD.

JUNE, 1976

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1. INTRODUCTION

This report describes the organization and use of the geothermal model which has been applied for the analysis of geothermal problems of the proposed ALCAN pipeline project in the Alaskan section. The proposed pipeline will begin at Prudhoe Bay, and runs southwards following closely the alignment of the Alyeska Pipeline to Delta Junction. At about this point, the direction of the proposed alignment changes toward the southeast to follow closely the route of the Alaska Highway up to the United States-Canada border.

The object of a geothermal analysis is to predict the changes in ground temperature that might follow a change in surface conditions during construction or by operation of a pipeline. In permafrost regions, the properties and the behaviour of the soil are quite different between frozen and thawed states. Thus, the results of a thermal analysis becomes necessary input to the geotechnical considerations for ground subsidence, river crossing design, slope stability analysis, drainage and erosion control, pipe buoyancy and right-of-way behaviour. In non-permafrost regions, frost heave might occur as a result of installing a chilled pipeline, depending upon soil types and availability of ground water. The results of a thermal analysis will predict the extent and the rate of a frost bulb growth which can be used as a part of the input for the prediction of frost heave.

In this report, a description of the mathematical background of the geothermal model and its input parameters will be made. The computer programs are divided into two groups. One is the so-called FRONT END; the other is the MODEL itself. The front end consists of programs written in a conversational language (BASIC) which generates data files required as input to the model that was written in FORTRAN language. The use of the front end programs enables the user to prepare the input data for a thermal problem in a conversational manner.

The model was applied to investigate possible effects on an existing oil pipeline due to construction of a chilled gas pipeline. It was found that the gas pipeline when constructed on the other side of the work pad for an existing oil pipeline, would not thermally affect the oil pipeline system.

II. A BRIEF DESCRIPTION OF THE GEOTHERMAL MODEL

2.1 General

The model consists of the following codes:

(1) A thermal conduction code with finite element formulation of the transient heat conduction mechanism during freezing and thawing in the ground, in which latent heat is considered as a heat source in the energy balance equation.

(2) A "Heat" Subroutine which considers the heat exchange mechanism at the ground surface with respect to meteorological data.

(3) A "Settle" Subroutine which adjusts the geometry of the thermal domain during the problem solution to account for thaw subsidence.

2.2 Heat Conduction in Soils

The flow and transfer of heat in a soil medium is a complex phenomena which are not clearly defined at the present time. The phenomena include suce diverse mechanisms as conduction, convection in the pore air and/or pore water, radiation through the voids, evapotranspiration and condensation, and moisture migration. In order to simplify the mathematical description of such complex phenomena, a conduction model is assumed so that the equivalent conductivity tensor can account for the aforementioned mechanisms. This is justifiable because in application, the soil and weather changes along the pipeline are likely to be gradual. Under these assumptions, the governing principle becomes the well-known Fourier's law of heat conduction.

A finite element technique using Rayleigh-Ritz method by means of a convolution variational theorem was formulated for numerical solution. In actually formulating the approximate solutions, the two-dimensional finite element method is applied. The method divides the thermal region of interest into triangular-shaped subregions. Triangles are selected because any boundary contour such as that between the pipe and the soil, between the atmosphere and the soil, and between stratified soils, can easily be fit with the edges of many triangles. By using the Rayleigh-Ritz method, the prime variable, the temperature in the present problem, is prescribed in terms of the values of the temperatures at the apexes of each triangle. These temperatures at the node points being common to adjacent subregions enable appropriate continuity requirements to be satisfied over the entire region.

The advantages of using triangle-shaped finite elements are numerous. The method is completely general with respect to geometry and material properties. Temperatures or heat flux boundary conditions may be specified at any point along the boundary of the finite element system.

The mathematical formulation will be described in Appendix A of this report.

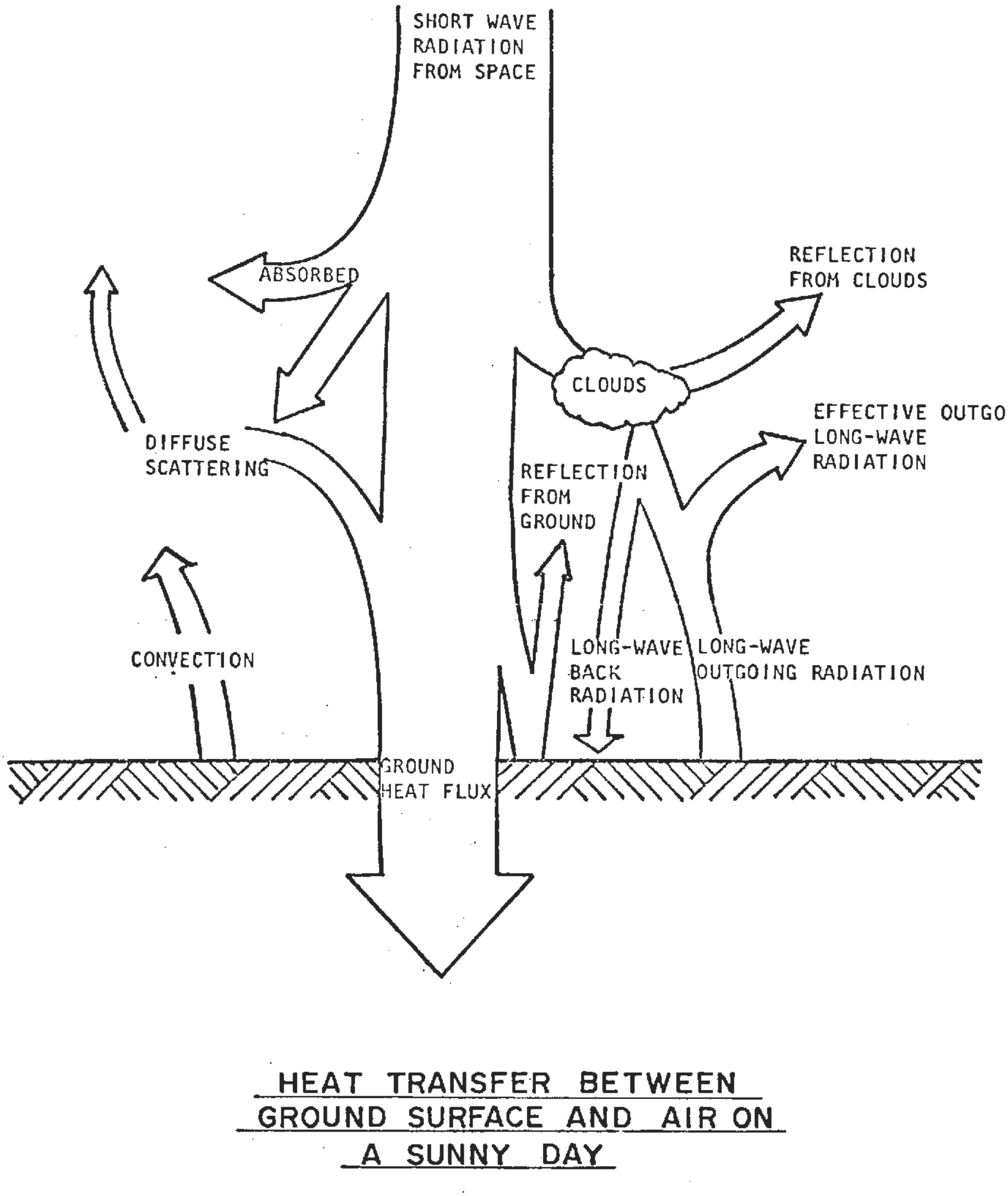
2.3 Heat Transfer at the Ground-Air Interface

The total net heat flux at the ground-air interface, QT, is:

$$QT = QL - QS + QC + QE$$

where,
- QL = net long wave radiation leaving the surface,
- QS = net short wave or solar radiation absorbed at the surface,
- QC = net convective heat flux, and
- QE = heat flux from evapotranspiration.

Figure 1 shows the heat transfer between ground surface and air on a sunny day. The total heat flux is calculated by a subroutine HEAT using the actual meteorological conditions supplied as input, the surface properties of the ground or snow cover, and the actual surface temperature. This actual surface temperature is determined by finite element conduction code at each location when HEAT is combined with it to supply the flux boundary condition. The effects of the pipe or changes due to construction are therefore included in the surface temperature calculation. Detailed calculations of various flux components are presented in Appendix A.



HEAT TRANSFER BETWEEN
GROUND SURFACE AND AIR ON
A SUNNY DAY

FIGURE 1

2.4 Thaw Settlement

Construction activities in permafrost terrain will cause some disturbance to the ground thermal regime. The usual consequence of such disturbance is local degradation of the permafrost table, resulting in subsidence of the ground surface. A progressive change in the geometry of a thermal regime and the corresponding change in thermal properties of the subsoil characterize the type of problem encountered in thermal analysis of permafrost terrain.

The change in thermal properties is due to thaw of ice-bearing soil which results in dissipation of excess water. When the soil refreezes, it does so at a reduced water content. Since water content is a significant parameter in evaluating thermal properties, this effect must be accounted for in thermal analysis. A decrease in water content results in an increase in thermal conductivity, and a decrease in latent heat, which accelerates the propagation of the thaw front.

A program subroutine named SETTLE was developed to account for the soil settlement and change in thermal properties in the analytical model. The two functions of this subroutine are therefore:

(a) The subroutine progressive adjusts the geometry of the thermal domain under study to simulate surface settlement.

(b) Thermal properties of the soil in any particular element are utilized which reflect the freeze-thaw history of that element.

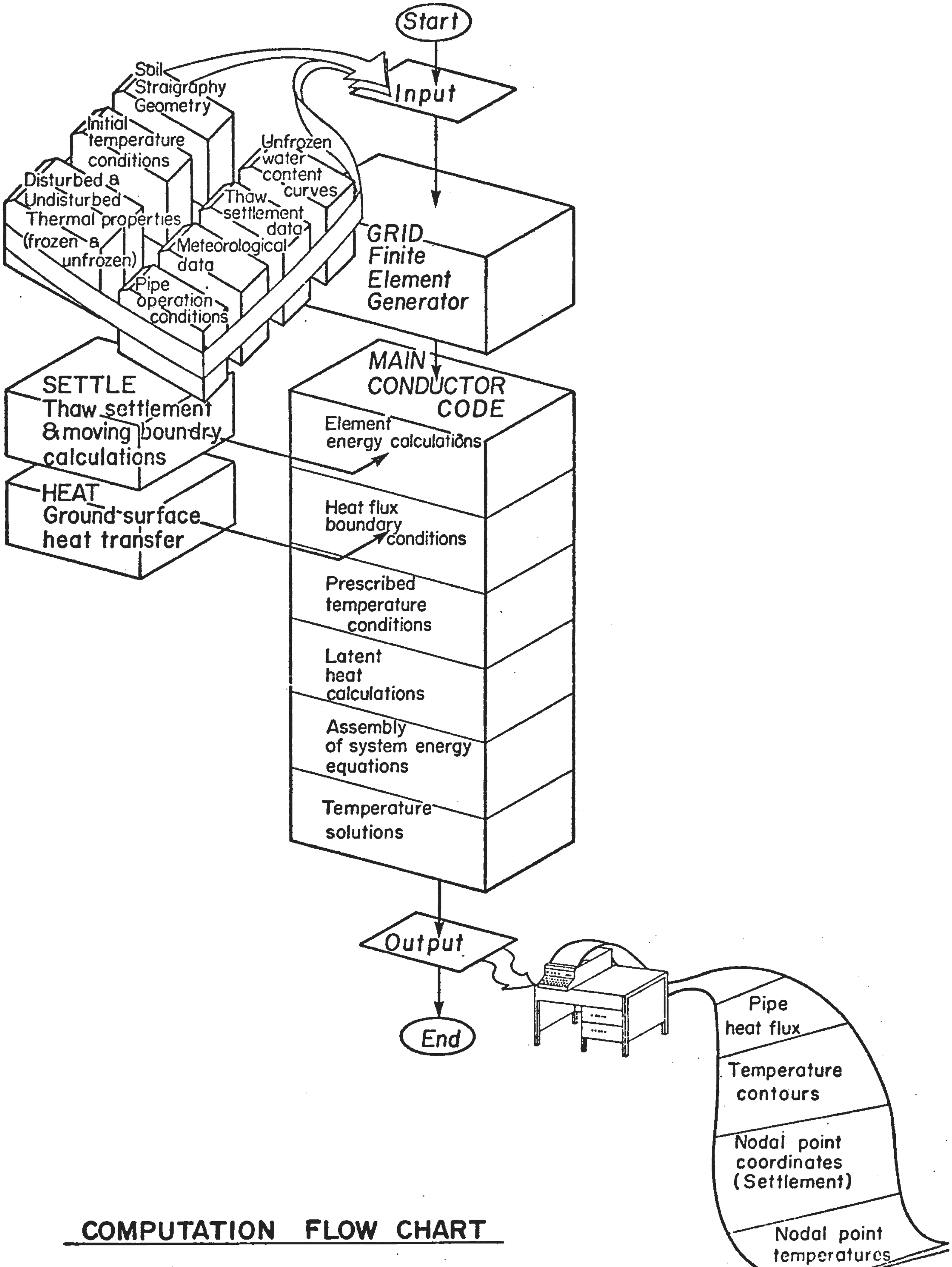
The input data required for the subroutine SETTLE is the thaw compressibility of each soil type, which is defined as the volumetric change upon thawing. Calculation technique and method of evaluating soil compressibility upon thawing are presented in Appendix A.

2.5 Computation Flow Chart

The simulation of a geothermal problem for a heated or a refrigerated pipe buried in the ground is illustrated in a computational flow chart in Figure 2. Various input parameters, as well as the output of the program are listed in the flow chart.

III. EFFECTS OF A CHILLED GAS PIPELINE ON AN OIL PIPELINE

The proposed gas pipeline will run closely with the alignment of the Alyeska Oil Pipeline for the most portion of the route. It is necessary to investigate the possible effect on the existing oil pipeline due to operation of a chilled gas line with respect to ground temperature and heat flux around the oil pipeline. The oil pipeline is 48 inches in diameter, and carries oil at about 150°F while the gas pipeline is 42 inches in diameter and carries gas at below freezing temperature. For the case under study, the gas temperature is assumed at 15°F. As the gas pipeline will not affect the VSM portion of the oil pipeline, as a matter of fact, it may enhance the VSM system due to its chilling effect, only areas where burial mode of the oil pipeline occurs will be investigated.



COMPUTATION FLOW CHART

FIGURE 2

3.1 Soil Properties

A representative soil stratigraphy was chosen at Fairbanks, Alaska*. The ground temperature is about 30°F to 31°F. Depth of the active layer is about 6 feet at the site. The soils consist of silt and fine sand. Thermal conductivities of various soils were evaluated by Kersten's Method. Table I lists thermal properties of the soils.

3.2 Meteorological Data

The meteorological and ground surface information are used as input for the thermal analysis. The data for Fairbanks is listed in Table II.

3.3 Results

As the two pipelines are spaced about 78 feet apart on both sides of the gravel pad, it was found that the ground temperature regime around the oil pipeline is almost not affected by the chilled gas pipeline, as shown in Figure 3.

The average heat flux out of the oil pipeline was also investigated. The effect due to the chilled gas pipeline is very minute, as can be seen in Table III.

Therefore, it can be concluded that the construction of a chilled pipeline on the other side of the work pad for an existing oil pipeline would not thermally affect the oil pipeline system.

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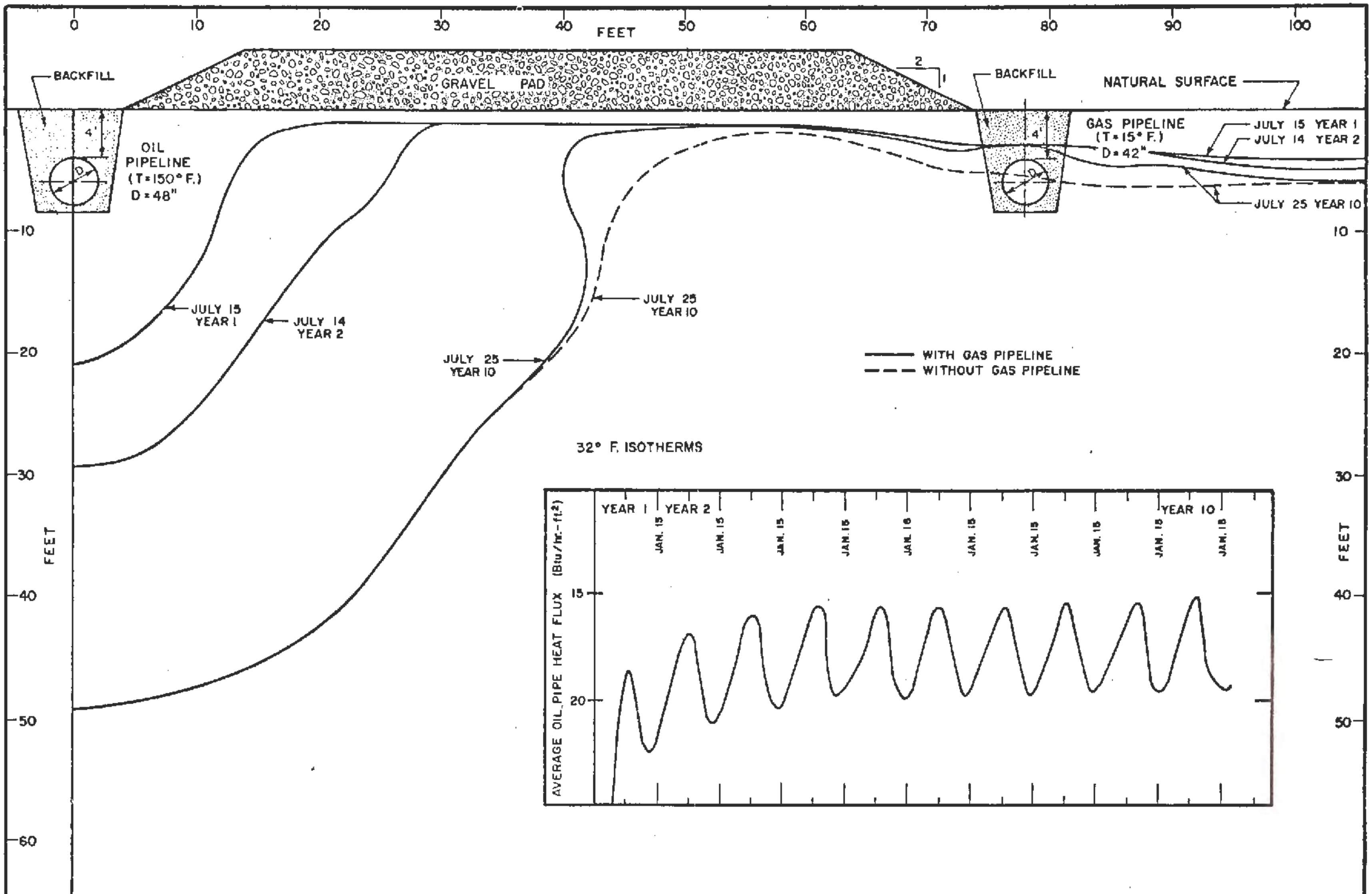
* U.S. Army CRREL Technical Report No. 180, February 1968



32° F. ISOTHERMS AND AVERAGE OIL PIPE HEAT FLUX

EBA Engineering Consultants Ltd.	
JOB No.: 1-1487	DATE: JUNE 21/76
DWG. BY: L. D.	DWG. No.: 3
REV'D BY:	

TABLE I

THERMAL PROPERTIES OF SOILS

DEPTH BELOW GROUND SURFACE (FEET)	SOIL TYPE	WATER CONTENT (% DRY WEIGHT)	TOTAL DENSITY (LBS/CU.FT.)	THERMAL CONDUCTIVITY (BTU/HR/FT/°F)		SPECIFIC HEAT (BTU/LB/°F)		LATENT HEAT (BTU/CU.FT.)
				FROZEN	UNFROZEN	FROZEN	UNFROZEN	
	GRAVEL PAD	10.0	100.0	0.64	0.73	0.20	0.25	1300
	BACKFILL	20.0	108.0	1.19	0.87	0.22	0.31	2590
0 - 17	SILT	30.0	110.5	1.08	0.67	0.26	0.37	3060
17 - 30	SANDY SILT	24.0	117.8	1.08	0.77	0.25	0.34	2600
30 - 58	FINE SAND	22.0	122.0	1.82	1.12	0.23	0.33	3170
58 -	FINE SAND AND SILTY SAND	30.0	117.0	1.74	0.95	0.24	0.37	3890

TABLE II

METEOROLOGICAL DATA

FAIRBANKS, ALASKA

(Latitude: 64°49'N; Longitude: 147°52'W; Elevation: 436 feet)

	AMBIENT TEMPERATURE (°F)	WIND VELOCITY (MPH)	SNOW DEPTH (FEET)	AVERAGE SOLAR RADIATION (BTU/HR/SQ.FT.)
15 JANUARY	-10.0	3.20	1.08	2.46
15 FEBRUARY	- 3.0	3.80	1.38	11.09
15 MARCH	9.0	4.70	1.17	32.80
15 APRIL	29.0	5.90	0.58	57.75
15 MAY	47.0	6.80	0.13	72.07
15 JUNE	59.0	6.40	0.00	78.69
15 JULY	61.0	5.80	0.00	68.22
15 AUGUST	56.0	5.70	0.00	49.13
15 SEPTEMBER	45.0	5.50	0.00	28.49
10 OCTOBER	30.0	5.00	0.00	13.80
15 OCTOBER	28.0	4.90	0.17	12.63
15 NOVEMBER	3.0	3.70	0.38	4.32
15 DECEMBER	- 9.0	3.00	0.63	0.92

TABLE II (cont'd)

PROPERTIES OF SNOW:

Thermal Conductivity	0.20 BTU/HR/FT/°F
Surface Emissivity	0.95
Surface Absorptivity	0.40

PROPERTIES OF GROUND:

Surface Emissivity	0.90
Surface Absorptivity	0.80

EVAPOTRANSPIRATION FACTOR:

Natural Surface	0.25
Gravel Surface	0.10

GREENHOUSE FACTOR: 0.837

CONVECTION CORRELATION COEFFICIENT: 0.02

TABLE III

AVERAGE HEAT FLUX AROUND

AN OIL LINE

TIME	AVERAGE HEAT FLUX AROUND OIL PIPELINE (BTU/HR/SQ.FT.)	
	WITHOUT GAS PIPELINE	WITH GAS PIPELINE
YEAR 10, March 8	17.861	17.865
YEAR 10, July 27	15.152	15.159
YEAR 11, January 5	19.606	19.610

IV. CLOSURE

The geothermal model has been verified by field performance at various test facilities and related projects, with satisfactory results.

Respectfully submitted,

EBA Engineering Consultants Ltd.

PROFESSIONAL ENGINEER ALBERTA C. T. HWANG

C. T. Hwang, P.Eng.

PROFESSIONAL ENGINEER ALBERTA R. SESHADRI

R. Seshadri, P.Eng.

CTH/sjm

APPENDIX A

DESCRIPTION OF THE GEOTHERMAL MODEL

1. INTRODUCTION

The Geothermal Model was developed to predict the thermal response of the soil to changes in the thermal environment. These changes can result from the operation of a pipeline at specified temperature, from the construction effects near the ditch or berm, and from alteration of the ground surface properties.

This appendix describes the organization and use of the package of computer programs which have been applied for the analysis of geothermal problems of the Alcan Pipeline Project. The programs can be divided into two groups. One is the so-called FRONT END; the other the MODEL itself. The front end consists of programs written in a conversational language (BASIC) which generate data files required as input to the model that was written in FORTRAN language. The use of the front end programs enables the user to prepare the input data for a thermal problem in a conversational manner.

Mathematical background of the model and its input parameters will be described. The method employed in the front end programs regarding the calculation of thermal properties are presented in detail.

II. THE GEOTHERMAL MODEL

The model consists of the following codes:

(1) A thermal conduction code with finite element formulation of the transient heat conduction mechanism during freezing and thawing in the ground, in which latent heat is considered as a heat source in the energy balance equation.

(2) A "Heat" Subroutine which considers the heat exchange mechanism at the ground surface with respect to meteorological data.

(3) A "Settle" Subroutine which adjusts the geometry of the thermal domain during the problem solution to account for thaw subsidence.

2.1 Conduction Code Formulation

The flow and transfer of heat in a soil medium are complex phenomena which are not clearly defined at the present time. The phenomena include such diverse mechanisms as conduction, convection in the pore air and/or pore water, radiation through the voids, evapotranspiration and condensation, and moisture migration. In order to simplify the mathematical description of such complex phenomena, a conduction model is assumed so that the equivalent conductivity tensor can account for the aforementioned mechanisms. This is justifiable because in application, the soil and weather changes along the pipeline are likely to be gradual. Under these assumptions, the governing principle becomes the well-known Fourier's law of heat conduction.

Considering the latent heat as a heat source during freezing and thawing, the field equations specifying the three-dimensional heat conduction problem in thermal analysis may be summarized in Cartesian tensor notation as follows:

Equation of Energy Balance

(1) $q_{i,i} + \rho c\dot{\theta} = h$ on $V \times (0, \infty)$

Constitutive Equation (of Heat Conduction)

(2) $q_i = -k_{ij}\,\bar{\theta}_{,j}$ on $V \times (0, \infty)$

Initial Conditions

(3) $\theta\,(\bar{r}, 0) = \bar{\theta}_o\,(\bar{r})$ on V

Temperature Boundary Conditions

(4) $\theta\,(\bar{r}, t) = \bar{\theta}\,(\bar{r}, t)$ on S_1

Heat Flux Boundary Conditions

(5) $Q\,(\bar{r}, t) = \bar{Q}\,(\bar{r}, t)$ on S_2

Surface Heat Transfer

(6) $Q\,(\bar{r}, t) = c_s\,(\bar{r})\,(\theta\,(\bar{r},t) - \hat{\theta}(\bar{r}, t))$ on S_3.

where	$\theta\,(\bar{r}, t)$	=	temperature
	$q_i(\bar{r}, t)$	=	Cartesian components of the heat flux
	$k_{ij}\,(\bar{r}, t)$	=	components of thermal conductivity tensor
	$c(\bar{r})$	=	specific heat
	$\rho(\bar{r})$	=	mass density
	$h(\bar{r}, t)$	=	rate of heat generation (including latent heat)
	$c_s(\bar{r})$	=	coefficient of surface heat transfer
	$\dot{\theta}(\bar{r}, t)$	=	time derivative of temperature
	$\bar{r}$	=	the position vector
	t	=	time

V	=	the spatial domain
$\bar{\theta}_o(\bar{r})$	=	the prescribed initial temperatures in V
$\bar{\theta}(\bar{r},t)$	=	prescribed temperatures on the surface S_1
n_i	=	Cartesian components of surface normal
$\bar{Q}(\bar{r}, t)$	=	prescribed heat input on the surface $S_2 = -q_i n_i$
$\hat{\theta}(\bar{r}, t)$	=	prescribed ambient temperature in contact with surface S_3
$V \times (0, \infty)$	=	the Cartesian product of the space and time domains

A finite element technique using Rayleigh-Ritz method by means of a convolution variational theorem was formulated for numerical solution.

The technique of variational calculus has been proven to be one of the most powerful methods in solving various complex engineering problems. By this technique, the equivalent of above equations is formulated in an integral form over the region of interest, including the energy exchanges at the boundary. This makes it possible to incorporate easily very complex boundary conditions as found in a pipeline problem. Moreover, this technique permits the use of many approximate methods of solutions. In deriving approximate solutions to a problem, arbitrary solutions may be assumed with undetermined parameters. These assumed solutions are then used in the integral which will result in a relation involving only the unknown parameters. This relation can them be minimized with respect to each of the parameters, giving as many equations as the unknown parameters and hence the approximate solution. This approximate solution will, in general, be different from the exact solution, but can be made as close as desirable to the true solution. This is possible because by the minimizing procedure, the method will automatically choose the closest approximate solution.

In actually formulating the approximate solutions, the two-dimensional finite element method is applied. The method divides the thermal region of interest into triangular-shaped sub-regions. Triangles are selected because any boundary contour such as that between the pipe and the soil, between the atmosphere and the soil, and between stratified soils, can easily be fit with the edges of many triangles. By using the Rayleigh-Ritz method, the prime variable, the temperature in the present solution, is prescribed in terms of the values of the temperatures at the apexes of each triangle. These temperatures at the node points being common to adjacent subregions, enable approximate continuity requirements to be satisfied over the entire region.

The advantages of using triangle-shaped finite elements are numerous. The method is completely general with respect to geometry and material properties. Temperatures or heat flux boundary conditions may be specified at any point along the boundary of the finite element system.

The mathematical formulation will not be described in this report. A more detailed description is available in the list of references[1].

In order to investigate the numerical accuracy, the conduction code was applied to solve a thermal problem with a closed form solution. The comparisons between the calculated value and the closed form solution are excellent, as shown in Figures A-1 and A-2.

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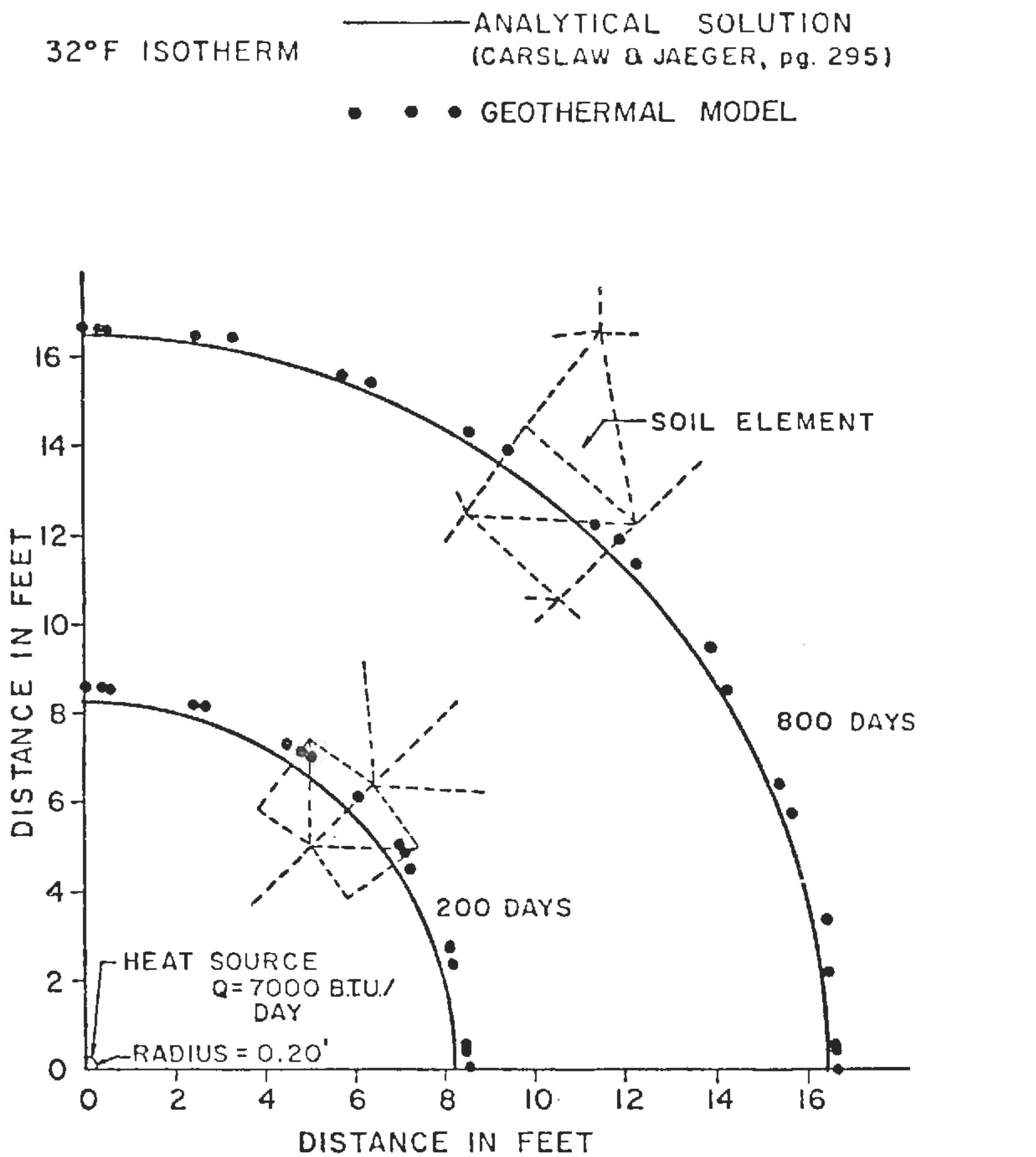
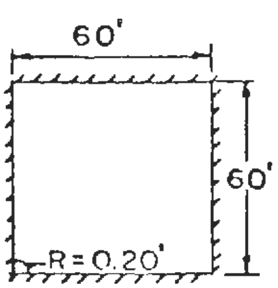
1. Hwang, C.T., Murray, D.W. and Brooker, E.W.; "A Thermal Analysis for Structures on Permafrost", Canadian Geotechnical Journal, Vol. 9, No. 1, February 1972.



COMPARISON OF SOLUTION TECHNIQUES

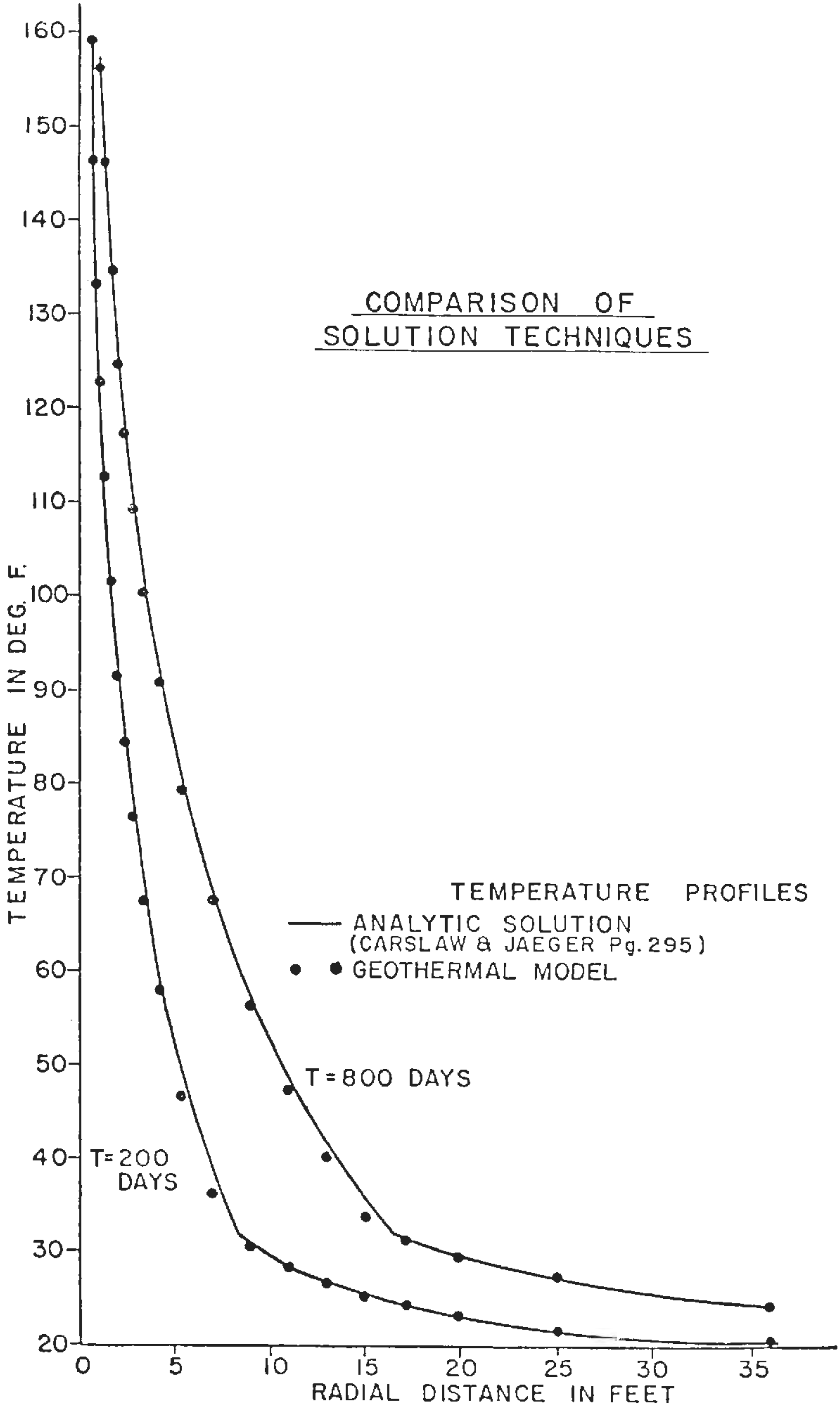


$K_f = 1.5$ BTU/HR./FT./°F
$K_t = 1.0$

$C_f = 40$ BTU/FT^3/°F
$C_t = 50$

L = 3000 BTU/FT.^{3} PHASE CHANGE AT 32°F

FIGURE A-1



COMPARISON OF SOLUTION TECHNIQUES
TEMPERATURE PROFILES
ANALYTIC SOLUTION (CARSLAW & JAEGER Pg. 295)
GEOTHERMAL MODEL
T=800 DAYS
T=200 DAYS
TEMPERATURE IN DEG. F.
RADIAL DISTANCE IN FEET
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
0
5
10
15
20
25
30
35

FIGURE A - 2

Input parameters for the conduction code such as thermal properties will not be discussed here. As these parameters are evaluated through use of the conversational programs, a detailed description will be presented in a later section.

The treatment of unfrozen water content variation with respect to temperature during freezing and thawing (Penner 1963; Williams 1964; Yong 1965; Dillon and Andersland 1966; Keune and Hoekstra 1967; Anderson et al 1973)[2] is similar to that by assuming the water changes phase at a definite temperature, 32°F. Figure A-3 shows the calculation of latent heat using unfrozen water content. Let the pore water undergo a change of phase over a temperature range from 32°F to T_o, the amount of water changes phase at some discrete temperature T_i (for this example, i = 1 to 5) is:

$$Q_i = (Wu^{T_i + \Delta T/2} - Wu^{T_i - \Delta T/2}) \times \gamma dry \times L$$

where $Wu^{T_i + \Delta T/2}$ = Unfrozen water content at temperatures $T_i + \Delta T/2$

$\Delta T = (32 - To)/n$, n = number of temperature increment

γdry = dry density of the soil

L = latent heat of fusion of water

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2 Penner, E. 1963, Frost Heaving in Soils, Proc. 1st Int. Conf. on Permafrost, Lafayette, Indiana, 1963.

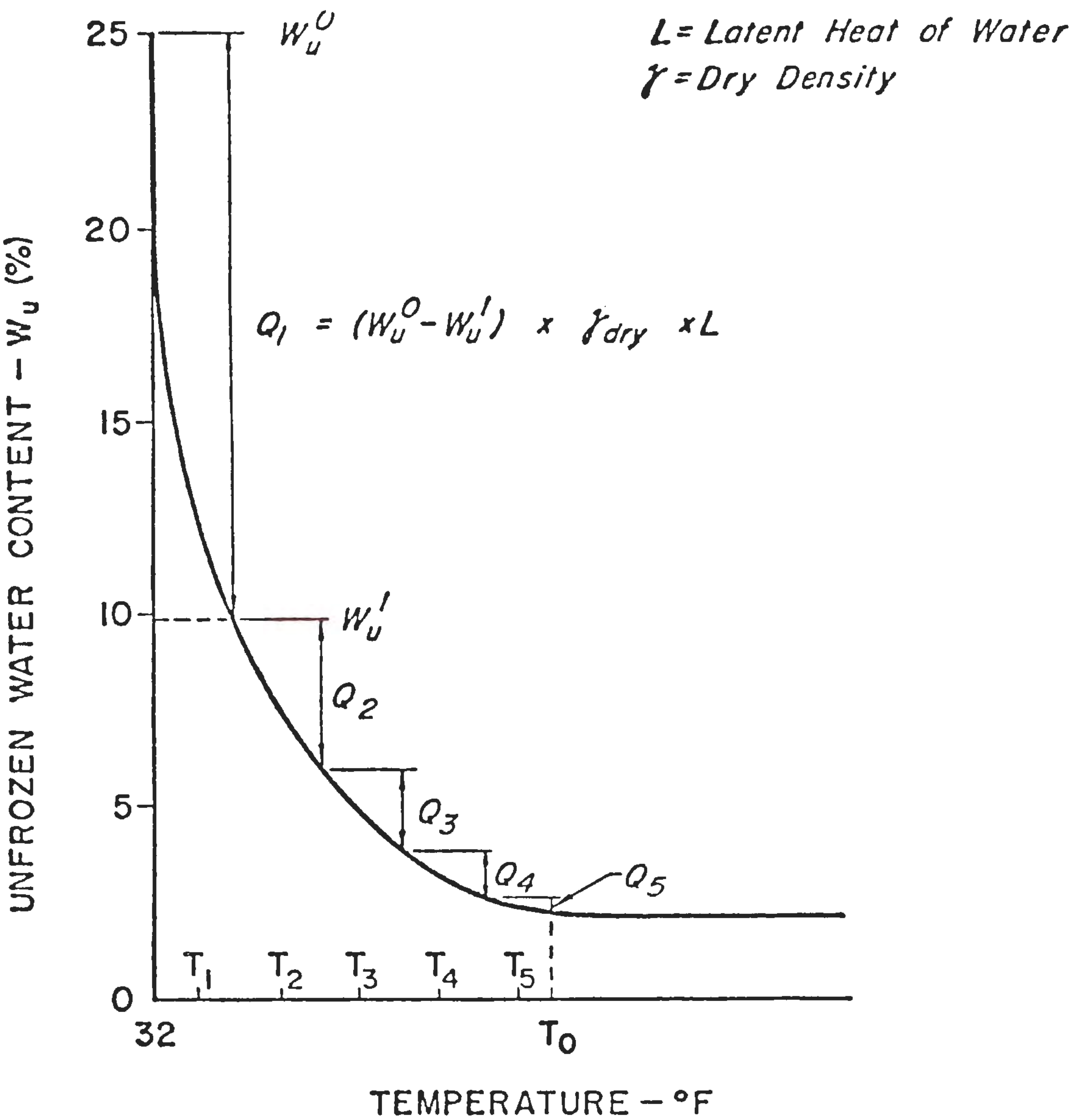
Williams, P.J. 1964, Unfrozen water content of frozen soils and soil moisture suction, Geotechnique 14, pp 231-246.

Dillon, H.B. and O.B. Andersland 1966, Predicting unfrozen water contents in frozen soils, Can. Geotech. J. 3:53-60.

Keune, R. and P. Hoekstra 1967; Calculating the amount of unfrozen water in frozen ground from moisture characteristics curves; Special Report 114, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, N.H.

Anderson, D.M., A.R. Tice and H.L. McKim, 1973; The unfrozen water and the apparent specific heat capacity of frozen soils; Proc. 2nd Int. Permafrost Conf. Yakutsk, USSR.

Yong, R.N. 1965; Soil suction effects on partial soil freezing, HRB Report No. 68, pp 31-42.



CALCULATION OF LATENT HEAT USING UNFROZEN WATER CONTENT CURVE

FIGURE A-3

Thus, the latent heat matrix in the balance equation during a thermal analysis (Hwang et al, 1973) will be evaluated as an integral with respect to T_i over the temperature range.

The equation governing the mechanism of heat balance for a soil element including ground water seepage is:

$$\text{div}\ (K\ \text{grad}\ T) = C_{soil} \frac{\partial T}{\partial t} + H + Cw\ Vi \frac{\partial T}{\partial Xi} \qquad (1)$$

where

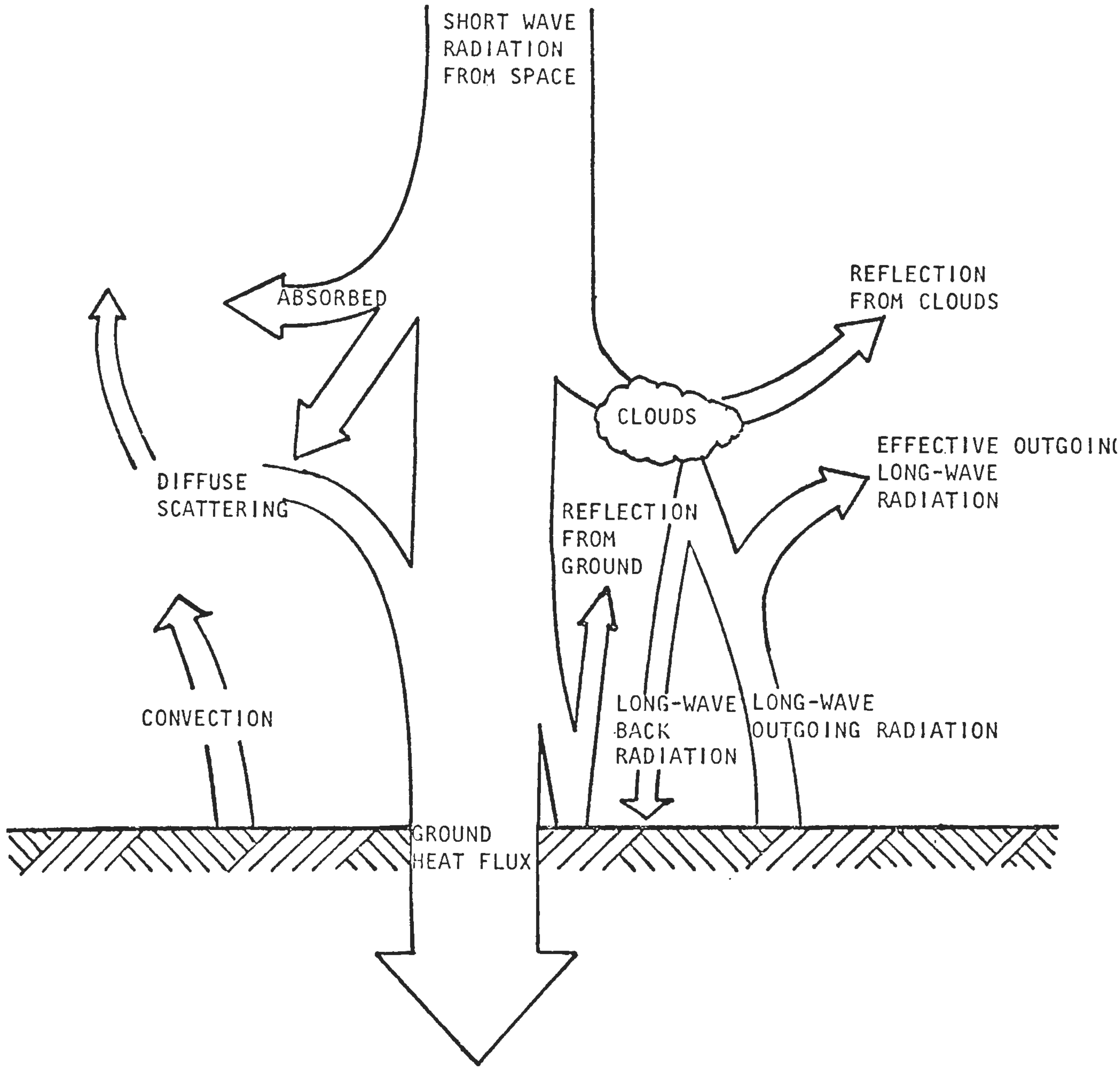
- T = temperature
- V_i = average seepage velocity of pore water with i denoting x, y, and z directions
- K = thermal conductivity of the soil
- C_{soil} = volumetric heat capacity of the soil
- Cw = volumetric heat capacity of the seepage water
- H = a function of the latent heat of fusion as well as element temperature. This function expresses the heat required to thaw a certain portion of the soil element.
- X_i = position coordinates, i represents x, y, and z directions.

The term on the left hand side of Equation (1) represents the net inflow of heat due to conduction. The first term on the right hand side represents heat absorbed by the element to raise its temperature. The second term represents the latent heat required to thaw a certain portion of the element. The third represents the convective heat transport by the seepage water.

The model in its present form does not include the convective heat transport. Since it is a standard procedure for finite element techniques to include such a term, the model is now being modified to include the convective heat transfer due to ground water seepage.

2.2 Subroutine HEAT

Subroutine HEAT is a heat transfer calculation routine that determines the total heat flux to the ground at the ground-air interface, as described graphically in Figure A-4. It determines this flux directly from the actual meteorological conditions supplied as input, the surface properties of the ground or snow cover, and the actual surface temperature. This actual surface temperature is determined by finite element conduction code at each location when HEAT is combined with it to supply the flux boundary condition. The effects of the pipe or changes due to construction are, therefore, included in the surface temperature calculation.



HEAT TRANSFER BETWEEN
GROUND SURFACE AND AIR ON
A SUNNY DAY

FIGURE A-4

The total net heat flux at the ground-air interface, QT, is:

$$QT = QL - QS + QC + QE$$

where, QL = net long wave radiation leaving the surface,

QS = net short wave or solar radiation absorbed at the surface,

QC = net convective heat flux, and

QE = heat flux from evapotranspiration.

The total net heat flux, QT, is then changed into a function of a linearized surface heat transfer coefficient and an effective ambient temperature at each surface location, so that the flux boundary condition at the ground-air interface becomes an implicit form for the conduction code. In doing so, the solution becomes unconditionally stable.

The linearized surface heat transfer coefficient, H_s, is defined as the change in the total net heat flux at the ground-air interface, caused by a change in the ground surface temperature, divided by the change in ground surface temperature. In the code, a 1°F change in ground temperature is used, and all other parameters are held constant over the time interval. The effective ambient temperature, Te_s, is then defined from:

$$QT = H_s \; (T_{sur} - Te_s)$$

where, QT is the total net heat flux over the time interval, with the surface held at the initial surface temperature, T_{sur}. If the surface heat transfer were convection only, the heat transfer coefficient would be the usual convective coefficient and the effective ambient temperature would be the actual air temperature. However, because the surface heat transfer is strongly affected by radiation (both short wave length of solar radiation, and long wave length re-radiation) and also by the presence of snow, the effective coefficient and temperature can be quite different from the convection coefficient and actual air temperature.

2.2.1 Short Wave or Solar Radiation

The short wave or solar radiation incident on a horizontal surface is supplied as input. These data are available for many locations on at least an average flux per month basis. This incident energy is converted to absorb short wave energy by multiplying an absortivity (1.0 minus the albedo) and a view factor. The view factor is supplied as input to the subroutine in table form, as a function of both position and time of year. It can include both shadow effects from berms, nearby trees or other obstructions, and inclination effects due to non-horizontal surfaces.

The net short wave or solar radiation absorbed at the surface, QS, becomes:

$$QS = SW \times (1 - a) \times VF$$

where,

SW = an averaged monthly flux ($BTU/hr/ft^2$) which can be obtained from the meteorological data bank along the proposed pipeline route, or from other sources.**

a = albedo, which is a measure of reflected solar radiation as a percent of the incident radiation.

** Data are available from radiation maps drawn by the Canadian Meteorological Service, and represents their best estimate of the distribution of solar radiation. The radiation data are the average of direct and diffuse radiation received on a horizontal surface.

VF = view factor, which includes both shadow effects from berms, nearby trees or other obstructions, and inclina tion effects due to non-horizontal surfaces. It is an output from the program SOLAR that will be described in the next section.

The value of the albedo depends greatly on the type of surface and to a lesser extent on the angle incident of the sun's rays. Since it is impossible to exactly characterize the infinite variety of surfaces found in nature, the following typical values were given by Geiger (1965)[3] (Table A-1).

2.2.2 Long Wave Radiation

The long wave radiation energy balance at the ground surface begins with the thermal radiation emitted by the surface, proportional to the fourth power of the surface temperature and the emissivity of the surface. However, a large part of this energy is returned to the surface by the greenhouse effect of the earth's atmosphere. This is caused mainly by the water vapour and the CO_2 in the atmosphere, and, to some extent, by cloud cover. The subroutine uses a greenhouse factor which is defined as the ratio of the long wave radiation returning from the atmosphere to the long wave radiation originally leaving the surface.

---

3. Geiger, R., "The Climate Near the Ground"; Harvard University Press, Cambridge, Mass. 1965.

TABLE A-1

ALBEDO OF VARIOUS SURFACES

	PERCENT
Fresh Snow Cover	75-95
Dense Cloud Cover	60-90
Old Snow Cover	40-70
Clean Firm Snow	50-65
Light Sand Dunes, Surf	30-60
Clean Glacier Ice	30-46
Dirty Firm Snow	20-50
Dirty Glacier Ice	20-30
Sandy Soil	15-40
Meadows and Fields	12-30
Densely Built-Up Areas	15-25
Woods	5-20
Dark Cultivated Soil	7-10
Water Surfaces, Sea	3-10

The long wave radiation leaving the surface becomes:

$$QL = E\sigma T_{sur}^{4} (1 - G),$$

where, E = surface emissivity,

G = greenhouse factor,

σ = Stefan-Boltzmann radiation constant ($= 1.713 \times 10^{-9}$ BTU/hr/ft^2/°F^4), and

T_{sur} = surface temperature (°F)

Typical values of infrared emissivities are listed as follows (Sellers, 1965)[4]:

A. WATER AND SOIL SURFACES

Water	92-96
Snow, Fresh Fallen	92-99.5
Snow, Ice Granules	89
Ice	96
Soil, Frozen	93-94
Sand, Dry Playa	84
Sand, Dry Light	89-90
Sand, Wet	95
Gravel, Coarse	91-92
Limestone, Light Grey	91-92
Concrete, Dry	71-88
Ground, Moist, Bare	95-98
Ground, Dry, Plowed	90

B. NATURAL SURFACES

Desert	90-91
Grass, High Dry	90
Fields and Shrubs	90
Oak Woodland	90
Pine Forest	90

C. VEGETATION

Alfalfa, dark green		95
Oak Leaves		91-95
Leaves and Plants		
	0.8η	5-53
(Wavelength	2.4η	70-97
in Microns)	10.0η	97-97

The amount of long wave radiation that does escape to space is primarily a function of surface temperature, the amount of water vapour in the atmosphere, and the cloud cover. From the information presented by London (1957) and Sellers (1965), the variation of greenhouse factor with latitude is

4. Sellers, W.D., "Physical Climatology", The University of Chicago Press, 1965

very small and can be regarded as constant, due to:

(a) the moisture content of the atmosphere is sufficiently high, so that it is the dominating influence on the direct loss of heat by radiation from the ground water cloudless conditions (water vapour alone can trap 75 percent of the terrestrial radiation, and

(b) that the greater cloud amount in the higher latitude compensates for smaller moisture content encountered there.

A typical seasonal variation of the greenhouse factor is shown in Figure A-5. All the data[5,6,7] seem to have the same seasonal trend, and are in good agreement. The increase in the greenhouse factor during the summer months is due to a constant 80 to 90 percent low cloud cover found over the Arctic.

A seasonal estimate of the greenhouse factor is suggested as the dashed line in the figure which lies somewhere between the data for clear sky, and that for actual cloudiness. Monthly values of the greenhouse factor are shown in Table A-2 following.

In order to investigate the effect of the greenhouse factor due to seasonal variation, comparisons were made using the same soil stratigraphy and meteorological data at Norman Wells, N.W.T.

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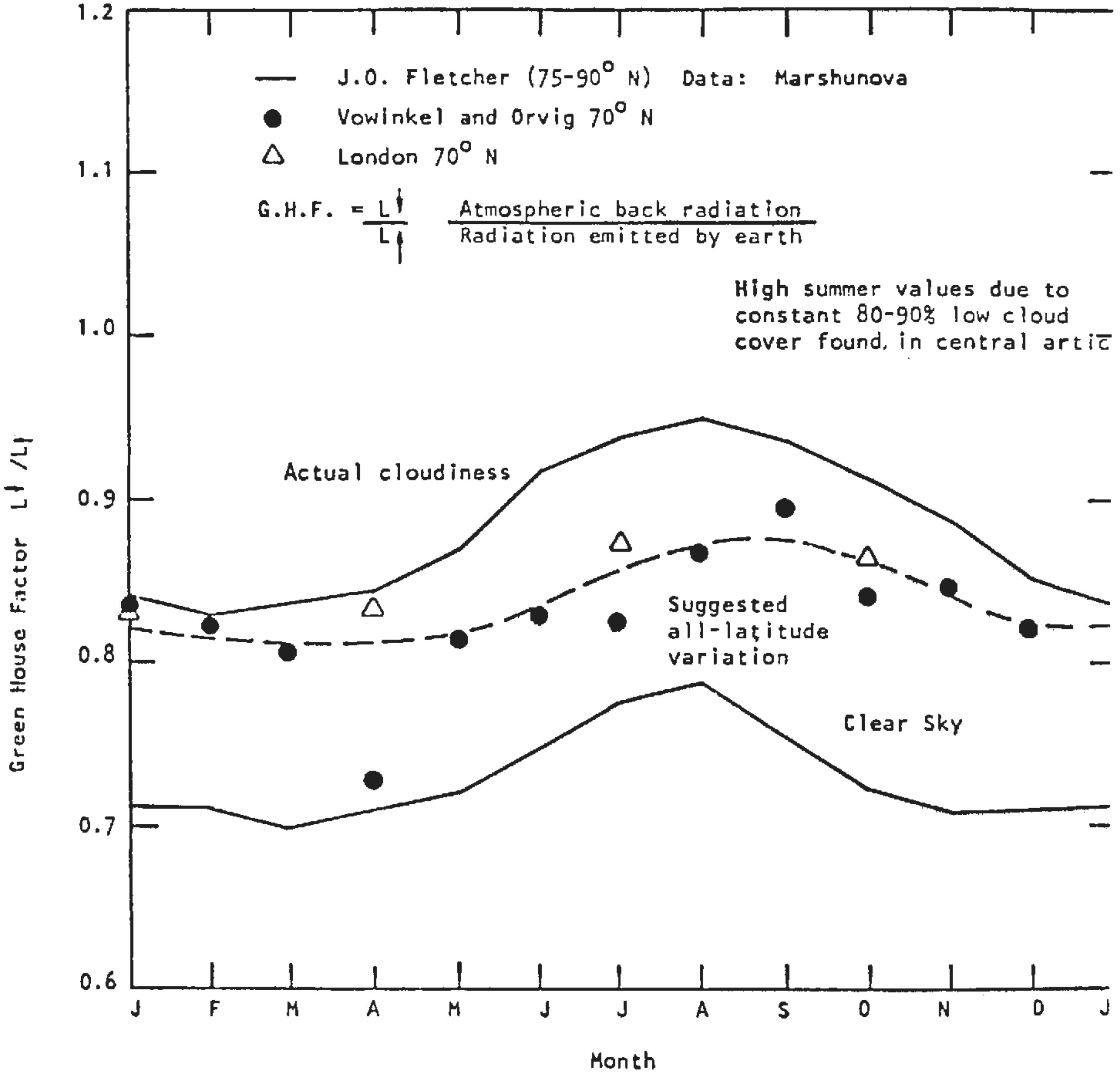
5. Fletcher, J.O., "The heat budget of the Arctic Basin and Its Relation to climate"; Rand Corp. Report R-444-PR, 1965.

6. London, J., "A study of the atmospheric heat balance", Dept. of Meteorology and Oceanography, New York University, Report AFCRC-TR-57-28-7, 1957.

7. Vowinkel, E., and Orvig, S., "Long wave Radiation and Total Radiatior Balance at the surface in the Arctic", Arch. Met. Geoph. Biokl. B.BC (4), pp 451-479, 1965.



YEARLY VARIATION OF THE GREENHOUSE FACTOR.

FIGURE A-5

TABLE A-2

MONTHLY VALUES OF GREENHOUSE FACTOR

JANUARY	0.815
FEBRUARY	0.810
MARCH	0.810
APRIL	0.815
MAY	0.825
JUNE	0.850
JULY	0.870
AUGUST	0.875
SEPTEMBER	0.870
OCTOBER	0.850
NOVEMBER	0.830
DECEMBER	0.825
AVERAGE	0.837

Results of the sensitivity study indicated that regardless of the effects due to evapotranspiration, the results show that there is no significant difference in both the ground surface temperature and the maximum depth of thaw due to seasonal variation. Therefore, it was concluded that for practical purposes, the greenhouse factor can be considered as constant throughout the year, with a value of 0.83.

2.2.3 Convection

The convection at the surface is calculated using a convective heat transfer coefficient and the difference between the air temperature and the surface temperature.

$$QC = Hc \times (T_{sur} - T_{air})$$

Assuming the convection mechanism is similar to that on a flat plate of a turbulent flow (Eckert, 1950; Kreith, 1958), the convective heat transfer coefficient is obtained from a correlation which uses the 0.8 power of the wind velocity and appropriate properties of the air as follows:

$$Hc = C \times K_{air} \times \left\{\frac{W \times \rho_{air}}{\eta_{air}}\right\}^{0.8}$$

where K_{air} = Thermal conductivity of air

= $0.01325 + 0.000026 \times T_{air}$ (BTU/hr/ft/°F)

ρ_{air} = Density of air at 1 Std. atm

= $38.84/T$ (lbs/cu.ft), where T is temperature in Rankin scale = T_{air} (°F) + 459.7

η_{air} = Viscosity of air
= $1.1075 \times 10^{-5} + 1.8 \times 10^{-8} \times T_{air}$ (lbs/ft/sec)

W = Wind velocity (mph)

T_{air} = Air temperature (^{o}F)

C = Correlation coefficient

The correlation coefficient, C, was obtained from a series of year-long calculations which matched the cumulative heat flux over the year to the measured geothermal flux. Experience shows that normally C is 0.02.

2.2.4 Snow Cover

When the ground is covered with snow, there are significant changes in the heat transfer mechanisms and these are modeled by the subroutine as follows. The time of continuous snow cover appearance and disappearance is supplied as input to the subroutine. The average snow depth as a function of time is also an input. This average snow depth can be changed as a function of position by multipliers called snow depth factors which are also supplied as input. When the ground is covered with snow at any location, the surface properties are switched to snow properties. In addition, the temperature of the surface of the snow is obtained from an energy balance neglecting the heat capacity of the snow. The heat conducted through the layer of snow is balanced by the radiation and convection at the surface of the snow. Because the conduction and convection terms depend on the first power of the surface temperature while the long wave radiation depends on the fourth power, a Newton-Raphson iteration procedure is used to obtain the snow surface temperature.

Thermal conductivity of snow has been correlated to its density (Yen, 1969)[7]. Figure A-6 shows the correlation. The density of snow is also affected by various types of vegetation and topographical features. Figure A-7 illustrates a time varying snow density correlation with vegetation type.[8]

It should be noted that the thermal conductivity used in the subroutine HEAT is constant throughout the year. Therefore, from Figures A-6 and A-7, the following averaged values are suggested for general inputs:

REGION	DENSITY (LBS/FT^3)	THERMAL CONDUCTIVITY (BTU/HR/FT/°F)
Arctic Coast	25.0	0.25
Tundra, Taiga	20.0	0.18
Boreal	17.0	0.12
Prairie	15.0	0.10

2.2.5 Evapotranspiration

Evapotranspiration is a term used to describe the combined process of evaporation from soil and plant sirfaces, and the transpiration of plants. Transpiration itself describes the phenomena of water evaporating

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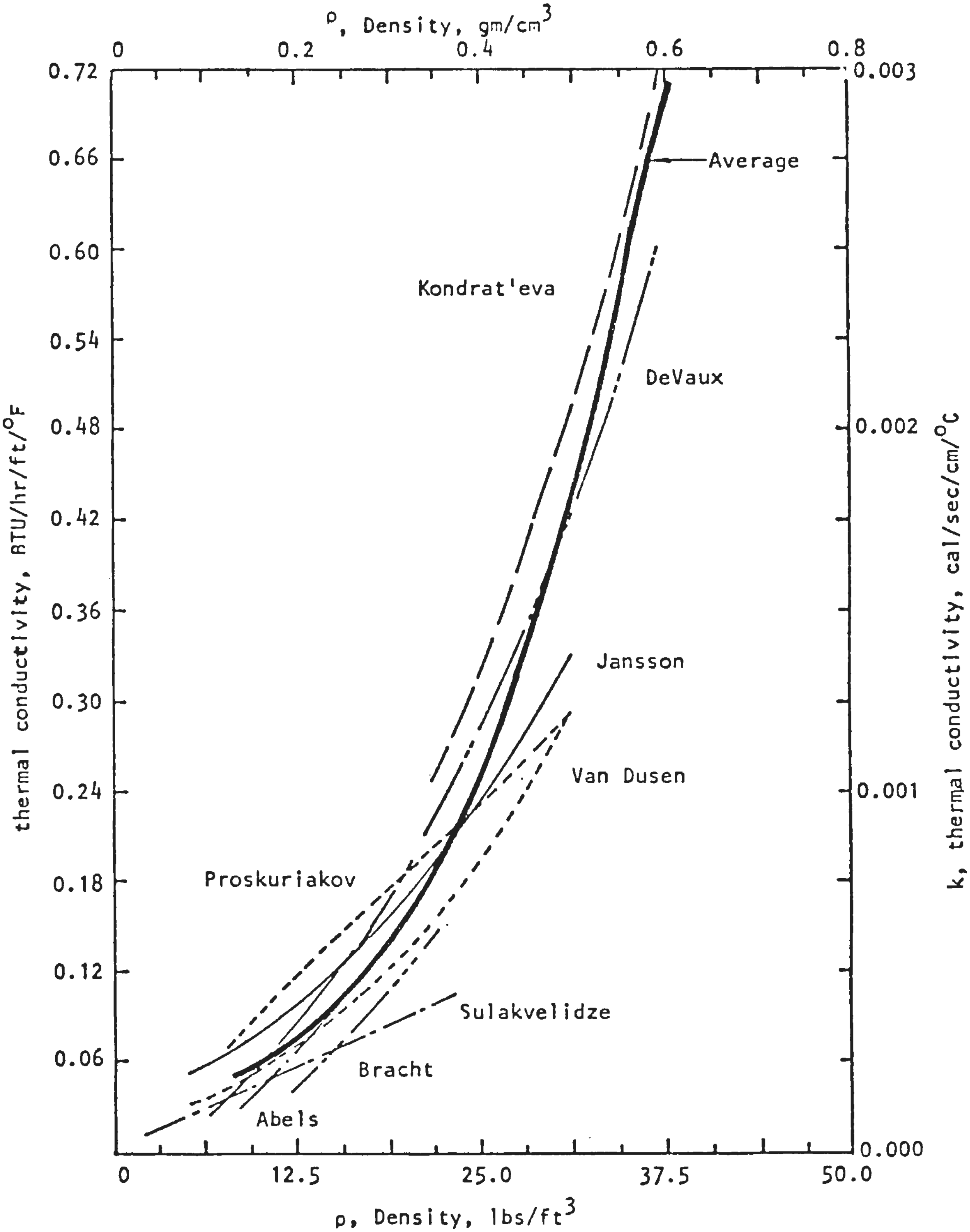
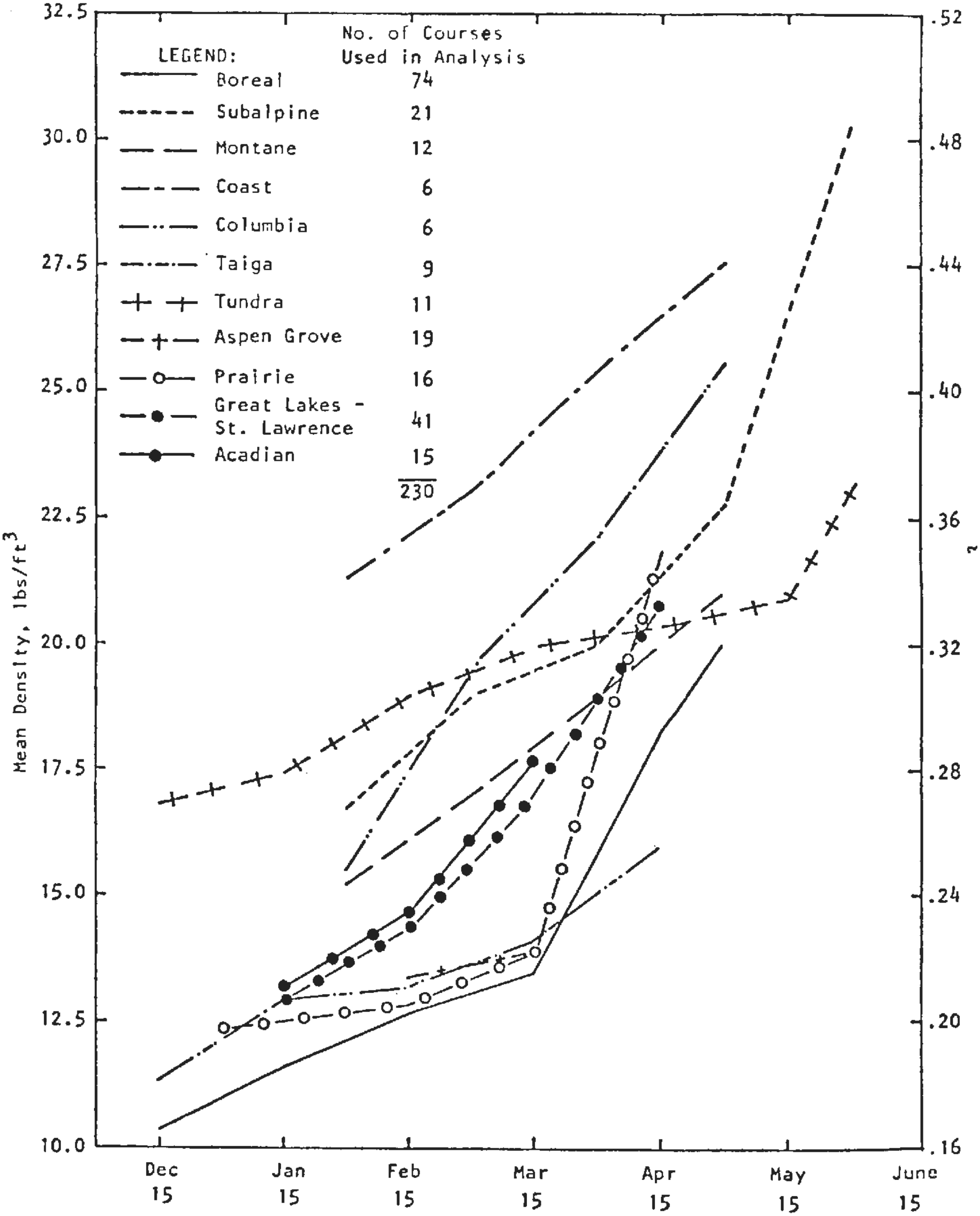
7. Yen, Yin-Chau, "Recent studies on snow properties", Advances in Hydroscience, Vol. 5, pp 173-214, 1969

8. McKay, G.A. and Findley, B.F., "Variation of snow resources with Climate and vegetation in Canada", Paper presented at Western Snow Conference, Billings, Montana, April 20-22, 1971.



SNOW THERMAL CONDUCTIVITY AS A FUNCTION OF DENSITY



TIME DENSITY VARIATIONS IN VEGETATION REGIONS from the plant pores (known as stomata). Evapotranspiration can be significant percentage of the energy budget at the surface. On a summer day in a well irrigated field, a crop can absorb almost all the incoming solar radiation via the evapotranspiration process, leaving very little radiant energy left in the form of sensible heat to the ground. In the natural undisturbed regions of Northern Canada, the evapotranspiration is likely to be much less of a heat sink, but can be expected to absorb at least 10-15 percent of the incoming solar radiation during the summer months.

The model chosen in the subroutine HEAT is that of Thornthwaite[10-14], which is an experimentally correlated function of mean monthly temperature with a daylight (a function of latitude) correction factor applied.

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10. Thornthwaite, Holzman, "The Determination of evapotranspiration from land and water surfaces", Monthly Weather Review, Vol. 67, pp 4-11, 1939.
11. Pelton, King, Tanner "An evaluation of the Thornthwaite mean temperature methods for determining potential evapotranspiration", Agron, J., Vol. 52, pp 387-395, 1960.
12. Mather, J.R., Investigation of Thornthwaite's evapotranspiration formula and procedure in "Estimating Soil Tractionability from Climatic Data", publications in Climatology/Drexel Institute of Technology, Centerton, Vol. 7, No. 3, 1954.
13. Thornthwaite & Mather, "Instructions and Tables for Computing Potential Evapotranspiration and Water Balance", publications in Climatology, Drexel Institute of Technology, Centerton, Vol. 10, No. 3, 1957.
14. Palmer & Havens, "A Graphical Technique for Determining Evapotranspiration by Thornthwaite Technique", Monthly Weather Review, Vol. 86, pp 123-128, 1958.

(1) The Thornthwaite Model

Thornthwaite basic formula for computing monthly potential evaporation is:

$$Eo = 16 \cdot (10\,T/I)^{a} \cdot D$$

where,

Eo	=	Monthly potential evapotranspiration in MM of H20,
T	=	monthly mean temperature (°C),
I	=	heat index,
D	=	daylight correction factor, and
a	=	an empirical determined exponent which is a function of I.

$$I = \sum_{1}^{12} \left(\frac{T}{5}\right)^{1.514}$$

$$a = 0.675 \times 10^{-7} \times I^{3} - 7.71 \times 10^{-5} \times I^{2} + 1.79 \times 10^{-2} \times I + 0.49$$

The equation is valid for air temperature between 0°C (32°F) and 26.5°C (80°F). Below 0°C, Eo is 0. For higher temperatures, Eo increases monotonically with temperature, independent of heat index I.

The daylight correction factor is daylight hours (as a function of latitude) divided by 12. The daylight hours along the proposed pipeline route have been stored in the climate data bank, which will be described in a later section.

(2) Modification Factor, F.

The most important factor affecting evapotranspiration is the availability of soil moisture, which depends on the local drainage pattern and precipitation. Type of vegetation should also affect the rate of evapotranspiration. In order to account for these effects, a modification factor, F, is introduced, such that:

$$E = F \,.\, Eo = F\ (16\ (10\ T/I)^{a}\ .\ D$$

where, E = modified monthly evapotranspiration in MM of H20
Eo = monthly potential from Thorhthwaite formula, and
F = modification factor varying from 0.0 to 1.

The following tabulated values of the modification factor, F, are obtained through correlation between the value calculated by the Thornthwaite formula and that measured in the field, such that:

$$F = E_1/E_2$$

where, E_1 = measured annual evapotranspiration, and
E_2 = calculated annual evapotranspiration by Thornthwaite Formula.

TABLE A-3

CORRELATION OF EVAPOTRANPIRATION FACTOR

REGION**	COMPUTED* ANNUAL EVAPOTRANSPIRATION POTENTIAL E_2 (INCHES)	MEASURED** ANNUAL EVAPOTRANSPIRATION E_1 (INCHES)	EVAPOTRANSPIRATION FACTOR F $(=E_1/E_2)$ CORRELATED	GENERALIZED
Marine Tundra	15.77	4.0	0.254	0.25
Taiga	19.21	5.0	0.260	0.25
Taiga Ecotone (Norman Wells)	19.50	6.0	0.308	0.30
Sub-Boreal Forest (Fort Simpson)	19.67	8.0	0.407	0.40

* Using Thornthwaite Formula

** From Burns, B.M., "The Climate of the Mackenzie Valley - Beaufort Sea", Environment Canada, Toronto, 1973.

The tabulated values may serve as general guidelines for the modification factor along the proposed pipeline route. They should be modified for specific local conditions, such as unusual drainage patterns or ponding. Until more field data are obtained, no exact guidelines are available at present for such special modification.

2.3 Subroutine SETTLE

2.3.1 General

Construction activities in permafrost terrain will cause some disturbance to the ground thermal regime. The usual consequence of such disturbance is local degradation of the permafrost table, resulting in subsidence of the ground surface. A progressive change in the geometry of a thermal regime and the corresponding change in thermal properties of the subsoil characterize the type of problem encountered in thermal analysis of permafrost terrain.

The change in thermal properties is due to thaw of ice-bearing soil, which results in dissipation of excess water. When the soil refreezes, it does so at a reduced water content. Since water content is a significant parameter in evaluating thermal properties, this effect must be accounted for in thermal analysis. A decrease in water content results in an increase in thermal conductivity, and a decrease in latent heat, which accelerates the propagation of the thaw front.

Ground subsidence due to thaw settlement, results in a progressively changing thermal domain. Thus, the heat source such as the summer ambient air temperature or hot pipe, moves closer to the permafrost table. This thermal effect increased as the excess ice content of the soil increases. The higher the excess ice content, the greater is the thaw settlement, and thus, the closer the distance between the heat source and the permafrost table.

2.3.2 Function

A program subroutine named SETTLE was developed to account for the soil settlement and change in thermal properties in the analytical model. The two functions of this subroutine are, therefore:

(a) The subroutine progressively adjusts the geometry of the thermal domain under study to simulate surface settlement.

(b) Thermal properties of the soil in any particular element are utilized which reflect the freeze-thaw history of that element.

2.3.3 Technique

In a thermal analysis, the temperature distribution is continuously calculated at a discrete time step, which are about 5 to 10 days. At each time step, the subroutine SETTLE locates the vertical distance over which the thaw front (32 degrees Fahrenheit isotherm) has propagated within that interval. The resulting settlement thus becomes the distance the thaw front has moved, multiplied by the local soil compressibility or excess ice content. A correction for the geometry of the thermal domain due to such settlement is made accordingly. At the same time, the freeze-thaw history of the soil is recorded which is used as a reference for selecting proper thermal properties. As the computation advances to the next step, the new geometry and correct thermal properties are used for temperature analysis.

The input data required for the subroutine SETTLE is the thaw compressibility of each soil type, which is defined as the volumetric change upon thawing.

2.3.4 Evaluation of Soil Compressibility Upon Thawing

(a) General

In order to compute the magnitude of thaw settlement in the combined geothermal analysis, compressibility can be defined as the percent change in volume as a result of thaw. Several methods have been proposed in the literature for the evaluation of soil compressibility. Although the method of direct determination by laboratory or field tests is preferable insofar as accuracy is concerned, it is usually not economically feasible on a large scale. In this section, a brief discussion of the various methods proposed for evaluating thaw-compressibility of the soil is presented.

(b) Excess Ice Content

Excess ice content of a soil is usually defined as ice in excess of the fraction that would be retained as water in the soil voids upon thawing. It is estimated in the field as a percentage of total sample volume which is composed of segregated ice. Since this is a visual estimation only, accuracy depends entirely on the experience and skill of the soils technician.

If it is assumed that the ground ice exists as segregated horizontal layers, then upon thawing, the compressibility of the soil is equivalent to the excess ice content. This method fails to consider the genesis of the ground ice which is believed to determine the in situ frozen effective stress. Large lock-in effective stresses can result in rebound on thaw, a phenomenon which will result in an over-estimation of the settlement. This usually only occurs at relatively small quantities of excess ice. For soils with large excess ice content, the method predicts the thaw settlement well.

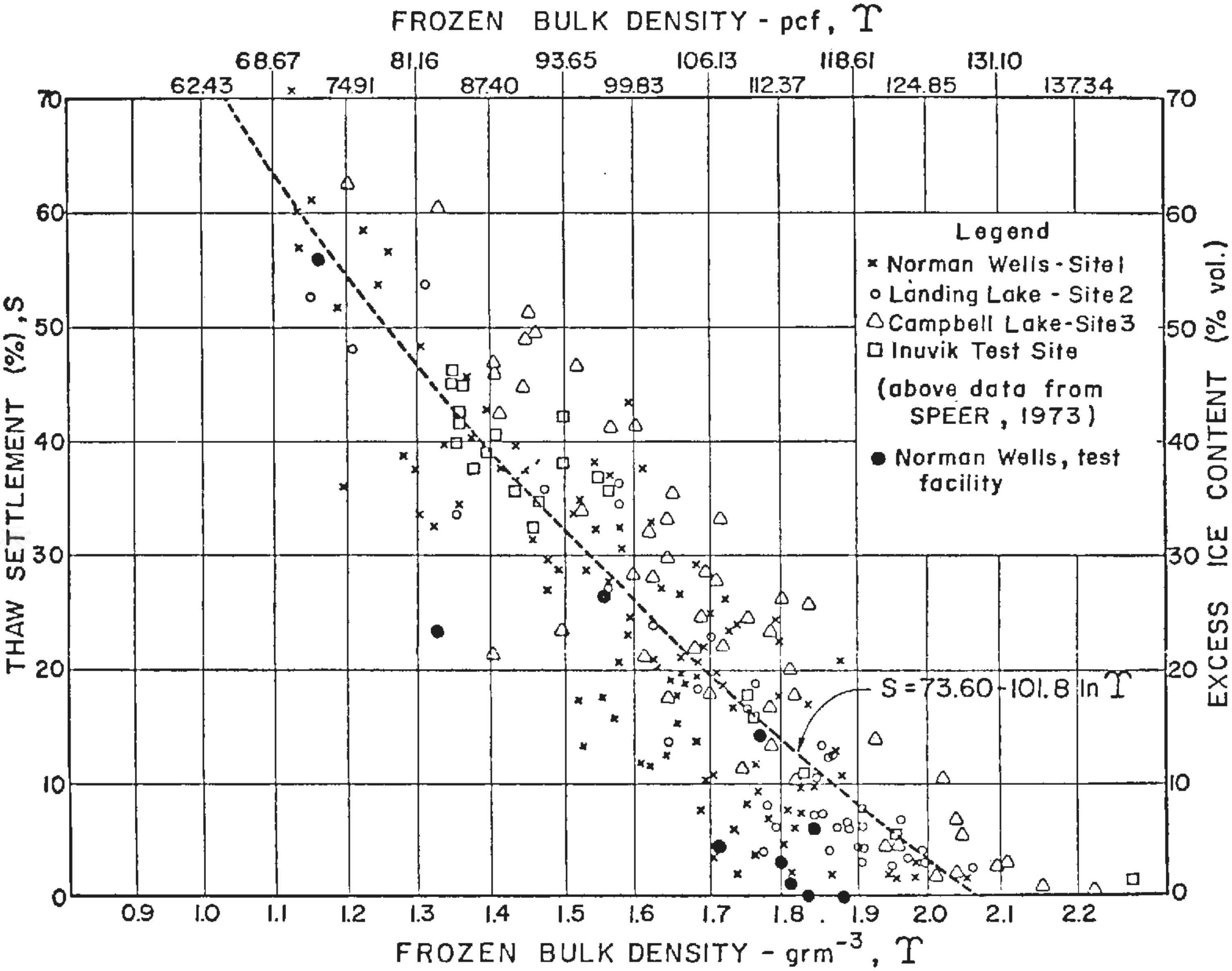
(c) Frozen Bulk Density

Laboratory consolidation testing, has resulted in a general relationship between thaw settlement and frozen bulk density. (Speer et al, 1973)*. However, the normal variation seems to be about 100% with respect to a statistically best fit curve. The large variation may be due to failure to consider cryogenesis of the ground ice, as cited in the previous method. It has been shown that the excess ice content and the frozen bulk density are inter-related (Figure A-8).

(d) Stability Index

A method for predicting thaw settlement of a frozen soil which considers the cryogenic texture of the ground ice has been proposed by Zhukov (1957). This method is derived from studies of soil behaviour and is expressed in terms of void ratio and effective stress with the description of the ground ice expressed in terms of the correlated stability index, n.

$$n = (e_o - e_n)/(e_o - e_m)$$



THAW SETTLEMENT vs FROZEN BULK DENSITY RELATIONSHIP
(after Speer et al, 1973)

where, e_o denotes the initial void ratio of the frozen soil,

e_n denotes void ratio of soil after thawing and consolidation under its own weight, and

e_m denotes void ratio of the soil consolidated under a pressure, p_m in an odometer, p_m is suggested to be no less than 55 - 80 psi.

The stability index, n, has been tabulated, and is shown in Table A-4. The compressibility of a thawed soil under effective stress, p, is therefore:

$$S = n(e_o - e_m)/(1 + e_o) + (1 - n)(e_o - e_m)P/(1 + e_o)P_m$$

Through laboratory determination of e_m and P_m for a particular soil type, one can predict the post thaw compressibility of a soil with variable initial ground ice structure. This requires selecting the appropriate n value taken from a table such as Table A-4 for use in the above equations. The equation can also be expressed in terms of water content, instead of void ratio, since they are interrelated. Although the index, n, has been correlated to type and composition as well as description of ice pockets, the degree of accuracy for field application is not known.

(e) Direct Determination

The method described in previous sections are more or less emperical techniques, which are sufficient for

TABLE A-4

STABILITY INDEX, N, OF THAWING SOIL*

TYPE & COMPOSITION OF SOIL DESCRIPTION OF ICE POCKETS	SANDS	SANDY LOAMS	SILTY LOAMS & SANDY LOAMS	LOAMS	CLAYS
Uniform, with fine ice crystals	0.7	0.6	0.2	---	---
The same, with coarse ice crystals	0.8	0.7	0.2	0.2	---
Complex, with fine ice lenses	0.9	0.7	0.3	0.3	0.2
The same, with ice interbeddings of average dimensions and considerable extent	---	0.8	0.6	0.6	0.7
The same, with large ice interbeddings	---	1.0	0.8	0.7	0.7
Cube-shaped fragmentation of mineral part with ice interstratifications	---	---	0.6	0.5	0.4
Mineral Interstratifications	---	Volume will stay unaltered after thawing		Heaving can occur after thawing	

* From "Settling of Thawing Ground" by V.F. Zhukov, CRREL, TL355, 1972.

preliminary analysis work. Thaw settlement can be determined directly from laboratory consolidation tests on undisturbed core. In this case, the soil compressibility can be expressed by:

$$S = (e_o - e_m)/(1 + e_o) = \Delta e/(1 + e_o)$$

by letting $P = P_m$.

The results implicitly include the cryogenic effect, provided a representative undisturbed sample is obtained. The range of stress variation is included in the laboratory e-log P curve. This is a conventional way of estimating settlement in soil mechanics practice.

III. PROGRAM ORGANIZATION

The programs employed to solve geothermal problems in connection with a buried pipeline are divided into two groups. One is the so-called FRONT END, the other is the GEOTHERMAL MODEL.

The frost end consists of programs written in conversational language (BASIC) which generate data files required as input to the geothermal model that was written in FORTRAN language. Figure A-9 shows the flow chart of computation. Figure A-10 and A-11 are the flow charts for one- and two-dimensional thermal analyses.

3.1 FRONT END (in BASIC)

3.1.1 GENINF

This program is for general information. It creates a file 'DAT2D1' which forms part of input data for running a two-dimensional geothermal problem. The file consists of the following general information:

(a) total number of soil types,
(b) meteorological region number,
(c) number of time steps per print out, and
(d) initial ground temperature distribution with depth.

3.1.2 MATERI

This program creates a data file for material properties. The data file is named 'DAT2D2', which consists of:

(a) thermal properties of each soil type (before and after thaw),
(b) thaw compressibility of each soil type, and
(c) temperatures of isotherms to be located.

Input to the program MATERI consists of the dry density, total and unfrozen water content of each soil type. The program will calculate the thermal properties such as thermal conductivity, specific heat and latent heat, according to Kersten's equations or DeVries' method.

3.1.3 GRIDDD

This program is to set up a data file for generating the finite element mesh of a ditch or berm configuration of a buried pipeline. Pipe temperature conditions such as start-up and shut-down are also considered. The data file created by this program is named "DAT 2D3".

3.1.4 METEOR

The program METEOR is used to create a data file for meteorological information, which is retrieved from the data bank where the meteorological data along the proposed pipeline route have been stored. The data file created is named 'DAT2D4', which consists of:

(a) monthly values of ambient air temperature, average wind velocity, snow depth and average solar radiation,
(b) monthly daylight hour correction factors,
(c) emissivity and absorptivity of ground surface and snow cover, and
(d) greenhouse factor (ratio of long wave radiation returning to leaving) and convection correlation coefficient.

3.1.5 GRID1D

This program sets up a data file for generating a one-dimensional grid according to specified soil layers. The created file is named 'DAT1D1'.

3.1.6 MATR1D

This program functions in a similar way as the program MATERI described in Section 3.1.2, except the data file 'DAT1D2' is created according to the format required for one-dimensional thermal code.

3.2 The Geothermal MODEL (in FORTRAN)

The geothermal model consists of the following computer programs, which will run with a data file or combined data files which were created by the Front End programs described previously.

3.2.1 2D-Model

The program is a two-dimensional finite element program. One of its uses is to simulate the geothermal problem of a heated or a refrigerated pipe buried in the ground with respect to ground temperature, ground surface settlement, pipe settlement, and pipe surface heat flux. Execution flow chart for a field program is shown in Figure 12.

3.2.2 1D-Model

The program is a one-dimensional finite difference program. It is used to establish the initial ground temperature variation with depth, which is required as input of initial condition for the two-dimensional program.

3.2.3 SOLAR

The program SOLAR is used to develop view factor tables for input to the 2D-Model. The view factor tables permit proper weighting of the solar radiation values as reported by various weather services. The reported value represents the total amount of diffuse and direct solar radiation incident on a 'horizontal surface' in a given 24-hour period, the view factor tables permit modification of the solar radiation with respect to the orientation and slope of a given surface. The program accounts for the following parameters:

(a) ratio of direct to diffuse solar radiation as a function of latitude and time of year,

(b) shadow length as a function of the height of an object and its orientation, and

(c) slope of ground surface and its orientation.

3.2.4 GDPLOT

The program GDPLOT will plot the finite element grid generated by the subroutine GRID according to specified soil stratigraphy and pipe location. Locations of all the nodal points are printed. Material number of each element is printed at the position of its centroid. Therefore, the program enables one to check the input data regarding the geometry of a thermal domain.

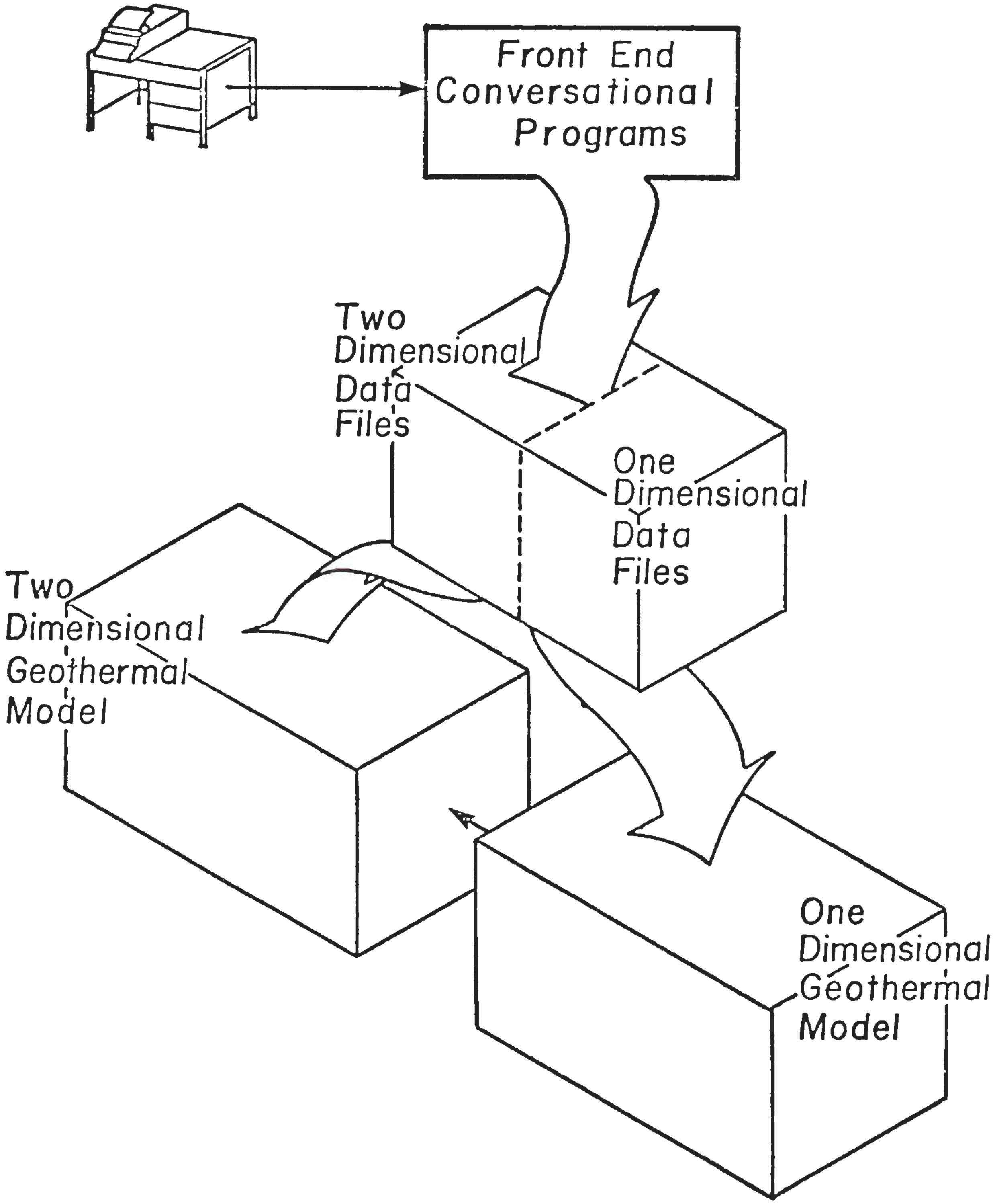
IV. PROCEDURE TO RUN THE GEOTHERMAL MODEL

The procedure to be followed in the solution of a geothermal problem in connection with a buried pipeline is as follows:

(1) Use the program SOLAR to calculate the view factors as required. Where the ground surface is level and no shadow effect is involved, this step can be skipped.

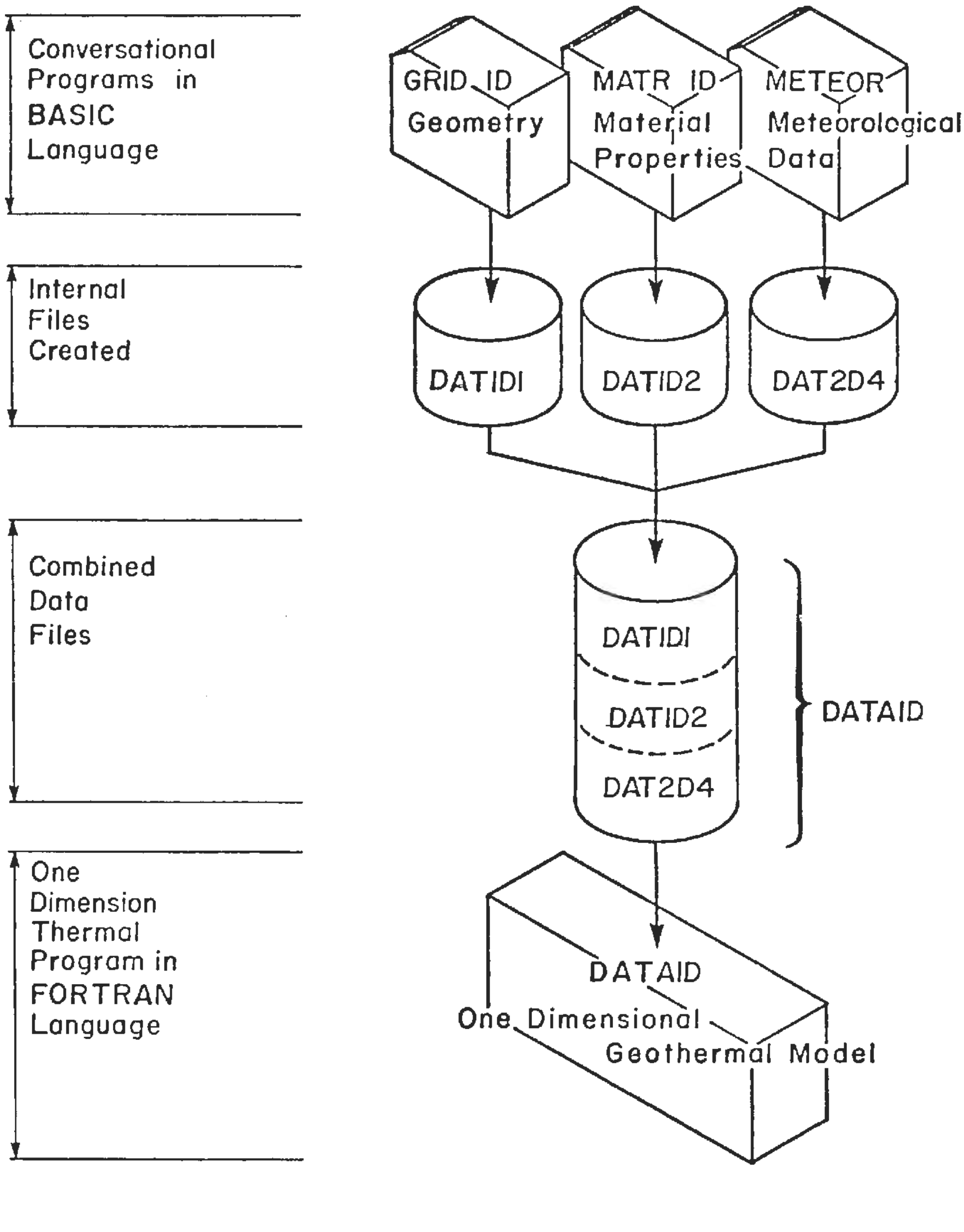
(2) Use the Front End Conversational Programs GRID1D, MATR1D, and METEOR to generate a data file for running the 1-D program which calculates the initial temperature distribution with depth (Figure A-10).

(3) Assemble the data for the 2-D program, using the Front End Conversational programs GENINF, MATERI, GRIDDD, and METEOR, and the results obtained from the 1-D model (Figure A-11).



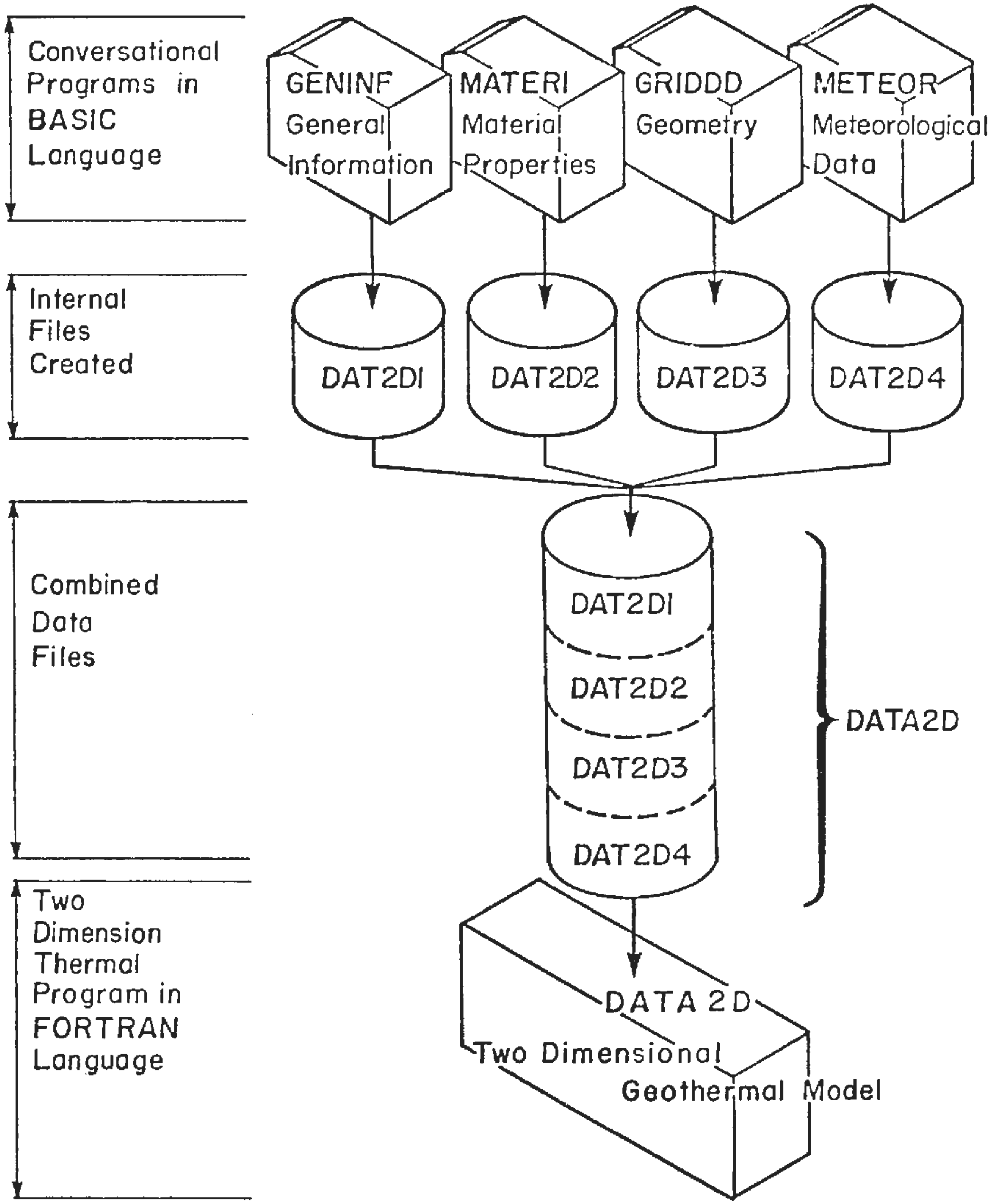
GENERAL FLOW CHART

FIGURE A-9



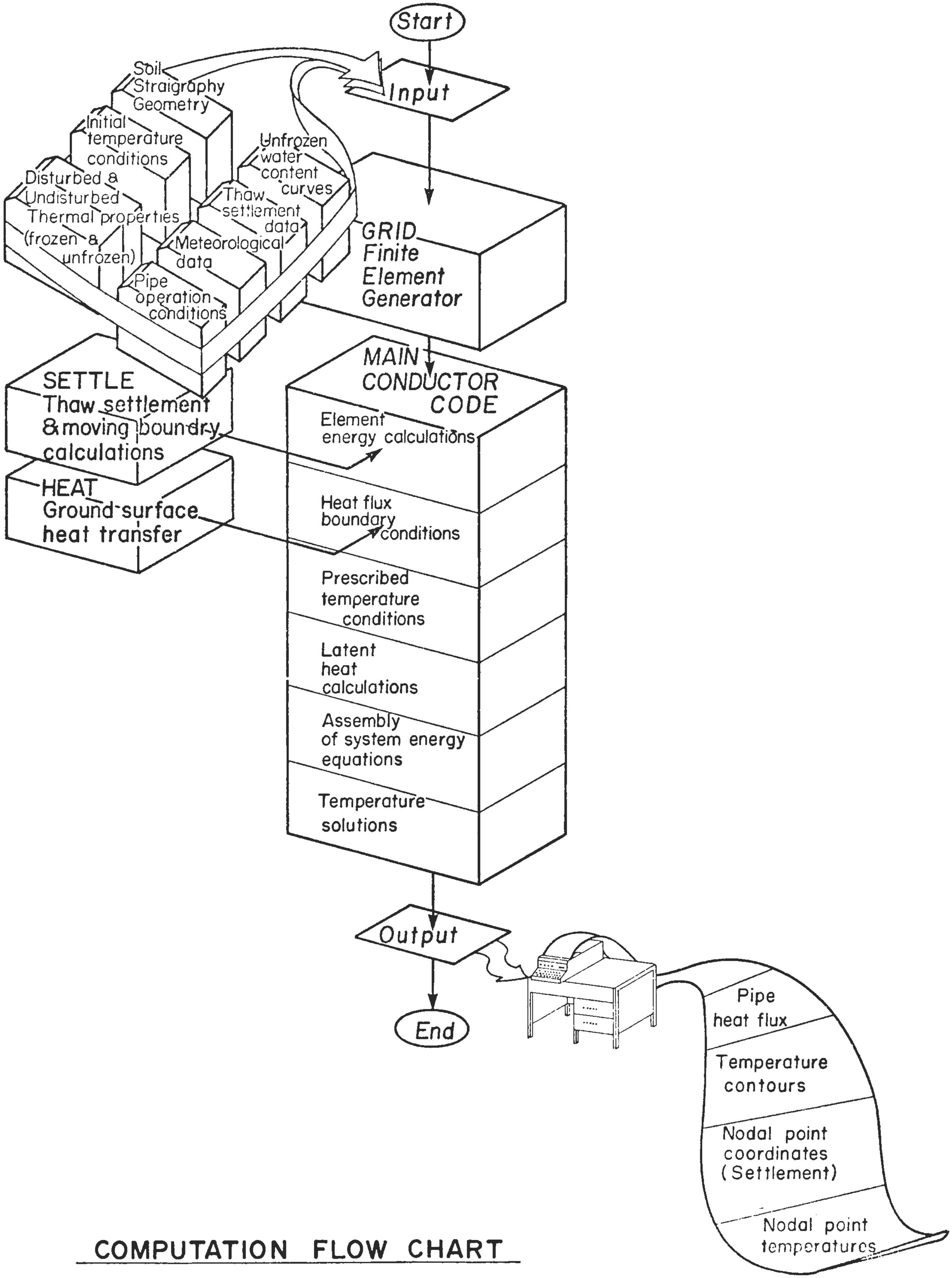
ONE DIMENSIONAL THERMAL ANALYSIS

FIGURE A-10



TWO DIMENSIONAL THERMAL ANALYSIS

FIGURE A-11



COMPUTATION FLOW CHART

(4) Check the finite element grid generated through the use of the program GDPLOT. The data set required is DAT2D3, which is created by the program GRIDDD.

(5) Run the two-dimensional program to solve the required geothermal problem.

V. INPUT PARAMETERS

5.1 General

This section describes the methods used by the conversational programs to calculate thermal properties required as input data to the geothermal model. Meteorological data stored in the data bank along the proposed pipeline route will also be described.

5.2 Thermal Conductivity K

Two methods have been programmed into the conversational programs MATERI and MATR1D for the calculation of thermal conductivity. One is through use of Kersten's experimentally correlated equations; the other is DeVries' Method.

5.2.1 Kersten's Equations*

a. Fine Grained Soils (silt and clay)

$$\text{Frozen: } K = 0.00083 \times 10^{0.022\gamma} + 0.0071 \times 10^{0.008\gamma} \times w$$

$$\text{Thawed: } K = (0.075 \times \log_{10} w - 0.017) \times 10^{0.01\gamma}$$

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* Kersten, M.S. "Laboratory Research for Determination of the Thermal Properties of Soil"; Final report, Engineering Experimental Station, University of Minnesota, 1949.

where K = Thermal conductivity (BTU/hr/ft/F)

w = Water content (%)

γ = Dry density (lbs/ft^3)

b. Coarse Grained Soils (Sand and Gravel)

Frozen: $K = 0.063 \times 10^{0.013\gamma} + 0.0027 \times 10^{0.0146\gamma} \times w$

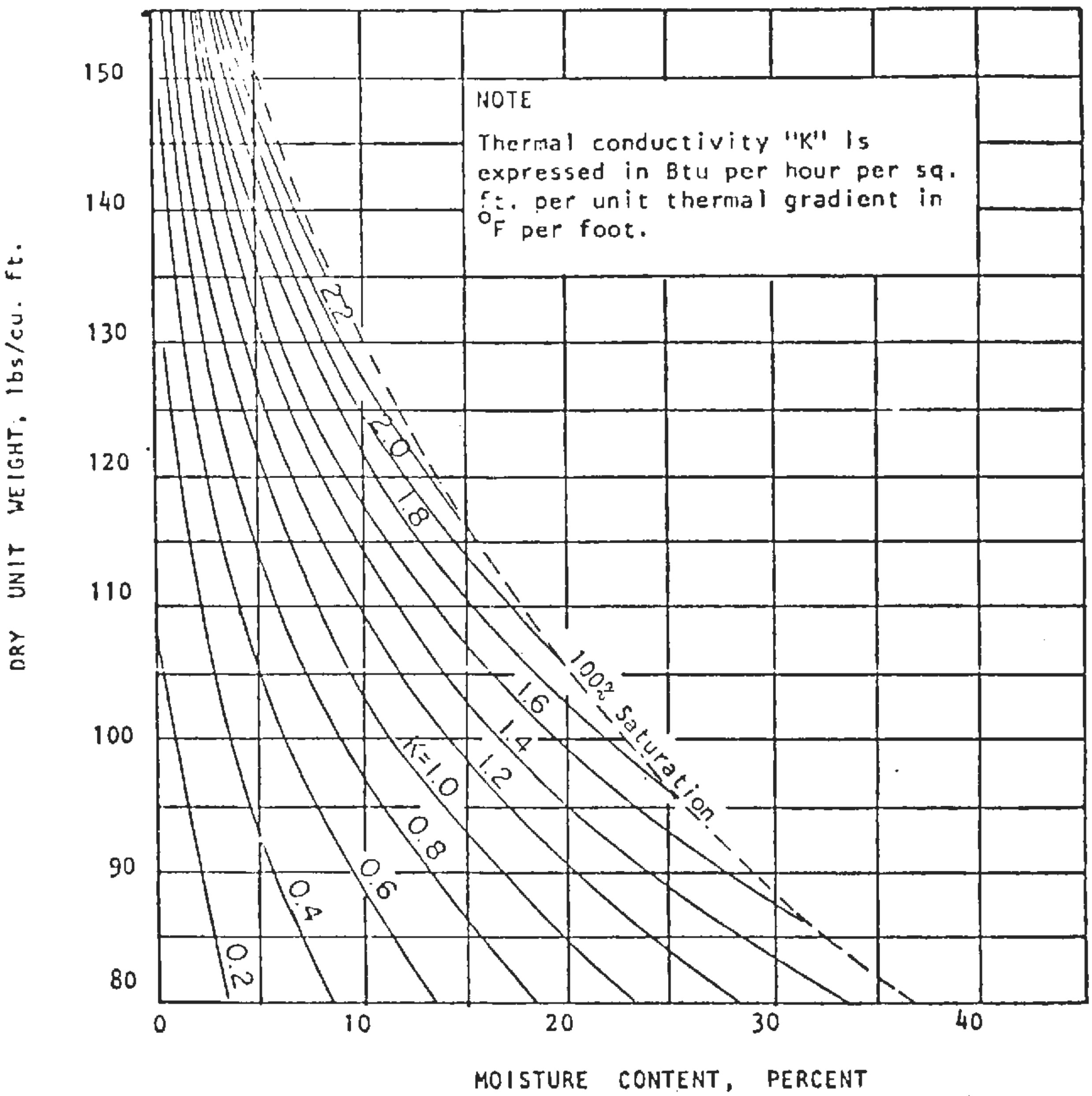
Thawed: $K = (0.058 \times \log_{10} w + 0.0333) \times 10^{0.01\gamma}$

Graphic forms of above equations are shown in Figures A-13 to A-16.

(c) Peat

Limited data were available for deriving a generalized equation as that for mineral soils. The experimental results for the Fairbanks peat obtained by Kersten (1949) were tabulated in the conversational program as shown in Figures A-17 and A-18. Linear interpolation technique was used between data points.

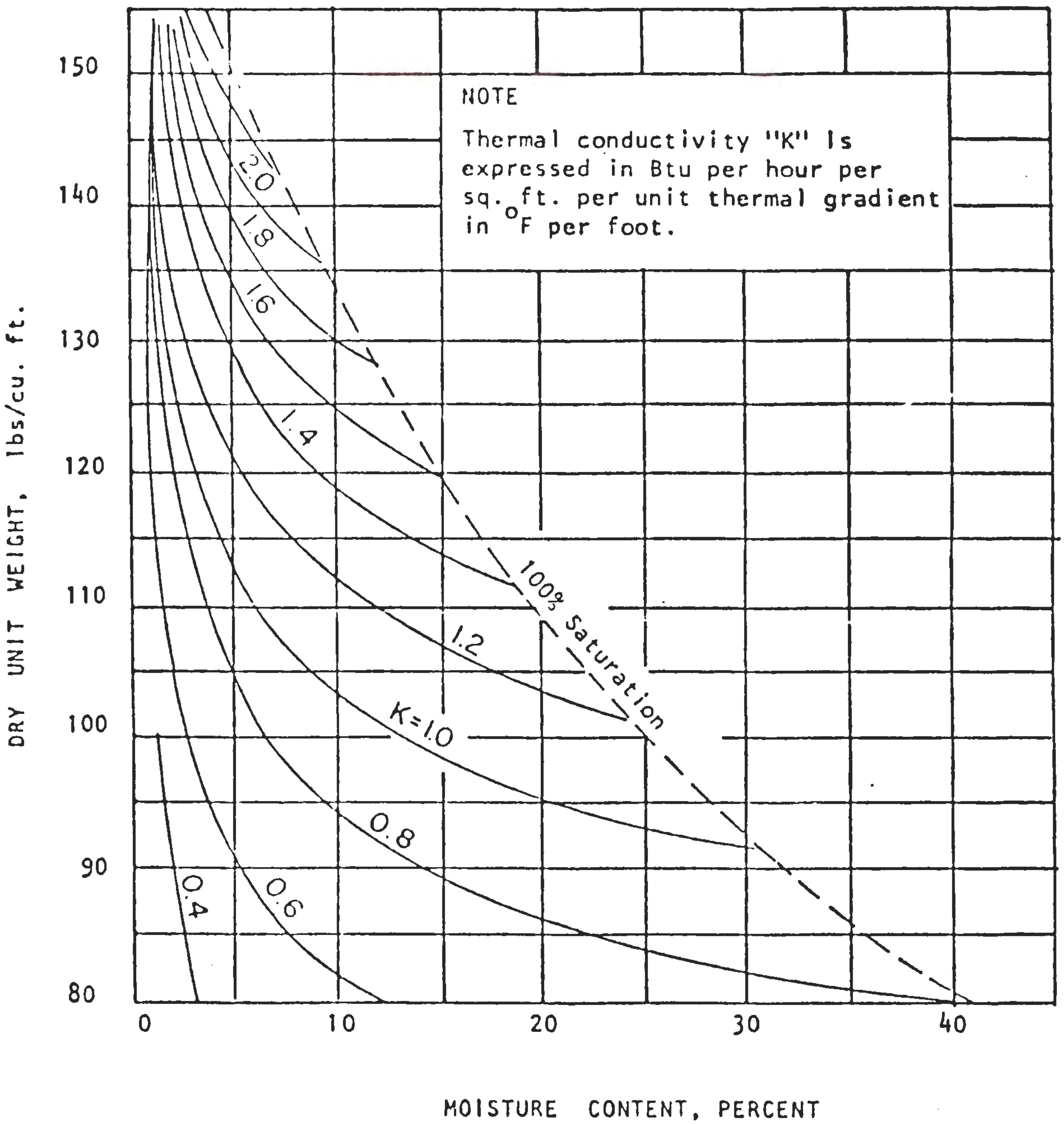
Therefore, the input data required for the calculation of thermal conductivity are the dry density and water content of each soil type.



AVERAGE THERMAL CONDUCTIVITY FOR SANDY SOILS, FROZEN

(from Kersten's Equation)

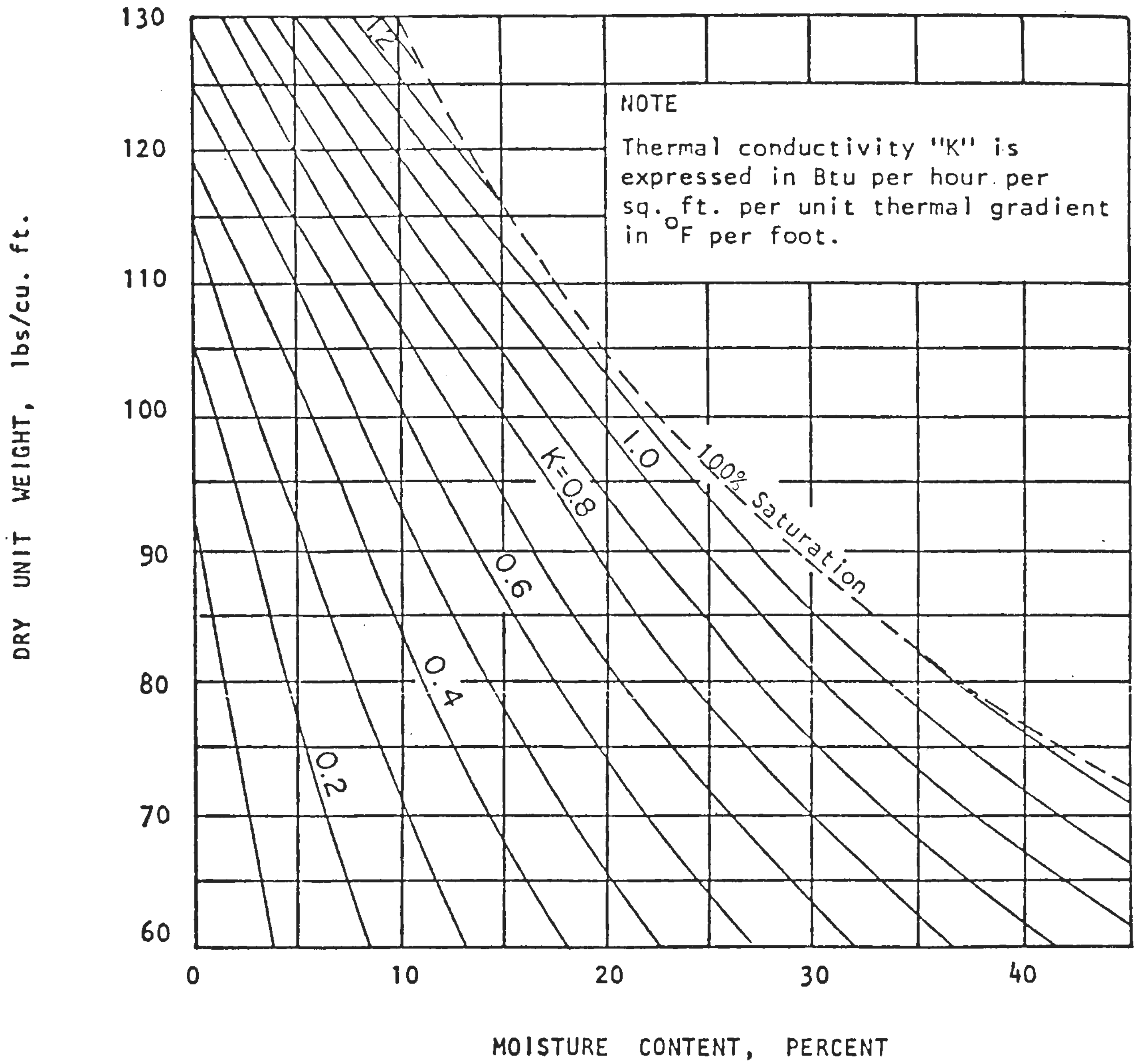
FIGURE A-13



AVERAGE THERMAL CONDUCTIVITY FOR SANDY SOILS, UNFROZEN

(from Kersten's Equation)

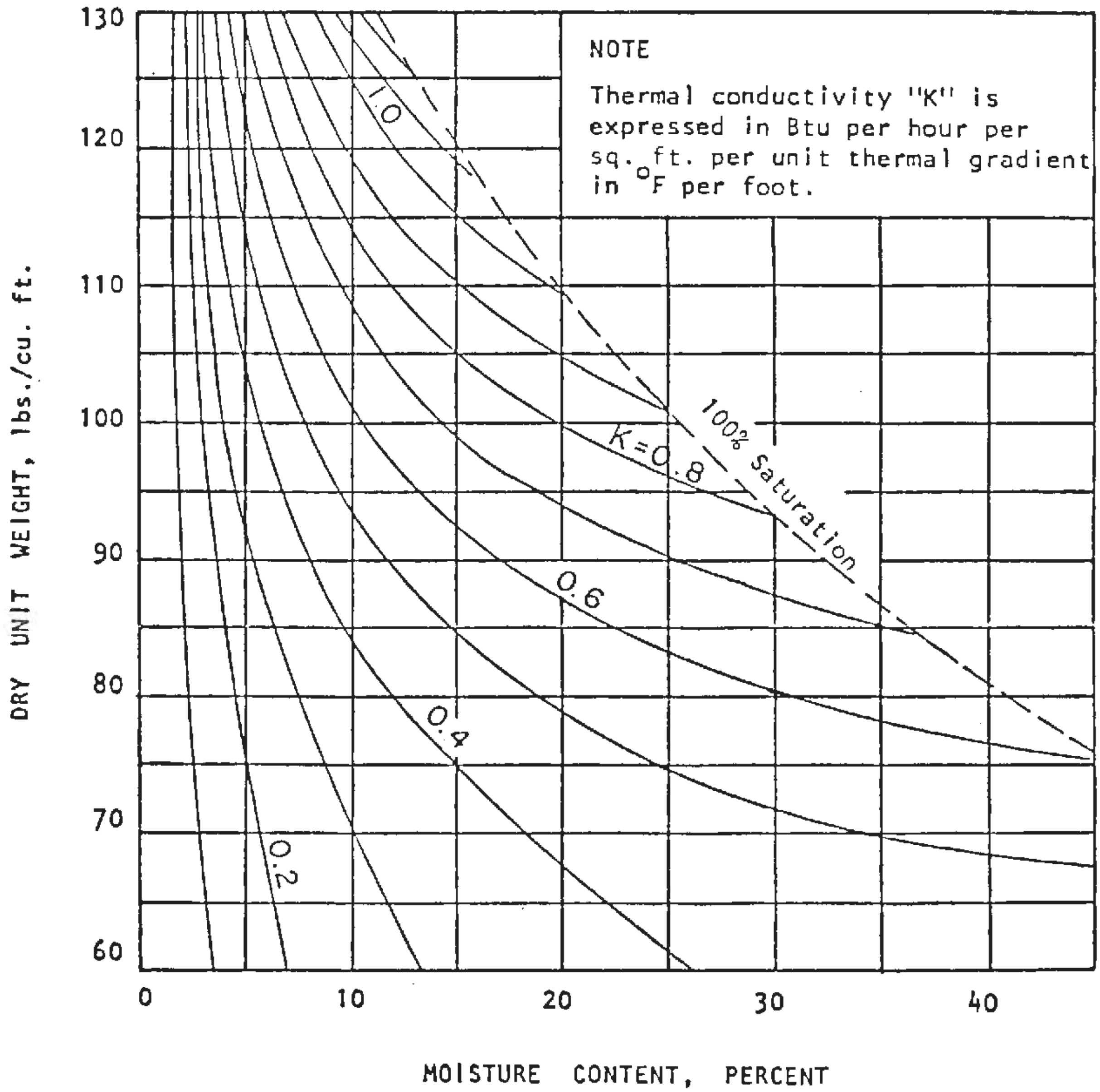
FIGURE A-14



AVERAGE THERMAL CONDUCTIVITY FOR SILT AND CLAY SOILS, FROZEN

(from Kersten's Equation)

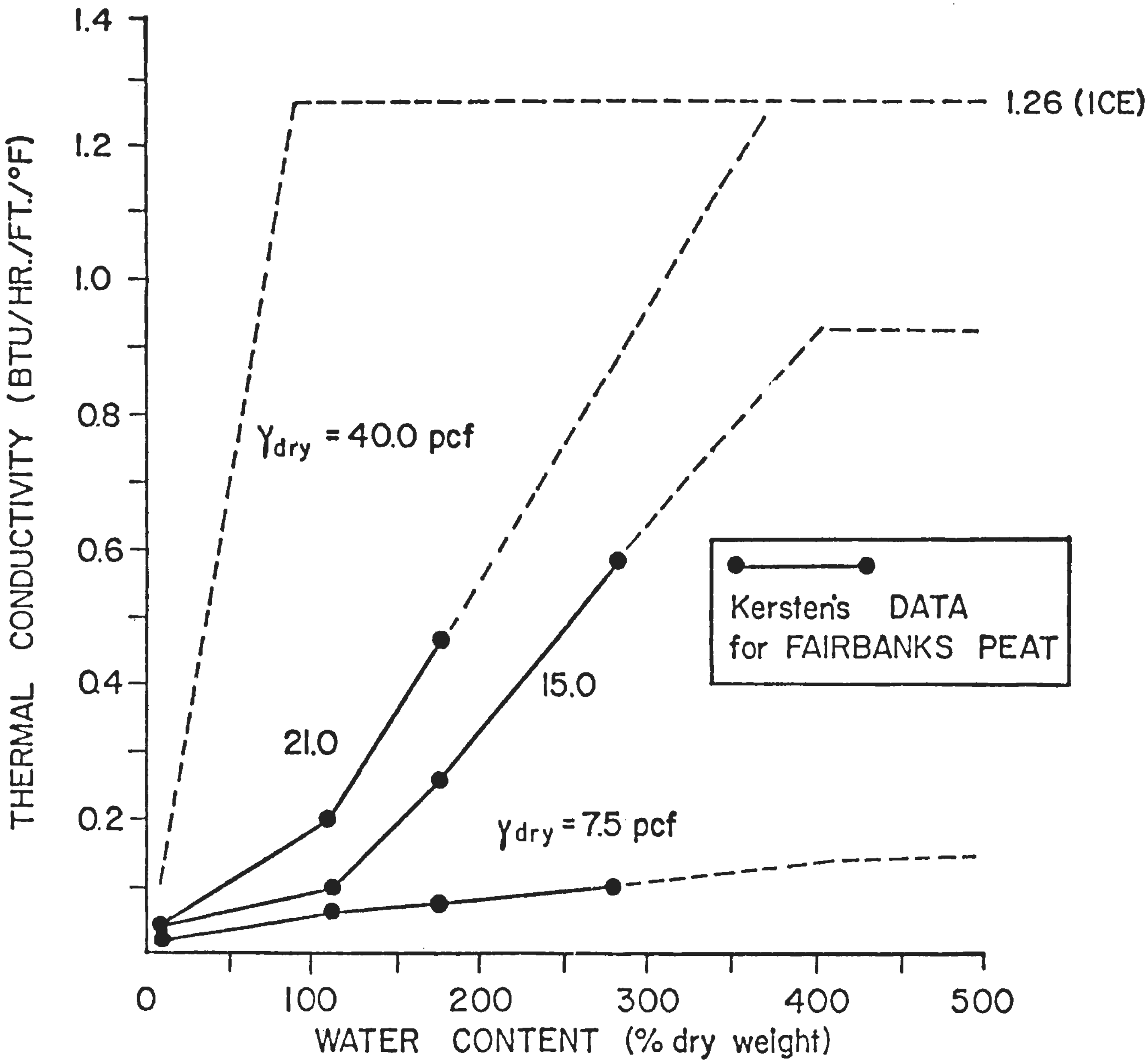
FIGURE A-15



AVERAGE THERMAL CONDUCTIVITY FOR SILT AND CLAY SOILS, UNFROZEN

(from Kersten's Equation)

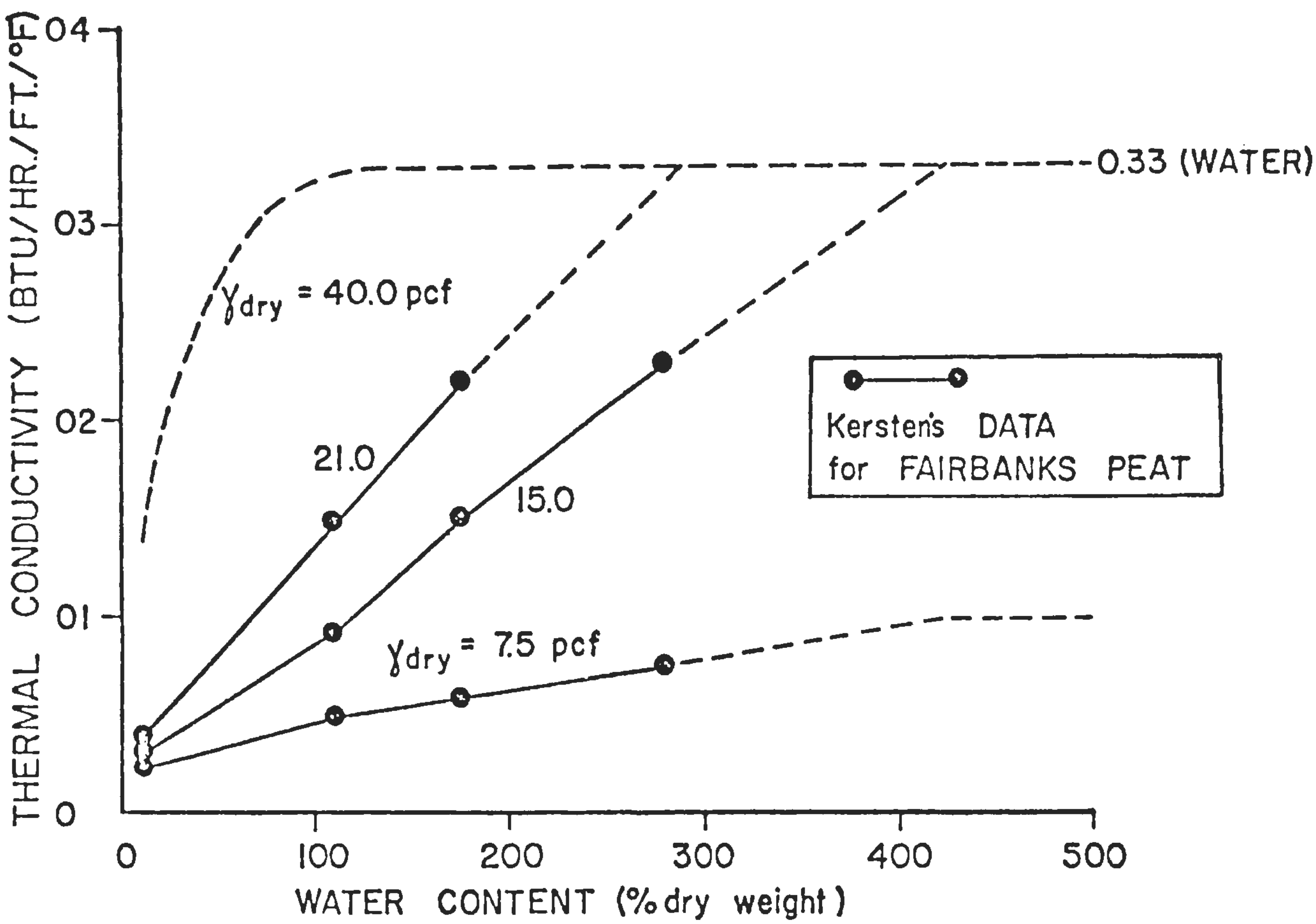
FIGURE A-16



FROZEN CONDUCTIVITY OF PEAT

(Mean Temperature = 25° F.)

FIGURE A - 17



UNFROZEN CONDUCTIVITY OF PEAT
(Mean Temperature = 40° F.)

FIGURE A-18

5.2.2 DeVries' Method**

The apparent thermal conductivity, k, of a multi-phase system with several constitutive materials is:

$$k = \frac{\sum_{i=o}^{N} h_i \; X_i \; \lambda_i}{\sum_{i=o}^{N} h_i \; X_i}$$

where

$$h_i = \frac{1}{3} \sum_{a,b,c} \{ 1 + (\frac{\lambda_i}{\lambda_o} - 1) \, g_a \}^{-1}$$

λ_i = conductivity of material i

X_i = volume fraction

ga = depolarization factor on the axes a, b, c and $g_a + g_b + g_c = 1$. The value of g_a for the soil particles was generally 0.125.

(a) Thermal conductivity of the constitutive materials.

The thermal conductivities (BTU/hr/ft/°F) of the constitutive materials are as follows:

Quartz	5.08
Clay minerals	1.69
Organic matter (peat)	0.145
Water	0.33
Pore ice	1.00 (1.26 for pure ice)
Air	0.0145

**DeVries, D.A. "Thermal Properties of Soils", Physics of Plant Environment, Chapter 7, edited by W.R. VanWigk, John Wiley & Sons, New York, 1963.

In order to simplify the input data, an average value of thermal conductivity of the solid material has been adopted. For the coarse grained soils, the Fairbanks sand, which consists of 60% (in volume) quartz and 40% of feldspar and other minerals, was used as typical soil. Thus, the average value of thermal conductivity of the solid material in a coarse grained soil is 3.72 (=5.08 x 0.6 + 1.69 x 0.4). For fine grained soils, the value of 1.45 for Healy Clay obtained from Kersten's work, was used as typical value. The soil consists of clay (55%), quartz (22%) coal (22%) and some other minerals (0.5%).

In summary, the following thermal conductivity for the solid material in mineral soils are used (BTU/hr/ft/°F).

Coarse grained soils	3.72
Fine grained soils	1.45

(b) Specific Gravity of Peat

The specific gravity of a peaty soil, which is a function of water content, has to be known in order to calculate the volume of the organic matter within the soil during the calculation of thermal conductivity. The experimentally correlated relationship between the specific heat and the water content, as shown in Figure A-19, of a peaty soil, the corresponding specific gravity will be used during the calculation of thermal conductivity.

(c) Partial Saturation

In partially saturated soil, the value of g_a of the air-filled pore and its apparent thermal conductivity have been considered.

C.1 g_a (for air bubble)

$$g_a = 0.333 - (1-S) \times (0.333 - 0.035),$$
where S = degree of saturation

C.2 λ ap, (Apparent thermal conductivity)

$$\lambda\ ap = \lambda\ air + \lambda v$$

where λ air = thermal conductivity of air = 0.0145 (BTU/hr/ft/$^{\circ}$F)

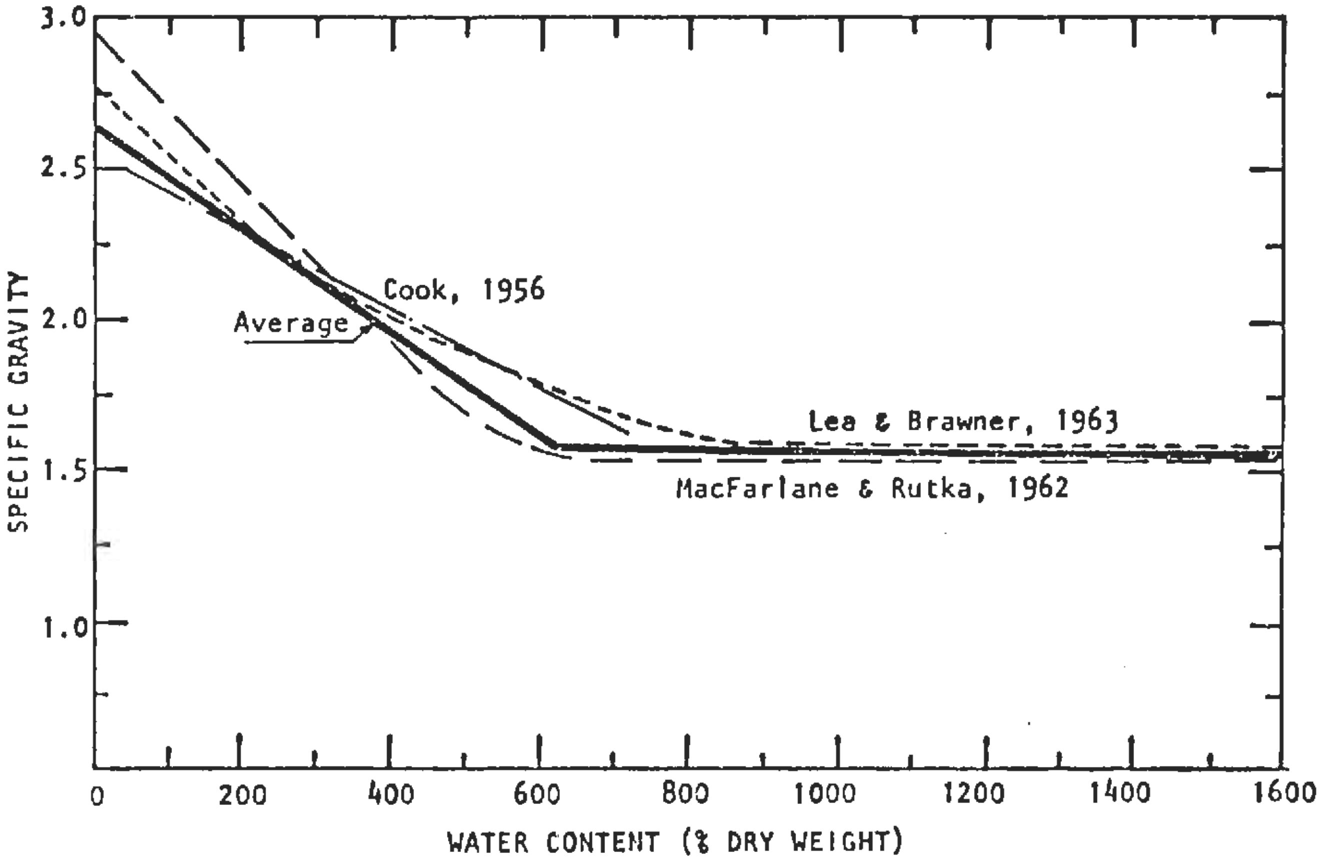
λ v = thermal conductivity contributed by vapor diffusion

For coarse grained soils, λv is equal to 0.0145 (BTU/hr/ft/°F) when frozen, and 0.0425 when unfrozen, if the volume fraction of water Xw is greater or equal to 0.03. For Xw < 0.03, the value of λv decreases linearly to zero when Xw = 0.

For fine grained soils, λv is treated the same way as that for coarse grained soils, except that the critical volume fraction of water Xw is 0.09 instead of 0.03.

5.2.3 Remarks

The method by DeVries suggests that a theoretical estimate of the thermal conductivity of a soil can be made if its mineral composition, its porosity and its water content are known. The accuracy of the method has



SPECIFIC GRAVITY
vs.
WATER CONTENT FOR MUSKEG
(Muskeg Engineering Handbook)
1969

FIGURE A-19

been found satisfactory with Kersten's experimental data regarding only unfrozen soils. However, the method consistently predicts higher values than the experimental results for frozen soils. This may suggest that the theoretical background of the method may not be applicable to frozen conditions.

Since DeVries uses only some of the experimental data by Kersten to verify the method, it is suggested that the equations suggested by Kersten, through correlation of all the experimental data, be used for mineral soils.

As for peaty soils, due to availability of limited data, the method by DeVries is suggested for application until more data or a better way of estimation is available.

5.3 Specific Heat and Latent Heat

5.3.1 Specific Heat

The specific heat of a mineral soil has been calculated by the equation:

$$C = \frac{100 \times Cs + (Wt-Wu) \times 0.489 + Wu}{100 + Wt} \quad \text{(frozen)}$$

$$C = \frac{100 \times G + Wt}{100 + Wt} \quad \text{(thawed)}$$

where, C = specific heat (BTU/lb/^{o}F)

Wt = total water content (% dry density)

Wu = unfrozen water content (% dry density)

Cs = specific heat of the solid

Cs = 0.17 when frozen, Cs = 0.176 when thawed

For peaty soils,

$$C = \frac{100 \times 0.462 + (Wt - Wu) \times 0.489 + Wu}{100 + Wt} \text{ (frozen)}$$

$$C = \frac{100 \times 0.462 + Wt}{100 + Wt} \text{ (thawed)}$$

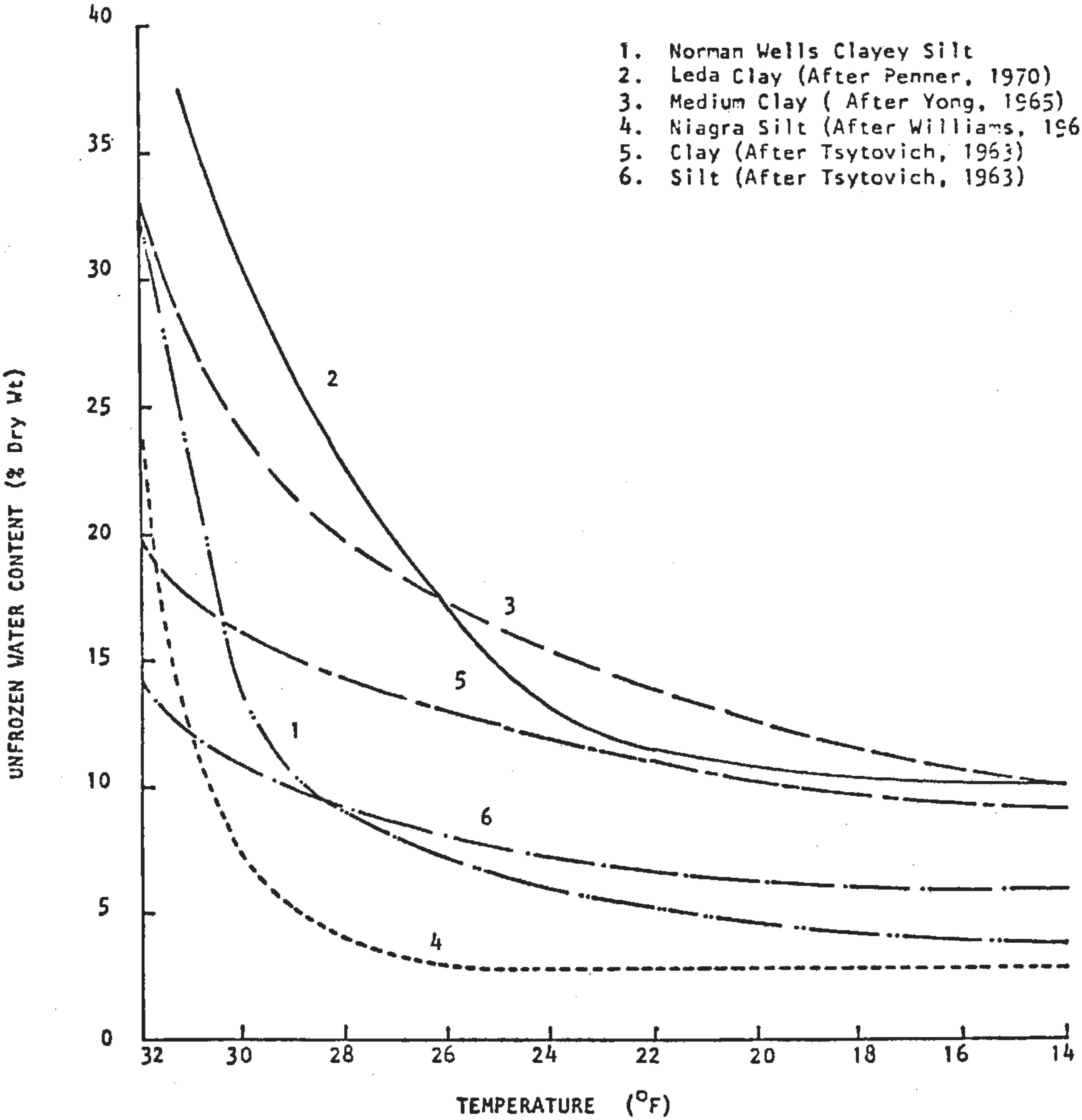
5.3.2 Latent Heat

$$L = 144 \times \gamma d \times \frac{(Wt - Wu)}{100}$$

where
L = Latent heat (BTU/ft^3)
γd = Dry density (lbs/ft^3)
Wt = Total water content (%)
Wu = Unfrozen water content (%)

5.4 Unfrozen Water Content

During the process of freezing and thawing, the water within the soil partially changes phase with temperatures. Typical curves showing the change of unfrozen water content with respect to temperature are presented in Figure A-20. In actual application of the model, the unfrozen water content versus temperature curves determined from the soil data along the route will be used.



UNFROZEN WATER CONTENT CURVES

FIGURE A-20

5.5 Meteorological Data

The climatic data along the proposed pipeline route (Figure A-21) will be averaged within regions of reasonably uniform terrain and climate.

The meteorological parameters of each region will be stored in computer data banks. The parameters stored are:

(1) air temperature (°F),
(2) wind velocity (mph),
(3) snow depth (ft.),
(4) average solar radiation (BTU/hr/ft^2),
(5) albedo,
(6) greenhouse factor,
(7) rainfall (in.), and
(8) snow fall (in.)

The data were obtained from published literature[18,19,20,21] or from field measurements.

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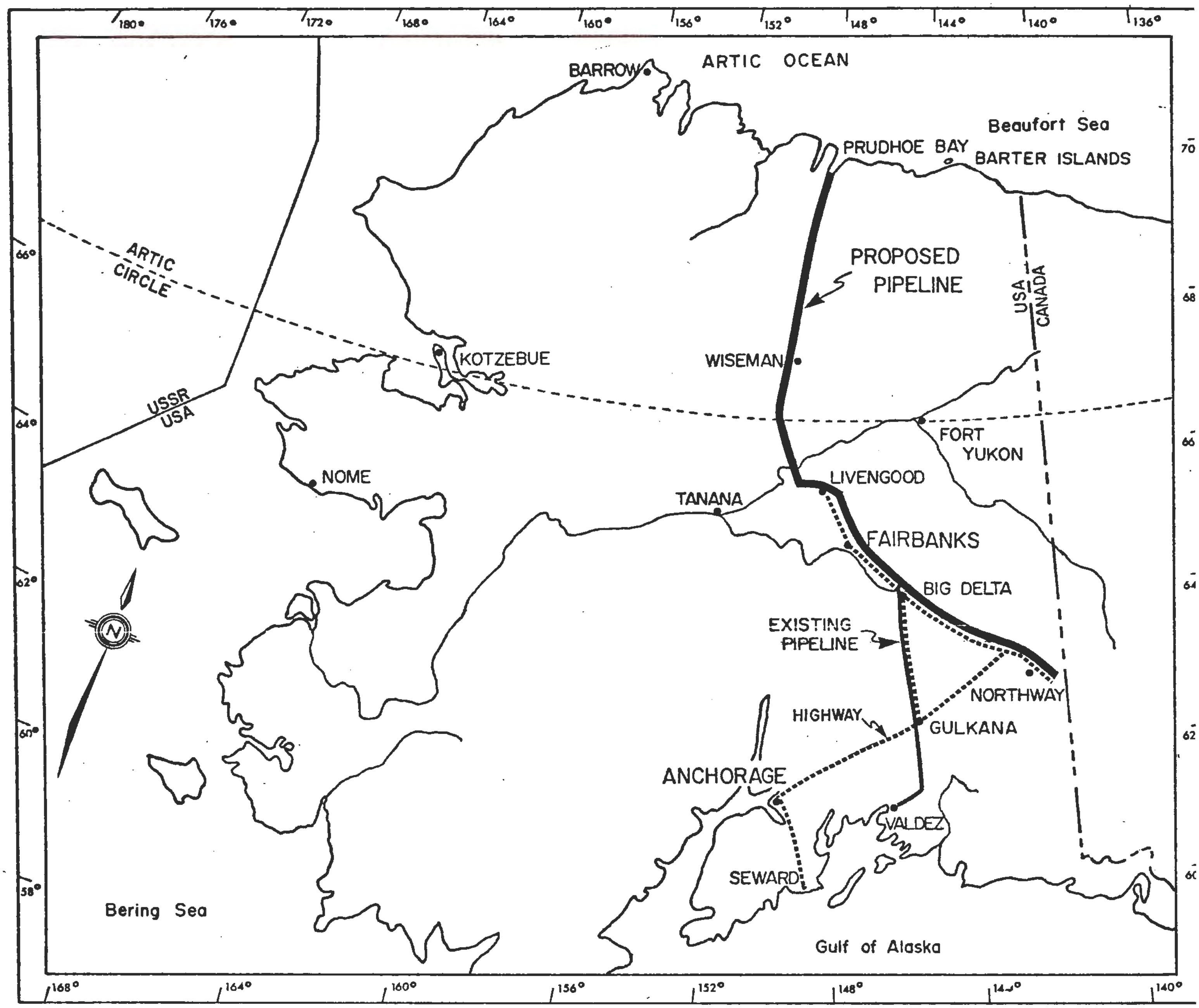
21. Ground Temperature Observations in Alaska, conducted by CRREL at Aniak, Barrow, Fort Yukon, Galena, Gulkana, Kotzebue, McGrath, Northway, 1962-1965.



PROPOSED ALCAN PIPELINE ALIGNMENT

FIGURE A-21

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ALCAN PIPELINE COMPANY
Docket No.
Exhibit No. Z2-3.2
Hearing Exhibit No. ___

3.2 FROST BULB OR FROST HEAVE

The report on the following pages, entitled Frost Heave Consideration, describes the problems caused by frost heave and a solution of these problems for the Alcan Pipeline project.

ALCAN PIPELINE PROJECT
FROST HEAVE CONSIDERATION

Submitted To

ENERGY SYSTEMS ENGINEERING LTD.

EBA ENGINEERING CONSULTANTS LTD.

JUNE, 1976

ALCAN PIPELINE PROJECT

FROST HEAVE CONSIDERATION

I. INTRODUCTION

Frost heave is a major problem that is encountered by geotechnical engineers where freezing temperatures prevail for a prolonged duration of time such as the operation of a chilled pipeline over non-permafrost soils. Frost heave is caused by the volumetric expansion of the in situ pore water upon freezing, as well as the freezing of water that migrates to the freezing front.

The former component is usually small, as compared with the latter, which is also termed as ice-segregation heave. For frost heave problems, the second component is of concern.

II. FACTORS TO INDUCE FROST HEAVE

The following conditions must exist for frost heave to occur:

(1) Freezing temperatures to produce a heat loss at the freezing front in order to change the water into ice. Therefore the freezing rate or the rate of heat removal is the prime factor.

(2) Availability of water.

(3) Soils with frost susceptibility - Frost susceptible soils are defined as those soils which due to their grain size distribution and physio-chemical properties, will induce the migration of pore water towards the freezing front, resulting in ice segregation. For a chilled gas pipeline the fine grained soils such as silts and clays belong to frost susceptible soils.

III. ENGINEERING APPROACH TO FROST HEAVE PROBLEM

3.1 Heave Rate Versus Overburden Pressure

Laboratory and field observations reported in the literature (Beskow 1935 Linell and Kaplar 1959; Vialov 1965; Aitken 1963, 1974; Arvidson and Morgenstern 1974) have supported such a principle that the ice segregation heave rate reduces as the overburden pressure increases. Therefore, the application of overburden pressure will reduce the frost heave rate and therefore the magnitude of frost heave. As the pressure is being increased, it will reach a condition where the water will no longer migrate toward the freezing front, but be expelled from it, such pressure is termed as shut-off pressure.

3.2 Laboratory Determination of Heave Rate

Heave rate under various overburden pressures to be encountered in the field can be determined in a laboratory test with finite length of soil samples under simulated freezing conditions. The soil will have free access to water. Such determined heave rate can be applied in conjunction with the geothermal model to calculate the frost heave of a pipeline.

Because of the free access of water during the tests in determining heave rate, the estimated frost heave will be conservative, in other words, the estimated values will be much greater than actual field conditions. This has been demonstrated at the Calgary Test Site of the Canadian Arctic Gas Pipeline Limited.

3.3 Analytical Study

The method presented in Section 3.2 is a semi-empirical approach. In order to improve the understanding and realistically estimate the frost heave, rigorous analytical modelling has been undertaken applying the theories of heat transfer and soil consolidation. The following factors are considered:

(1) A characteristic suction at the freezing front defined for each specific soil type,

(2) the variation of effective pressure acting at the freezing front as a function of time (as the frost depth increases, the effective suction at the freezing front decreases due to an increase in the weight of soil above it),

(3) the freezing rate and thus, the rate of heat removal causing water to change into ice,

(4) soil consolidation and characteristics governing soil water flow, and

(5) the two-dimensional flow of water in the soil surrounding the pipe and front bulb.

IV. DESIGN MEASURES TO ALLEVIATE PROBLEMS CAUSED BY FROST HEAVE

The induced pipe strain and thus pipe stress, due to frost heave is a result of differential heave along the pipeline, which is related to the pipe-soil interaction and the location of the ice segregation. Segregation heave immediately adjacent to the pipe will induce higher pipe stresses than that at the freezing front located several feet below the pipe. Due to relatively high rate of freezing, it is unlikely that significant heave will occur in direct contact with the pipe. Further migration of pipe stresses is provided when the pipe and frozen soil creates a relatively stiff system when the frost bulb is increasing, which increases the overall resistance to differential heave as a result of ice segregation at depth.

With the experience gained in the construction of the Alyeska Oil Pipeline, better understanding of terrain as well as permafrost distribution along the proposed route will be obtained.

Frost heave in cold permafrost areas (ground temperature less than 30°F) is not anticipated to be a significant problem due to:

(1) shallow active layer,
(2) low ground temperature, and
(3) rapid freezeback of thawed soils beneath the pipeline.

In the thawed zone of discontinuous permafrost or non-permafrost areas, the following design measures may be used:

(1) increase the burial depth of the pipe,

(2) applying surcharge loading on the ground surface by constructing a soil berm,

(3) replacing frost susceptible soils beneath the pipe with frost stable material, such as sands and gravels.

(4) lowering water table, and

(5) insulating the pipeline.

It is felt that with the above measures, the proposed chilled gas pipeline can be properly designed.

Respectfully submitted,

EBA Engineering Consultants Ltd.

PROFESSIONAL ENGINEER C. T. HWANG ALBERTA

C. T. Hwang, P.Eng.

CTH/sjm

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ALCAN PIPELINE COMPANY
Docket No.
Exhibit No. Z2-3.3
Hearing Exhibit No. ___

3.3 PIPE STRESS ANALYSIS

The report on the following pages, entitled Pipe Stress Analysis, gives the design methods and procedures used to ensure the structural integrity of the pipeline during construction and operation.

PIPE STRESS ANALYSIS
INDEX

ALCAN PIPELINE PROJECT

PIPE STRESS ANALYSIS

EXECUTIVE SUMMARY

Prepared For:

Energy Systems Engineering Ltd.

Calgary, Alberta

Prepared By:

Pipe Line Technologists Ltd.

Calgary, Alberta

June 30, 1976

Introduction

Stress analysis is an important part of pipeline design, particularly in the cold and seismically active region which the ALCAN pipeline will traverse. Using stress analysis, the potential movements and deformations of the pipeline resulting from mechanical and environmental loads during construction and operation can be calculated. When the calculated movements or deformations are considered excessive, remedial action such as anchoring the pipe, restricting its bending, or monitoring its movement will be taken.

Mechanical loads result from handling, fabrication and installation procedures; and the pressure and temperature changes and additional weight caused by the subsequent flow of compressed, refrigerated gas in the pipeline. Environmental loads are caused by movements of the soil supporting the pipe due to frost heave, settlement, or buoyancy; and earthquakes.

Virtually all of the ALCAN pipeline will be buried underground or in a gravel berm, so it will be fully or partially restrained by the surrounding soil. Some isolated sections of above ground piping will occur at valve locations, compressor stations and some river crossings.

To evaluate the potential movements and deformations of the buried pipeline it is necessary to establish the properties of the steel pipe and the soil in which it is buried, the mechanical and environmental loads which may be imposed on the pipe during its lifetime, and the geometrical configurations which the pipeline will need to take to conform to the route and the topography. Design criteria must be established to define excessive pipe movement or deformation. The criteria are based on the applicable standards, codes and regulations and other considerations which ensure the safe operation of the pipeline.

Parametric studies can be performed to determine the extent of pipe stresses, movement and deformations for the range of conditions encountered. These are subsequently applied in the detailed mile-by-mile final design stage.

Summary

In this report, the results of preliminary stress analysis investigations are presented. The factors which induce the stresses, movements and deformations in the pipe are described in general terms in the section Design Considerations. The soils aspect of the analysis and the design is presented in the section Geotechnical Analysis and Design. The applicable Standards, Codes and Regulations are listed in the next section. The structural design aspects of the analysis and design, including the design procedure and results of preliminary studies, is presented in the section Structural Analysis and Design.

The preliminary studies, although limited in scope, investigated a considerable number of design considerations for soil conditions with sub-standard engineering properties representative of much of the soil to be encountered along the route (i.e. silt). Preliminary design criteria were established, typical loadings and other basic data determined (including loadings resulting from an earthquake of 8.5 Richter magnitude), and some preliminary parametric studies for sidebends, sagbends, overbends, differential settlement and frost heave conducted.

The preliminary studies demonstrate the design methods and procedures being used. For the range of parameters investigated, few potential design limitations were encountered. Prior to final design, the entire range of conditions encountered along the route will be investigated in similar studies.

Conclusions

(1) Once approval to construct the pipeline is received, the final design will proceed in a timely manner, facilitated by the following:

(a) The transportation corridors which the pipeline will follow have been previously established as viable transportation corridors capable of supporting transportation systems and maintaining their structural integrity. Over significant portions of the route, this has been confirmed by actual operating experience.

(b) Since previous construction projects have been undertaken along the entire route, considerable detailed geotechnical (soils) information is already available.

(c) The analytical tools and techniques required to evaluate the structural design considerations are well established, have been tested and used extensively in particular by ALYESKA and can be applied quickly and effectively to analyse a broad range of conditions in a minimum amount of time.

(d) The pipe which has been selected for construction of the line will operate at stress levels which are significantly less than those permitted by the applicable standards, codes and regulations or the other design criteria. This obviates the need for the intricate analysis and cautious approach which would be required if the stress levels were at or very close to the maximum allowable levels; and therefore, expedites the design of this line.

(2) The preliminary studies have indicated few potential structural design limitations at the loading conditions the pipeline will be subjected to during normal operating, maximum operating and maximum contingency conditions.

(3) The effect of earthquakes, a special design consideration in Alaska, has been shown to be well within the structural capability of the pipeline in straight buried sections. Further work is required to define the extent of special construction at potential faults.

(4) The construction of the line during the summer months and the refrigeration of the gas along the entire Alaska portion will help minimize the loading due to temperature differential extremes to which the buried line will be subjected. The actual temperature change of the pipe, neglecting earthquake, could range from +60°F when the line is not in operation to -60°F when the line is in operation.

Alcan Pipeline Company
Docket No. CP76
Exhibit Z2-3.3
Hearing Exhibit No. ____

ALCAN PIPELINE PROJECT

PIPE STRESS ANALYSIS

Prepared For:

Energy Systems Engineering Limited

Calgary, Alberta

Prepared By:

Pipe Line Technologists Ltd.

Calgary, Alberta

June 23, 1976

ALCAN PIPELINE PROJECT

PIPE STRESS ANALYSIS

TABLE OF CONTENTS

1.0 SUMMARY

In this section, the design methods and procedures used by the design group to ensure the structural integrity of the pipeline during construction and operation are outlined and demonstrated. The design considerations which affect the structural integrity of this pipeline are introduced in general terms. The geotechnical aspects of the design considerations are reviewed including a general description of geotechnical conditions (as related to structural design) along the route, the geotechnical design criteria, the analytical methods used to model soil response, and the results of preliminary studies. The standard codes and regulations affecting the structural design of the pipeline are listed, and particularly relevant sections noted. The structural analysis and design aspects of the design considerations are presented next, including the design procedure to be used in establishing the final design, the design criteria, the analytical methods and preliminary studies.

2.0 CONCLUSIONS

(1) Once approval to construct the pipeline is received, the final design will proceed in a timely manner, facilitated by the following:

(a) The transportation corridors which the pipeline will follow have been previously established as viable transportation corridors with physiographic conditions capable of supporting transportation systems and maintaining their structural integrity. Over significant portions of the route, this has been confirmed by actual operating experience.

(b) Since previous construction projects have been undertaken along the entire route, detailed geotechnical information is readily available.

(c) The analytical tools and techniques required to evaluate the structural design considerations are well established, have been tested and used extensively in particular by ALYESKA for the same physiographic conditions, and can be applied quickly and effectively to analyze a broad range of conditions in a minimum amount of time.

(d) The pipe selected for construction of the line will operate at stress levels which are significantly less than those permitted by the applicable standards, codes and regulations or the other design criteria. This obviates the need for the intricate analysis and cautious approach which would be required if the stress levels were at or very close to the maximum allowable levels; and therefore expedites the design of this line.

(2) Preliminary studies have indicated few potential structural design limitations at the loading conditions the pipeline will be subjected to during normal operating, maximum operating and maximum contingency conditions.

These preliminary studies, although limited in scope, investigated a considerable number of design considerations for soil conditions with sub-standard engineering properties but representative of much of the conditions to be encountered along the route.

(3) The effect of seismic ground excitation, a special design consideration in Alaska, has been shown to be well within the structural capability of the pipeline in straight buried sections. Further work is required to define the extent of special construction at potential faults.

(4) The construction of the line during the summer months and the refrigeration of the gas along the entire Alaska portion will help miminize the loading due to temperature differential extremes to which the buried line will be subjected. The actual temperature change of the pipe, neglecting earthquake, could range from +60°F when the line is not in operation to -60°F when the line is in operation.

3.0 DESIGN CONSIDERATIONS

In order to ensure pipeline structural integrity, the following general design approach has been adopted.

(1) Establish the range of design loadings and physiographic (geotechnical) conditions to which the pipeline may be subjected during construction and operations.

(2) Establish critical pipe material behavior which should not be exceeded to prevent excessive pipe deformations. These are the structural design criteria. They are established conservatively and are well below rupture conditions.

(3) Using a systematic approach, perform a parametric study to determine the allowable pipe geometrical configurations for the range of physiographic (geotechnical) conditions and loadings to which the pipeline may be subjected, such that the structural design criteria are not exceeded.

(4) Based on a detailed mile-by-mile evaluation of the route and the results of the parametric study, the pipeline design will be established at all locations along the route.

The conditions under which the pipeline will be operated can generally be classified as:

(1) Normal Operating Conditions - Conditions encountered during normal operation including internal pressure temperature differential and other conditions which are present more or less continuously.

(2) Maximum Operating Conditions - Conditions which are likely to occur occasionally during normal operations but not continuously, including moderate (probable) earthquakes, and normal operating conditions.

(3) Maximum Contingency Conditions - Conditions which may occur only several times during the life of the project, including severe (maximum) earthquakes and normal operating conditions.

The design criteria are established for each of these conditions.

A number of the loading conditions result from displacement constraints applied to the pipeline (settlement, frost heave, temperature and earthquake). The resulting stresses are referred to as secondary stresses or self limiting stresses. They are also called self relieving stresses when the displacements result in plastic deformation as in the case of earthquakes.

Because of the plastic work, the development of a plastic zone relieves the stresses in the rest of the structure. However, a limit on plastic straining must be established and this limit depends on the stress strain relationship of the pipe material, as well as the fracture mechanics behavior of the material.

Whereas full structural integrity is essential under operating conditions, a certain amount of plastic deformation is tolerated under contingency loading conditions provided that adequate provisions are made in design, construction and maintenance programs for efficient shutdown, repair and startup procedures.

The following factors will induce the stresses and deformations which occur in the pipe.

(1) Internal Pressure

Internal pressure causes circumferential (hoop) tensile stresses and strains in the pipe wall be expanding the pipe radially. If the pipe is fully or partially restrained, tensile stresses develop in the longitudinal (axial) direction in the pipe wall, as a result of Poisson's effect.

(2) Differential Temperature

Changes in pipe temperature from its temperature at time of restraint result in longitudinal (axial) stress and strain if the pipe remains fully or partially restrained. The stress and strain are tensile for a decrease in temperature and compressive for an increase in temperature, with respect to the restraint or tie-in temperature.

(3) Structural Behavior of Sidebends

Sidebends become necessary at changes in pipeline alignment. They are illustrated schematically in Figure 3.1. Axial forces in the pipe can induce longitudinal movement and bending moments at sidebends if the reactionary force of the soil at the apex of the bend and the longitudinal friction force is not sufficient to fully restrain the pipe. The axial force can result from internal pressure, temperature differential, and seismic excitation, and can be tensile or compressive. Lateral movement of the pipe and changes in curvature can occur. In ice-rich frozen soil, the reactionary force of the soil and its displacement will be time and load dependent due to soil creep. Vertical instability may occur if vertical restraint is not adequate.

(4) Structural Behavior of Overbends and Sagbends

Overbends and sagbends are required to accommodate undulations in the longitudinal ditch profile, which generally conforms to the topography. They are illustrated schematically in Figure 3.2 and 3.3. Frequently, overbends and sagbends occur in close proximity to accommodate hills or valleys. Axial loads due to internal pressure, differential temperature, and seismic activity that are not fully restrained by longitudinal friction force and soil reactionary forces at the bend apex, will cause bending moments and curvature changes at the bends. In the case of overbends, it is necessary to ensure that pipe elongation resulting from longitudinal compressive stress, does not push the bend out of the soil. In the case of a sagbend, tensile stress should not cause the bend to pull out of the soil. Where the resulting pressure of the pipe on the soil is downwards, design criteria for the pipe should not be violated when the pipe-soil interaction is taken into account. The bearing capacity of the soil should not be exceeded.

(5) Longitudinal Restraint and Anchor Requirements

Longitudinal axial stress develops in full or partially restrained pipelines due to internal pressure, differential temperature, and seismic activity. This stress may be tensile or compressive. At bends in the pipe such as sidebends, sagbends, overbends or above to below ground transitions, the soil reactionary forces may not be sufficient to restrain pipe movement, and bending or pipe movement may exceed acceptable limits. It may then become necessary to isolate the axial force from the bend by anchoring the pipe.

(6) Ice-Wedge Polygons

Ice-wedge polygons occur in permafrost due to seasonal temperature changes causing fractures in the soil. During the summer months, these cracks fill with surface water which causes further cracking when it freezes. The cracks form an interlocking polygon pattern in plan view. The cracks are typically 0.1 to 0.5 inches wide at the top and extend to a depth in excess of 10 feet.

Field studies were carried out by the Institute of Arctic Environmental Engineering, using 40 inch diameter pipe to evaluate the effect of the ice-wedge cracking on the longitudinal strain in the pipe. The results indicated that ice-wedge cracking does not induce additional detectable strain in the pipe.

(7) Stability of Pipeline with Inadequate Support

When axial compressive loads are imposed on a straight section of pipeline and adequate lateral restraint is not provided, the pipe can become unstable and undergo large lateral deflections for small lateral forces. These lateral forces can result from weight of the pipe or buoyancy of the pipe. The large lateral deflections could result in the pipe pushing out of the ditch and could also result in excessive bending moments at transitions from restrained to nonrestrained sections.

(8) Buoyancy

In muskeg or swamp areas, pipeline buoyancy or neutral buoyancy will occur when the weight of the pipeline is less than or equal to the water saturated soil it displaces, shown schematically in Figure 3.4. In the presence of compressive axial loads on the pipe, such as those due to positive temperature differentials, the lateral force due to buoyancy would be sufficient to buckle the pipe out of the ditch. In these areas, it will be necessary to provide anchors or weights to mitigate buoyant uplift.

(9) Differential Settlement

Differential settlement can occur as a result of differential compaction or thaw settlement beneath the pipe inducing bending moments in the pipe as it attempts to conform to the settled soil profile. Figure 3.5 illustrates this schematically. This type of settlement is likely to occur in transitions from stable soil or permafrost to unstable soil or thawing soil. To prevent undue bending or longitudinal straining from occurring, it is necessary to determine the maximum differential settlement which can be allowed to occur for various settlement spans such that the design criteria are not violated.

(10) Frost Heave

Frost heave can occur as a result of ice lense formation or water-ice transformation below the pipe, causing differential displacement of the pipe as shown in Figure 3.6. In the case of a chilled gas pipeline it is aggravated by the presence of a frost bulb or frozen zone around the pipe. Frost heave exerts a vertical upward force on the pipe which depends on the pressure in the frost bulb, the size of the bulb, the amount of the bulb above the water table and the bearing pressure exerted by the pipe on the trench bottom.

(11) Ice-Rich Soils

In permafrost regions, the pipeline may be partially buried in high ice content permanently frozen soil. During construction and prior to start-up, thawing of the high ice content soil will occur. Following start-up and during operations, the soil and water around the pipe will refreeze due to the presence of the chilled gas line. It will be necessary to ensure that excessive thaw settlement does not occur during the construction phase. This could be achieved by usine select backfill or using a shallow trench, gravel berm construction method, to avoid excavation in the ice rich soil.

Another phenomenon associated with ice rich soils is creep. When subjected to a bearing pressure such as those which will be imposed by the pipe, the ice deforms, or creeps, with time and consequently, pipeline restraint in such soils is time dependent.

(12) Seismic Activity and Faults

Seismic activity will result in additional stress on the pipe due to ground deformation from either:

(a) seismic waves; or

(b) faulting.

Seismic waves consist of shear and compression waves. The only significant strain induced in a straight buried pipeline by these waves is in the longitudinal direction. The effect of this longitudinal strain must be considered in conjunction with other loads and the pipe-soil interaction.

Faulting in the vertical or horizontal directions can occur. The amount of differential movement which the buried pipeline can withstand must be determined. If potential faulting is considered greater than the allowable differential movement, remedial action must be taken to reduce the soil restraint of the pipeline, thereby allowing it to deform over a greater length.

(13) Overburden

When backfill is installed above the empty pipe the weight of the soil bears directly on the upper surface of the pipe inducing hoop stresses and bending moments in the wall of the pipe tending to flatten it. This is shown schematically in Figure 3.7. For normal burial depths, typically three to four feet, this is not a problem. However, at greater depths up to 18 to 20 feet, it is possible for excessive flattening to occur. In such cases remedial action will be needed, such as providing firm shaped soil support for the bottom half of the pipe. It will also be necessary to ensure that the design criteria, expressed in terms of minimum radius of curvature, are not exceeded when the pipe conforms to the longitudinal profile of the ditch.

(14) Flexing and Loading During Construction

Flexing and longitudinal loadings of the pipe will occur during construction since the pipe must be lowered from its welded position on skids beside the ditch to the ditch bottom. The pipe configuration during this operation is shown schematically in Figure 3.8. The construction techniques for performing this operation without excessive flexing of the pipe have been well established in more conventional pipelining areas. The amount of flexing which occurs will be aggravated by externally applied weights. The minimum radius of curvature of the pipe during construction will be restricted to a minimum value in accordance with the design criteria.

At river crossings, it will be necessary to pull welded sections complete with external weights, through the ditch across the river. It will be necessary to ensure that the stresses and strains which occur as a result of flexings as the pipe conforms to the ditch bottom while simultaneously being pulled along the ditch bottom, do not exceed those specified in the design criteria.

(15) Water Crossings

Special design consideration will be given to water crossings. The pipe will be buried deeply enough at the water crossing to avoid the effects of ice scour and erosion and provide adequate lateral support to stabilize the pipe under lateral loads, e.g. buoyancy. If excessive burial depths are required, it may be necessary to provide aerial crossings, for example the Yukon River crossing. To reduce longitudinal friction and reduce flexing when pulling pipe sections across the river, the pipe will be supported on rollers on shore. The effective weight of the pipe in the water will be considerably less than on shore so that friction forces there will be reduced. It will be necessary to determine the amount of external weighting required to hold the pipe down prior to backfill and allow it to conform to the ditch bottom.

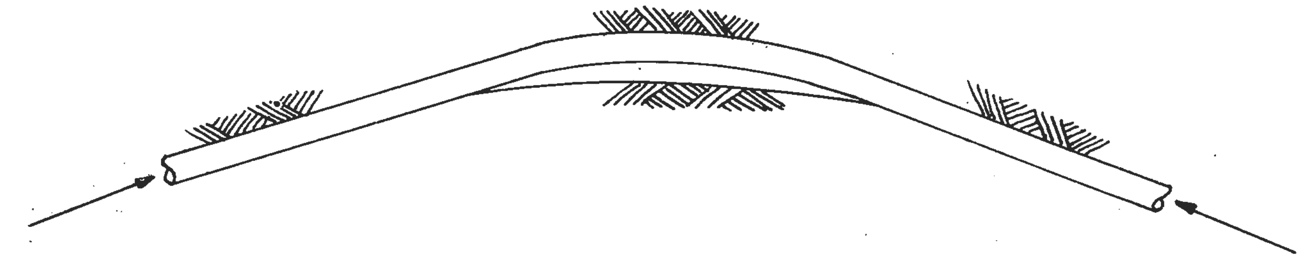

FIGURE 3.1 SIDE BEND CONFIGURATION

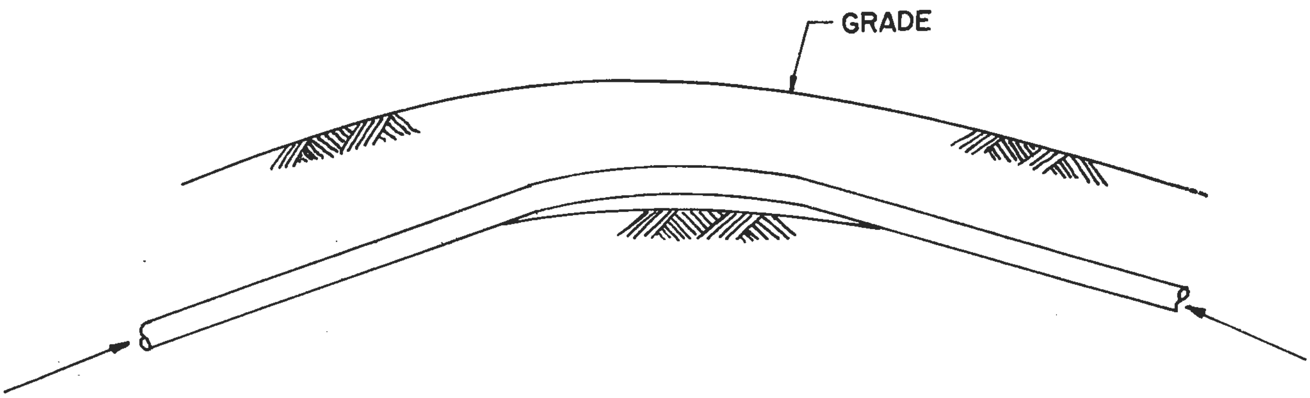

FIGURE 3.2 OVER BEND CONFIGURATION

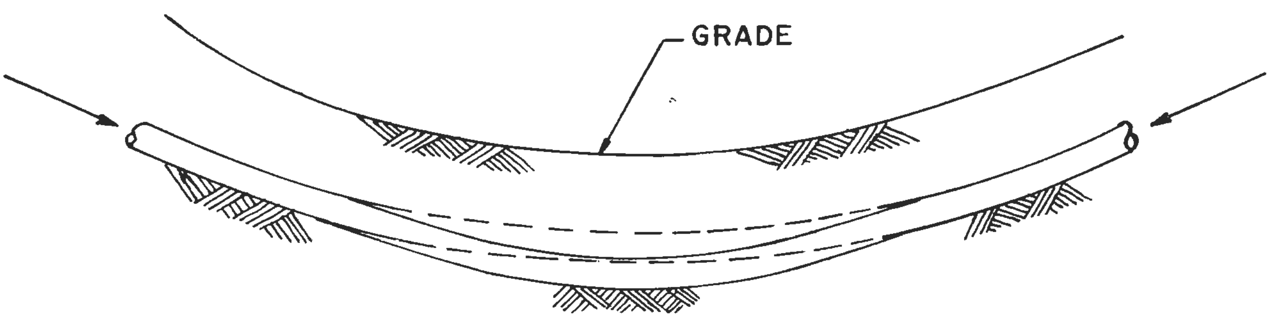

FIGURE 3.3 SAG BEND CONFIGURATION

GEOMETRICAL PIPE CONFIGURATIONS

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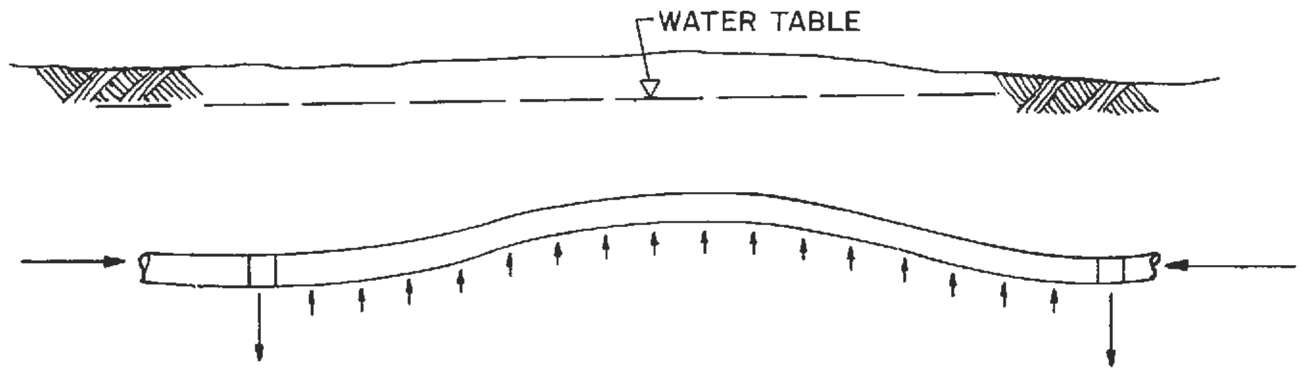

FIGURE 3.4 BUOYANT UPLIFT

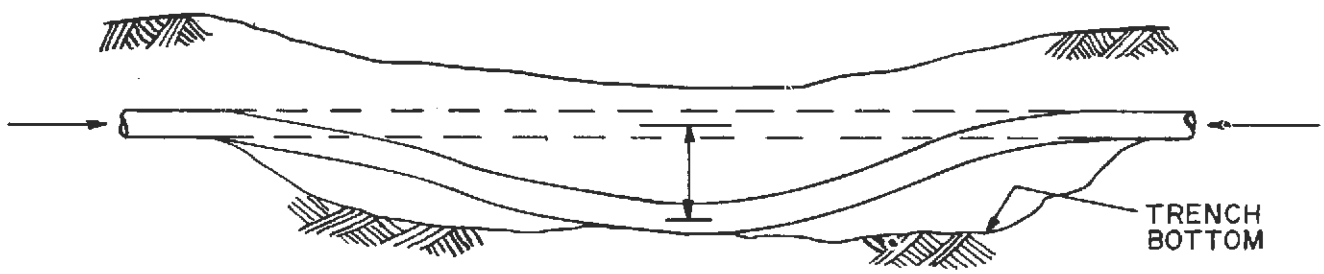

FIGURE 3.5 DIFFERENTIAL SETTLEMENT CONFIGURATION

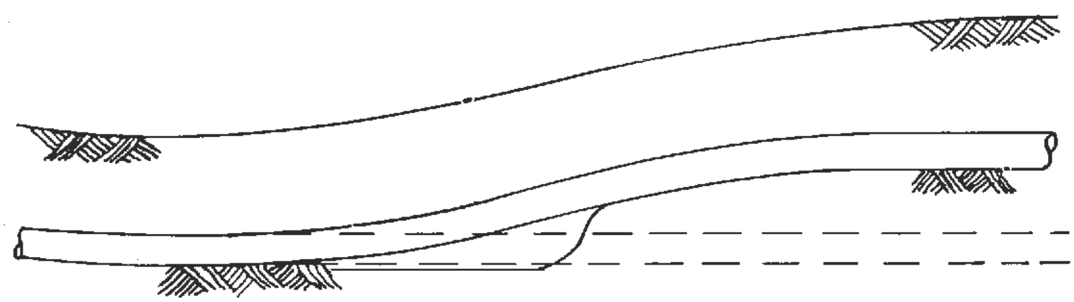

FIGURE 3.6 DIFFERENTIAL FROST-HEAVE CONFIGURATION

DIFFERENTIAL DISPLACEMENTS

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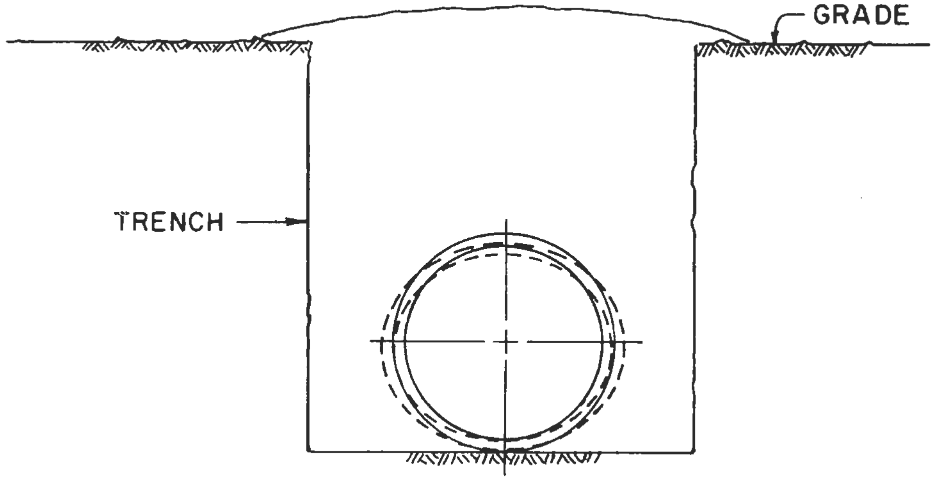

FIGURE 3.7 OVALLING DUE TO OVERBURDEN

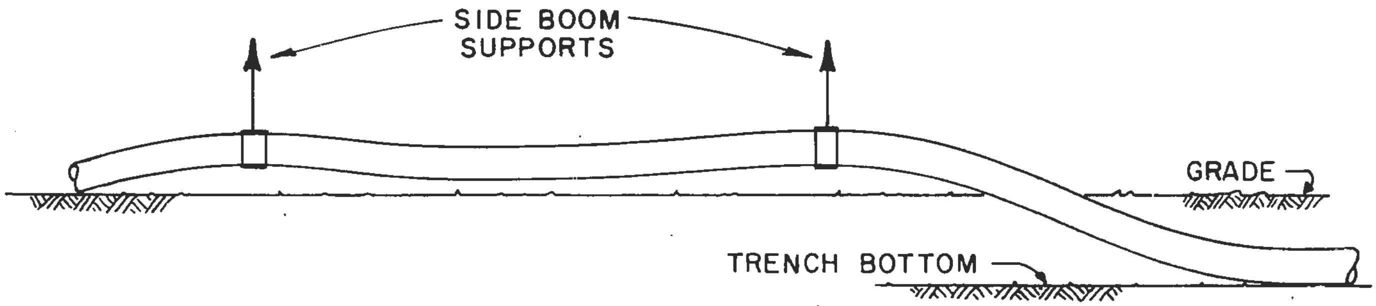

FIGURE 3.8 FREE BENDING DUE TO CONSTRUCTION

CONSTRUCTION LOADINGS

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4.0 GEOTECHNICAL ANALYSIS AND DESIGN

4.1 INTRODUCTION

This section addresses itself to the soil phase of the pipe-soil interaction problem and develops geotechnical models and parameters necessary for pipe stress analyses. The chosen geotechnical models are based on most recent published theoretical work confirmed by model testing and field performance.

To demonstrate the applicability of the geotechnical models, geotechnical parameters were developed for one representative soil with lower than average engineering properties, namely silt, in both unfrozen and frozen states.

The pipe-soil interaction designs are based on pipe design criteria for permissible strains or curvature changes, and pipe displacement. The adequacy of soil restraint adjacent to field bends and transitions will be checked at selected bends and transition conditions by reviewing the soil limit capacity.

4.2 GEOTECHNICAL ENVIRONMENT

The proposed ALCAN Pipeline route from Prudhoe Bay to the Yukon border crosses three of the four major Alaskan Physiographic Divisions, namely, Interior Plains, Rocky Mountain System and Intermontane Plateaus respectively. For design purposes they are further subdivided into smaller divisions (Wahrhaftig, 1964) which are more representative of the major soil conditions. The following physiographic divisions and general soil conditions are encountered from Prudhoe Bay:

Arctic Coastal Plain is a smooth plain rising very gradually southwards towards the Arctic Foothills. This area is in continuous permafrost and is underlain by surficial marine ice-rich silts and sand. The active layer is less than four feet deep and the permafrost is continuous with the exception of local thaw bulbs beneath large lakes and active water courses. Ice-wedge polygons are predominant.

Arctic Foothills consists of rolling plateaus and low linear mountains underlain by glacial tills and fluvial and colluvial sediments. The soils vary from fine grained ice-rich silts to granular sands and gravels which are relatively ice free. Permafrost is generally continuous.

Brooks Range consists of rugged glaciated mountain ridges with valleys underlain by granular colluvial soils and active and inactive flood plains covered with coarse gravel to ice-rich silt deposits. Permafrost is continuous with the exception of some areas in the active flood plains.

Interior Plateaus and Lowlands is the largest area traversed by the pipeline route and consists of generally undulating topography broken by flats and wide valley flood plains. The soils are predominantly fine grained alluvium, loess and colluvial deposits.

The permafrost is discontinuous with its presence governed by vegetation, direction of slopes, soils and presence of major water bodies. Between Yukon River and Tanana River there are several areas with organic ice-rich fine grained soils containing ice wedges and lenses. These areas may require special design considerations to preserve their equilibrium.

Alaska Range Northern Foothills consists of flat topped, east-trending ridges separated by rolling lowlands. The surficial soils are dense, glacial, fine to coarse grained tills underlain by sedimentary bedrock. The area has discontinuous permafrost with ice-rich silts found in depressions.

The proposed route from Delta Junction to Yukon border just borders this area.

The physiographic areas show that the proposed pipeline route will cross the following geotechnical conditions:

Flat cold permafrost area underlain by relatively uniform silts and sand in the Arctic Coastal Plains.

Predominantly continuous cold permafrost but variable soils from silts to coarse granular talus and bedrock in the Arctic Foothills and Brooks Range.

Undulating topography with fine grained soils and discontinuous permafrost to Delta Junction. In this area there are broad unfrozen flood plains with coarse granular material and high ice-rich fine grained soils with ice lenses between the Yukon River and Fairbanks.

Finally bordering northern Alaska Range foothills underlain by dense glacial tills and sporadic permafrost with localized ice-rich soils.

The proposed pipeline route is in a moderately seismic active area and crosses a number of recently dormant faults between Brooks Range and the Yukon Border.

4.3 DESIGN PROCEDURE

4.3.1 Problem Identification

The pipeline will be constructed in a buried mode. Where the ditch bottom is uneven or where the spoil contains large frozen chunks or rocks that would damage the coating or the pipe, the pipe will be protected by placing the pipe in a trench on a minimum one foot bedding layer of select granular fill, surrounding the pipe with a minimum of one foot compacted granular fill and filling and crowning the rest of the trench with the excavated material as shown on Figure 4.1 (a). Definitions of the trench and pipe geometrics are shown on Figure 4.1 (b).

The pipe-soil interaction design has to take into consideration the various soils, groundwater and permafrost conditions encountered along the route and the environmental changes which may take place, such as: frost heave, groundwater flow, static and thaw settlement, liquefaction, earthquake motions and water erosion. The environment and its changes have to be considered for the construction phase and the operation phase of the chilled pipeline. Disturbance of the ground cover during the construction phase may degrade the existing permafrost in the discontinuous permafrost areas which in turn may decrease the support strength of soil, initiate thaw settlement and create buoyancy conditions. The operation of the chilled pipeline will lead to permafrost aggradation in the discontinuous permafrost areas and frost heave in previously unfrozen fine grained soils. The pipeline stress design will take the above aspects into consideration.

4.3.2 Establish Soil Conditions and Problems

It is necessary to identify the soil, groundwater and permafrost conditions along the pipeline route for the purpose of developing a range of soils and their properties for which the pipe has to be designed. Most of this information is available because the proposed pipeline will follow to a large extent the under construction Alaska Oil Pipeline from Prudhoe Bay to Delta Junction and the existing Trans Alaska Highway from Delta Junction to the Yukon Border. The design of the proposed pipeline will therefore require only the development of detailed soils information for the mile-by-mile conditions where the proposed pipeline deviates from the Alaska Oil Pipeline route and the Alaska Highway.

Presently there is ample soils information to establish the major soil conditions and their representative soil properties to identify the geotechnical problems and start on a parametric study of the pipe stress design.

To demonstrate the capability of the pipeline stress analysis a common and representative soil, a silt, was selected and geotechnical parameters and necessary functions developed. A silt may experience the whole range of design problems, such as: buoyancy due to thaw settlement, or liquefaction, loss of support due to erosion or thaw settlement, frost heave and low shear strength for pipe restraint and resistance to outward forces at bends. In this demonstration of single bend design the groundwater table has been assumed to be below the bottom of the pipe.

4.3.3 Development of Geotechnical Input for Detailed Parametric Design

Existing soils information will be analyzed to establish the major soil conditions and their engineering properties for the parametric study and the design guidelines which will be established subsequently will be followed in the mile-by-mile design. Additional field data will be obtained along the existing Alaska Oil Pipeline to review the effect of the pipeline construction on the natural vegetation, soil and permafrost conditions and detailed subsurface infromation will be obtained from Delta Junction to the Yukon Border. The data will consist of the determination of the subsurface stratigraphy, index and engineering properties of the soil strata, ground water conditions and thermal regime.

4.3.4 Analytical and Design Methods

The geotechnical theories and models to develop the load-deformation-time relationships for the major soil groupings for the pipe stress parametric study are available and are discussed in subsequent section 4.5.

4.3.5 Mile-By-Mile Design

The buried pipe may encounter a wide range of subsurface conditions which will be evaluated and designed for in the mile-by-mile design. The soils may vary from fine grained silts and clays, through to sands, gravels and bedrock or mixtures thereof in form of tills all of which may exist in unfrozen or frozen states.

The mile-by-mile design will consist of subdividing the pipeline route into short segments by soil conditions encountered and selecting from these trench and pipe designs developed from parametric studies.

4.4. DESIGN CRITERIA

The pipe-soil interaction design will be based on pipe design criteria on permissible strains or curvature and pipe displacement. The soil phase will be checked to assure that it provides sufficient restraint adjacent to the strained portions of the pipe section and that the soil portion in the yield range is limited to the immediate area of the bend apex or transition zone.

The design procedure will consist of the development of soil loadings, settlement or heave profiles and load-deformation-time functions for the range of soil conditions to be encountered along the pipeline route for pipe stress parametric study and checking these results for adequacy of soil restraint.

4.5 GEOTECHNICAL INPUT PIPE STRESS DESIGN

The following is a brief outline of design conditions for which geotechnical input is required, a presentation of the basic geotechnical model for analyses, and geotechnical parameters to be used to the pipe stress analyses.

The geotechnical input for pipe stress analysis consists of the development of load-deformation-time functions for the representative soil conditions to be encountered along the pipeline route. The load-deformation functions for unfrozen soils are represented by an elastic-perfect plastic model shown on Figure 4.2 where the initial slope is obtained by assuming the soil to be linearly elastic and the second slope is obtained from an equilibrium solution of the ultimate resistance. The initial slope or spring constant is developed from Terzaghi's 1955 work on the modulus of subgrade reaction and its value is obtained from field plate load tests adjusted for the pipe surface contact area. The two separate analyses are correlated at the intersection of the two slopes at the yield point by checking the yield deformation against published yield deformations from field and model studies.

In case of frozen soil a similar bilinear model will be developed but the phenomenon of creep will be incorporated. A frozen fine grained soil normally creeps under stress with the creep going possibly through three stages, namely, primary, secondary and tertiary creep, as illustrated on Figure 4.3 (a). The creep rate is a function of soil, ice content, temperature and stress level. The effect of stress level is shown on Figure 4.3 (b) which shows that the initial, primary and secondary creep increase with stress. Finally Figure 4.3 (c) illustrates that because of creep the long term shear strength decreases with time and tends to reach a unique and constant value.

The load-deformation-time relations for pipe stresses analysis will be modelled as shown on Figure 4.4 (c). Briefly, the load-deformation will be modelled as for the unfrozen soil using a spring constant and an ultimate resistance. The spring constant will contain the initial elastic displacement and the primary creep deformation component and the ultimate resistance will be based on the ultimate long term frozen shear strength illustrated in Figure 4.3 (c). The creep will be developed only for the secondary creep and will be given in terms of secondary creep rates for selected stress states as illustrated on Figure 4.4 (b).

4.5.1 Overburden Pressure

Isolated areas may be encountered along the pipeline route where it will be necessary to bury the pipe at deeper than the normal proposed depth with an overburden cover of 3.0 feet. A maximum depth limited by the weight of the overburden and based on pipe stress criteria will be determined for typical granular overburden. A conservative approach will be taken in the calculation of the overburden pressure by assuming the groundwater is located below the bottom of the pipe and zero arching in the pipe trench. The overburden pressure is given by:

$$\sigma = C\gamma D \quad K/FT$$

where C, γ and D are given in Figure 4.1.

4.5.2 Buoyancy

The pipeline may be subjected to buoyancy forces when crossing streams and lakes and when buried in saturated soils generally present in low lying areas, such as: floodplains, marshes, muskeg and local depressions. The buoyant force may vary from the weight of the volume of water displaced in a static water condition to a greater force existing when the soil-water phase is in a slurry form or in the presence of excess pore pressures produced by thaw consolidation of fine grained ice-rich soils.

The buoyant force in the slurry is determined by the volume of slurry displaced by the pipe times its unit weight. In the case of thaw consolidation the total buoyant force equals the weight of the displaced water plus an excess pore water pressure component determined from thaw consolidation. The uplift buoyant forces are resisted by the weight of the pipe plus overburden in static ground and thaw consolidation conditions but by only the weight of the pipe in a soil slurry.

The buoyancy conditions may eliminate any effective soil restraint and the pipe integrity may be governed by its own structural rigidity.

4.5.3 Loss of Support

A loss of support over short sections of the pipeline may be created by several processes, namely, thaw settlement, consolidation of organic soils such as: muskeg and swamps under added overburden, and water erosion of soils. The above processes will reduce the bearing capacity of the bedding and may leave the pipe unsupported for a span equal to the length of the loss of support. The geotechnical loading would be represented by the overburden carried by the pipe.

Thaw settlement may occur during the construction phase as a result of the melting of the permafrost caused by construction disturbance of the surface insulation. The problem would manifest itself in fine grained ice-rich soils where the settlement is the result of excess water draining from thawing soil. In dense coarse granular soils with little free ice the thaw settlement would be small and can be neglected.

Settlement may occur in soft organic soils due to the weight of overburden of the ditch cover. The resulting compression and/or consolidation of the soft organics may reduce the bearing resistance of the ditch bottom or create a loss of support.

Loss of support by water erosion can occur in local depressions and at active and non-active river crossings. The danger periods for erosion occur during heavy runoffs resulting from either rainfall or snow melt.

Geotechnical input for the pipe stress analyses for loss of support consists of modelling the loss of a bearing surface over different span lengths.

4.5.4 Longitudinal Restraint

The ditch material provides the pipe with longitudinal restraint to resist longitudinal forces. In unfrozen soils the restraint is calculated from normal soil pressure against the pipe and coefficient of friction between the soil and pipe.

The available longitudinal restraint is calculated from:

$$L_R = \pi D \, K_{ave} \gamma \; (C + \frac{D}{2}) \; \tan \beta \qquad \text{K/FT}$$

where L_R = Restraint per unit length

D, C & γ = as shown on Figure 1

K_{ave} = average earth pressure coefficient normal to pipe surface

and β = pipe-soil friction angle

The K_{ave} value is dependent on the properties of the backfill surrounding the pipe and its method of compaction. For pipe stress analysis a K_{ave} of 0.75 may be assumed based on a vertical and horizontal coefficient of earth pressure equal to 1.0 and 0.5 respectively. For present study the pipe-soil friction angle has been interpreted as 20 degrees from published data by Potyandi, 1961.

Load-deformation functions will be developed for the different soil conditions and burial depth from maximum restraint capacities calculated by the above equation and deformations estimated from uplift performance data from piles and buried anchors such as Adams and Klym, 1972 and Bhatnager, 1969. A maximum longitudinal deformation of 0.5 inch is estimated for pipe with a three foot cover depth.

4.5.5 Overbends

Changes of gas pressure and temperature produce upward forces which are resisted by the stiffness of the pipe, weight of the pipe and overburden and the resistance of the overlying soil to upward movement. For soil-pipe interaction calculations the weight of the pipe and overburden, and soil resistance are combined to give an uplife resistance which is fully mobilized at deformations obtained from performance data on uplift problems. The uplift load-deformation functions will be developed only for unfrozen soils since this is representative of the start-up time and represents a conservative case consisting of unfrozen active layer.

The uplift resistance is given by the following relationship:

$$U = W_s + W_P + 2T_s \qquad K/FT$$

where W_s = effective weight of soil overburden directly over the pipe

W_P = effective weight of the pipe which will be buoyant in submerged condition

and T_s = tangential shear against the ditch wall.

In cohesive soils T_s is calculated from the undrained shear strength. In cohesionless soils T_s is calculated from the effective horizontal stresses on the ditch wall obtained from the effective overburden stresses multiplied by earth pressure coefficient at rest, K_o, times the tangent of the angle of friction of the soil.

The load-deformation function is obtained from the yield displacement taken as one percent of the cover (Bhatnager, 1969) and the maximum uplift resistance.

4.5.6 Sagbends

The load-deformation functions for the sagbends will be derived from the modulus of subgrade reaction with a linear elastic relationship and the ultimate resistance obtained from a bearing capacity analysis. The intersection of the modulus and the ultimate resistance gives the yield point. The yield deformation may be checked against performance data from model and field plate load tests.

The ultimate capacity in cohesionless soil is given by:

$$P = (\gamma H N_q + 1/2 \gamma B N_\gamma)\ B \quad K/FT$$

where N_q and N_γ are bearing capacity factors proposed by Meyerhof, 1963 and found to give good correlation with performance data by Chen and Davidson, 1973.

The ultimate capacity in cohesive soils is given by:

$$P = N_c S_u B \quad K/FT$$

where N_c is a bearing capacity factor equal to 7.0 for a normal shallow ditch and may be greater for deep ditches (Skempton, 1951 as reported by Lambe and Whitmann, 1969) and

S_u = undrained shear strength.

The modulus will be estimated primarily from work on the coefficients of subgrade reaction by Terzaghi, 1955 and supplemented by other recently published data.

The modulus for the pipe has to be corrected for the effective width of the bearing surface which is given in Kips of resistance per inch delfection per foot of pipe by

$$k = k_{si} \left(\frac{B + 1}{2B}\right)^2 \quad K/IN/FT$$

where k_{si} is the modulus determined for a one foot square plate.

Detailed analyses are not being considered for frozen soils because of their great bearing capacity.

Sagbends in fine grained ice-rich soil will be checked using modelling similar to the load-deformation function developed for sidebends.

4.5.7 Sidebends

Outward forces are produced by the pipe at sidebends which are resisted by the soil at the ditchwall. The load-deformation function will be developed from the horizontal subgrade reaction and passive earth pressure resistance checking the yield deformation with published performance data on passive earth pressure problems and horizontal anchors. The unfrozen and frozen soils are treated separately in the analyses.

Unfrozen Soils

The ultimate resistance for sidebends will be obtained by considering the sidebend to be a passive earth pressure problem with a correction factor because the pipe behaves as a horizontal anchor and not a wall extending to the ground surface.

For cohesionless soils the ultimate sidebend resistance is given by

$$P_p = 1/2\gamma H^2 \quad K_p A$$

where A is a reduction coefficient obtained from D/H ratio after Oversen 1972

γ, H and D as defined in Figure 4.1

and K_p = passive earth pressure coefficient

For cohesive soils the ultimate sidebend resistance is calculated by a method proposed by Meyerhof in 1953 and is given by

$$P_p = (S_u N_c + \gamma H) \quad B$$

where γ, H and B are as defined in Figure 4.1.

S_u is the undrained shear strength

and N_c a shape factor depending on the burial ratio H/B after Meyerhof, 1953.

The moduli for the load-deformation are obtained from the horizontal coefficient of subgrade reation as developed by Terzaghi, 1955 and estensively used in the alanysis of lateral deformation of piles (Broms, 1964 and Davisson, 1970).

The moduli for sidebends are obtained from the relationship:

$$k_h = n_h \frac{D + 1/2D}{B} \quad \text{for sand}$$

where k_h is the horizontal subgrade reaction for a given depth, n_h is a constant of horizontal reaction for vertical beams or piles and C_1D and B are shown on Figure 4.1.

and $$k_h = \frac{k_{si}}{1.5B} \quad \text{for clay}$$

where k_{si} is the vertical subgrade of reaction for clay for a one foot square plate for one foot wide long strip.

Frozen Soils

Frozen soils have very high immediate shear strengths but their creep under load will reduce the ultimate long term strength to a considerably smaller value. Furthermore, the soil-structure may fail before the ultimate load is reached due to excessive creep deformation. Frozen soils exhibit three phases of creep being primary, secondary and tertiary. The initial and limiting ultimate loadings and the creep rates are a function of soil type, ice content and temperature and the creep rates being also a function of stress. For a given temperature the worst soil-ice mixture is pure ice with lowest ultimate load and greatest creep rate and the best soil-ice mixture is dense coarse gravel with no free ice.

The load-deformation functions for frozen soils will be represented in a similar fashion as the unfrozen soil with the addition that the creep phenomenon will be included. The maximum long term passive resistance will be calculated from the ultimate long term frozen soil shear strength for the design soil and temperature and the modulus and creep will be modelled by:

a) Combining the initial elastic deformation and primary creep in one frozen soil modulus.

b) Developing secondary creep rate for the ultimate long term shear stress and intermediate stresses.

The tertiary creep rate is not included in the model because it leads to failure which has been precluded by the use of the ultimate long term shear strength.

The maximum sidebend resistance will be based on the passive earth pressure relationship:

$$P_p = 1/2\gamma\ H^2K_p$$

where γ and H are as defined in Figure 1 and

$K_p = 1 + \frac{2S_f}{\gamma H}$ where S_f is the frozen limiting long-term strength bond as Vailov, 1968, Rain et al, 1975 and Ladanyi, 1972.

The limiting long-term shear strength is a function of the soil type, its density and ice content and its temperature will be obtained from laboratory uniaxial tests data on representative soils and correlation with published data.

The moduli of subgrade reaction for frozen soils which will include the initial elastic deformation and primary creep will be developed from horizontal plate load tests and/or pressure meter tests, uniaxial load-creep tests and published data. The moduli have a similar form to the unfrozen clay moduli with the addition that they will also be dependent on soil temperature and will include the primary creep component.

$$k = \frac{k_{si}}{B} \; F \text{ (temp, soil)}$$

where k_{si} is for one square foot plate obtain from plate load test and B is as in Figure 1.

The secondary creep rates will be based on the accepted relationship of

$$\frac{d\varepsilon^c}{dt} = A\sigma_e^n$$

where $\frac{d\varepsilon^c}{dt}$ is the secondary creep rate for a given soil, temperature and stress, σ_e is the appropriate equivalent stress and A and n are constants. The constants will be developed from uniaxial creep compression tests, field plate load tests and published data.

The load-deflection-time functions will be developed from major works carried out by Glen, 1955 on ice, and Vailov, 1965 and Ladanyi, 1972 & 1975, Ladanyi and Johnston, 1973 & 1974, Rowley et al, 1973 & 1975, McRoberts, 1975 and Sayles and Haynes, 1974.

4.5.8 Frost Heave

The operation of a chilled gas pipeline in unfrozen fine grain soils may lead to frost heave of the pipe and thereby introduce bending stresses which are a function of the magnitude and geometrics of the frost heave. Small magnitude and uniformly distributed frost heave would have minimal affect on the stresses of the pipe while differential and large heave over short spans of 10 to 200 feet may have a major effect.

It should be noted that frost heave is a gradual phenomenon which can be monitored and corrective measures taken before critical stresses are reached.

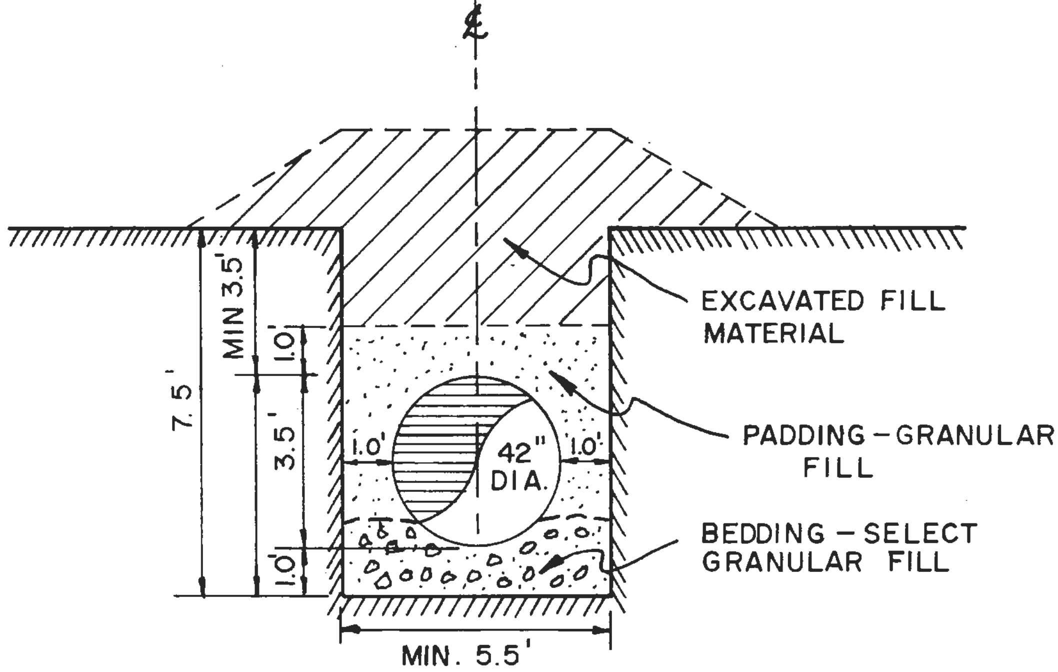
Frost heave is caused by the expansion of water on transformation to ice and the growth of ice lenses at the interface between the frozen and unfrozen soil. The first is a simple relationship of change of volume due to transformation, while the second is governed to a large extent on the availability of water for the growth of ice lenses. Some factors which are conductive to frost heave are:

freezing temperature in soil.

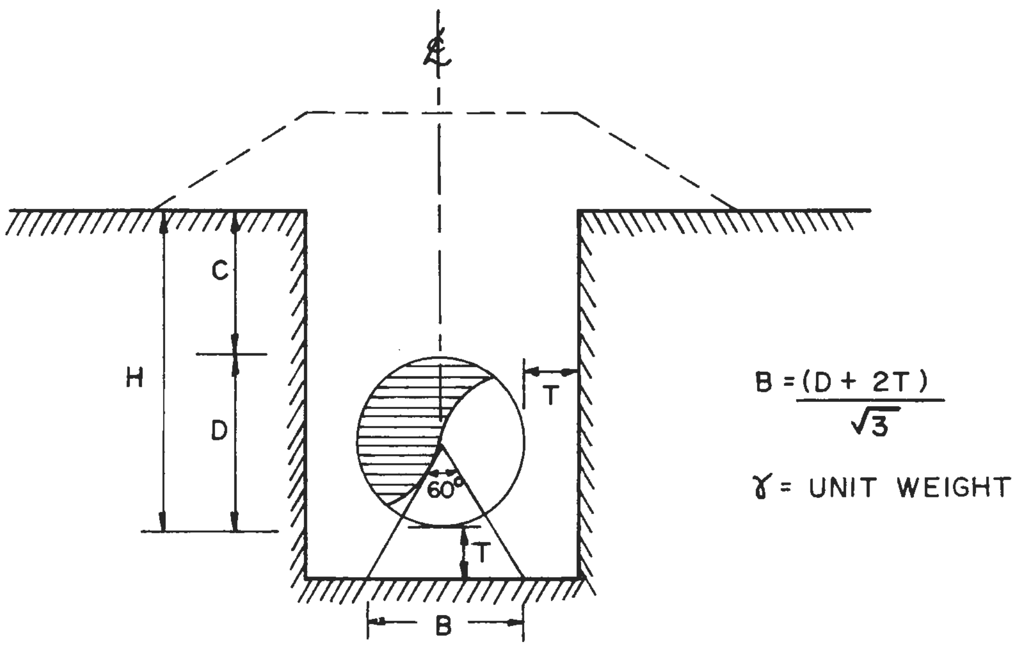
frost susceptible soil which allows adequate flow of water to the frozen-unfrozen soil interface by capillary action. Coarse sands and gravels do not meet this criterion because of large voids and clays normally are not considered frost heave susceptible because of the low permeability.

availability of groundwater as indicated by high groundwater level.

Frost heave studies using computer models, field studies and literature research will be conducted to determine the magnitude of the frost heave which can be anticipated along the proposed applicant route. To carry out parametric studies of pipe stress due to frost heave, frost heave magnitudes of 1 to 5 feet with variable span lengths will be used.



a) TYPICAL DITCH CROSS-SECTION



b) DEFINITION OF SYMBOLS
(FOR UNSATURATED SOIL WITH GROUND-WATER BELOW PIPE)

FIGURE 4.1

BURIED PIPE CROSS-SECTION

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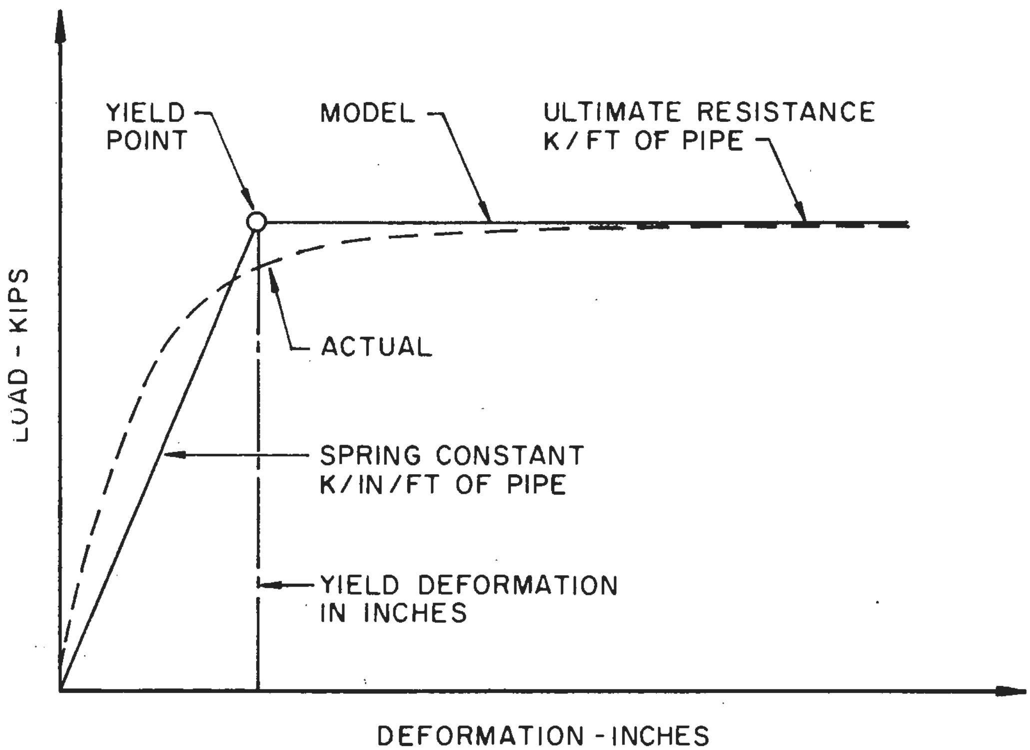

FIGURE 4.2

LOAD DEFORMATION CURVE - GENERAL FORM FOR UNFROZEN SOIL

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ALCAN PIPELINE COMPANY

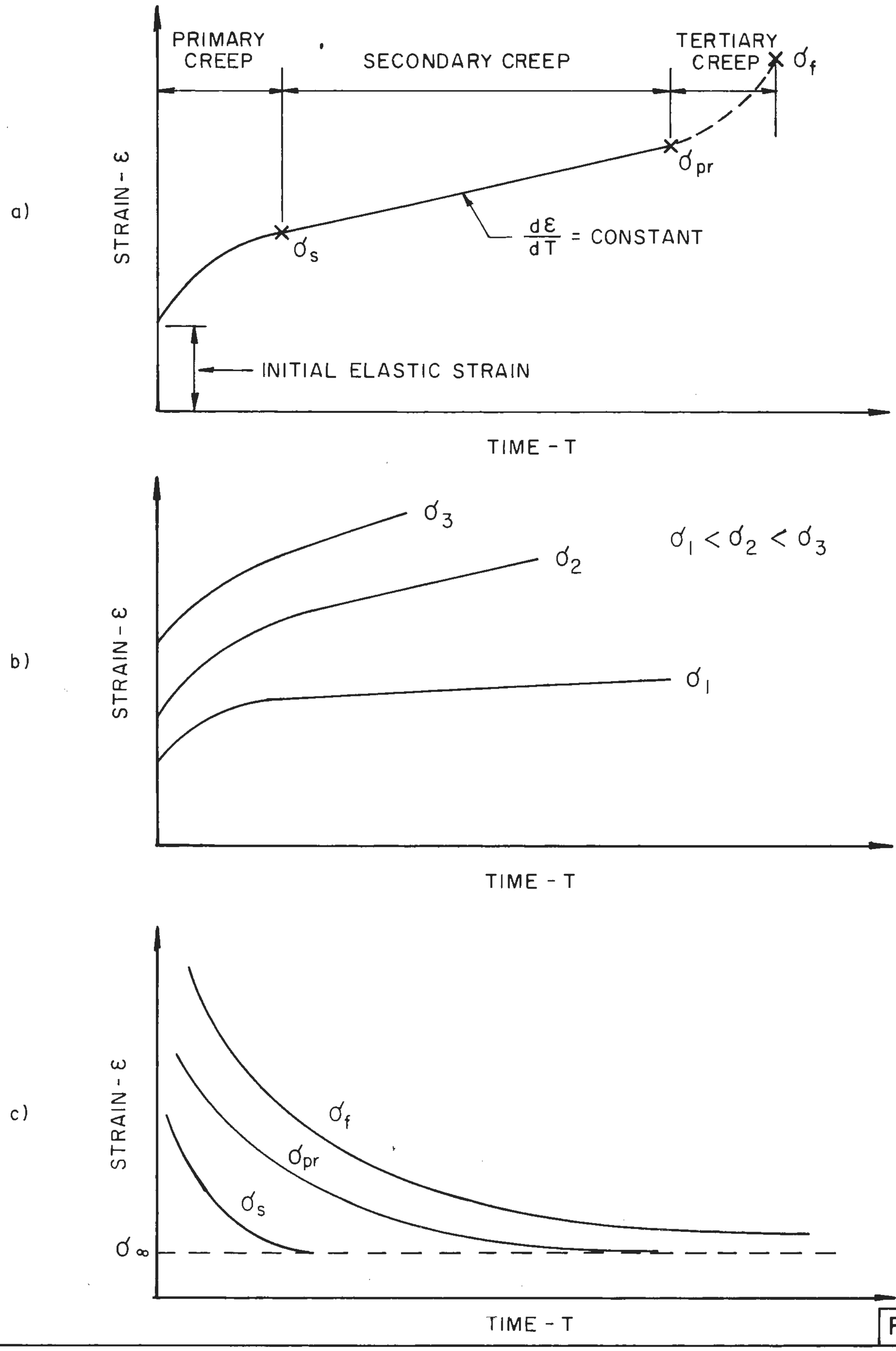

FIGURE 4.3

STRESS/STRAIN TIME CURVES RELATIONS FOR FINE GRAINED FROZEN SOIL

PIPE LINE TECHNOLOGISTS LTD.
CALGARY ALBERTA

ALCAN PIPELINE COMPANY

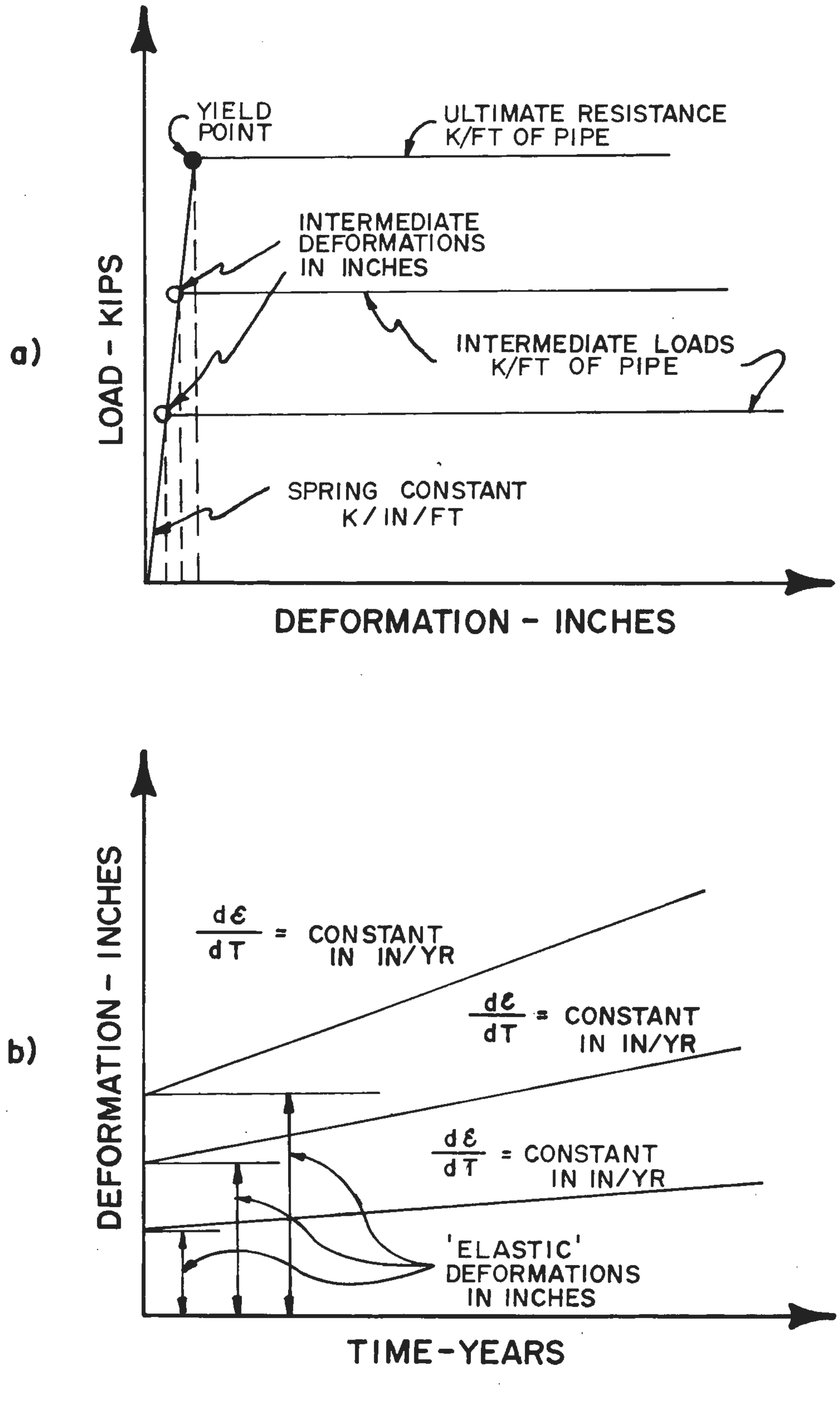

FIGURE 4.4

LOAD-DEFORMATION-TIME CURVES (MODEL FOR FINE GRAINED FROZEN SOIL)

PIPE LINE TECHNOLOGISTS LTD.
CALGARY ALBERTA
JUNE 1976

ALCAN PIPELINE COMPANY

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5.0 STANDARDS, CODES AND REGULATIONS

The construction and operation of the pipeline will conform with the applicable standards, codes and regulations regulating pipeline construction and operation in the United States and the State of Alaska. They are:

(1) ANSI - B31.8 - Gas Transmission and Distribution Piping Systems.

(2) Code of Federal Regulations, Part 192 - Transportation of Natural and Other Gas by Pipeline: Minimum Federal Safety Standards.

(3) Uniform Building Code, 1970 or latest. (For environmental loads).

(4) USAS - B31.7 - 1969 or latest. (Nuclear Power Piping).

(5) API - Standard 1102 (For traffic over the pipe).

(6) API - RP 5L1. (Transportation of pipe, handling, storage and hauling of pipe).

The following sections are particularly applicable to the structural design of this pipeline:

ANSI B31.8 - 1968

Chapter 3	Article 834 and 835
Chapter 4	Article 841

<u>Code of Federal Regulations, Part 192</u>

Subpart C	Article 192.101 to .115
Subpart D	Article 192.161
Subpart E	Article 192.221 to .245
Subpart G	Article 192.301 to .327
Subpart J	Article 192.501 to .517
Subpart L	Article 197.601 to .623

6.0 STRUCTURAL ANALYSIS AND DESIGN

6.1 DESIGN PROCEDURE

The sound structural design of the pipeline will be evolved using a systematic approach. This calls for an understanding of the various aspects of the design, the activities involved and the performance of these activities within a time scaled network plan. This approach will facilitate interfaces among the various aspects of the design such as geotechnical, route, stations and terminals, stress analysis and structural design, corrosion, river engineering, hydraulic and environmental. This time scaled network plan will likely be established using a management computer program for scheduling projects, such as Project II. The following design procedure will be followed, subject to further revision as required.

(1) <u>Correlation of Computer Programs with Experimental Data</u>

The below ground pipeline analysis is mainly a soil structure interaction problem and as this is quite complex, the solution will involve extensive use of computer programs. There are special purpose computer programs like PIPLIN for handling pipeline problems and general purpose programs like MARC, ANSYS, and STARDYNE to handle general elastic structural design.

It is essential that any program to be used should be submitted to careful checks by direct comparison with experimental data or indirectly with any other program which has been verified in this manner. Considerable experimental work was done at the University of California, Berkeley, for the Alyeska Pipeline Project. Correlation with these experimental data should be made.

(2) <u>Establishing Minimum Radius of Curvature</u>

The objective of this work is to develop a design criterion expressed in terms of radius of curvature for the prevention of localized buckling or wrinkling of the thin walled pipe. Such instability occurs when excessive compressive strains develop as a result of the loads, settlement, heave and other effects. In view of the many design tasks to be performed in the development of pipe line configurations, the investigation of the buckling behavior will be performed at an early stage of the analysis. A preliminary analysis is included in this report and is discussed in detail seperately.

(3) Developing Preliminary Pipe-Soil Response Functions

Further analysis depends on information related to soil structure interaction. This information will be furnished by the geotechnical group from general site investigation. Since the detailed geotechnical studies are somewhat time consuming and it will be necessary to progress with the various structural designs in the absence of final results from geotechnical studies, it is necessary to assemble material on soil structure interaction and to specify an appropriate range of spring constant values to facilitate preliminary structural design. The information used at this stage should be considered as only preliminary in nature.

(4) Developing Design Loadings

The objective here is to develop design loads - static, dynamic, thermal and pipe pressures and associated allowable stresses. Further study of material and codes of practice applicable to this activity will be made, and the various loading conditions established. Most important at this point will be the comparison of these loading conditions with the design criteria related to stress and strains.

(5) Parametric Study of Subsidence and Loss of Support

This activity will assess the structural integrity of the pipeline under various combinations of settlement amplitudes and longitudinal profiles. The scope of work involves both straight line and bends and will identify the maximum amplitude of settlement for a matrix of profiles (step, sinusoidal, rectangular and triangular) and spanning lengths. The minimum radius of curvature and maximum strains defined earlier will be used as a criterion in this analysis to define the limiting differential settlement. A preliminary analysis is included in this report.

(6) Parametric Study of Frost Heave

This activity will assess the structural integrity of the pipeline under various lengths of frost heave. The minimum radius of curvature and maximum strains defined earlier will be used as a criteria to define the limiting frost heave. A preliminary analysis is included in this report.

(7) Parametric Study of Below Ground Geometrical Configurations

This work consists of stress analysis studies using the range of soil properties and loading conditions described in previous activities. The objective is to design the various below ground configurations (linear, sagbends, overbends, sidebends, and multibends), and to establish their limits of applicability in terms of soil properties.

Information on soil properties will be furnished by the geotechnical group and the pipe-soil interaction obtained from the parametric studies. The objective is to identify the critical configurations which will be subjected to detailed investigations. Four or five general types of soil representing the pipeline route will be considered; five to six bend angles in each of the bend modes are considered sufficient to identify the critical cases. Preliminary studies have been performed and the results are included in this report.

(8) <u>Establish Design Guidelines in Regard to Geotechnical</u>

The object will be to define structural and geotechnical guidelines with respect to which the below-ground concepts will be established and refinement of the route will be made. Technical and economic factors will be considered to encompass the whole range of terrain conditions and topographies. The most significant parameters to be considered will be thaw stability of the soil, presence of permafrost or rock, settlement amplitudes, slope stability, ice content and frost heave.

This work will examine the implications of the allowable geometric configurations, settlement and frost heave in terms of the remedial action or maintenance requirements and their associated costs. The work will include assessing borrow material facilities and transportation and cost estimating.

(9) <u>Below-Ground Bend Anchors</u>

The object is to optimize the pipeline alignment to minimize the number of anchors. Anchors have a significant effect on the pipeline cost and can be used as an objective function in preparing alignment alternatives. Over the right-of-way corridor and the structural limits of the buried line, the construction costs can be estimated for various alignments: for a given operating condition and soil condition, the allowable bend angels not requiring mechanical anchors will be determined. For bend angles greater than these, mechanical anchors will have to be provided. When anchors are provided, the adjacency criteria will have to be established to determine which configurations can be adjacent to each other without imposing unacceptable loads on the anchors.

During the design stage, in addition to stress analysis, considerations will be given to availability of materials, ease of construction, attachment to pipe and other pertinent items that arise. Detailed working drawings and material specifications will be prepared.

(10) Pipeline Monitoring Requirements

The structural design of the pipeline will identify potential problem areas. A monitoring program will be established to routinely monitor deflection, subsidence, heave, changes of curvature anchor movements or other variables in such areas to detect potential problems and take remedial action.

(11) Traps and Valves

This will involve the analysis and design of valve and piping supports, S-bend offset details, anchor blocks, catwalks, site grading and drainage, access roads, fences, etc., at trap and valve sites. Transitions from below ground to above ground will be evaluated to ensure against movement of valves and traps.

(12) River Crossings

All river crossings encountered along the route will be investigated and classified on the basis of the construction and design problems associated with each one. Standardized designs will be established for each classification group. Construction techniques will be established to ensure the design criteria are not exceeded.

(13) Road, Railway, Pipeline and Other Crossings

The implications of these crossings on pipe structural integrity will be analyzed using PIPLIN and other analytical methods. Loading conditions during construction and operation will be considered.

(14) Station Piping

The structural behavior of station piping will be analyzed using a general purpose computer program such as MARC or ANSYS. Design criteria will be established and a structural design evolved such that these criteria are not exceeded under the range of possible loading conditions.

6.2 DESIGN CRITERIA

The design loadings will impose stresses and strains in the pipeline. For safe and efficient operation of the pipeline, the different loading conditions must be identified and the resulting stresses and strains comply with the applicable standards, codes and regulations.

This section describes the design criteria and its basis.

A high pressure gas transmission pipeline is essentially a straight or a curved cylindrical shell. Stresses and strains can therefore be approximately classified as Membrane and Bending.

The establishment of criteria depends on the nature of the stress, whether Primary or Secondary. A primary stress is imposed by a load or force which is not relieved by straining and is developed to satisfy only equilibrium. A secondary stress is due to the pipe line's constraint and is required to satisfy the conditions of compatibility. It is partly or fully relieved by plastic straining.

Another important factor in the establishment of criteria is the nature of the loading conditions as Design Maximum Operating and Design Maximum Contingency. This classification is necessary so the criteria can be related to the levels of risk involved.

The Design Maximum Operating condition includes sustained loads such as internal pressure, temperature, live loads, dead loads, and environmental loads as operating earthquake, differential settlement, overburden and movements at bends.

The Design Maximum Contingency condition includes sustained loadings for normal operating condition combined with occasional loadings for extreme ambient influences which may require shutdown of the system. Design Maximum Contingency conditions will occur rarely during the lifetime of the system. When loadings reach the design maximum contingency levels, the pipeline will be inspected and may be shut down for maintenance, but the structural integrity of the line is not compromised. The loadings include all sustained loadings plus contingency earthquake, fault displacements, loss of supports, vacuum, seismic liquefaction and contingency differential settlement or frost heave and overburden.

The criteria established in this section are preliminary and may be modified on the basis of further data and investigation of the assumptions.

6.2.1 Membrane Stresses

(1) Hoop Stress due to Pressure: (S_H)

The hoop stress S_H is found from the following relationship $S_H = PD/2t$.

The hoop stress is limited by the codes and regulations as shown in Table 6.1.

Table 6.1 - Allowable Hoop Stress

Class Location	Allowable Hoop Stress
1	0.72 x SMYS
2	0.60 x SMYS
3	0.50 x SMYS
4	0.40 x SMYS

(2) Maximum Longitudinal Tensile Stress due to pressure, negative temperature differential and design maximum earthquake (S_L').

$$S_L' = \gamma S_H - E\alpha\Delta T - E\alpha\Delta T_e$$

where ΔT_e is the equivalent temperature differential for earthquake. Negative values for ΔT and ΔT_e are to be substituted in the above expression.

Assuming the pipe to deform with the ground without any interface slipping, ΔT_e can be obtained from the following relationship:

$T_e = \pm \frac{(\ V)}{(\ 2C)} \frac{1}{\alpha}$ where V is the ground velocity and c is the seismic shear velocity.

The effect of bending due to seismic effects is neglected as this part of the strain is very small.

As S_L' is a membrane type of stress, it is limited to the values in Table 6.1.

(3) Combined Membrane Stress in Straight Pipe Due to Pressure, Temperature Differential and Earthquake

(3.1) Stress Intensity Due to Pressure and Positive Temperature Differential

The pipe element is in a state of biaxial stress-hoop and longitudinal. A combination of these stresses, known as "stress intensity" or "effective stresses" cause yielding. During normal operating conditions of pressure and temperature, to prevent excessive ductile yielding leading to all-around wrinkling, a limitation is placed on this effective stress, which is given by the follwoing expressions.

$$S_{eff} \text{ (Tresca)} = S_1 - S_3$$

$$S_{eff} \text{ (Von Mises)} = (S_1^{\,2} - S_1 S_3 + S_3^{\,2})^{1/2}$$

Here S_1 and S_3 are the major and minor principal stresses. S_2, the intermediate principal stress normal to the thickness, is assumed as zero. Normally, S_1 and S_3 will be respectively S_H and S_L. A limitation of 0.9 SMYS is placed on the effective stress. In practice, both Tresca and Von Mises values are used. The Tresca criterion is more conservative, but the Von Mises criterion complies with the test results better. The same criterion is also specified in ANSI B31.4-1974 for petroleum piping. The criterion also defines a maximum allowable positive temperature differential.

(3.2) Stress Intensity due to Pressure, Temperature Differential and Earthquake

Siesmic loadings are probabilistic in nature. Because of this, two levels of earthquake are defined - the design probable and design maximum in the order of increasing severity. The design probable earthquake is usually associated with a return period of approximately 30 to 50 years representing the life of the pipeline and the design maximum is associated with a return period of 100 to 200 years and has a lower probability.

For the design probable earthquake condition, the effective stress due to pressure, temperature differential and design probable earthquake is limited to 1.0 SMYS and for the design maximum earthquake loading condition it is limited to 1.10 SMYS. It is to be noted that the calculations are based on an elastic basis and that where the effective stress reaches SMYS, yielding is initiated and yielding has been permitted because of the contingency nature of earthquake.

6.2.2 Combined Membrane Strain

(1) Maximum Longitudinal Compressive Strain due to Pressure, Positive Temperature Differential and Design Maximum Earthquake

The previous stress criterion does not indicate the allowable magnitude of strain beyond the proportional limit. A compressive strain criteria is necessary to prevent local buckling. This requires an inelastic analysis to be carried out and the total longitudinal compressive strain corresponding to the above maximum loading condition is tentatively assumed as 0.4 percent.

It is to be noted that normal pipeline design practice or codes do not require inelastic analysis or correlation between computed elastic stress and actual strain.

(2) Combined Bending and Membrane Strains

Differential settlements and frost heave impose bending strains in addition to the strains caused by other design loads. Ductile yielding becomes inevitable and an inelastic analysis is required.

For preliminary analysis the maximum longitudinal compressive strain (ε_c) for the maximum contingency condition is taken as 0.6 percent and maximum longitudinal tensile strain (ε_t) is taken as 0.5 percent. Similar figures were obtained in the Berkeley Alyeska Tests. The actual limits, however, depend on p, ΔT and D/T ratio and will be established later. The compressive strain criteria is to prevent bellows wrinkling and the tensile strain criteria is to prevent excessive tensile stress being developed. The tensile criterion is also related to metallurgical requirements. These strains represent a contingency situation including design maximum earthquake.

For the maximum operating condition, 75 percent of the maximum values are used. The maximum operating condition considers a design probable earthquake.

The above strain can be related to an allowable change in curvature which can be used to estimate allowable differential settlement or frost heave in a particular region during the design of the pipeline and can also be used if strains exceed the allowable levels in areas where the pipeline is monitored during operation. In this case, the net allowable strains after allowing for earthquake will serve as the monitoring criteria.

6.2.3 Bending of Pipeline Due to Buoyant Uplift or Loss of Support

Criteria are necessary to prevent overall structural instability under the action of axial load when the line is subject to buoyant forces. These criteria determine the safe span length between the anchor points.

The total axial load F_A is limited to 0.8 F_{cr} where F_{cr} is the Euler buckling load given by $4\pi^2 EI/L^2$ and F_A is the total equilibrated force given by:

$$F_A = \gamma S_H A - E\alpha\Delta TA - PA_e$$

Note that the term PA_e does not develop a stress in a straight section of the buried line, but adds to the bending moment if the pipe is bent by some loading condition.

The effective stress calculated from the temperature, pressure and buoyant loading is limited to SMYS. The effective stress is not permitted to exceed SMYS, as buoyant uplift is a primary load which will not be alleviated by vertical deflections of the pipe. The same criteria are used to estimate safe span length for loss of support.

6.2.4 Free Bending of Pipe During Construction

Compressive strains imposed during construction are limited to prevent wrinkling. These strains may result from stringing and laying operation of cross-country lines, laying and pulling operations at river crossings or from natural radius of curvature of the trench. After the initially straight pipe is laid for preliminary design, the strain for wrinkling is assumed as 0.38 percent, a value corresponding to one of the Berkeley Alyeska Tests. The actual limit however, will be established later. The allowable value is assumed as 75 percent of this wrinkling strain. This strain may be related to the change in curvature of the pipe and if this change is maintained during operation, the allowable curvature change due to settlement and other causes must be corrected by this initial curvature.

It is to be noted that free bending during construction does not include field bending of pipe in a bending machine.

6.2.5 Ovalling of Pipe Due to Weight of Backfill

Weight of backfill impose circumferential bending stresses in an unpressurized pipe resulting in ovalization of the pipe leading to collapse. The bending stresses are therefore limited to 0.8 SMYS. From this limitation, the maximum depth of burial can be determined. Limitations are placed on deflection also so that the passage of pigging devices is not hindered.

6.2.6 Seismic Design Criteria

As the Alaska region is mostly seismic prone, seismic considerations is an important factor. The design philosophy has been reasonably well established by N. M. Newmark.

In accordance with the principles developed for the design of nuclear power plants, the criteria encompasses two levels of earthquake hazard. The design probable (DPE) associated with a return period of 50 years and the design maximum (DME) associated with a return period of 100 to 200 years. The relationship between the intensities of these two earthquakes is arbitrarily taken as two. The DME governs the design in general and represents a contingency situation. The pipeline designed for DPE will generally be able to continue operation.

The buried pipeline responds to earthquake motions in general by moving with the ground in such a way as to have nearly the same curvature and strains as the ground. The response spectrum concept usually used for structures does not apply to the buried pipe.

In general, earthquake motion on buried pipeline produces essentially secondary effects, as the strains are independent of the pipe geometry and thickness. Even though there may be a slight slip between the pipe and the medium, the reduction on the strain from this slip is not considered in design.

Longitudinal strains arise from either compressive waves transmitted in the ground or shear waves, transmitted normal to the pipe axis. Since they do not act together only one of the two sources is considered. The ratio of the ground velocity is twice the velocity of the waves. The shear velocity assumes a value of 2500 ft/sec. for moderately competent materials and 2000 ft/sec. for lesser competent materials.

Newmark suggests that a reasonable criterion for permissible strains to avoid rupture is of the order of 1 to 2 percent, considering all effects.

The usual procedure for design is to treat the seismic strain as an equivalent thermal strain and include this in the temperature differential effects.

DESIGN CRITERIA - BELOW-GROUND PIPELINES

1.0 Membrane Stresses

1.1	Hoop Stress due to pressure	0.72 SMYS*
1.2	Longitudinal Tensile Stress Maximum longitudinal tensile stress due to pressure, negative temperature differential, and tensile stress due to design maximum earthquake	0.72 SMYS*
1.3	Combined Membrane Stress in Straight Pipe Due to Pressure, Temperature Differential, and Earthquake	
1.3.1	Stress intensity due to pressure and positive temperature differential	0.90 SMYS*
1.3.2	Stress intensity calculated on elastic basis due to pressure, positive temperature differential, and compressive stress due to design probable earthquake	1.00 SMYS
1.3.3	Stress intensity calculated on elastic basis due to plastic, positive temperature differential, and compressive stress due to design maximum earthquake	1.10 SMYS

2.0 Membrane Strains

Maximum longitudinal compressive strain computed using an inelastic analysis due to pressure, positive temperature differential, and compressive strain due to design maximum earthquake 0.40 percent.

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* Criteria as per Code ANSI - B31.8 in Class 1 locations

3.0 Combined Bending and Membrane Strains

3.1 Design Maximum Contingency Conditions

Combined longitudinal strains due to maximum settlement or frost heave, soil creep, or movement at field bends, design maximum earthquakes and membrane strains due to pressure, temperature differential and design maximum earthquake, computed in an inelastic analysis.

Maximum longitudinal tensile strain	ε_t
Maximum longitudinal compressive strain	ε_c

For a given temperature differential and pressure, these strains may be expressed in terms of a critical change in curvature.

(For preliminary design, the maximum tensile strain is taken as 0.5 percent, and the maximum compressive strain is taken as 0.6.)

3.2 Design Maximum Operating Conditions

Combined longitudinal strains and membrane strains due to allowable settlement, frost heave, soil creep, or movement at field bends due to pressure, temperature differential and design probable earthquake, computed in an inelastic analysys.

Maximum longitudinal tensil strain	$0.75\varepsilon_t$
Maximum longitudinal compressive strain	$0.75\varepsilon_c$

Note: The lesser of the minimum curvature change or maximum strain obtained from either of the above conditions governs the design.

4.0 Pipeline Buoyancy and Loss of Support

Safe span length between anchors in areas where pipe is subject to buoyant uplift or loss of support shall be governed by:

Stress intensity due to pressure, temperature differential, and maximum bending stress	1.00 SMYS

5.0 Pipeline Stability

Safe span length between anchors in areas where pipe is subject to buoyant uplift is the smaller span determined from the following conditions:

5.1 Axial compressive load due to pressure and positive temperature differential $\leq 0.8\ F_{cr}$

where, F_{cr} = critical (Euler) load for instability

5.2 Stress intensity due to gas pressure, temperature differential, and maximum compressive bending stress ≤ 1.00 SMYS

6.0 Free Bending During Construction

(This does not include field bending of pipe in a bending machine.)

6.1 Maximum longitudinal compressive bending strain for wrinkling ε_c'

6.2 Allowable longitudinal compressive bending strain during construction $0.75\varepsilon_c'$

This strain may be related directly to a change in curvature in the pipe. If a change in curvature imposed during construction is maintained during operation of the pipe, then the allowable operating curvature changes due to settlement, etc., must be corrected.

7.0 Ovalling During Construction

7.1 Maximum circumferential stress due to weight of overburden under zero internal pressure to protect against collapse of the pipe (including initial out-of-roundness effects and possible vacuum conditions)

7.2 Out-of-roundness due to overburden at deep burial depth should be limited in design so as not to interfere with the passage of pigging devices.

6.3 ANALYSIS AND DESIGN METHODS

6.3.1 Basic Approach

The methods of structural analysis involves first, investigation of the basic behavior of the pipe under typical loadings and establishment of the mathematical relationships defining the resulting behavior. This approach allows prediction of the loads, stresses and deformation with a reasonable degree of accuracy and helps to simplify the overall design process. The basic analytical methods have been briefly outlined in this section.

(a) Hoop Stress

$S_H = P\ D_o/2t$ (Barlow's formula)

(b) Axial force due to thermal effects in a fully restrained pipe

$F = EA\propto\Delta T$

(c) Longitudinal stress for a fully restrained pipe

$S_L = -E\propto\Delta T + \gamma S_H$

(d) Compressive force required to buckle a pipe with lateral support from soil (Column buckling)

$F = 2\sqrt{EI\beta}$ (H. L. Langhaar)

(e) Critical pressure P_{cr} at which pipe becomes unstable from loading due to soil backfill

$P_{cr} = \frac{2E}{1-\mu^2}(t/D)^3$ (P.189 Strength of Materials by Timoshenko)

(f) External Load Due to Soil Backfill

$W_{soil} = C_d\ \sigma BD$ where

$C_d = \frac{1 - e^{-2k\mu H/B}}{2K\mu}$

where e = base of natural logarithm

K = ratio of active lateral pressure to vertical unit pressure

μ = tan Ø = coefficient of internal friction of fill material

H = depth of cover

B = width of trench

$K\mu$ for representative soils are as shown below:

$K\mu$	Soil	
0.192	granular without cohesion	
0.165	sand and gravel	(maximum)
0.150	saturated top soil	(maximum)
0.130	clay	(maximum)
0.110	saturated clay	(maximum)

(g) Deflection of Pipe Due to Soil Backfill

$$\Delta = \frac{TkW_{soil}}{0.67E(t/D)^3 + 0.061\ Z}$$

where Δ = pipe deflection (in)

T = time lag factor

K = bedding factor

W_s = soil load (lb/in)

E = modulus of elasticity

Z = soil resistance factor

Values of the parameters:

Compaction	T	Z	Bedding Angle	K
Semidense	1.50	700	30°	0.102
Dense	1.25	1080	45°	0.096

(h) Bending Stress in the Pipe Due to Vacuum and Out-of-Roundness

$$S_B = \frac{3\ D\ Wo}{t^2\ (1-P/P_{cr})}$$

P = pressure on pipe - vacuum or external

Wo = maximum initial radial deviation (in)

(i) Stress from Overburden

$$So = \frac{4.32\ Et\Delta}{D^2}$$

where Δ = 2Wo (deflection in ins)

(j) Stress Due to Overburden + Vacuum

$$S_T = \frac{(1.5\ PD}{t^2\ (1-P/P_{cr})} + \frac{4.32\ Et\ )}{D^2}\ D$$

Expressions (f) to (j) are from Soil Engineering by M. G. Sprangler - overburden calculation for highway crossings should also be checked with API Standard 1102.

(k) Length of line corresponding to sinusoidal settlement profile

$$L = \Pi \sqrt{\sigma 2R}$$

σ = settlement

R = radius of curvature

(l) Force required to completely restrain free end of pipe

$$F_{anch} = -p\ \frac{(\Pi Di^2)}{4} - (E\alpha\Delta T + \gamma S_H)\ A$$

(m) Soil Friction

$$S_F = C_f\ (W_{pipe} + W_{gas} + W_{backfill})/ft$$

C_f = coefficient of friction between pipe and soil

(n) Distance from free end to point of fixity

$$L = F_{anch}/S_f$$

(o) Minimum burial length

$$\bar{L} = 2L$$

(p) Movement of free end of pipe

$$\Delta L = \left(\frac{L}{2}\right)\left[\frac{(F_{anch})}{(E\ A)}\right]$$

(q) Approximate Analysis of Bends

Assumptions - ends of bend are completely restrained

- deflected pipe is symmetrical

- soil forces are not significant as lateral deflection are small

$$Mo = PR\ (1 - \sin \phi\ /\ \phi)$$

$$\sigma A = \frac{R^2 \sin^3 \phi}{EI}\left[\frac{PR \sin^2 \phi}{3} - \frac{Mo}{2}\right]$$

$$P = EA \propto \Delta T - \frac{EA\ \sigma_A}{R \sin \phi}$$

where Mo and P are the intermediate moment and force at the center and ϕ is one-half the subtended angle.

Solution of the above equation, give Mo, σA and P; where σA is movement parallel to P. Other available methods involve theory of curved beams. More accurate analysis should consider soil structure interaction. This can be solved only by using computer models, described in the next section.

(r) Radius of Curvature

$R = EI/M$ for elastic analysis

$R = \dfrac{y_c}{\varepsilon_c} = \dfrac{y_t}{\varepsilon_t}$ from strains at top and bottom

Where ε_c and ε_t are extreme fibre strains in compression in tension and y_c and y_t are distances from the neutral axis.

(s) Overall Stability of Pipe Under Primary Lateral Loads as in Buoyancy

Ref: P.6, 16: Theory of Elastic Stability by Timoshenko:
For an axially loaded beam column subject to uniform lateral load, with ends fixed (no rotation at the ends), the following expressions are botained for the anchor and mid-span moments

$$M_{anch} = \frac{-qL^2}{12} \quad \frac{3(\tan u - u)}{u^2 \tan u}$$

$$M_{centric} = \frac{+qL^2}{24} \quad \frac{6(u - \sin u)}{u^2 \sin u}$$

$$\text{where} \quad u = \frac{L}{2} \sqrt{\frac{F_A}{EI}}$$

Where F_A is the axial load, L the span of the beam column and q is the net buoyant uplift

$$F_A = \gamma S_H A - E\alpha \Delta TA - PAe$$

PAe does not develop a stress in a straight section of the pipeline, but adds to the axial bending moment if the pipe is bent by some loading condition.

The deflected shape is obtained by superimposing the deflection produced by the lateral load and that produced by the end moments.

The deflection at center due to end moments M_{anch} is given by

$$\sigma = \frac{M_{anch}}{8EI} \quad L^2 \quad \frac{2(1 - \cos u)}{u^2 - \cos u}$$

When u becomes $\pi/2$, σ becomes very large and instability sets in

$$F_{cr} = 4\pi^2 \, EI/L^2$$

6.3.2 Computer Models

Design of the below-ground pipeline involves consideration of the interaction between pipe and surrounding soil. As the soil structure interaction is a very complex problem involving large deformation, creep, frost heave, etc., the procedures call for computer models using sophisticated forms of element idealization.

The following computer programs are worthy of mention:

(a) POWELL - 2D (PIPLIN)

(b) POWELL - 3D (PIPANL)

(c) DRAIN PIPE

(d) SOLID SAP

(e) MARC CDC

The capabilities of these programs and their application to the below ground line are discussed in this section.

(a) PIPLIN

This program was developed by Dr. G. H. Powell at the University of California to analyze the bending response of a buried pipeline including inelastic behavior. The program was originally developed for the Alyeska Pipeline Company. Modifications and additions were subsequently made.

The program undertakes a plan beam column analysis and considers nonlinear effects due to yielding of the pipe steel, settlements, creep and forest heave, large displacements, lifting of the pipe from soil and movements at field bends. Modern finite element procedures are used in the program. Validity of this program has been verified by comparing the results of analysis with the results of full scale pipe tests carried out at the University of California. This program therefore has a high level of confidence with the pipeline industry.

The special features of this program are mentioned here. The nonlinear material behavior is assumed to be made up of a number of simple elastic plastic components acting in parallel. The program determines these components.

During the successive yielding of the component materials, Possion's ratio automatically changes and reaches a value of 0.5 for fully plastic conditions.

Yielding is governed by Von Mises criterion and the flow rule is determined according to Druckers' normality criterion. A special feature is that non-isotopic properties resulting from prestraining operations beyond the yield strain in one direction, and unloading can be handled.

The finite element analysis is carried out using the direct stiffness method in a step by step fashion in a series of linear steps, values at the end of one step being used for the next step. When yielding occurs as part of a cross-section, the number is further subdivided into a number of elements (typically 30) and the state of stress and strain is determined at the center of each element. The program automatically subdivides the load sequence into steps, with the size of the load steps determined by the program based on the yielding of an element and limited by a permissible overshoot of the nominal yield value.

An equilibrium correction is applied at the end of each step.

The stiffnesses to be calculated for the members are their tangent stiffnesses. In addition to the six degrees of freedom (three at each end) an extra degree of freedom on the axial direction is considered. This is to permit linear variation of longitudinal strain along the member. Large displacement effects are accounted for by adding the geometric stiffness matrix. The departure of the final results from the "exact" solution is minimized because of the inclusion of geometric stiffness and the equilibrium correction at the end of each step.

The program handles the effects of soil creep and frost heave on the pipeline. Values of the parameters Kp, Cp and Cs - spring and dashpot coefficients in an idealized soil creep model are to be input in the program. These parameters depend on both temperature and pressure. In the case of frost heave analysis, input related to frost bulb dimensions, bulb base pressures, overburden load factors for proportion of pipe displacement contributing to frost bulb size, frost bulb dimensions history and ice segregation heave rates are necessary.

The program is limited to piping in one plane and only static loadings are considered. No flattening or wrinkling is considered. Load sequence is arbitrary and may include unloading and load reversal.

(b) PIPANL (Powell - 3D)

This program was also developed by Dr. G. H Powell at the University of California to analyze three-dimensional piping problems. The limitation is that it uses an elastic method of analysis. Support behavior can, however, be nonlinear. Such nonlinear supports can represent restraint by surrounding soil. Again, as in Piplin, only static loadings are considered;

(c) DRAIN PIPE

For dynamic analysis as in the case of seismic loading, a special program has been developed by Dr. Powell. The program handles two-dimensional elastic piping with nonlinear supports. The limitation to plane structures prevents analysis of the pipeline under the simultaneous action of all three components of ground acceleration. The restriction to two-dimensional shaking is, however, believed to be acceptable. As the program handles only dynamic loads, a separate static elastic analysis is also required. The stresses are added directly. This implies that both material and geometric nonlinearities are not handled.

(d) SOLID SAP AND MARC CDC

There are several general purpose linear elastic structural analysis finite element programs. The most promising are SOLID SAP, NASTRAN, STARDYNE and ANSYS. Of these, SOLID SAP has been used on pipeline industry before.

MARC-CDC is also a general purpose program, but it can handle both linear as well as nonlinear problems and is widely used for nonlinear analysis. It can handle static, dynamic, plasticity, creep, large displacement and buckling problems.

Both SOLID SAP and MARC CDC can be used to analyze stresses and change in pipe diameter under overburden loads.

6.4 PRELIMINARY STUDIES

6.4.1 Introduction

Preliminary studies have been conducted to investigate pipe stress and strain under anticipated design loading conditions, and the resulting pipe-soil interaction for several of the significant design considerations; and to demonstrate the analytical techniques which are being used by the design group for structural design of the pipeline.

All pipe-soil interaction studies with exception of frost heave, were performed using the pipe-soil response functions for unfrozen silt, a material with less than average engineering properties, but representative of much of the soil to be encountered along the ALCAN route through Alaska. The frost heave analysis was performed using the frost heave properties of saturated silt.

The following general approach was adopted in the preliminary studies:

(1) Establish preliminary loading conditions and other basic data.

(2) Establish the hoop, longitudinal and effective stresses in straight buried pipeline and compare with allowable stresses.

(3) Establish the minimum allowable radius of curvature due to free bending.

(4) Perform parametric studies of major design considerations and determine critical conditions if they exist.

6.4.2 Loading Conditions and Basic Data

(1) Pipe Specifications

Nominal Outside Diameter	42 inches
Nominal Wall Thickness	0.6 inches
Specified Minimum Yield Strength	65,000 psi @ Strain .005
Grade - API 5LX, SR5 and SR6	
Maximum Allowable Operating Pressure	1337 psig
Maximum Design Operating Pressure	1250 psig
Minimum Design Temperature	$-10^{o}F$

(2) Dead Loads

(2.1) Weight of Steel

$$A = \frac{\pi}{144} (D_o^2 - (D-2t)^2)$$

$$= 78.037 \text{ in}^2$$

$$W_s = \frac{\sigma s \times A \times 12}{12^3}$$

$$= 266 \text{ \#/lin. foot}$$

(2.2) Weight of Soil

$$W_{soil} = C \times \sigma soil \times B^2$$

For 3' unfrozen silt cover in a 4.5' wide ditch

$$W_{soil} = 1260 \text{ \#/lin. foot}$$

(3) Live Loads

(3.1) Weight of Gas

GAS DENSITIES		
	STATION DISCHARGE	STATION SUCTION
Pressure (psig)	1250	995
Temperature (^oF)	25	15
Density ($\#/ft^3$)	6.12	4.99

(3.2) Maximum Weight of Gas

$$= \frac{\sigma gas \times \pi \times (D_o - 2t)^2 \times 12}{4 \times 12^3}$$

$$= 55.5 \ \#/\text{lin. foot}$$

(3.3) Weight of Test Medium

$$W_W = \frac{\pi \times \sigma_W \times (D_o - 2t)^2 \times 12}{4 \times 12^3}$$

$$= 566 \ \#/\text{lin. foot}$$

(4) Internal Pressure

Maximum Design Operating Pressure - 1250 psig

(5) Earthquake

Longitudinal strain due to seismic shear waves

$$= \pm \frac{V}{2C}$$

The values of V and C for several seismic zone Richter magnitudes and soil conditions are as shown in the following data:

Seismic Zone Richter Magnitude	Design Velocity in./sec.	Ground Motion, ft./sec.
8.5-8.0	29	2.42
7.5	22	1.83
7.0	14	1.17
5.5	6	0.50

C = wave propogation velocity, taken as follows for generalized soil conditions:

Soil Condition Generalized	Value of C, ft./sec.
Rock or Permafros	4000
Gravel	3500
Sand	3000
Silt and Clay	2500

(5.1) Maximum Operating Earthquake

For an 8.5 Richter Magnitude in silt

$$\varepsilon_e = \pm \frac{V}{4C}$$

$$\varepsilon_e = \pm 2.42 \times 10^{-4}$$

Equivalent temperature differential

$$\Delta T_e = \frac{\varepsilon}{\alpha}$$

$$= \pm 37^{\circ}F$$

(5.2) Maximum Contingency

$$\varepsilon_e = \pm \frac{V}{2C}$$

For an 8.5 Richter Magnitude in silt

$$\varepsilon_e = \pm 4.84 \times 10^{-4}$$

Equivalent temperature differential

$$\Delta T_e = \frac{\varepsilon}{\alpha}$$
$$= \pm 74^{\circ}F$$

(6) Temperature Data*

(6.1) Operating Temperatures

Minimum Operating Temperature (@ 2.4 BCFD in Summer @ Station Inlet) $+10^{\circ}F$

(6.2) Tie-In Temperatures

Minimum @ Mile Post 0 (North Slope) in April $0^{\circ}F$

Maximum @ Mile Post 500+ (Fairbanks) in July $50^{\circ}F$

(6.3) Temperature Differentials
Operating

Maximum Negative Temperature Differential $= 10-50 = -40^{\circ}F$

Maximum Positive Temperature Differential $= 10- 0 = +10^{\circ}F$

* All Temperatures are given in $^{\circ}F$

Non-Operating

	SUMMER			WINTER		
	T GROUND	T		T GROUND	T	
MILE POST	@ 2' DEPTH	MIN.	MAX.	@ 2' DEPTH	MIN.	MAX.
0-100	31	31	-19	1	1	-49
140-160	37	37	-13	8.5	8.5	-41.5
200-230	41	41	- 9	19	19	-31.0
230-345	45	45	- 5	25	25	-25
345-415	48	48	- 2	29	29	-21
415-455	50	50	0	30.5	30.5	-19.5
600-640	40	40	-10	29.5	29.5	-20.5
640-730	42	42	- 8	29	29	-21

(6.4) Maximum Normal Operating Design Temperature Differentials

Maximum Temperature Differentials

	Positive	Negative
Operating	+10	-40
Non-Operating	+50	-49
Design	+60	-60

(6.5) Maximum Design Temperature Differentials Including Earthquake Equivalent

Maximum Temperature Differentials

	Positive	Negative
Maximum Operating	+ 97	- 97
Maximum Contingency	+134	-134

6.4.3 Stress in Straight Buried Pipeline

The actual and allowable hoop stress in straight buried pipeline is shown in Table 6.2 for each design loading condition. The actual hoop stress does not exceed 92% of the allowable stress established as the design criteria.

The actual and allowable longitudinal stress in straight buried pipeline is shown in Table 6.3 for each design loading condition. The actual longitudinal stress does not exceed 82% of the allowable stress established by the design criteria.

The actual and allowable effective stress in straight buried pipeline as determined using the Von Mise yield criteria is shown in Table 6.4 for each design loading condition. the actual effective stress doen not exceed 72% of the allowable stress established by the design criteria.

TABLE 6.2

HOOP STRESS IN BURIED STRAIGHT OVERLAND PIPELINE

DESIGN LOADING CONDITION	INTERNAL PRESSURE psig	TEMPERATURE DIFFERENTIAL ^{o}F	HOOP STRESS ACTUAL ksi	HOOP STRESS ALLOWABLE ksi
Normal Operating	1250	+ 60	43.1	46.8
	1250	- 60	43.1	46.8
Maximum Operating	1250	+ 97	43.1	46.8
	1250	- 97	43.1	46.8
Maximum Contingency	1250	+134	43.1	46.8
	1250	-134	43.1	46.8

TABLE 6.3

LONGITUDINAL STRESS IN BURIED STRAIGHT OVERLAND PIPELINE

DESIGN LOADING CONDITION	INTERNAL PRESSURE psig	TEMPERATURE DIFFERENTIAL TEMP. CHG. °F	TEMPERATURE DIFFERENTIAL EARTH-QUAKE EQUIV. °F	LONGITUDINAL STRESS ACTUAL PRESSURE ksi	LONGITUDINAL STRESS ACTUAL TEMPERATURE CHANGE ksi	LONGITUDINAL STRESS ACTUAL EARTHQUAKE ksi	LONGITUDINAL STRESS ACTUAL TOTAL ksi	LONGITUDINAL STRESS ALLOWABLE TOTAL ksi
Normal Operating	1250	+60	0	12.9	-11.3	0	+ 1.6	-
	1250	-60	0	12.9	+11.3	0	+24.6	46.8
Maximum Operating	1250	+60	+37	12.9	-11.3	- 7.0	- 5.4	-
	1250	-60	-37	12.9	+11.3	+ 7.0	+31.2	46.8
Maximum Contingency	1250	+60	+74	12.9	-11.3	-14.0	-12.4	-
	1250	-60	-74	12.9	+11.3	_14.0	+38.2	46.8

TABLE 6.4

EFFECTIVE STRESS IN BURIED STRAIGHT OVERLAND PIPELINE

	INTERNAL PRESSURE psig	TEMPERATURE DIFFERENTIAL		EFFECTIVE STRESS*	
		TEMPERATURE CHANGE °F	EARTHQUAKE EQUIVALENT °F	ACTUAL ksi	ALLOWABLE ksi
Normal Operating	1250	+60	0	42.3	58.5
	1250	-60	0	37.5	58.5
Maximum Operating	1250	+60	+37	46.0	65.0
	1250	-60	-37	38.6	65.0
Maximum Contingency	1250	+60	+74	50.5	71.5
	1250	-60	-74	40.9	71.5

* According to the Von Mise yield criteria

6.4.4 Minimum Radius of Curvature due to Free Bending

The minimum radius of curvature to which the pipe can be bent without local wrinkling of the pipe wall occurring, is established by using the computer program PIPLIN to calculate stress and strain in the pipe wall during bending in the presence of axial loads to be encountered under various loading conditions. This considers only free bending, and is not the minimum radius of curvature for field bending in a bending machine.

Two possible bending conditions are considered:

(1) The bend ends are free to move in the translation and rotational sense as shown in Figure 6.1.

(2) The bend ends completely restrained from translational movement and only permitted rotational movement as shown in Figure 6.2.

The axial loads considered present during the bending are shown in Table 6.5; and correspond to the range of possible pressure, temperature differential and earthquake loadings.

The maximum tensile strain will occur on the outside of the bend when the bend ends are restrained translationally, and the pipe is subjected to a negative temperature differential. The maximum compressive strain will occur on the inside of the bend when the bend ends are free to move translationally and the pipe is subjected to a positive temperature differential.

TABLE 6.5

EQUIVALENT AXIAL LOADS ON PIPE CROSS - SECTIONS FOR STRAIGHT OVERLAND BURIED PIPELINE

DESIGN LOADING CONDITION	INTERNAL PRESSURE psig	TEMPERATURE DIFFERENTIAL °F	AXIAL LOAD k
Normal Operating	1250	+ 60	-1508
	1250	- 60	287
Maximum Operating	1250	+ 97	-2055
	1250	- 97	806
Maximum Contingency	1250	+134	-2600
	1250	-134	1351

Figure 6.3 shows the maximum compressive strain as a function of curvature for two positive temperature differentials corresponding to maximum operating and design contingency loading conditions.

Figure 6.4 shows the maximum tensile strain as a function of curvature for two negative temperature differentials corresponding to maximum operating and design contingency loading conditions.

Using the structural design criteria limits on maximum axial tensile and compressive strains, adjusted for residual strains due to pressure expansion, the maximum curvatures and equivalent minimum radii of curvature were established for the various loading conditions as shown in Table 6.6.

The minimum radius of curvature is used in conjunction with the other design criteria to establish allowable pipe configurations under various loading conditions. It is believed that the strain criteria provide a more realistic assessment of critical conditons. The axial loads assumed to establish the minimum radius of curvature can change substantially during pipe deformation.

TABLE 6.6

MINIMUM RADIUS OF CURVATURE

LOADING CONDITION	TEMPERATURE DIFFERENTIAL	INTERNAL PRESSURE	K	R
	^{o}F	PSIG	ft^{-1}	ft
Maximum Operating	+ 97	1250	.00171	585
	- 97	1250	.00181	552
Maximum Contingency	+134	1250	.00203	493
	-134	1250	.00239	418

6.4.5 Parametric Studies of Major Design Considerations

(1) Purpose

The purpose of this section is to demonstrate the techniques and procedures that will be used in the detailed design of the pipeline. Several representative design configurations have been selected and analyzed. These include sidebends, sagbends, overbends, differential settlement, and differential frost heave. Studies were carried out over an appropriate range of parameters to determine the combined membrane stresses resulting from temperature; differential internal pressure, pipe, gas and overburden weights; and earthquake loads. A summary of the analysis, results, and conclusions is included. Studies such as these can be carried out for the full range of parameters and configurations encountered, and final designs developed on the basis of design criteria established.

(2) Procedure

All design configurations considered have been modelled and analyzed with the use of the PIPLIN computer program for nonlinear two-dimensional analysis of the pipe-soil interactions and response associated with a buried pipeline. The program represents the pipe as a number of pipe elements connected at nodal points. Transverse and longitudinal soil restraints are idealized as springs acting on the pipe at each nodal point. Input of appropriate bilinear soil spring constants allows the consideration of a complete range of soil types. Localized supports, and distributed and localized loads may be introduced as required to realistically model each configuration. For each different support-load-configuration situation established, pipe strains and response are determined using a finite element analysis.

(3) General Parameters

All studies were carried out at a pressure of 1250 psig. An operating temperature change range from plus 60°F to minus 60°F has been considered. Allowance for earthquake loads has been made by adjusting these temperatures to plus and minus 97°F for maximum operating conditions (design probable earthquake), and to plus and minus 134°F for maximum contingency conditions (design maximum earthquake). These earthquake loads will vary for different geographical regions and soil types, and studies will be carried out for the full range of combinations occurring. The design maximum earthquake Richter Magnitude of 8.5 considered in these studies is the maximum encountered along the route. Similarity, while the pipe-soil response of unfrozen silt has been used for all studies done, a full range of soil parameters will be considered in the actual design. The dead weight load, where required in the studies carried out, is considered to be composed of the weight of pipe, gas, and overburden.

(4) Models

(4.1) FIELD BENDS

Sidebends, sagbends, and overbends configurations have all been modelled as shown in Figure 6.5. The bend shown in the figure is situated above the x-axis, and represents directly the model used for sidebends and overbends.

For sagbends, the bend is located below the x-axis. The x-y plane is considered to be in the horizontal plane for sidebends, and in the vertical plane for sagbends and overbends. Soil properties for the transverse supports were adjusted as required for each of the bend configurations. Care was taken to ensure that the pipe is completely restrained by the soil at each end. All field bends were assumed to be at a radius of 140 feet (40D), slightly greater than that permitted in the codes and regulations. Temperature change, pressure, and earthquake loads were considered for all bend cases, with the addition of dead weight loads for the sagbends and overbends.

(4.2) DIFFERENTIAL SETTLEMENT

Two particular differential settlement situations have been modelled; a gradual settlement following a sinusoidal curve as shown in Figure 6.6, and an abrupt step function settlement as shown in Figure 6.7. In both cases, the pipe is completely restrained by the soil at each end and with loads due to pressure, temperature change, earthquake, and dead weight applied to the pipe, the ground is allowed to settle away from below the pipe. Different settlement depths were considered for both cases, and the additional effect of varying the span length was investigated for the gradual settlement case.

(4.3) FROST HEAVE

The effects of frost heave on a section of the line over a period of time have been analyzed using the model shown in Figure 6.8. The pipe was completely restrained by the soil at each end, and the center segment was allowed to heave. The frost heave rate is controlled by frost bulb paramenters supplied by the geotechnical group. While only one set of parameters have been considered in this study, a full range of parameters can be investigated. The length or span of line subject to frost heave can be varied, and the effects analyzed. Loads due to pressure, temperature change, and dead weight were applied to the pipe in this model.

(5) <u>Results</u>

(5.1) SIDEBENDS

Studies were carried out for 6°, 9°, 12°, and 15° bends at temperatures of $-134^{\circ}F$, $-97^{\circ}F$, $+97^{\circ}F$ and $+134^{\circ}F$. The variations of axial strains, change in curvature, and pipe movement at bend apex with bend angle and temperature are shown in Figures 6.9 and 6.10. From results obtained, it would appear that all situations considered are within acceptable limits established.

(5.2) SAGBENDS

Studies were carried out for 6^{o}, 9^{o}, 12^{o}, and 15^{o} bends at temperatures of $-134^{o}F$, $-97^{o}F$, $+97^{o}F$ and $+134^{o}F$. The variations of axial strains, change in curvature, and pipe movement at bend apex with bend angle and temperature differential are shown in Figures 6.11 and 6.12. Results obtained indicate that all of the sagbend situations investigated are well within the limit established by the design criteria.

(5.3) OVERBENDS

Studies were carried out for 6^{o}, 9^{o}, 12^{o}, and 15^{o} bends at temperature of $-134^{o}F$, $-97^{o}F$ $+97^{o}F$ and $+134^{o}F$. The variations of axial strains, change in curvature, and pipe movement at bend apex with bend angle and temperature have been plotted and are shown in Figures 6.13 and 6.14. Particular attention is drawn to Figure 6.13 where it appears that for larger bend angles the pipe movement of the apex of the bend has exceeded acceptable limits.

(5.4) DIFFERENTIAL SETTLEMENT - STEP SETTLEMENT

Studies were carried out at temperatures of $-134^{o}F$, $-97^{o}F$, $+97^{o}F$, and $+134^{o}F$ with settlements of up to five feet allowed to take place in each case. The effects of settlement depth on pipe strain and change in pipe curvature are shown for all four temperatures in Figure 6.15. The longitudinal membrane strain criteria governs the maximum allowable settlement for the negative temperature differential cases, although the radius of curvature criteria is not exceeded, due to the additional tensile loading imposed by the settlement.

(5.5) DIFFERENTIAL SETTLEMENT - SINUSOIDAL SETTLEMENT

Pipe response was analyzed at temperatures of $+97^{o}F$ and $+134^{o}F$ for settlement span lengths of 100 feet, 150 feet, 200 feet, and 250 feet, allowing settlement of up to five feet to occur in each case. The maximum allowable settlement before buckling occurs, based upon the design criteria established, and the maximum deflection occurring for various ground settlement depths are both shown as a function of settlement span length in Figures 6.16 and 6.17

(5.6) FROST HEAVE

Studies were carried out to demonstrate the method used to evaluate the effect that frost heave would have on the pipe. Analysis was carried out over a time period of fifteen years and at a temperature of $60^{o}F$. Frost heave span lengths of 50 feet and 100 feet were considered. The resulting axial strains, change in curvature, and maximum pipe movement are shown for each span length as a function of time in Figures 6.18 and 6.20. The effects of frost heave will be given careful consideration in the final design stage.

(6) Conclusions

The ability to effectively model and analyze the pipe-soil interactions and responses has been demonstrated in the design consideration studies. The design criteria used in conjunction with this type of analysis provides the basis required for development of the detailed design for the range of physiographic and loading conditions which will be encountered along the route. These studies will be extended to include the range of temperature changes, earthquake loads, soil types including creep effects in frozen soils and pipe configurations prior to detailed mile-by-mile design of the pipeline.

6.5 LIST OF SYMBOLS:

S_H = hoop stress

S_L = axial stress

F = axial force

E = modulus of elasticity for steel

I = moment of inertia of crossection of pipe

= coefficient of thermal expansion for steel (assumed as 6.5×10^{-6} in/in/^{o}F)

= Poisson's ratio for steel

t = pipe wall thickness

Do = outer diameter of pipe

Di = inner diameter of pipe

A = cross-sectional area of pipe wall

A_e = cross-sectional area of pipe opening

R = radius of curvature

T = temperature change

P = pipe internal pressure

P_{cr} = force required to buckle a column

K = curvature

= density

W_s = weight of pipe

B = width of top of ditch

V = ground motion velocity

C = wave propogation velocity

T_e = equivalent temperature change due to earthquake

E = strain

Ee = strain due to earthquake loading

6.6 REFERENCES AND RELATED DOCUMENTS:

1. ANSI B.31.8 - 1968: Gas Transmission and Distribution Piping Systems

2. ANSI B.31.4 - 1971: Liquid Petroleum Transportation Piping Systems

3. Part 192 - Federal Safety Standards

4. ASTM-A370 - Standard Methods and Definitions for Mechanical Testing of Steel Products

5. ASME Boiler and Pressure Vessel Code Published by American Socity of Mechanical Engineers, N.Y. 1971

6. API - Standard 1102

7. API - Standard 5LX

8. AISC - Manual of Steel Construction

9. BOUKAMP, J. G., and STEPHEN, R. M.: Large Diameter Pipe Under Combined Loadings, ASCE - Journal, Volume 99

10. BEEDLE, L. S.: Plastic Design of Steel Frames, John Wiley and Sons

11. SEALY, F. B., and SMITH, J. O.: Advanced Mechanics of Materials, John Wiley and Sons, 1952

12. TIMOSHENKO, S. P., and GERE, J. M.: Theory of Elastic Stability - 1961, McGraw Hill Company

13. TIMOSHENKO, S. P., and WOINOWSKY-KRIEGER: Theory of Plates and Shells - 1959, McGraw Hill Company

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16. ZIENKIEWICZ: Finite Element Method in Engineering Science, McGraw Hill Company - 1971

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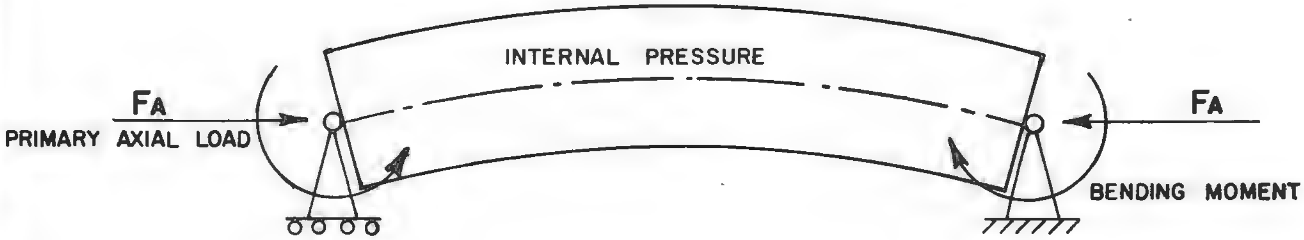
18. NEWMARK, N. M., and ROSENBLUETH, E.: Fundamentals of Earthquake Engineering, Prentice Hall - 1971

19. SPANGLER, M. G., and HARDY, R. L.: Soil Engineering, Intext Educational Publishers, New York - 1973

20. Part 192 - Federal Safety Standards

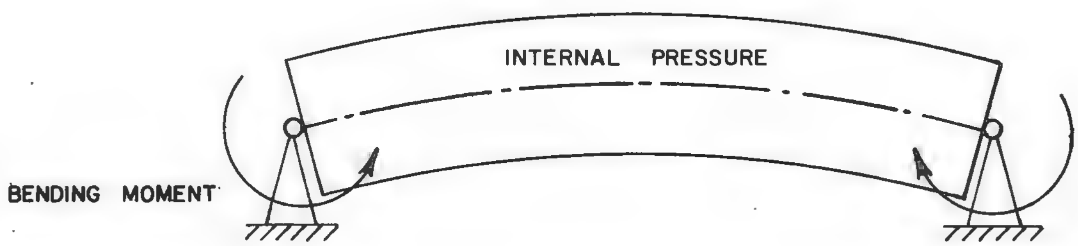
21. POWELL, G. H.: Documentation of POWELL-2D (PIPLIN) and POWELL-3D Computer programs



BENDING WITH TRANSLATIONAL END MOVEMENT

FIGURE 6.1

$\epsilon_a = -\alpha \Delta T$



BENDING WITH NO TRANSLATIONAL END MOVEMENT

FIGURE 6.2

RADIUS OF CURVATURE MODELS

PIPE LINE TECHNOLOGISTS LTD.
CALGARY ALBERTA
PROJ. Nº 1396 JUNE 1976

ALCAN PIPELINE COMPANY

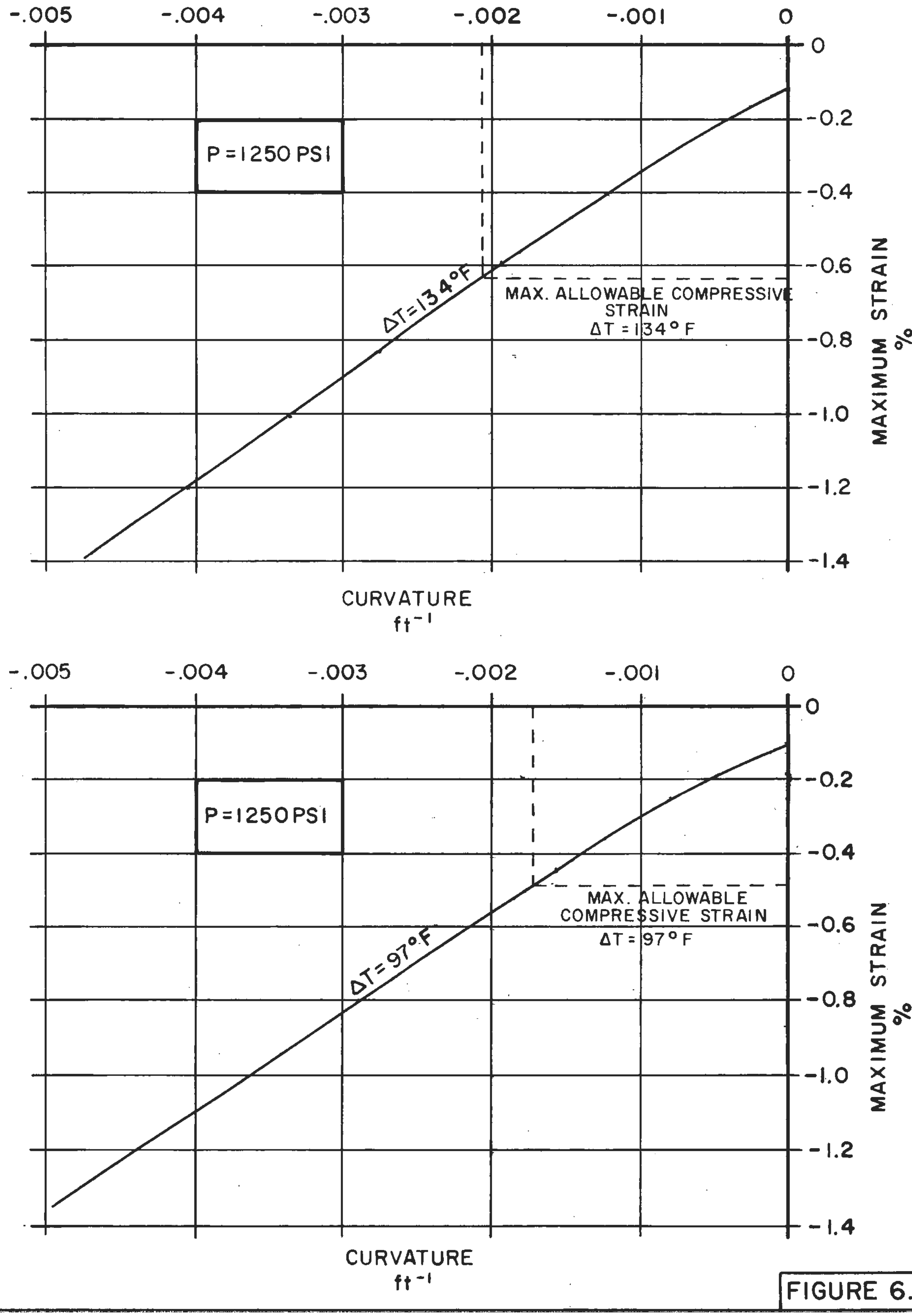


FIGURE 6.3

MAXIMUM ALLOWABLE CURVATURE CHANGE FOR COMPRESSION

PIPE LINE TECHNOLOGISTS LTD.
CALGARY ALBERTA

PROJ. Nº 1396 JUNE 1976

ALCAN PIPELINE COMPANY

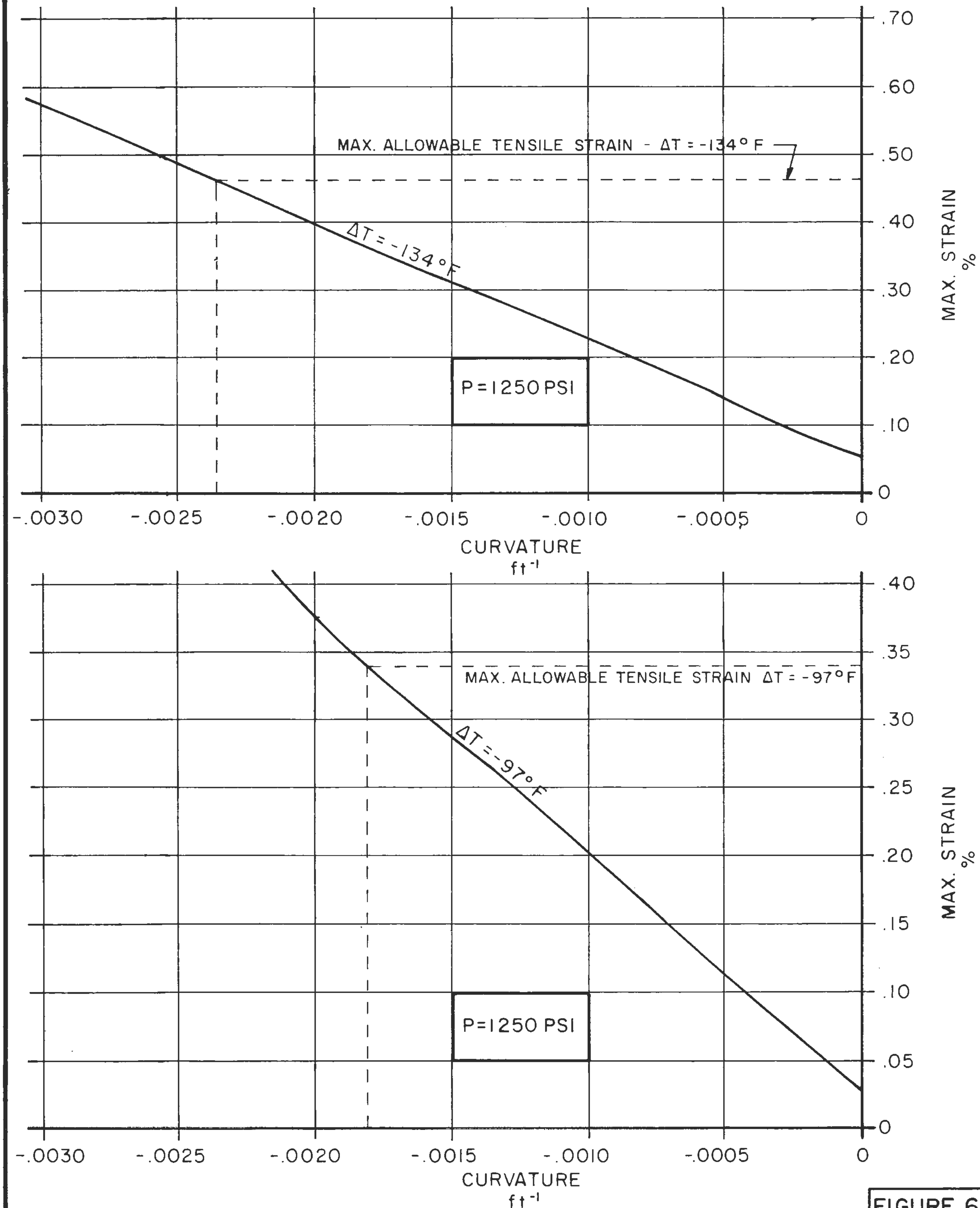


FIGURE 6.4

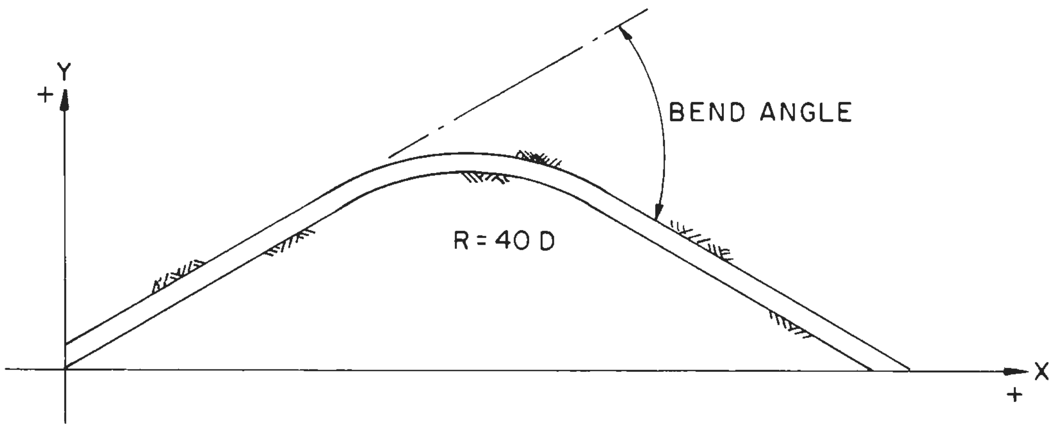
MAXIMUM ALLOWABLE CURVATURE CHANGE FOR TENSION

PIPE LINE TECHNOLOGISTS LTD.
CALGARY ALBERTA

PROJ. Nº 1396

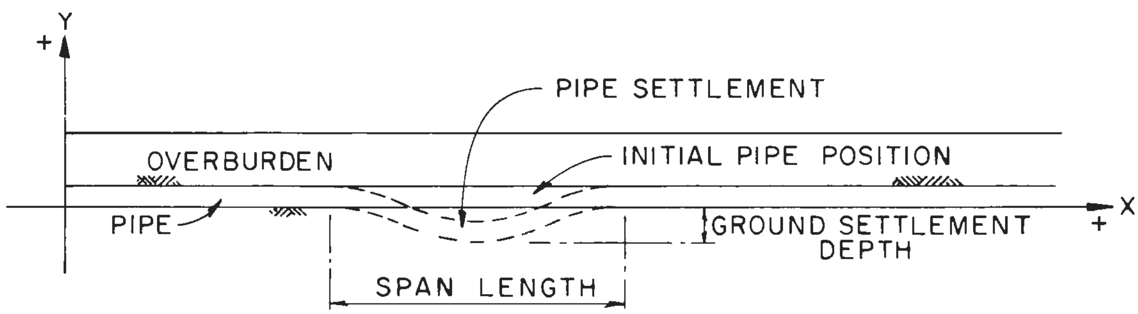
JUNE 1976

ALCAN PIPELINE COMPANY



FIELD BEND MODEL

FIGURE 6.5

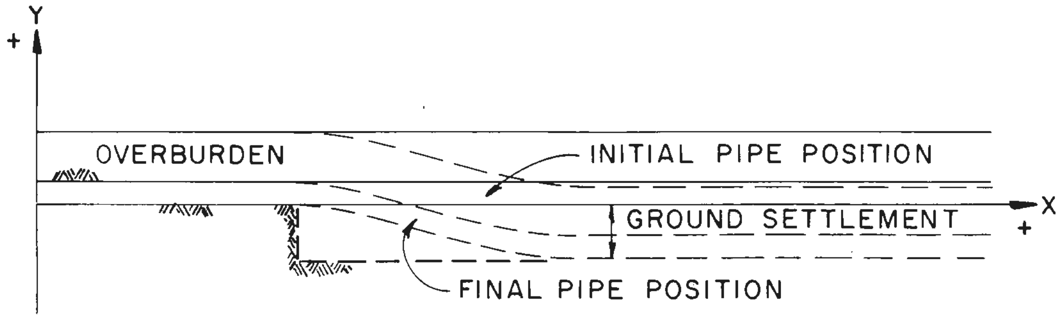


DIFFERENTIAL SETTLEMENT MODEL
GRADUAL SETTLEMENT

FIGURE 6.6

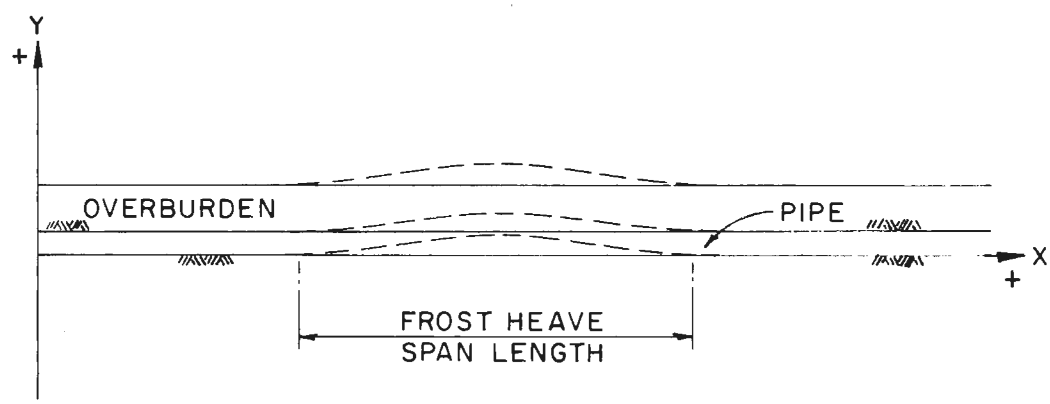
PIPE CONFIGURATION MODELS

PIPE LINE TECHNOLOGISTS LTD. CALGARY ALBERTA PROJ. Nº 1396 JUNE 1976	ALCAN PIPELINE COMPANY



DIFFERENTIAL SETTLEMENT MODEL
ABRUPT SETTLEMENT

FIGURE 6.7



FROST HEAVE MODEL

FIGURE 6.8

PIPE CONFIGURATION MODELS

PIPE LINE TECHNOLOGISTS LTD. CALGARY ALBERTA PROJ. Nº 1396 JUNE 1976	ALCAN PIPELINE COMPANY

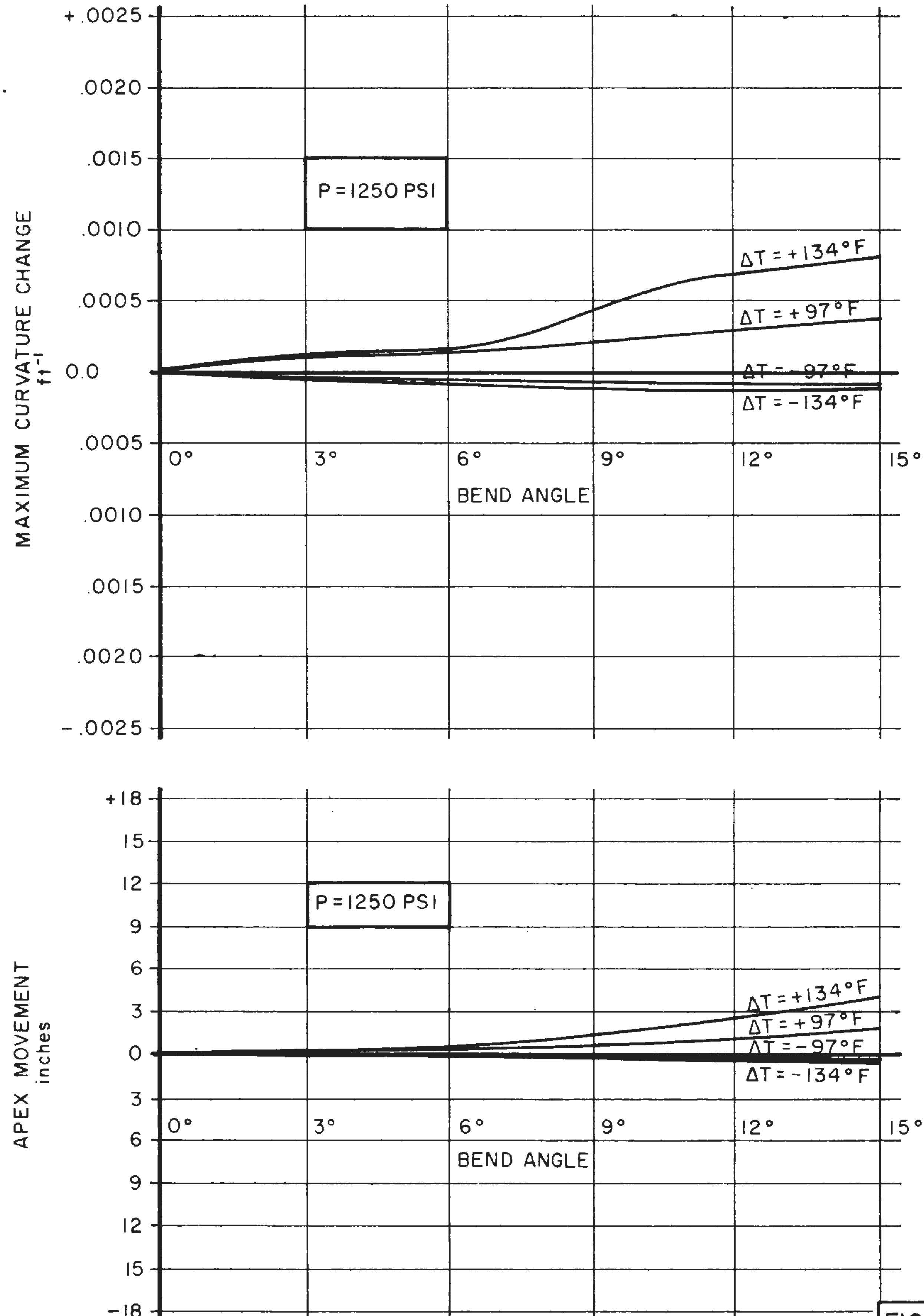


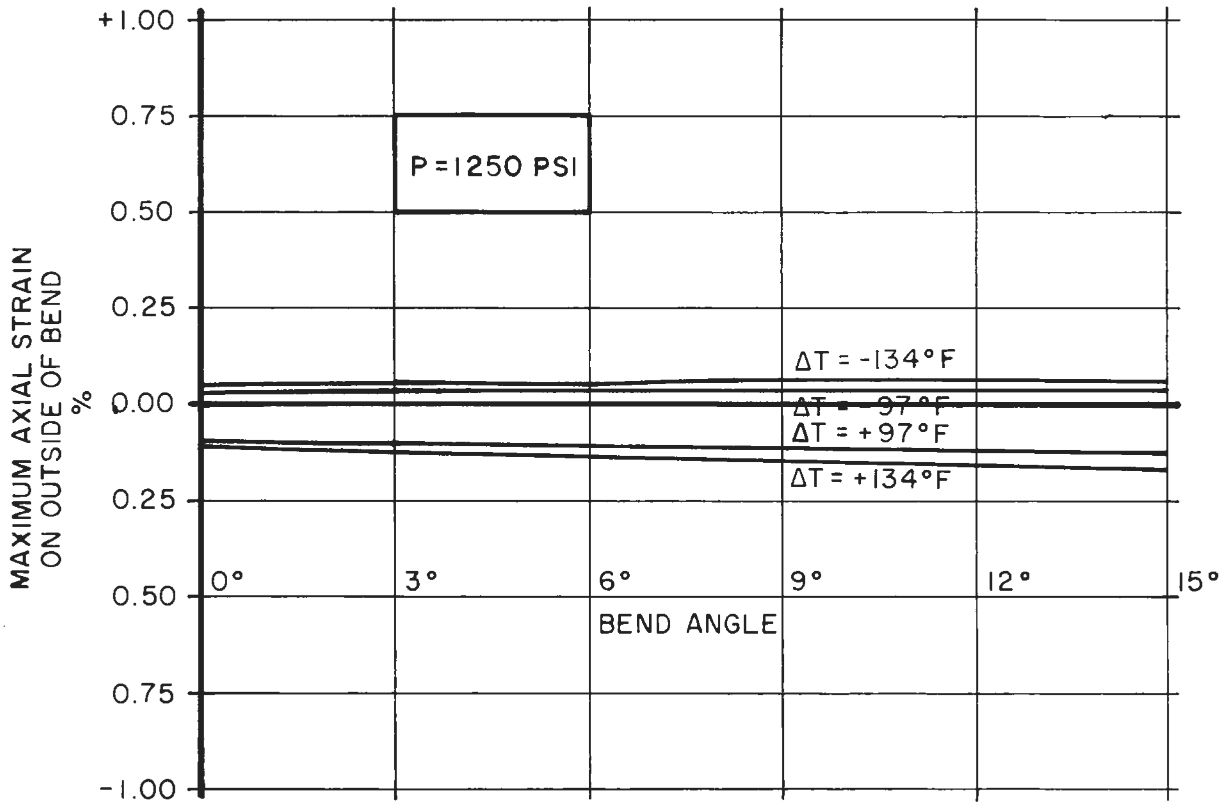
FIGURE 6.9

SIDE BEND CHARACTERISTICS

PIPE LINE TECHNOLOGISTS LTD.
CALGARY ALBERTA

PROJ. Nº 1396 JUNE 1976

ALCAN PIPELINE COMPANY



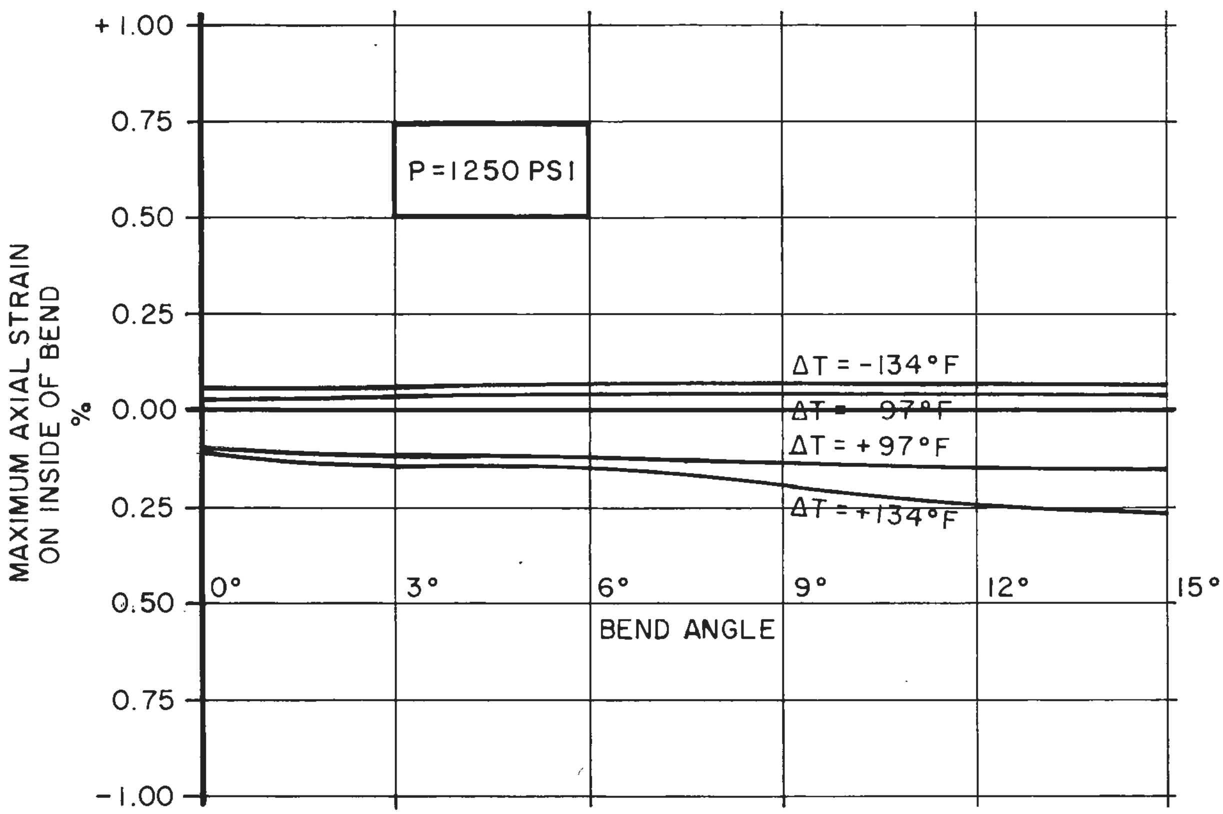


FIGURE 6.10

SIDE BEND CHARACTERISTICS

PIPE LINE TECHNOLOGISTS LTD.
CALGARY ALBERTA

PROJ. Nº 1396

JUNE 1976

ALCAN PIPELINE COMPANY

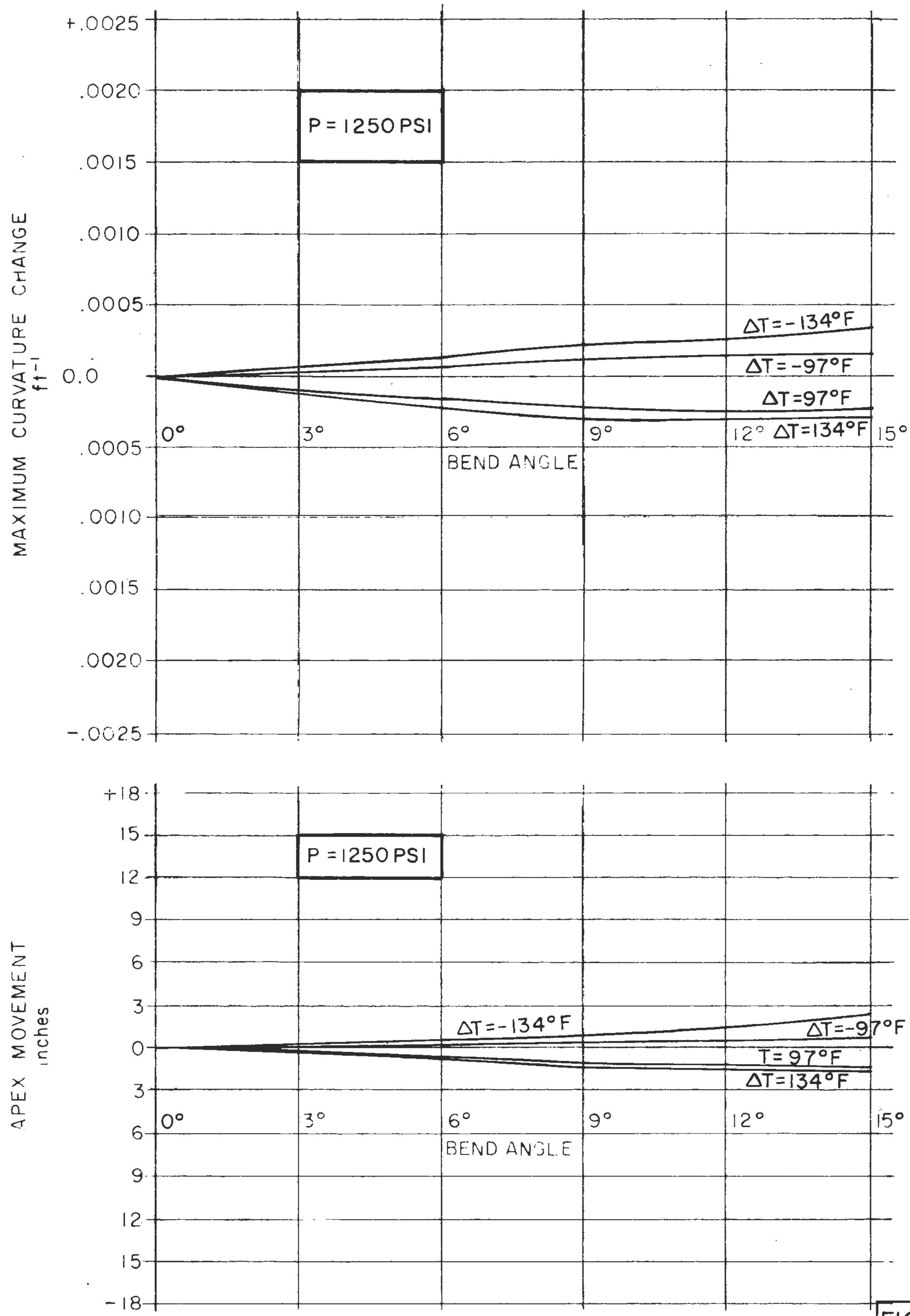


FIGURE 6.11

SAG BEND CHARACTERISTICS

PIPE LINE TECHNOLOGISTS LTD.
CALGARY ALBERTA

PROJ. Nº 1396 JUNE 1976

ALCAN PIPELINE COMPANY

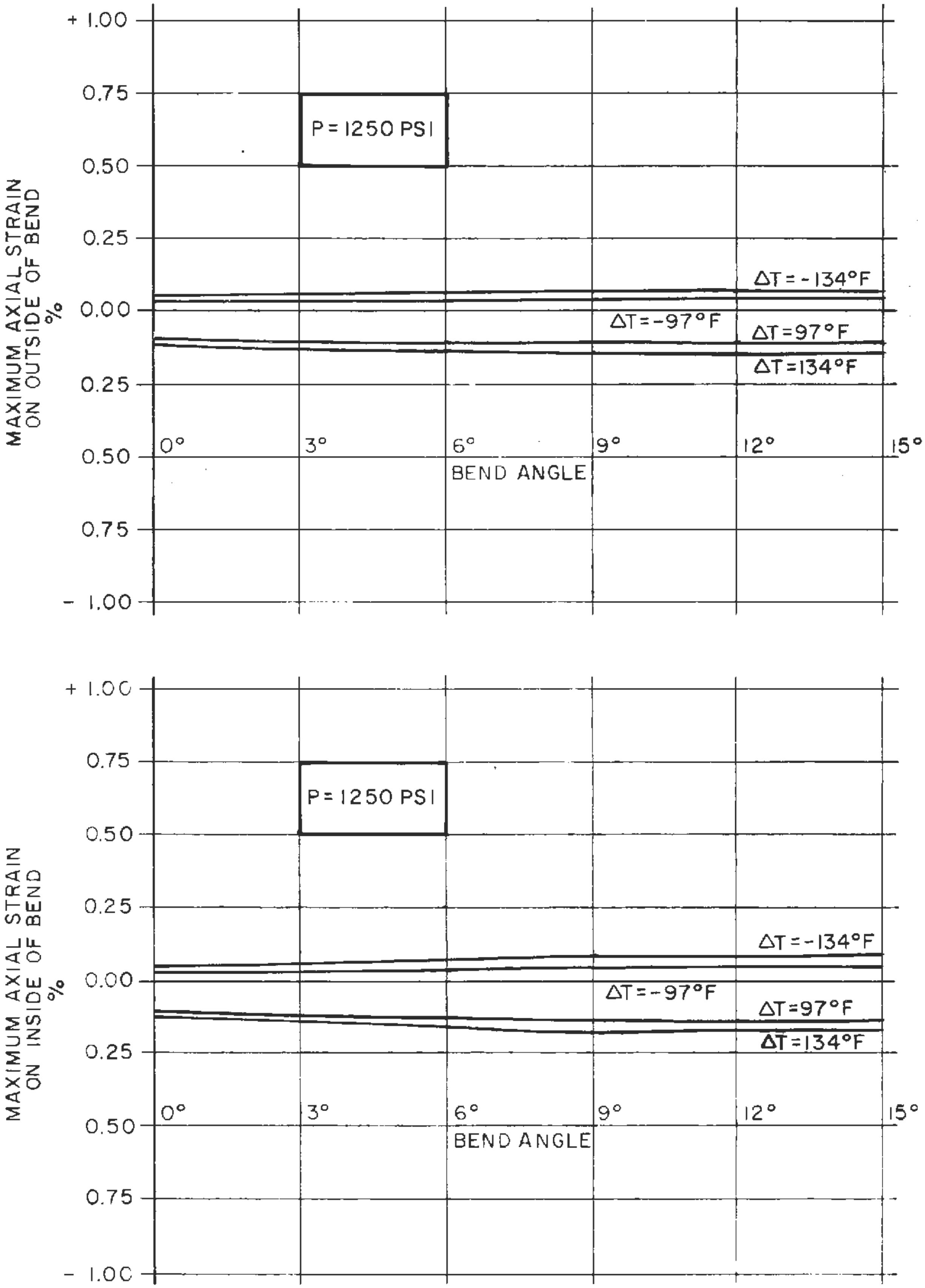


FIGURE 6.12

SAG BEND CHARACTERISTICS

PIPE LINE TECHNOLOGISTS LTD.
CALGARY ALBERTA

PROJ. Nº 1396

JUNE 1976

ALCAN PIPELINE COMPANY

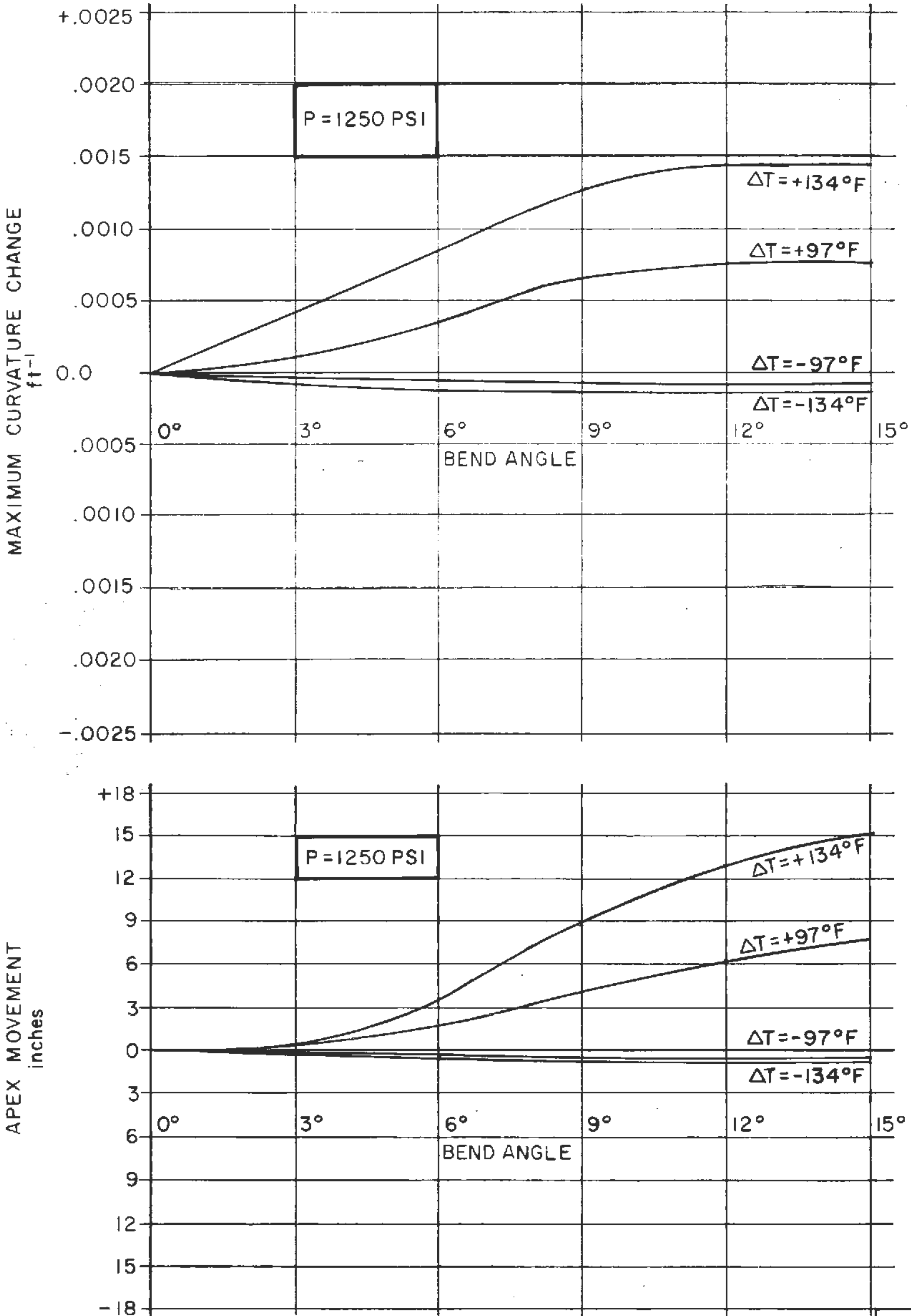


FIGURE 6.1

OVER BEND CHARACTERISTICS

PIPE LINE TECHNOLOGISTS LTD.
CALGARY ALBERTA

PROJ. Nº 1396 JUNE 1976

ALCAN PIPELINE COMPANY

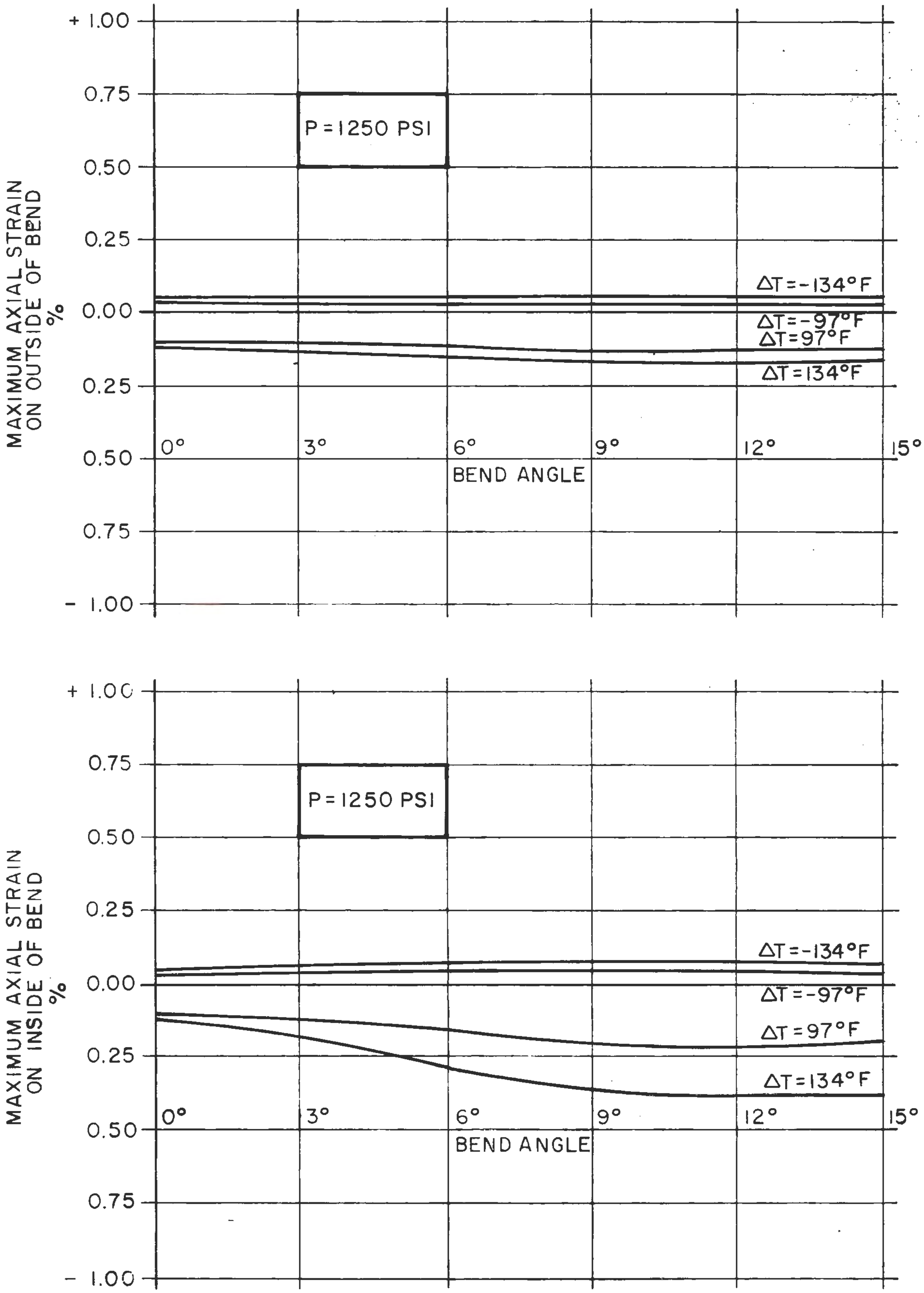


FIGURE 6.14

OVER BEND CHARACTERISTICS

PIPE LINE TECHNOLOGISTS LTD.
CALGARY ALBERTA

PROJ. Nº 1396

JUNE 1976

ALCAN PIPELINE COMPANY

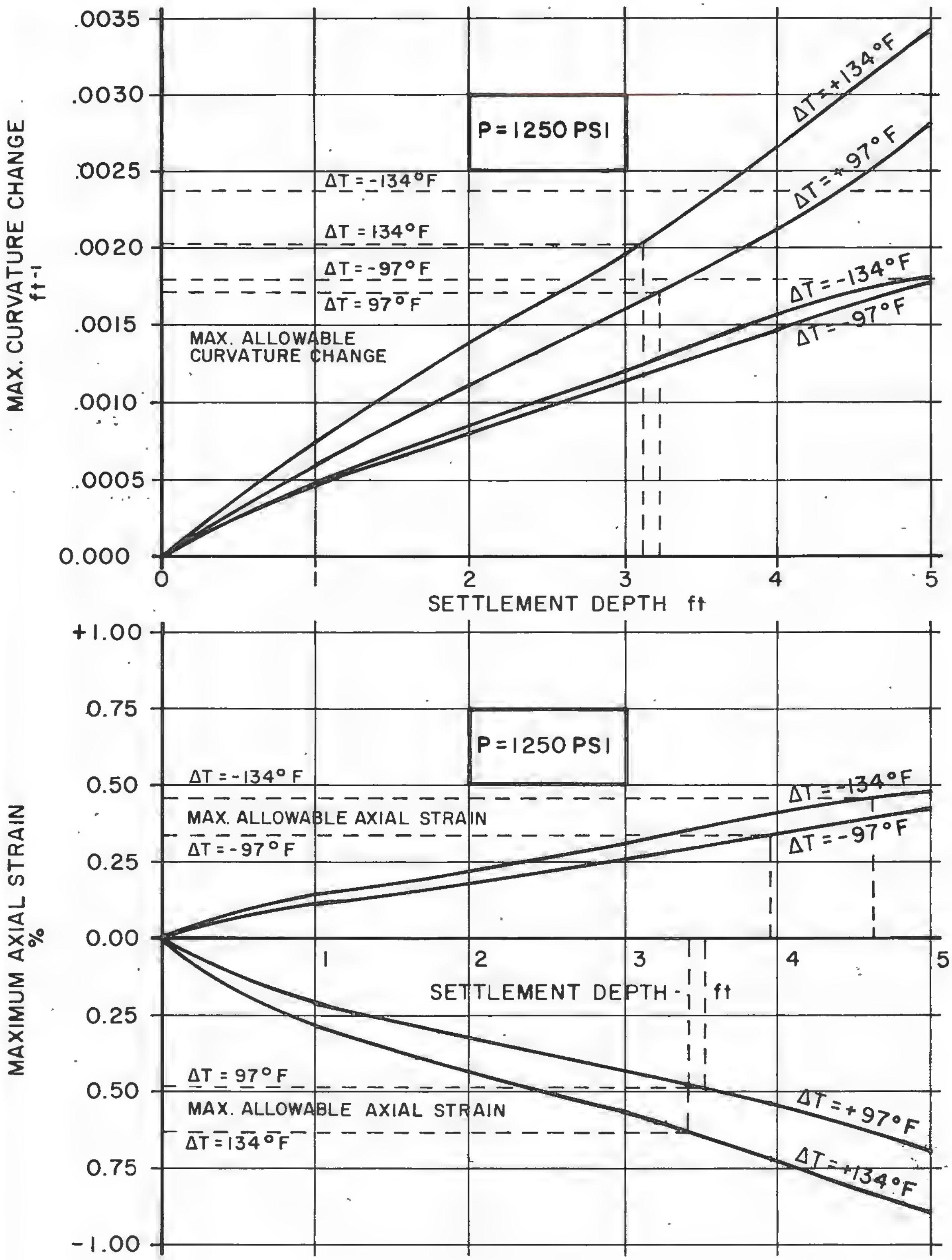


FIGURE 6.15

PIPE RESPONSE TO ABRUPT DIFFERENTIAL SETTLEMENT

PIPE LINE TECHNOLOGISTS LTD. CALGARY ALBERTA PROJ. Nº 1396 JUNE 1976	ALCAN PIPELINE COMPANY

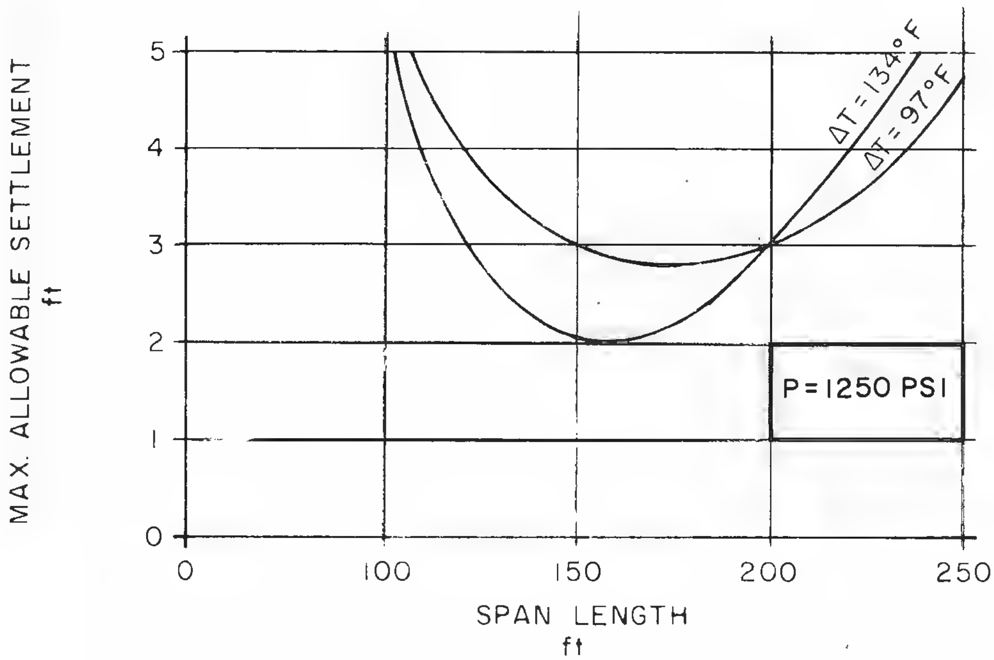


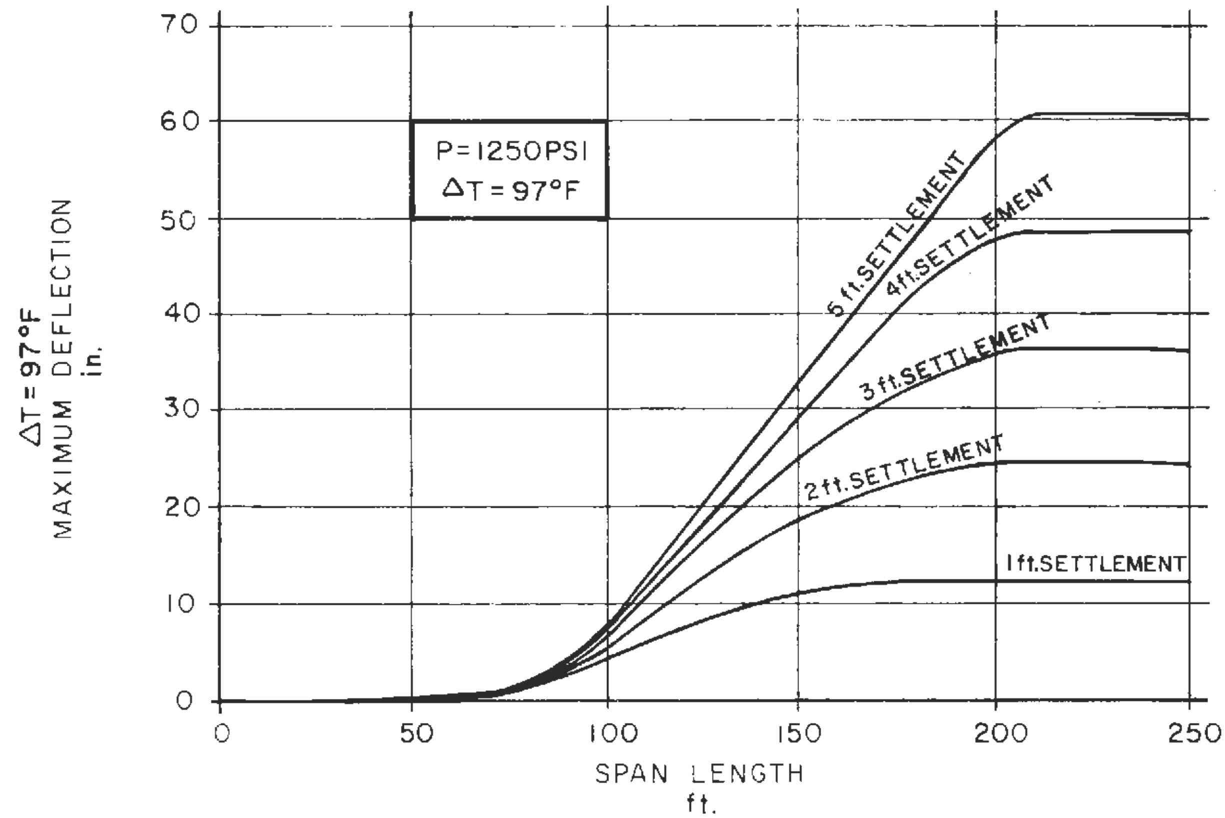
FIGURE 6.16

ALLOWABLE GRADUAL DIFFERENTIAL SETTLEMENT

PIPE LINE TECHNOLOGISTS LTD.
CALGARY ALBERTA

PROJ. Nº 1396 JUNE 1976

ALCAN PIPELINE COMPANY



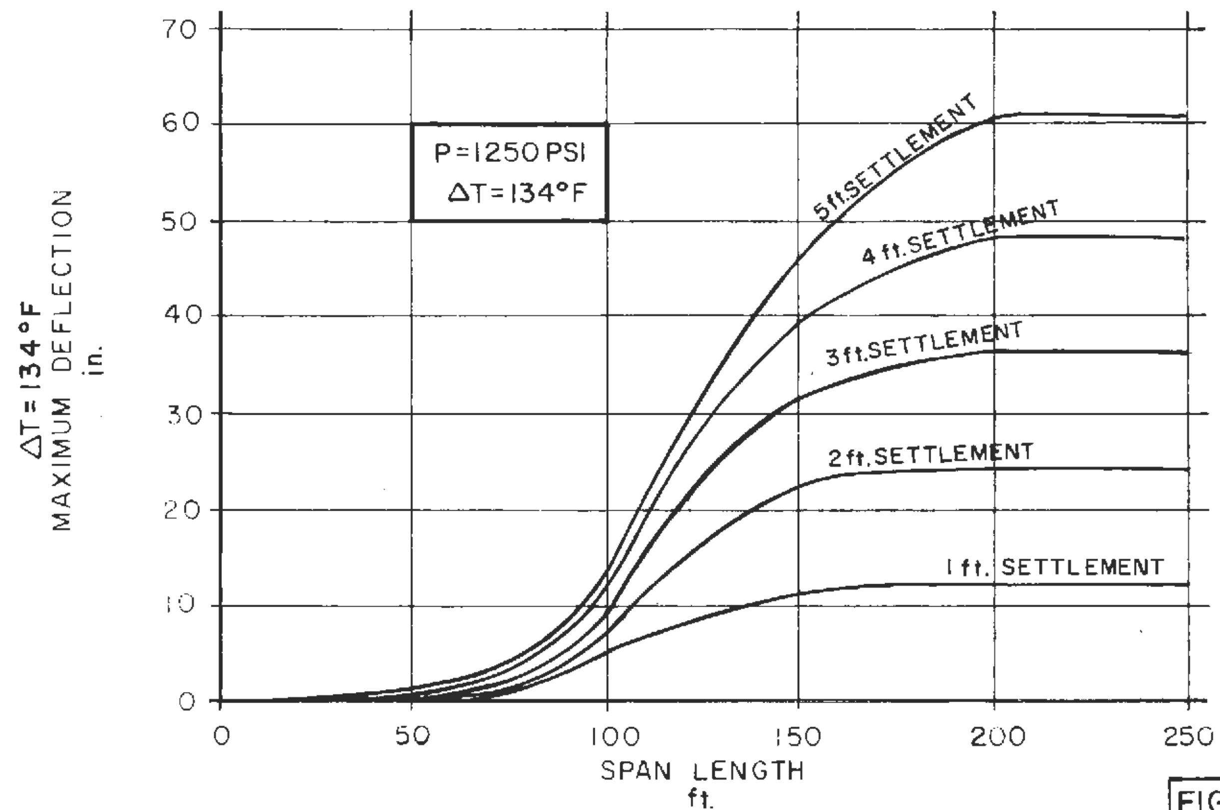


FIGURE 6.17

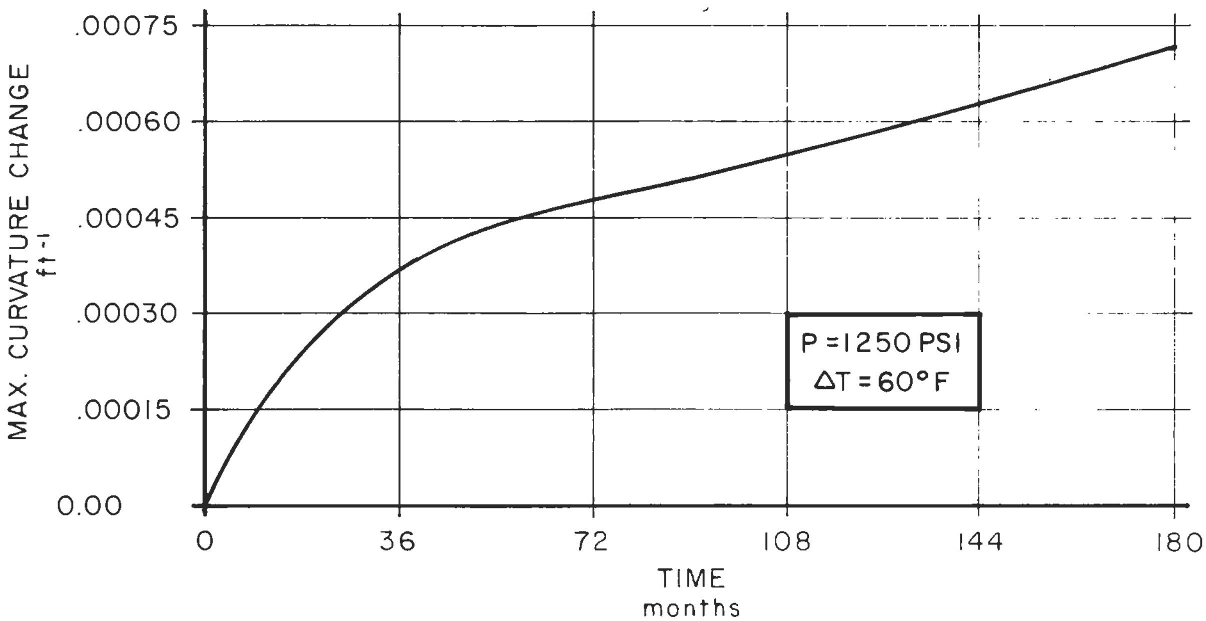
PIPE RESPONSE TO GRADUAL DIFFERENTIAL GROUND SETTLEMENT

PIPE LINE TECHNOLOGISTS LTD.
CALGARY ALBERTA

PROJ. Nº 1396 JUNE 1976

ALCAN PIPELINE COMPANY

100 FT. SPAN LENGTH



50 FT. SPAN LENGTH

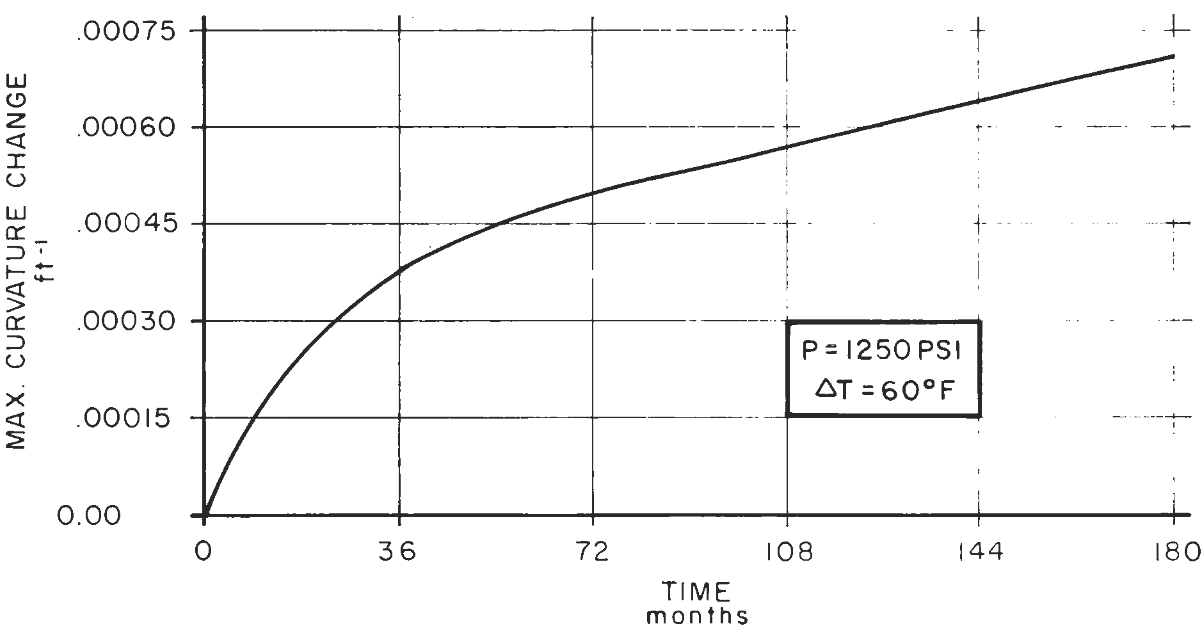
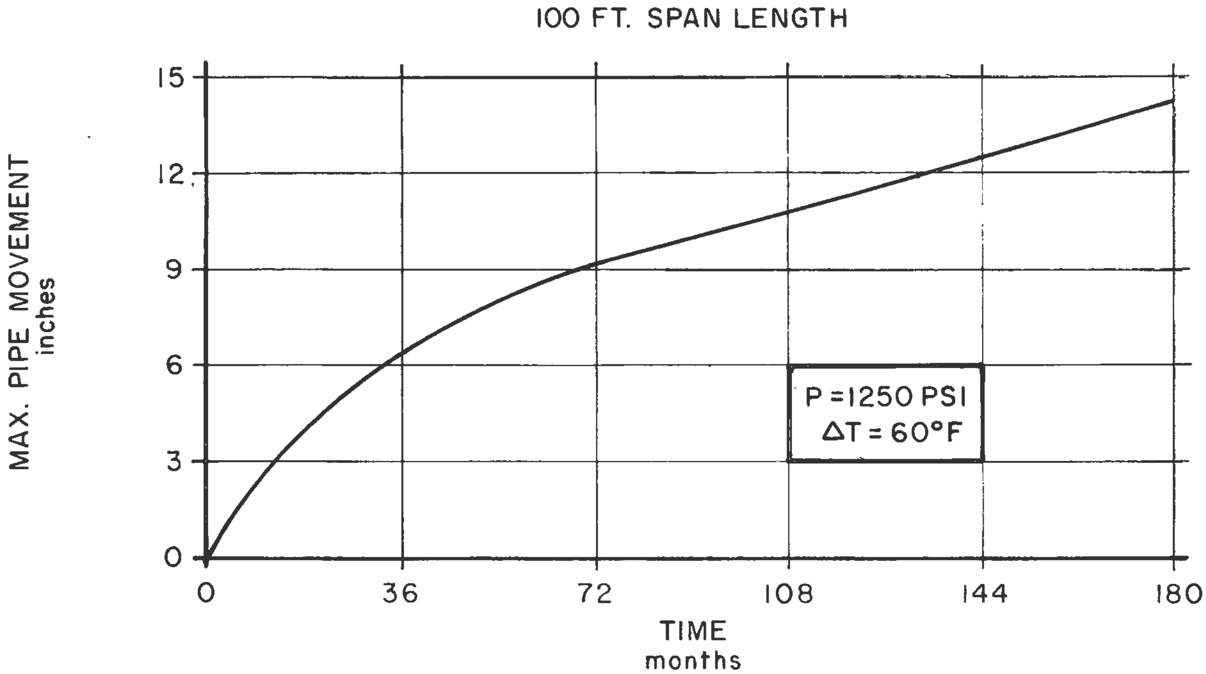


FIGURE 6.18

FROST HEAVE EFFECTS

PIPE LINE TECHNOLOGISTS LTD.
CALGARY ALBERTA
PROJ. Nº 1396
JUNE 1976

ALCAN PIPELINE COMPANY



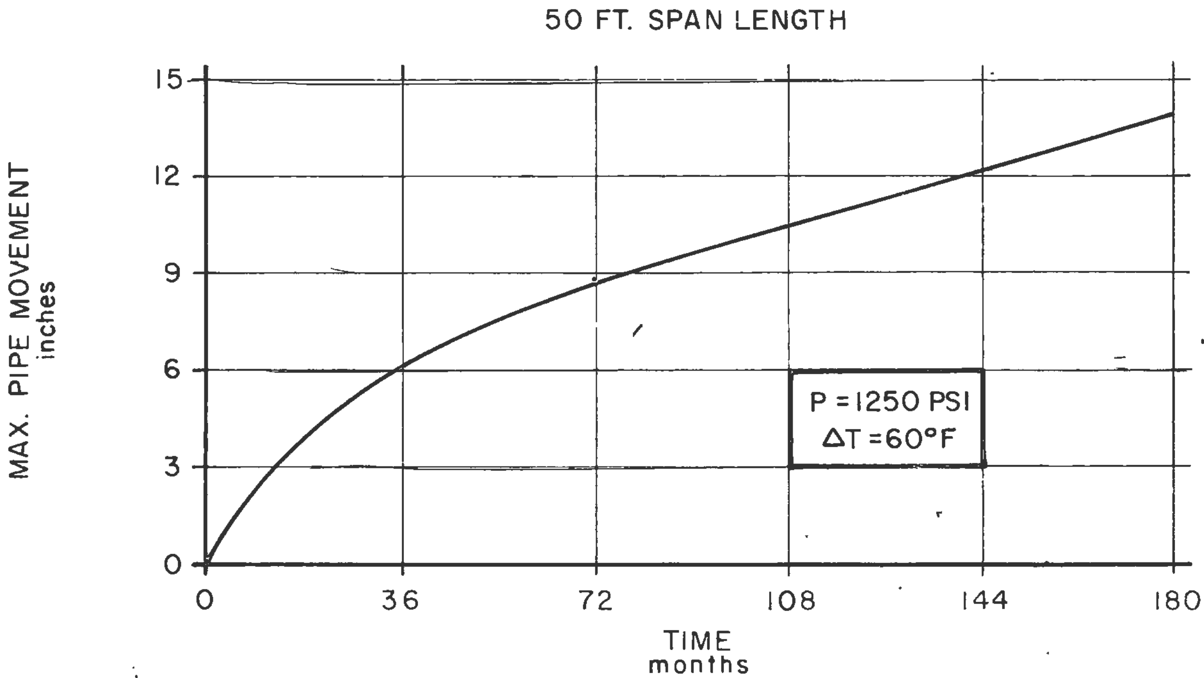
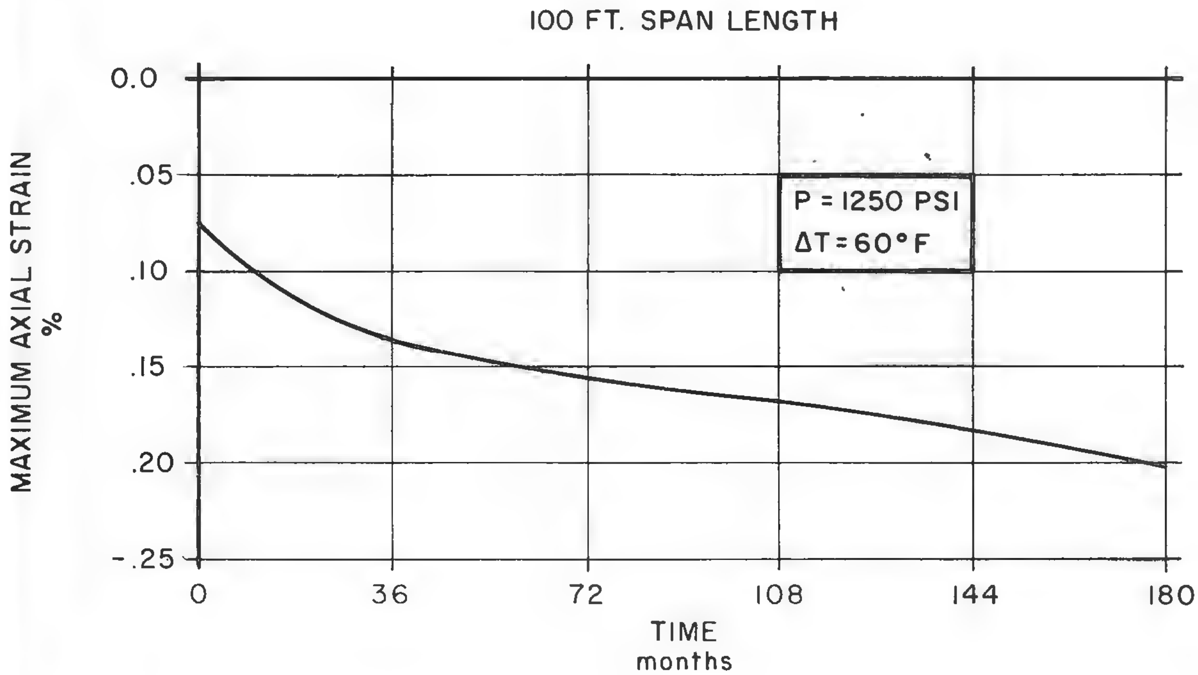


FIGURE 6.19

FROST HEAVE EFFECTS

PIPE LINE TECHNOLOGISTS LTD.
CALGARY ALBERTA
PROJ. Nº 1396
JUNE 1976

ALCAN PIPELINE COMPANY



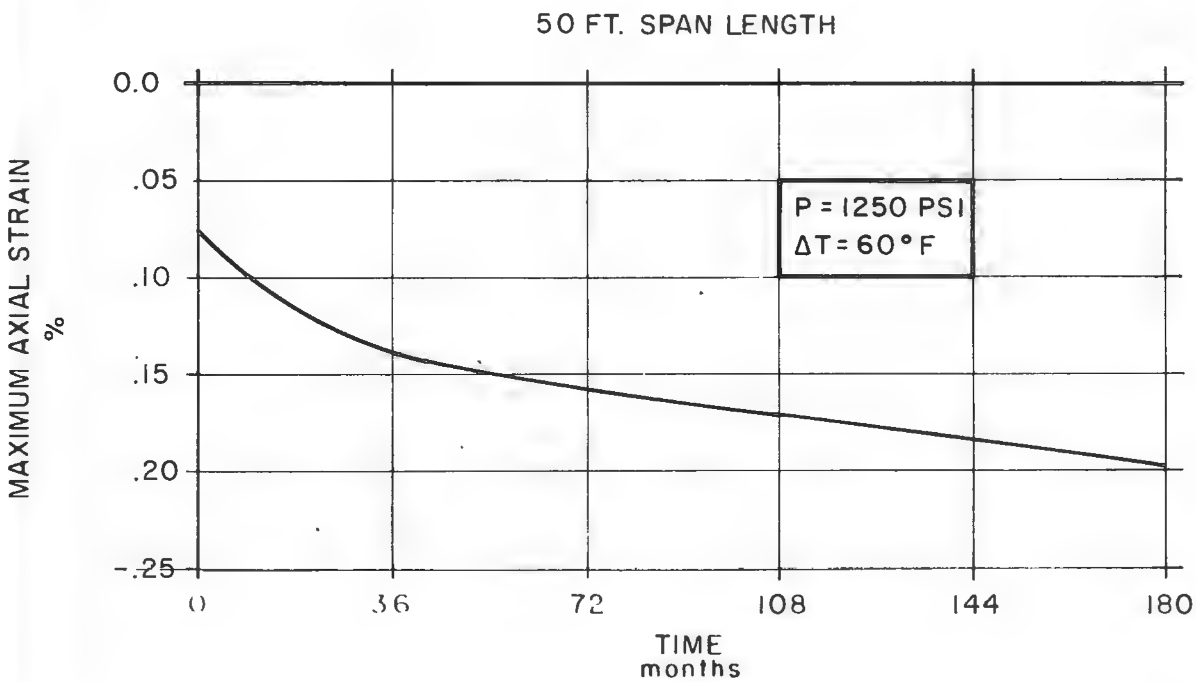


FIGURE 6.20

FROST HEAVE EFFECTS

PIPE LINE TECHNOLOGISTS LTD.
CALGARY ALBERTA

PROJ. Nº 1396 JUNE 1976

ALCAN PIPELINE COMPANY

GULF INTERSTATE ENGINEERING COMPANY

SPECIFICATION FOR LARGE DIAMETER HIGH TEST LINE PIPE

1.0 SCOPE

This specification covers the manufacture, testing, and inspection of large diameter pipe for use in cold climate pipelines and related facilities conveying natural gas; constructed, operated, and maintained in accordance with the United States Department of Transportation, Hazardous Material Regulations Board, Part 192, Transportation of Natural and Other Gas by Pipeline. Unless otherwise specified herein, pipe supplied under this specification shall meet the minimum requirements of API Standard 5LX, or API Standard 5LS, latest edition, and shall meet any additional requirements as set in this specification or on the accompanying Request for Quotation or Purchase Order. The following sections are numbered to correspond with the section numbers shown in the API Standards.

2.0 PROCESS OF MANUFACTURE AND MATERIAL

2.1 PROCESS OF MANUFACTURE

The pipe supplier shall manufacture the pipe in accordance with a qualified procedure as determined by Section 4.0.

Physical Properties and Tests

The pipe shall be manufactured by longitudinal or spiral butt welding cold preformed plate or coiled strip with the automatic submerged arc welding process using at least two weld passes, one of which shall be on the inside of the pipe. The quality of the weld shall be such as to produce a joint efficiency factor of 1.0.

The pipe shall be straightened, sized and hydrostatically tested.

2.2. COLD EXPANSION

The Manufacturer shall specify if the pipe is non-expanded or cold expanded. Expansion shall not exceed 1.5%.

2.3 MATERIAL

The Manufacturer shall furnish Purchaser the steel making process and the type of deoxidation practice to be used. The plate or strip shall be killed or semi-killed, open hearth electric furnace or basic oxygen steel. The quality of the plate or coiled strip as determined by ultrasonic testing shall show that there are no detrimental laminations exceeding 2 mm in any direction within 25 mm of the beveled edges of the plate or strip and that there are no laminations within 25 mm of the prepared ends of the finished pipes. Isolated laminations in the body of the plate or coiled strip shall not exceed 100 mm in any direction.

2.4 HEAT TREATMENT

The rolled plate or skelp or the pipe shall not be heat treated. The Manufacturer shall furnish a detailed description of any thermal treatment incident to thin film coating and the effects of such treatment on the mechanical properties of the pipe. Any special cooling or heating of the plates or skelp shall be considered a heat treatment.

3.0 CHEMICAL PROPERTIES AND TESTS

Pipe made under this specification shall be suitable for manual and/or automatic welding under field conditions.

3.1 COMPOSITION

The composition, based on ladle analyses, shall be as specified in Table 3.1 API 5LX, for X65 Welded pipe, or for other ordered grades, or as agreed upon by the Manufacturer and the Purchaser. The carbon equivalent (based on the formula $\%C + \%Mn/6 + \frac{\%Cr + Mo + V}{5} + \frac{\%Ni + Cu}{15}$) shall not exceed 0.43, for pearlite reduced steel and shall not exceed 0.45 for accicular ferrite type steels. The Nb content shall not exceed 0.06% and the V content shall not exceed 0.10%.

3.2 LADLE ANALYSES

The Manufacturer shall furnish the Purchaser a report giving the ladle analysis of each heat of steel. All additives used in the steel making process for the purpose of deoxidation, grain refinement, increased strength and increased toughness shall be reported.

3.3 CHECK ANALYSES

The Manufacturer shall furnish the Purchaser a report on check analyses of the finished pipe. The carbon equivalent (C + Mn/6) shall not exceed 0.42.

4.0 MECHANICAL PROPERTIES AND TESTS

The Manufacturer shall perform all fabrication and welding in accordance with established procedures for each diameter and wall thickness. The procedures shall be prepared in written form and shall include but not be limited to the following:

1. Material
2. Type of weld seam (longitudinal or spiral)
3. Joint Design
4. Plate preparation
5. Welding procedure:

    a) Type, size and grade of filler metal and flux
    b) Speed of welding
    c) Electrical characteristics
    d) Number of weld passes, size, depth of fusion and penetration of each weld pass.

6. Percentage of expansion, or description of other sizing procedures.

Procedure Qualification Tests

A completely finished pipe made at the beginning of normal production or after any change in welding procedures shall be visually inspected for compliance with dimensional tolerances of plate thickness, diameter, ovality straightness, weld contours, surface imperfections, etc.

After having been visually inspected and accepted, the pipe shall be tested as specified below.

Testing Procedures and Test Requirements

Record of Procedure Qualification Tests

The Manufacturer shall submit to the purchaser a procedure qualification report giving the results of all tests, micrographs of weld cross-section specimens and the radiographic film of the weld.

Procedure Qualification Test Requirements

The following tests shall be performed as part of the procedure qualifications:

1. The welds shall be 100% ultrasonically examined,

and each end for a distance on 12" shall be radiographed.

2. Four transverse weld bend test specimens shall be removed from points selected at random. Two specimens shall be bent on the face of the weld and two on the reverse side. For spiral welded pipe two additional specimens shall be taken from a connection weld. One shall be a face bend and the other a root bend. The diameter of the pin shall be as determined by the API Standards.

3. Two transverse weld, and two transverse base material tensile test specimens shall be removed at random points. For spiral welded pipe one transverse weld and one all-weld tensile test specimen shall be taken from a connection weld. The transverse weld specimens shall be tested for yield strength, ultimate strength and elongation.

4. Twelve weld cross-section specimens shall be removed at equally spaced points. They shall be polished and etched to show the metallurgical structure.

5. Enough Charpy V-Notch specimens shall be removed from plate material and tested at various temperatures to determine the ductile to brittle transition characteristics of the material.

6. Three drop weight tear tests shall be removed from the plate material and tested at 0°F. At least 85% shear area shall be measured on each specimen.

Production Test Requirements

In addition to the mandatory tests specified in the A.P.I. Standard, the following requirements are noted:

4.1 TENSILE PROPERTIES

The pipe shall meet the tensile requirements for Grade X65 pipe, or for other grades as stated on the purchase order.

4.4 TRANSVERSE TENSION TESTS

The record of the transverse tension tests shall be supplied to the Purchaser.

4.5 WELD TENSION TESTS

The record of the weld tension tests shall be made available to the Purchaser.

In addition, the Purchaser may require the testing of a weld tension test specimen from each shift's production as a monitor of weld properties.

4.11 MILL-CONTROL TENSION TESTS

The record of mill-control tension tests shall be made available to the Purchaser.

4.17 FRACTURE TOUGHNESS TESTS

The Manufacturer shall conduct full size Charpy V-Notch tests and drop-weight tear tests and shall furnish the Purchaser with the test records. The test methods shall be in accordance with API 5LX, SR5 and SR6, with the following exceptions:

Charpy V-Notch Tests

Complete transition curves shall be furnished on 10% of the heats of steel.

Three specimens shall be tested at a temperature corresponding to the lowest temperature at which approximately 90 percent of the Charpy specimens are expected to exhibit 100 percent shear area (CV-100). Further, it is anticipated that the remaining 10 percent of specimens will exhibit shear areas of 85 percent or greater.

The CV-100 test temperature shall be estimated based on preliminary data on the pipe material, the manufacturing procedure qualification test data, and periodic temperature curves required for 10 percent of the heats. In any event, the selected test temperature shall be subject to purchaser's agreement.

a) If any of the specimens fail to exhibit 100 percent shear, but not less than 85 percent shear, the resulting Charpy 100 percent shear energy shall be computed by dividing the measured absorbed energy by the shear area. The average Charpy V-Notch 100 percent shear energy for the three specimens from each heat of steel shall conform to the stipulated minimum values set forth in the table.

b) If any of the specimens from any heat of steel exhibit a fracture appearance of less than 85 percent shear; three additional specimens from the same pipe shall be tested at a temperature not more than 20°F higher than the previous test temperature. Test results from all specimens, (at least three) with 85 percent shear or greater, shall be interpreted as per paragraph (a) above.

c) Alternate procedures to determine Charpy energy at the lowest 100 percent shear area temperature may be acceptable. The following notch toughness properties shall be obtained:

Minimum CV-100 Energies

Average of Three Specimens Any Heat	Average of Three Speciments 50% of the Heats*
50 ft.-lbs.	80 ft.-lbs.

*for each 10 miles of pipe shipped

A sample will be selected daily, by the Purchaser's inspector for impact tests of weld metal. Additional samples will be taken in the event of changes in essential variables of the welding procedure. Specimen orientation and location will be determined at the preproduction meeting.

For acceptance, the following properties shall be obtained on 10mm x 10mm specimens when tested at the minimum design temperature at 0^{O}F, or as specified in the Pipe Specification Sheet.

Minimum Charpy V Energy
Average of 3 Specimens
50 ft. lbs.

Drop Weight Tear Tests:

Two drop weight tear test speciments shall be cut from this sample and tested as described in the applicable standard. The test temperature shall be the minimum design temperature of 0^{O}F, or as specified on the Pipe Specification Sheet. The following tabulation sets forth the minimum shear areas to be obtained.

Minimum Shear Area

Average of Two Specimens Any Heat	All Heat* Average
60%	85%

* for each 10 miles of pipe shipped.

Retests

The purchaser's Inspector is authorized to permit a retest if there is reason to believe that the failure of a specimen to show the minimum impact value required is due to some fault in its preparation or testing or that it has not provided a true indication of the notch ductility of the material.

If any sample fails to pass the test, the remainder of the plates of pipes in the heat may, at the Manufacturer's option be submitted individually for test and acceptance.

4.18B SUBMERGED-ARC GUIDED BEND TESTS

The record of guided-bend tests shall be made available to the Purchaser.

5.0 HYDROSTATIC TESTS

5.1 MILL INSPECTION HYDROSTATIC TEST

The test pressure to be used for mill inspection hydrostatic tests shall be calculated in accordance with paragraph 5.3 of API 5LX so as to develop a stress equal to 95% of specified minimum yield strength, provided the dimensional tolerances set forth in these specifications can be maintained. The test pressure shall be held for a period of 10 seconds.

6.0 DIMENSION, WEIGHT AND LENGTHS

6.2 DIAMETER

The maximum variation of the diameter shall not exceed +1/4 inch, -1/8 inch. It is further specified that the Manufacturer shall minimize variation of the diameter.

6.5 LENGTHS

All pipe furnished under this specification shall be in double random lengths of not less than 35 feet. Manufacturer shall specify in the Quotatation anticipated maximum and minimum lengths.

6.7 PIPE ENDS

a. API Standard 5LX shall apply except that the root face dimension shall be 3/32" ± 1/32" and the Purchaser may specify one end beveled for double jointing.

b. Special attention shall be given to insuring that the deviation from the required root face at the beveled ends is kept to a minimum within the specified tolerances. If the root face is less than the minimum, it shall not be brought into tolerance by filing or grinding. It shall be required to rebevel the entire face.

6.9 JOINTERS

Welded jointers shall comply with the requirements of API 5LX Appendix A. The welding procedure must be approved by the Purchaser. Each jointer weld shall be completely radiographed.

7.0 NON-DESTRUCTIVE TESTING

The Manufacturer shall furnish a detailed description of non-destructive inspection practices. All of the weld seam of the pipe furnished to this specification shall be non-destructively inspected in accordance with the applicable provisions of Section 7 of API Standard 5LX. Non-destructive testing of the weld shall be performed after hydrostatic testing, but may also, additionally, be performed prior to hydrostatic testing.

Ultrasonic Testing

Prior to beginning production ultrasonic testing, the Manufacturer shall, in the presence of the purchaser's representative, perform ultrasonic testing for the purpose of establishing the production testing procedure. Verification of the ability to detect weld defects shall be done on test pieces having known defects in the nature of lack of penetration or fusion, porosity, slag inclusions and cracks, or on test pieces with machined notches and holes. These test pieces shall be sections of pipe having the same wall thickness as the pipe being inspected. The Manufacturer shall also perform ultrasonic inspection of plate showing the method and procedure used to detect laminations.

7.13 WELD REPAIR

Repair of defects in the weld is permitted, provided that the Manufacturer demonstrates to the satisfaction of the Purchaser that the mechanical properties, including toughness, are not impaired by such repair.

8.0 WORKMANSHIP, VISUAL EXAMINATION AND REPAIR OF DEFECTS

8.1 INSPECTION NOTICE

The purchaser reserves the right to conduct or require the manufacturer to perform additional testing. The testing methods and procedures shall be confined to those herein defined. Such testing shall be done at the purchaser's expense and without interfering with normal production provided the pipes thus inspected are within the limits of acceptability.

8.2 PLANT ACCESS

The purchaser may at his discretion place engineers and quality control technicians in the manufacturer's plant. The engineers and quality control technicians will work in conjunction with the manufacturer's quality control personnel in witnessing procedure qualification, hydrostatic testing, verification of length and weight and other control measures. The purchaser shall have free entry and access at all times to all parts of the Manufacturer's plant which concern the manufacturing and testing of the pipe during the work on the contract.

The Manufacturer shall afford the purchaser all reasonable facilities necessary for determining compliance with this specification.

8.3 REJECTION

In the event that defective materials or workmanship are detected, the Manufacturer and purchaser shall mutually agree on additional inspection requirements and procedures for correcting the cause of the defects. In such case the cost shall be borne by the Manufacturer. It shall be the Manufacturer's responsibility to remove from lots of pipe to be presented for inspection all pipes not meeting the requirements of the specification. Repeated recurrence of purchaser having to reject pipe for visual reasons shall be sufficient cause to refuse to accept for final inspection all pipes until the cause is corrected.

8.4 COMPLIANCE

Under no circumstances shall any action of the purchaser relieve the Manufacturer of his responsibility for the quality of the finished pipe. In all cases where the pipe does not meet the minimum requirements herein the burden of proof to the contrary lies solely with the Manufacturer.

8.5a DENTS

All cold formed dents deeper than 1/8 inch with a sharp bottom gouge shall be considered injurious and cause for rejection. Removal of such defects by grinding is not permitted. Dents without sharp bottom gouges adjacent to or extending across the weld are also cause for rejection.

8.5b OFFSET OF PLATE EDGES

The radial offset (misalignment) of plate edges in the mill seam shall not be greater than 1/16 inch.

8.5d HEIGHT OF OUTSIDE WELD BEAD

The outside weld bead shall not extend more than 1/8 inch above the prolongation of the original surface of the pipe.

8.5h HARD SPOTS

The maximum hardness of any hard spot, regardless of size, shall be 25 Rockwell C.

8.7 INJURIOUS DEFECTS

f. Disposition

Pipe containing an injurious defect may:

1. Have the defect removed by grinding, provided the remaining wall thickness is within tolerance.

2. Have the section of pipe containing the defect cut off provided that the pipe is still within the limits of the length requirements.

3. Be rejected.

8.8 REPAIR OF INJURIOUS DEFECTS

a. Parent Metal of Welded Pipe

Repair of injurious defects in the base metal by welding is not allowed.

Minor surface defects on the weld or parent metal may be removed by grinding provided the remaining wall thickness beneath the ground area is not less than 90% of the minimum allowable wall thickness and that there is a smooth transition between the ground area and the original contour.

b. Weld Seam

Repair of defects in the weld seam shall be permitted provided that the Manufacturer demonstrates to the satisfaction of the Purchaser that the mechanical properties, including toughness, are not impaired by such repairs.

9.0 MARKINGS AND COATINGS

9.3 Identification markings shall be paint stenciled on the outside surface of each length of pipe. Identification will include those categories specified in Paragraph 9.3 and 9.4 of API 5LX and shall also include the heat number and pipe number.

j. Supplemental Requirements

The pipe shall have the markings specified by API 5LX SR5 and SR6 applied in the same manner and location as other markings.

9.5 DIE STAMPING

Die stamping (hot or cold) of the finished pipe is prohibited.

9.6 The pipe surface shall be free of loose mill scale, dirt, grease, or any other substance which might interfere with coating applications.

Handling, Storage and Shipment

a. All handling of the pipe in the mill and shipping yard shall be with nylon slings or special type end hooks with soft metal insets subject to Purchaser's approval.

b. Finished pipe to be stored for a significant period of time shall be stored in a manner to minimize the effects of corrosion inducing conditions.

c. Pipe to be shipped by rail shall be loaded in accordance with the provisions of the latest edition of API Recommended Practice 5L1 as a minimum requirement. A loading diagram showing the stacking arrangements, location of bearing strips, use of spacers, tie-down straps, etc., shall be furnished to the Purchaser and its agents for review prior to shipment.

d. Pipe to be shipped by barge, ship or truck shall be loaded as agreed upon by the Manufacturer and the Purchaser.

WARRANTY

Manufacturer shall furnish the conditions of warranty regarding the pipe to be furnished including the conditions of a seek and find repair clause in the field due to mill defects.

3.5 PRELIMINARY WELDING PROCEDURE

In order to establish preliminary welding procedures to be utilized in the construction of the Alcan 42" pipeline system, Gulf Interstate Engineering has been in contact with Lincoln Electric Company of Cleveland, Ohio, and has furnished to them both the chemistry of the pipe proposed to be used and Gulf Interstate's recommendations as to the welding procedures.

Definitive welding procedures cannot be established until pipe samples have been obtained and welded under these procedures. However, tests have been run on similar pipe which reveal that this welding procedure is in fact effective and produces welds of acceptable quality under governmental rules and regulations.

It is intended that for the double jointed pipe that Lincoln's 790 Flux and L-70 wire, or equal, can be utilized without preheat. For the line pipe, Lincoln 65+ rod/or equal will be utilized with preheat up to 200-300°F. Hot pass welders and stripper welders will follow stringer beads so as to deposit sufficient and adequate weld material so that overnight temperature effects will not be detrimental to the welds. Three beads will be deposited in sequence before the conclusion of the day's work. Back-end welders will then complete the weld and the quality of their work will be confirmed by x-ray inspection and the interpretation thereof.

3.6 HYDROSTATIC TEST SPECIFICATIONS

Pipeline hydrostatic testing will be performed after backfilling. The pipeline will be tested in accordance with the Code of Federal Regulations, Part 192, Title 49, "Minimum Federal Safety Standards: Transportation of Natural and other Gas by Pipeline."

The minimum test pressure will be 1.1 times the design maximum allowable operating pressure using water as the test medium.

Compressor station piping, road crossing piping, meter station piping, mainline block valves and river crossings will also be tested in accordance with the Code of Federal Regulations, except that the minimum test pressure will be 1.5 times the design maximum allowable operating pressure using water as the test medium. Hydrostatic testing will be carried out during that part of the year when freezing conditions are not likely to occur.

The pipeline will be tested in segments, the lengths of which will to a large extent be dependent upon the pipeline route elevation changes. Test segments will be chosen so that the minimum required test pressure is developed at the highest elevation on that test segment while the pressure concurrently developed at the lowest point in the test segment will not cause an internal tangential stress of more than 95 percent of the yield strength of the pipe material. Each segment will be tested to the above minimum pressure specification for a minimum of 24 hours. Pressures will be verified by dead weight gauges and a continuous record of pressures and temperatures will be obtained by recording instruments.

Following the hydrostatic test all water used will be treated and tested to minimum State and Federal Environmental standards before being returned to the natural drainage.

3.7 X-RAY SPECIFICATIONS

Non-destructive testing by x-ray inspection will be performed on all (100%) of the girth welds on the main pipeline as well as the girth welds on the main gas suction and discharge lines and the propane refrigerant piping within the compressor station yards and all meter station gas piping.

Records of all x-rays will be retained for the life of the pipeline along with all pertinent data such as milepost, engineering station, or geographic features.

X-ray testing will be carried out in accordance with API Standard 1104.

Alcan Pipeline Company
Docket No. CP76
Exhibit Hearing No.____

EXHIBIT Z2-4

STATION DESIGN

Alcan Pipeline Company
Docket No. CP76
Exhibit Hearing No.____
Exhibit Z2-4

STATION DESIGN INDEX

DRAWINGS

4.0 COMPRESSOR STATIONS

Location

Compressor stations will be located at points which will allow the horsepower requirements at all stations to be approximately equal. These proposed station sites are:

Station No.	Mileposts	Elevation	Main Gas Compressor Installed ISO Horsepower
1	43.5	410	26,500
2	83.7	1,050	26,500
3	118.6	2,575	26,500
4	157.7	2,955	26,500
5	210.8	1,405	26,500
6	261.9	1,360	26,500
7	305.9	1,371	26,500
8	355.0	1,000	26,500
9	400.7	960	26,500
10	442.6	1,360	26,500
11	497.4	806	26,500
12	543.6	1,223	26,500
13	590.3	1,598	26,500
14	639.4	1,649	26,500
15	684.1	2,225	26,500

Station Description

Basically all compressor stations will be designed and equipped for unattended operation. That is, they will not require on site operating personnel on a 24 hour basis. Operators will be dispatched from the district bases to visit the compressor stations to perform routine equipment checks, effect minor adjustments, repairs, etc. This philosophy has been followed on all stations, even those located in close proximity to the four district bases.

All compressor stations will include equipment for natural gas compression, refrigeration and control; individually designed foundations for each site; buildings to house personnel and equipment; and auxiliary systems for electrical power, heating, communications, automation and instumentation.

Each compressor station will be equipped with one 26,500 horsepower gas turbine-driven single stage centrifugal mainline gas compressor unit. These two-shaft variable speed units will be integrally designed and totally packagea o be self-contained. Natural gas from the pipeline will supply the fuel requirements.

All equipment, within practical limits will be mounted on a single baseplate for easier field erection. The unit will be installed in a building adequately sized and ventilated for safety and service. Major components of each of the mainline compressor units will include:

- Aircraft derivative gas generator
- Industrial type two-stage power turbine
- Single stage centrifugal gas compressor
- Inlet air filter, silencer and plenum chamber
- Anti-icing system
- Exhaust silencer and stack
- Lubricating and seal oil systems
- Explosion-proof electrical equipment
- Automatic control system
- Anti-surge control system

The gas turbines and compressors will pass comprehensive tests at their place of manufacture and assembly prior to shipment to the job-site. Also, the automatic controls, including start-up and shut-down sequencing, will be checked prior to shipping. The automatic control system for each unit will provide for local and remote starting, operating and shutdown. The basic gas turbine control system will be electronic.

Controls and Instruments

Compressor station control will be by means of a programmed sequence having appropriate checks at various stages throughout the sequence. The start/stop sequence control will be remotely initiated with provisions for local manual override. The stop sequence will be designed to safely unload the compressor and shut down the machine either as a command stop or as an emergency stop.

The variables which indicate the unit performance will be measured and regulated according to the demand of the system or according to unit performance limitations. Auxiliary systems will be monitored, and annunciation of improper conditions will provide a warning, as well as an indication of the trouble.

The protection system will consist of devices which will actuate to safely shut down the machine or annunciate a potentially dangerous condition. All malfunctions will be annunciated.

Control devices will be 24 volt DC, except for certain electronic instruments which require 110 volt 60 Hz power. The 110 volt power will be obtained from an inverter to be operated from a 24 volt battery source.

Sensing devices and transmitters will be mounted on the compressor unit. This control equipment will meet the requirements for a Class 1, Group D, Division 1 location specified by the National Fire Protection Association, Standards and Codes.

An auxiliary instrument panel will be mounted in close proximity to the unit. Gauges will be included to locally monitor critical operation parameters. Auxiliary operating instrument panel mounted equipment will also meet Class 1, Group D, Division 1 location requirements.

Emission Level

The typical compressor station particulate emission level will be in accordance with the latest Federal and State Environmental Standards.

Noise Level

The gas turbine exhausts, relief and vent valves will be constructed in such a manner as to restrict noise levels to applicable Federal and State Standards or less.

In addition, all personnel will be required to wear approved "safe-sound" ear protectors when working in the vicinity of this equipment.

Figures 4.2.1 and 4.2.2 are graphic representations of a typical compressor station.

Discharge Gas Chilling System

The compressor station discharge gas will be chilled to mitigate the possibility of thawing the permafrost. The objective is to control the temperature of the gas in the line so that at all times it is lower than the melting point of the permafrost.

Temperature control will be achieved by monitoring both station discharge temperature and the suction temperature of the next station. The critical temperature of the two monitored will control, therefore refrigeration requirements will be minimized. Probes will be placed along the pipeline to monitor the effect of discharge temperature. Results will provide data in optimizing refrigeration requirements.

Refrigeration will be provided at all compressor stations with discharge temperatures both locally and remotely adjustable. The major system components will include a propane compressor and condenser and a natural gas heat exchanger (chiller).

Two stage centrifugal propane compressors driven by gas turbines will be housed in a building adjacent to the chiller building. Electric motor-driven air cooled propane condensers will be located away from the turbine air intake to prevent the turbines from sucking air from the condensers.

Compressed propane gas will flow from the refrigeration compressor to the air cooled condensers. In the condenser, the propane will be cooled and liquefied. The liquid propane will then flow from the condensers to the natural gas chillers where expansion cooling will occur. The cooling cycle will be completed with the propane gas refrigerant flowing from the natural gas chillers back to the refrigeration compressor suction.

Packaging, control, instrumentation, and installation of the refrigeration units will be the same as outlined for the mainline gas compressor units.

Fuel and Starting Gas Systems

The gas for starting and fueling the mainline gas turbine compressor units will be taken from the station suction piping downstream of the station fire gate valve. The gas will be metered and supplied as required by the unit. Other required fuel and starting gas will also be taken from the same source.

The fuel gas will be routed through a fuel gas scrubber and preheater where it will be cleaned and heated, regulated to an intermediate pressure, and metered. Intermediate and low pressure gas only will be routed through the utilidors, utilities building, propane compressor building and living quarters.

An individually metered stream of fuel gas will be routed to the propane compressor building for starting and fueling the refrigeration compressor units.

All other fuel gas will be routed to the utilities building where it will serve as fuel for the gas turbine generators. Fuel for the turbine generators will be individually metered.

fuel for the living quarters will be used for cooking and water heating.

Electrical System

Electrical power will be provided by three gas-fired, 1140 ISO HP turbine generator sets, each producing 800 kw. These sets will be capable of operating singly or in parallel. Three phase power will be generated at 480 volts, 60 Hertz, and distributed to each building. Feeders will be enclosed in rigid conduit and routed through the utilidors.

Two 800 kw generator sets at each station will normally supply power for all life support systems and station operations. One unit will always be on standby duty and will activate automatically in case of a loss of a unit in the primary power supply. Feeders to the station living quarters will be isolated to assure the availability of electricity for life support.

The generator sets will be standard production units designed for continuous operation. The basic set will consist of a gas turbine, reduction gearbox and generator. To the extent possible, operating systems will be mounted on a single rigid base. The completely packaged and factory tested set will only require fuel, starting and control power, and the interconnections to make it operative.

Fuel and starting power for the generator sets will be natural gas, supplied from the pipeline. All three 800 kw sets at each compressor station will be equipped for dual-fuel operation to allow the use of diesel fuel in emergencies and during station start-up. The system will provide for starting on either gas or diesel and the mode can be switched during operation.

The generator sets will have a complete integral lube oil system. This system will include a skid-mounted oil reservoir, a lube oil pump and an air-to-oil cooler to be mounted off the generator skid. The lube oil reservoir will have provisions for external heating.

The generator will maintain efficient performance when the load is varied from no load to rated load. The sets will include controls for steady state voltage regulation, transient voltage regulation, voltage drift, overload capabilities for short periods of time and short circuit capabilities up to 10 seconds.

The sets will have an automatic control system and a floor standing panel for local and remote control. The primary function of the generator control system will be to provide sequencing during starting, running and shutdown; to provide necessary protection during all phases of operation; and to monitor critical parameters during operation. The panel will be mounted near the generator set. A second panel duplicating select controls and indicators will be mounted remotely in the station control room.

The gas turbine generator sets will be enclosed for sound attenuation and will be installed in equipment rooms adequately sized and ventilated for safety and service.

Hot Water/Glycol Heating System

A hot water/glycol system will be used for space heating and for heat exchanger service. The hot water/glycol heating will be safe within buildings having potentially hazardous atmospheres. The basic space heater will be a wall mounted unit with forced air across hot finned water/glycol tubes.

The system will be a closed system using a waste heat water heater ducted to the exhaust of the 800 kw generator units to heat a mixture of water and glycol. Electric-driven centrifugal pumps will circulate the hot mixture to each building. The water heater and the circulating pumps will be located in the utilities building.

The water/glycol piping will be insulated to retain heat, and generally routed within the utilidors.

Instrument and Utility Air Systems

The instrument and utility air will be provided by a dually powered air compressor. Normal power will be supplied by an electric motor with a small diesel engine used as a source of emergency power. The unit will be sized to supply full station requirements. Compressed air will be supplied through separate systems to the main gas compressor building, propane compressor building, chiller building, and to the utilities building.

For safety reasons, the instrument air will be used within buildings to power pressure control valves, vent valves, recycling valves, purge valves, small valve operators, louvers and pneumatic instruments. The utility air system will be used for power tools, cleaning or other maintenance operations.

The low volume instrument air will be filtered, dried and refiltered prior to leaving the utilities building. The higher volume utility air will be compressed ambient air delivered to an adequately sized receiving tank from which it will be distributed to various building outlets.

Centralized Control System

Equipment to control and monitor the station prime movers will be located in a control room in the utilities building. Each prime mover will have a vendor-supplied panel providing manual and automatic start/stop sequence control, unit status monitoring. Automatic start/stop sequencing for prime movers will be interlocked with appropriate safety and control devices to insure that the machine will be started properly.

Central monitoring of station operations will be provided by a panel that will schematically represent major piping and equipment. Status (on/off, open/close, percent of travel, etc.) of significant valves and equipment will be displayed on the panel. A relay-type annunciator will sound the alarm in case of abnormal conditions, and, if appropriate, protective measures (sequenced shut-down emergency stop, etc.) will be initiated.

An emergency shut-down system (ESD) will be included with actuators appropriately located throughout the station. The system when activated will shut down the station and vent all gas piping and equipment, and shut down the normal electrical power supplies.

Valves

All large station valves will be ball type valves with ends and trim to suit the design service. Valve operators will be air piloted, gas-hydraulically powered, and electrically actuated.

Inlet Gas Scrubber

Gas scrubbers will be installed in the suction piping and fuel gas piping of each compressor station.

Fresh Water

Fresh water will be used only in the living quarters and in the closed water/glycol systems. Fresh water will be trucked to the sites and/or drawn from local wells and stored inside the utilities building.

Sewage and Waste Disposal

Sanitary facilities will be located only in the living quarters and utilities building. Collected sewage will be temporarily stored, hauled away, and disposed of by methods approved by Alaskan authorities, and other applicable Federal and local codes.

Protection Against Corrosion

All steel structures, piping and closed water systems will be protected against corrosion. The above ground steel structures will be protected by painting. Below ground piping will be coated, wrapped and protected by the pipeline cathodic protection system. The closed water systems will be protected by rust inhibitors.

Fire Fighting System

Fire fighting equipment will be provided in all buildings.

All buildings will have an automatic fire detection and alarm system. Each detector and alarm system will report as a zone into a master panel located in the station control room.

All buildings will have either an automatic fire extinguishing system or an appropriate number and type of hand-held portable fire extinguishers with some buildings equipped with both systems.

First Aid Equipment

First aid equipment and supplies will be located in the living quarters at all compressor stations and maintenance bases. All personnel will be trained in the use of this equipment.

Buildings and Sites

Buildings located at the compressor station sites will be of two types. Major structures will be rigid frame buildings with prefabricated panels. Minor structures will be preconstructed sectional units.

The compressor station sites will be covered with a gravel pad to prevent thaw penetration into the underlying permafrost.

Gravel pads at each individual site will be of uniform thickness with a slight slope to the area perimeter to provide drainage for precipitation and snow-melt. Gravel pads will vary in thickness from site to site depending mainly on the mean daily air temperatures during the thawing season, length of thawing season and existing surface and sub-surface conditions.

The material used for pads will be non-frost susceptible sand and gravel.

North of the Brooks Range, pads will be designed such that the entire zone of freezing and thawing will be contained within the gravel fill material. Fill material will be placed by end dumping and compacted by construction traffic to minimize disturbance to the vegetated surface.

It is anticipated that pad thickness of five to six feet will be required at stations located in areas of permafrost.

At other stations, six feet of gravel fill will be used to prevent the thaw penetration into the soil.

At some stations, it is anticipated that bedrock, overlain with residual soils, will be found at a depth of five to eight feet. In these instances, gravel pad requirements will depend on the actual conditions encountered, but it may be possible to prepare existing soils in such a manner that little off-site gravel will be required for these construction pads.

Foundations

Foundations for equipment and buildings at the various compressor station sites will be individually designed to accommodate the existing soil conditions.

The following are notes on the geology of each of the individual stations sites as derived from a field trip conducted on 6/16/76.

Field Trip Notes of 6/16/76 by Howard Grey
Site Visit to 15 Proposed Compressor Station Sites
Gas Pipeline Project

METER STATION NO. 1

Prudhoe/Deadhorse

The proposed Meter Station is to be located in the general vicinity of the oil pump station No. 1. The significant surficial features include several shallow lakes and ponds together with polygonal ground, which indicates the presence of vertical ice wedges. The polygons are generally low centered (as opposed to high centered) and indicative of poor drainage.

The area is covered by an organic mat created by the decomposition of successive layers of tundra vegetation under swampy conditions. At shallow depth beneath the organic mat, the soils generally consist of a few feet of silts and sands. These are generally in turn underlain by poorly graded gravels composed of resistant rock types (i.e. cherts, quartz, etc.).

Although the soils in this area are normally frozen to great depths, it is anticipated that thaw bulbs will be present beneath the larger lakes and ponds. In some instances, the thaw bulb condition can be used to advantage in foundation construction.

COMPRESSOR STATION NO. 1

Approx. Four Miles South of Franklin Bluff Camp

This site has been tentatively located adjacent to the Sag River flood plain. In the flood plain, the subsurface soils will generally consist of gravelly sands and sandy gravels with occasional silt lenses. It is expected that the gravels will be unfrozen within the flood plain thaw bulb, although surficial freezing will occur during winter months.

The soils immediately adjacent to the flood plain are, in general, frozen but poor draining. Extensive areas of polygonal ground are visible, indicating the presence of vertical ice wedges. At the time of our inspection, much of the area immediately adjacent to the flood plain was covered by from six inches to one foot of water.

As with the oil pipeline in this area, it may be advantageous to locate the station above the unfrozen gravels within the flood plain. Careful attention should be paid to locating the site at a somewhat higher elevation than the river; otherwise, extensive quantities of fill may be required to attain sufficient elevation. Since the site is likely to be subject to flood hazards and related erosion, rip-rapping or other means of bank protection will be required.

COMPRESSOR STATION NO. 2

1/2 Mile South of Happy Valley Camp

The Station has been tentatively sited in the Sag River flood plain, near the middle. The subsurface soils are expected to consist primarily of sandy gravels and gravelly sands with some interbedded silts. The area should be within the flood plain thaw bulb, with surficial freezing taking place during the winter months.

The banks of the flood plain are expected to be composed of frozen silty sands, with a relatively high ice content. Polygonal ground is visible but not to the extent noted in the vicinity of Station No. 1 .

The best foundation conditions are likely to be found within the flood plain. At the same time, extensive filling and rip-rapping are likely to be required. During the spring and early summer, site access may become a problem if the roads are washed out due to flooding.

COMPRESSOR STATION NO. 3

Approx. 12 Miles South of P.S. No. 3

The Station has been tentatively sited between the pipeline and a small creek. The area is at an elevation of 15 to 20 feet above the creek and gently rolling. It is expected that the site soils are frozen to a considerable depth.

The surficial soils are indicative of a ground moraine. Large boulders are visible at the surface and in the creek bottom. It is expected these large boulders are present in a matrix of poorly consolidated silts and sand with a fairly high ice content. Available geologic data indicates the adjacent ridges are composed of Cretaceous sediments including sandstones and shales.

We expect the site soils will be subject to considerable settlement if thawed. If possible, consideration should be given to shifting the location to one of the adjacent ridges where there is a higher probability of encountering rock. In this regard, consideration might be given to the materials site south of this location.

COMPRESSOR STATION NO. 4

2 Miles South of P.S. No. 4

The area inspected is on a bank above the adjacent river flood plain. Although coarse gravels are apparent at this site, they have been deposited on a silt matrix which is likely to have a high ice content and thus be thaw sensitive. The oil pipeline has been constructed above grade in this vicinity.

The adjacent hills are in part composed of Cretaceous sediments. The lower flanks of these hills are generally composed of material derived from decomposition or erosion of the more well indurated rock types. As a result, conditions can vary over a relatively short distance.

COMPRESSOR STATION NO. 5

8 Miles South of Dietrich Camp

This is an area of gently sloping ground above and east of the river. Some rock exposures were noted in the river bank, which is quite steep and on the order of 20 to 25 feet in height. Above the rock, soil conditions may consist of terrace gravels overlain by colluvial or alluvial silts. Although it is difficult to ascertain based on visual reconnaissance, it appears that the soils become finer grained adjacent to the valley walls.

It is expected that all soils will be frozen (permafrost) with the silts being particularly thaw sensitive. Since the pipeline is fairly close to the river bank, it may be necessary to shift the Station site upslope (possibly encountering a thicker mantle of silt). With additional field reconnaissance, it may be possible to locate the site above a shallow bedrock exposure.

Localized faulting should be expected in this general vicinity.

there is bedrock along the ridge top although it is discontinuous. Where discontinuous, the soils consist of deep wind blown silts in a frozen condition with a high ice content. The shallow bedrock would provide for good to excellent foundation conditions whereas the silts would be thaw settlement sensitive.

The Compressor Station should be carefully sited so as to take advantage of shallow bedrock. Available geologic data indicate rock is present in the vicinity of the disposal area.

COMPRESSOR STATION NO. 9

Approx. 4 Miles South of Livengood Camp

The Station will be located on the ridge line south of Livengood Camp. Many cut slopes are visible on the oil line right-of-way which generally show bedrock under a soil cover. Available geologic data indicates the bedrock is composed primarily of graywacke and shale. As with Station 8, the bedrock may not be continuous along the ridge line and where absent the soils are likely to consist of ice rich silts. With careful siting, good foundation support can be obtained from the shallow bedrock. It should be noted that the Geologic Survey maps indicate this area has some regional faulting.

COMPRESSOR STATION NO. 10

The site is on a ridge top in the general vicinity of where Murphy Dome Road intersects the pipeline right-of-way. At the time of our inspection, pipe was being placed in trenches excavated into shallow bedrock. Both the bedrock and thin soil cover in this area are likely to be frozen.

This general area should provide excellent foundation conditions if founded on bedrock.

COMPRESSOR STATION NO. 11

11 Miles South of P.S. No. 8

The area inspected is a fairly gentle sidehill above the pipeline, a little north of Redmond Creek. There are no apparent drainage problems, although available data indicates the area is underlain by frozen silts which will be thaw settlement sensitive. If the soils are silts, even moderately high cut slopes may become unstable.

COMPRESSOR STATION NO. 6

3 Miles North of P.S. No. 5

The area inspected is near the north end of Grayling Lake. The flanking ridges to the west consist of conglomeritic sandstones, whereas those on the east consist of granites. It is expected that the side slopes will be formed on colluvium with some gravels being present in the creek bottom. The soils should generally be frozen although a thaw bulb may be present in the valley bottom adjacent to the lake and related ponds. The oil pipeline is above ground in this area.

Due to limited space, some difficulty may be encountered in obtaining sufficient useable acreage in this area. The hillside soils above the pipeline are likely to be ice rich and thus unstable in large cuts as the materials thaw. It is possible that a sufficiently large site can be created between the roadway and pipeline although the soils may likewise be sensitive to thaw.

COMPRESSOR STATION NO. 7

3 Miles South of Old Man Camp

The Station is tentatively located near the base of the hill on the west side of the oil line. Geologic data indicates the adjacent hills are composed of igneous rocks. Talus is present on the upper portion of the slope.

The lower portions of the slope near the pipeline vary from nearly flat to moderately sloping. The more level portions display a heavy tundra mat and are likely underlain by thick deposits of frozen silt. Although soils beneath the sloping portions are also likely to be frozen, there is a strong possiblity that coarser materials containing less ice would be present.

The oil pipeline in this area is above grade where the ground is relatively flat but buried where sloping.

COMPRESSOR STATION NO. 8

1/2 Mile South of P.S. No. 6

This site will be located on a ridge top immediately south of Pump Station No. 6, near the Yukon River crossing. Based on exposures and available geologic data, There is a possibility that the silts may be interfrozen with coarser alluvial materials in this area. This possiblity should be more fully explored since gravels would provide for better foundation conditions.

COMPRESSOR STATION NO. 12

1000 Feet East of AK Hwy. Milepost 526

Station No. 12 will be located in a hilly area, possibly on high ground adjacent to a tilled field. Exposures in the area indicate the soils will consist primarily of sand and gravel although a silt mantle may be present on top.

Shallow ponds and wet areas are visible in the low areas in the vicinity. Thus the site should be selected on the higher ground. Due to the irregular topography, a moderate amount of cutting and filling may be needed to develop a large flat site.

COMPRESSOR STATION NO. 13

1000 Feet East of AK Hwy. Milepost 479

This is to be located on a broad alluvial fan or terrace deposit above the nearby flood plain. The area is gently undulating with several wet drainage channels and shallow swamp areas. The swampy areas should be avoided if possible but they appear shallow and could likely be drained and filled if necessary. The largest swampy area noted covered about two acres.

It is expected the soils will primarily consist of gravelly sands and sandy gravels which should provide relatively good foundation conditions.

COMPRESSOR STATION NO. 14

This station is to be located in the general vicinity of the existing Haines Pipeline Pump Station. The ground is generally level and the soils consist primarily of sands and gravels derived from alluvial fan deposition. Several pits 8 to 10 feet deep were visible with no indication of high groundwater conditions. These gravels should provide excellent foundation conditions.

The present tank farm is located on an isolated hill behind the pump station. Numerous exposures indicate the hill is basically a basalt bedrock knob protruding through the alluvium. The hillside would also provide for excellent foundation support but blasting is likely to be required for major cuts.

In summary, few problems are anticipated with this site. Some care should be taken to watch for localized trash dumps which have been covered with gravel.

COMPRESSOR STATION NO. 15

This Station may be located in or near an existing materials site where a considerable quantity of gravel is being stockpiled. The materials site is well above the adjacent flood plain and would have excellent foundation characteristics as well as a low watertable. The Station could be located in the valley bottom although groundwater may be high depending on the location.

The main problem with the materials site is its small size. It is situated on the flank of a broad hillside which becomes somewhat steeper above the road. Thus extensive expansion up the slope could result in a massive cut at the rear of the site. A site of adequate size could be developed by staying low on the hillside and perhaps placing some fill into the adjacent valley.

Meter Stations

Two mainline meter stations will be required for this pipeline. One will be located at Prudhoe Bay in close proximity to the producer's gas processing plant. The other will be located at the Alaska/Yukon border near Scottie Creek.

The mainline meters will have orifice tubes designed to handle the maximum anticipated volume with orifice beta ratios of about .65 and a maximum differential of 100 inches of water.

The orifice meter runs will be designed for interchangeability between the two stations. The runs will consist of 24 inch O.D. tubes with straightening vanes and senior type orifice fittings. The maximum allowable working pressure will be 1250 psig with a design factor of .5. The number of tubes required at both meter station sites will be five (see drawings 4.2.3, 4.2.4, 4.2.5, and 4.2.6).

The design will include automatic switching to maintain a satisfactory differential regardless of changes in flow rates.

The flow will be calculated by a digital gas flow computer which can read out the flow rate and totalized flow for the individual tubes as well as the entire meter station.

The station sites will be surrounded by an eight foot fence with a drive-in gate, communications tower, a meter run building and a controls building.

In addition to the mainline meter stations, a smaller sales meter station will be required near Fairbanks to meter gas to this community.

This station will be similarly designed as the mainline stations except it will only contain three six inch meter tubes and two six inch regulator runs (see drawing 4.2.7).

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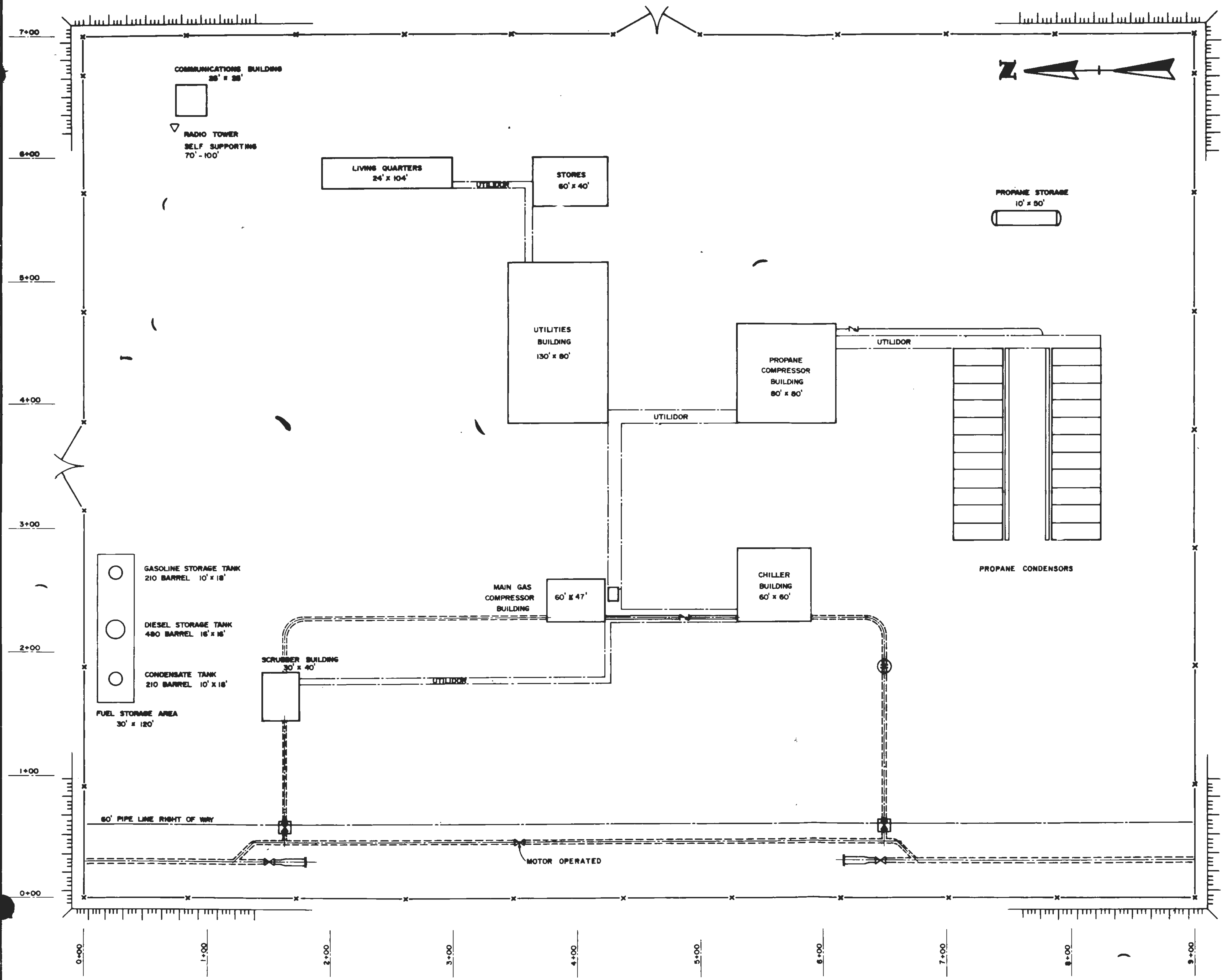
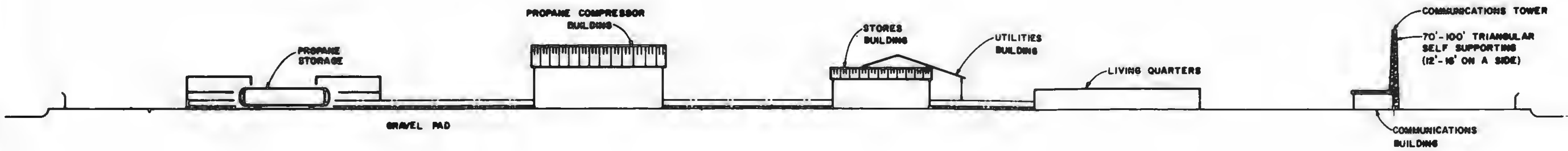


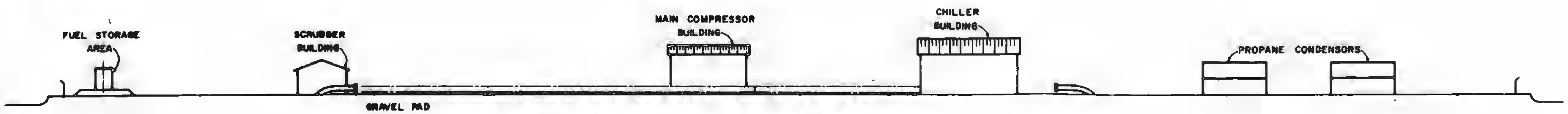
6-28-76

PRELIMINARY

GULF INTERSTATE ENGINEERING COMPANY		
ALCAN PIPELINE COMPANY		
TYPICAL STATION LAYOUT		
DRWN.	SCALE 1" = 80'	DATE JUNE 21, 1976
APPRVD. J.E.M.	DRWG. NO. 4.2.1	REV. NO. 0



VIEW FROM EAST SIDE OF STATION



VIEW FROM WEST SIDE OF STATION

7-2-76 ⚠

PRELIMINARY

GULF INTERSTATE ENGINEERING COMPANY		
ALCAN PIPELINE COMPANY		
TYPICAL STATION ELEVATIONS		
DRWN.	SCALE 1" = 80'	DATE JUNE 21, 1976
APPRVD. J.E.M.	DRWG NO. 4/2.2	REV. NO. 0

Alcan Pipeline Company
Docket No. CP76______
Exhibit Z-2-4
Hearing Exhibit No. __
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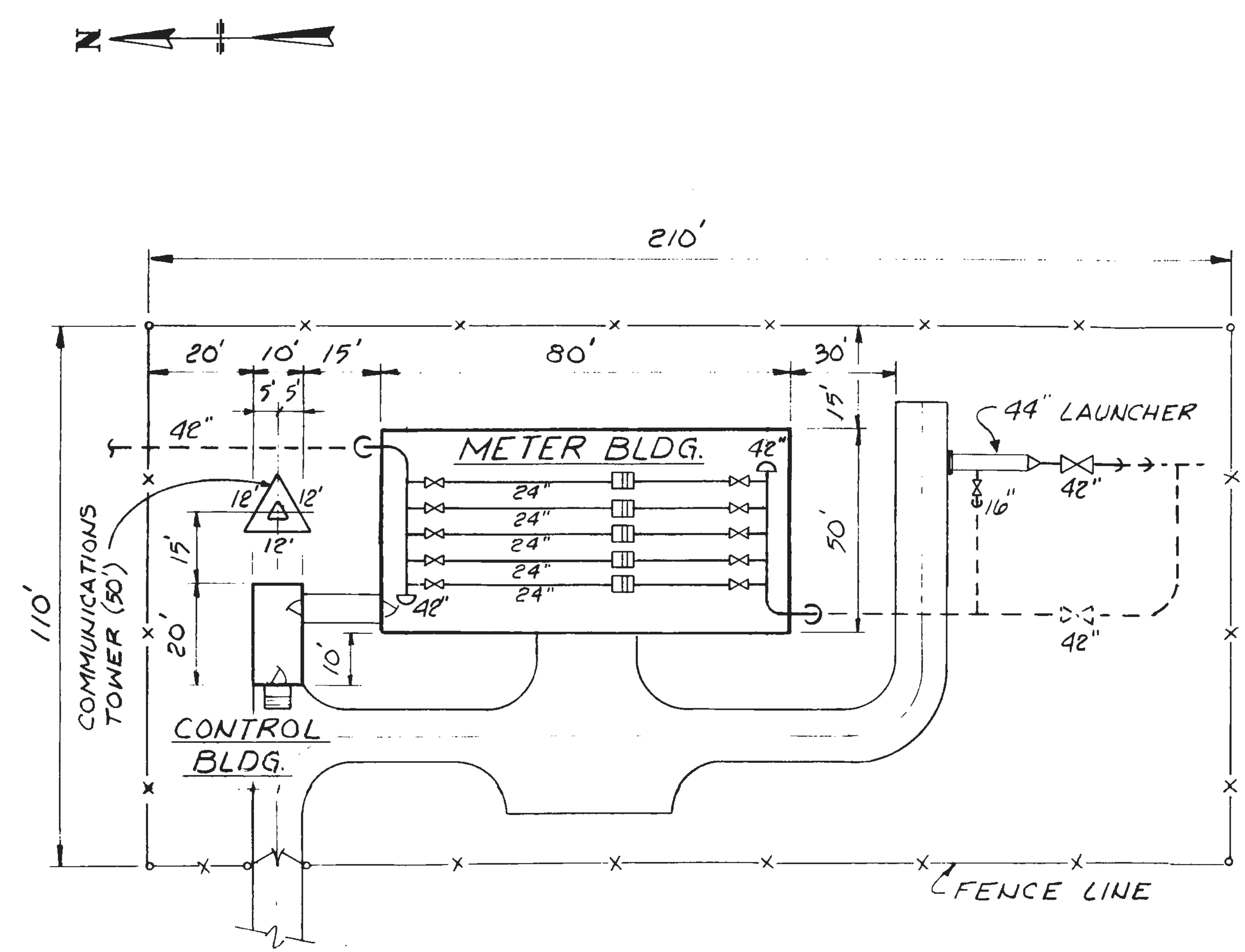
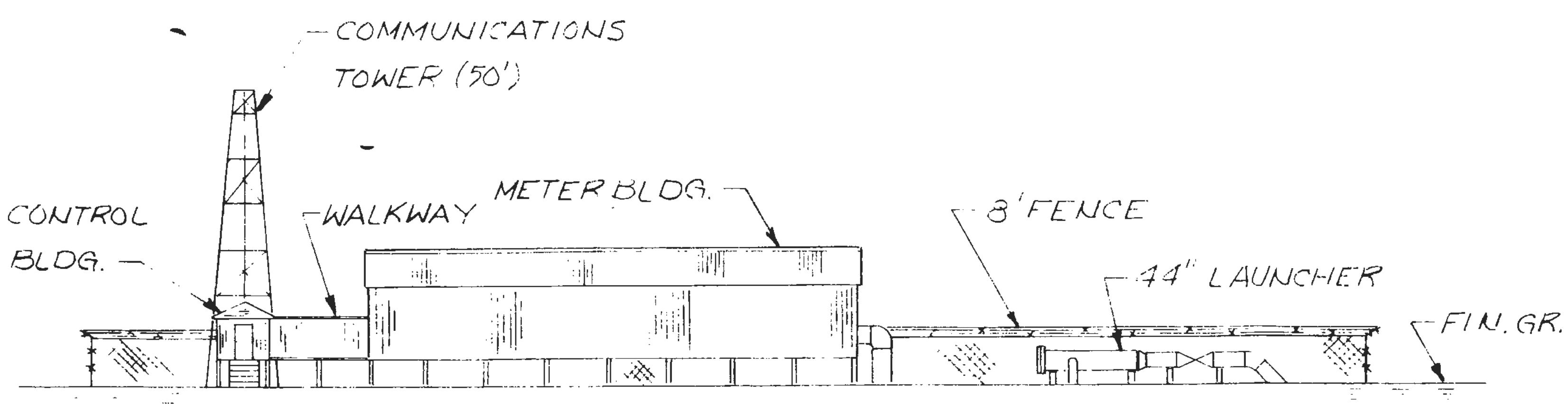


PLAN

2 6/25/76

PRELIMINARY

GULF INTERSTATE ENGINEERING CO.	
ALCAN PIPELINE COMPANY	
PRUDHOE BAY MAINLINE METER STATION	
DATE 6-24-76	SCALE 1" = 30'-0"
DRAWN BY PRESLAR	APPROVED
CHECKED BY JEM	JOB NO. 1198
APPROVED JEM	4-2-5



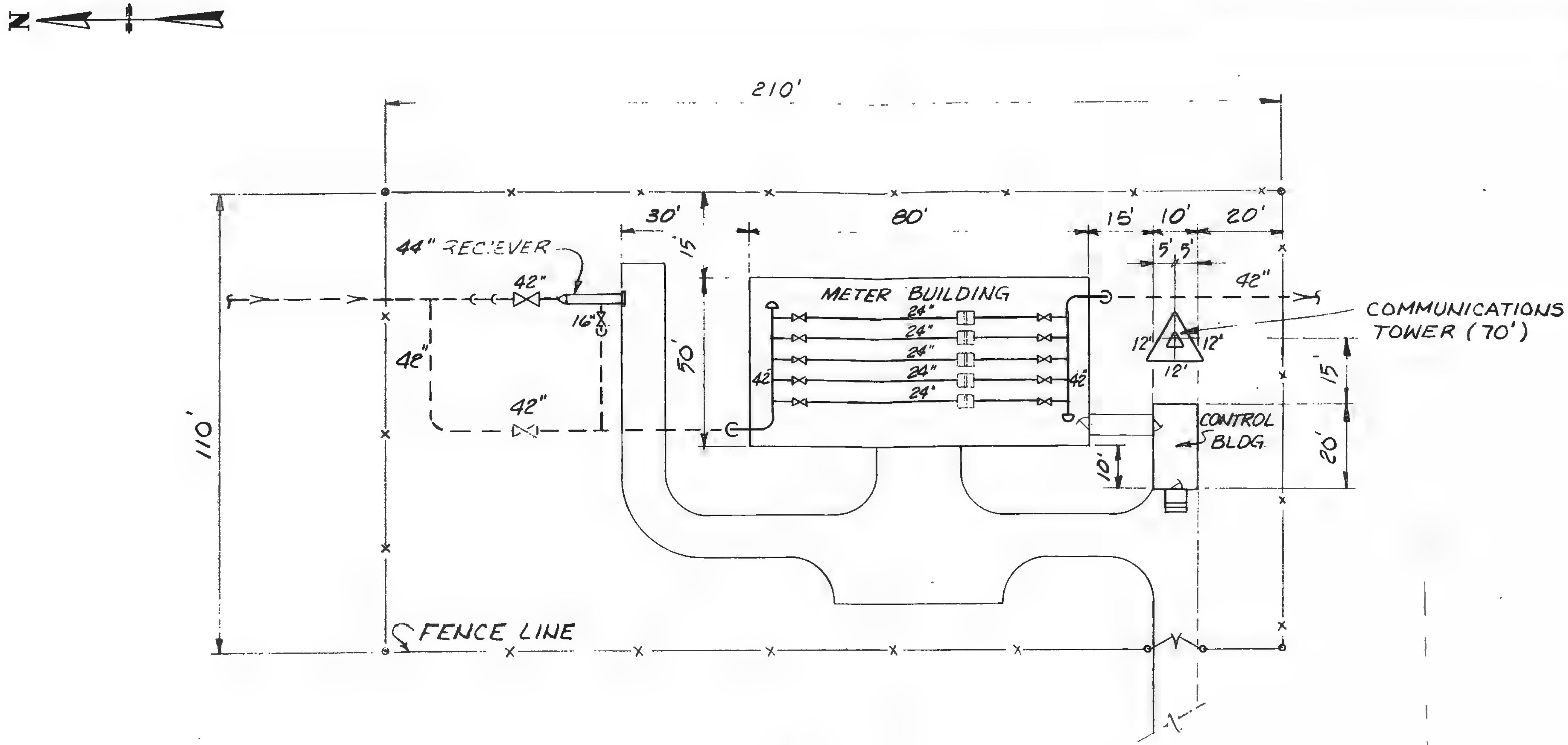
WEST ELEVATION

3 6/28/76

PRELIMINARY

GULF INTERSTATE ENGINEERING CO.	
ALCAN PIPELINE COMPANY	
PRUDHOE BAY MAINLINE METER STATION	
DATE 6/28/76	SCALE 1" = 30'-0"
DRAWN BY PRESLAR	APPROVED
CHECKED BY JEM	BOOK NO. 1198
APPROVED JEM	4-2-4

Alcan Pipeline Company
Docket No. CP76______
Exhibit Z-2-4
Hearing Exhibit No. __
Page 22 of 24



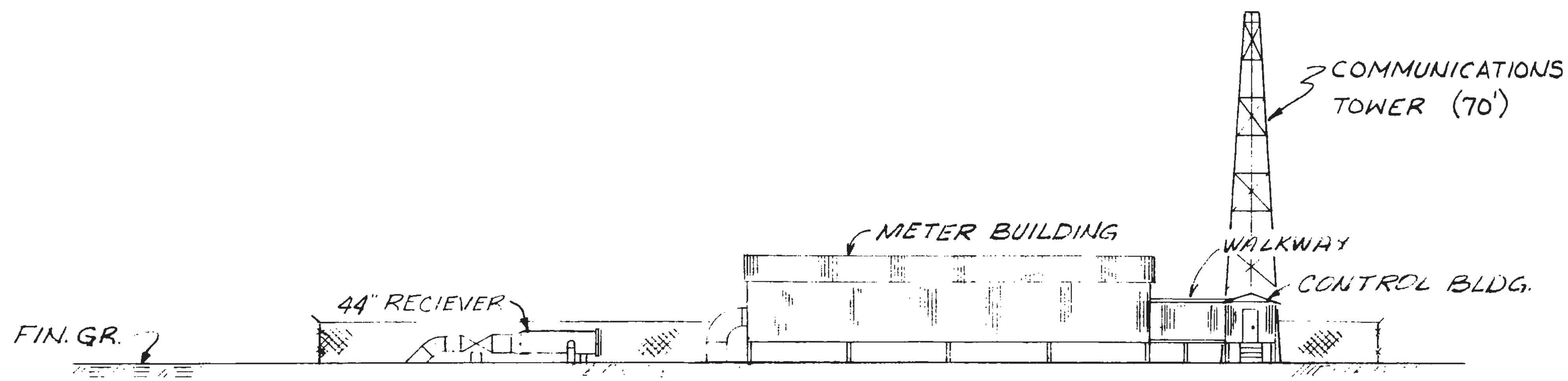
PLAN

6-29-76 4

PRELIMINARY

GULF INTERSTATE ENGINEERING CO.	
ALCAN PIPELINE COMPANY	
ALASKA/YUKON BORDER METER STATION	
DATE 6-24-76	SCALE 1" = 30'
DRAWN BY Eaves	APPROVED
CHECKED BY JEM	B No. 1138
APPROVED	4 2.5

Alcan Pipeline Company
Docket No. CP76_______
Exhibit Z-2-4
Hearing Exhibit No. __



WEST ELEVATION

6-24-76 4

PRELIMINARY

GULF INTERSTATE ENGINEERING CO.

ALCAN PIPELINE COMPANY

ALASKA/YUKON BORDER METER STATION

DATE 6-24-76	SCALE 1" = 30'
DRAWN BY	APPROVED
CHECKED BY JEM	JOB NO. 1198
APPROVED	4-2-6

Alcan Pipeline Company
Docket No. CP76______
Exhibit Z-2-4
Hearing Exhibit No. __
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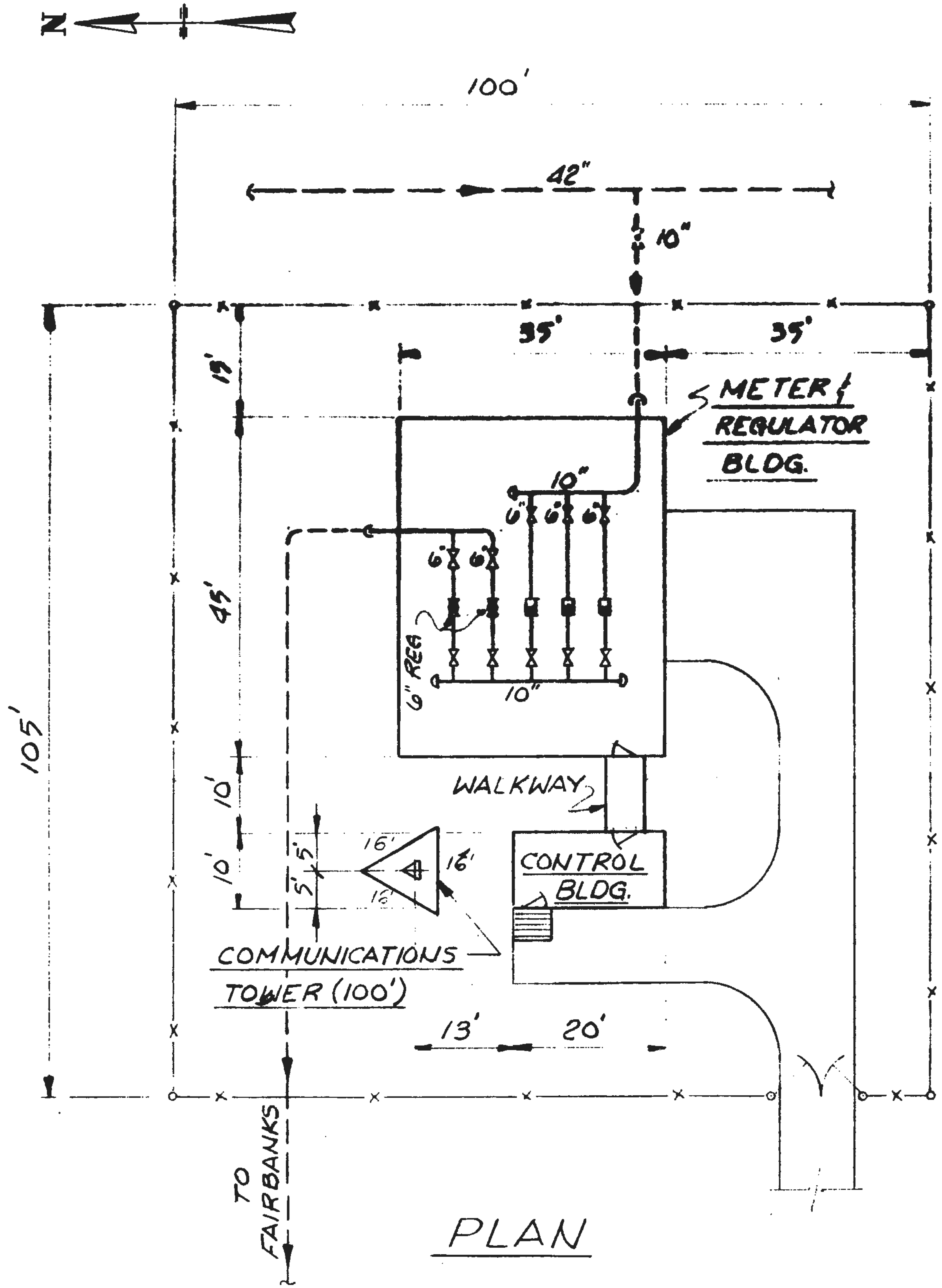
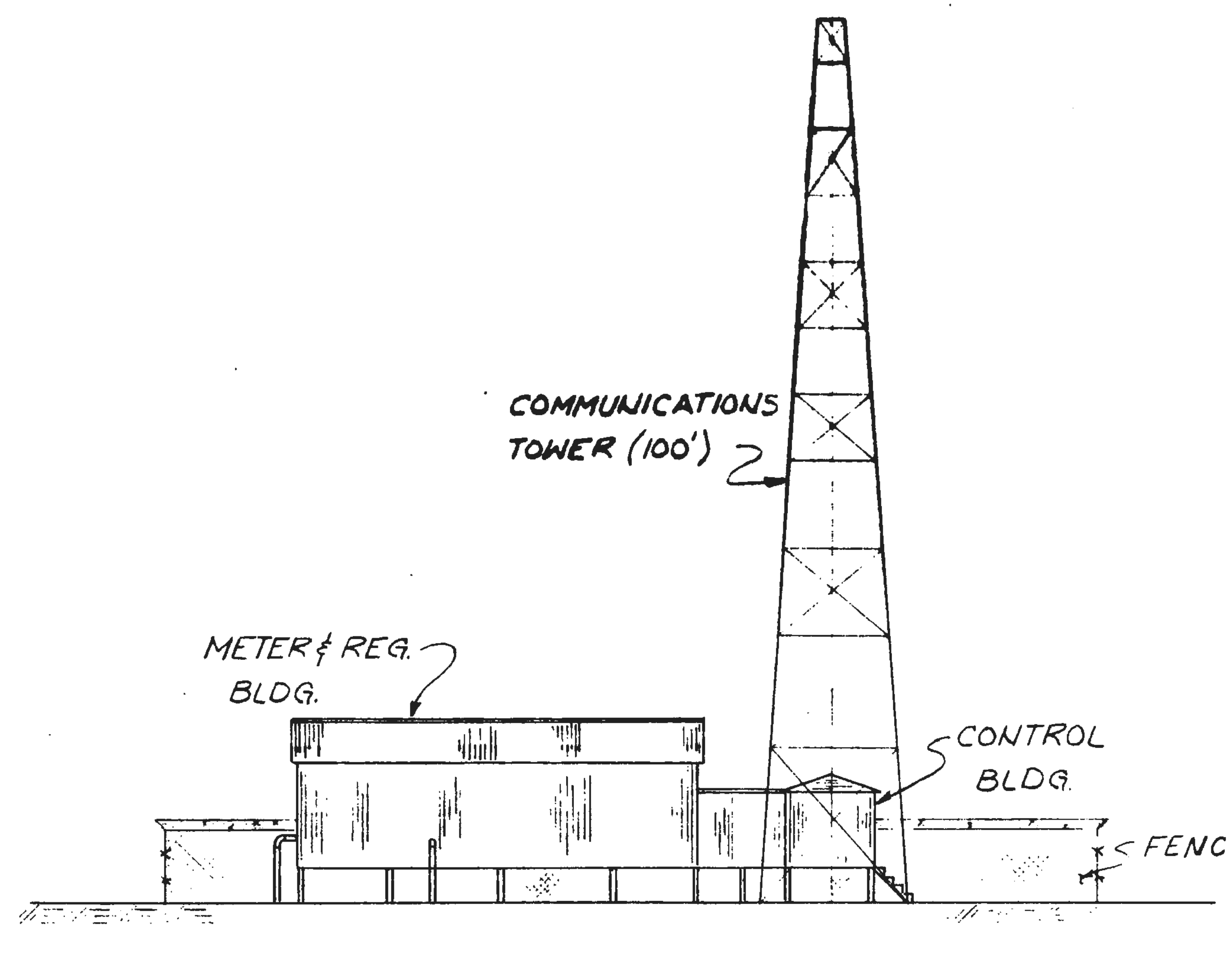


PLAN



SOUTH ELEVATION

△3 6-29-76

PRELIMINARY

GULF INTERSTATE ENGINEERING CO.	
ALCAN PIPELINE COMPANY	
FAIRBANKS SALES METER STATION	
DATE 6-25-76	SCALE 1" = 20'-0"
DRAWN BY PRESLAR	APPROVED
CHECKED BY JEM	JOB NO. 1193
APPROVED JEM	9-2-7

Alcan Pipeline Company
Docket No. CP76-
Hearing Exhibit No. ___

EXHIBIT Z2-5

COMMUNICATIONS AND CONTROL

5.0 COMMUNICATIONS AND CONTROL

5.1 COMMUNICATIONS

Voice and data channels required for normal voice communications, supervisory control and data acquisition, and mobile radio will be provided under existing tariffs by R.C.A. Alaska Communication.

Between Prudhoe Bay Metering Station and Delta Junction, the microwave backbone communication system serving the Alyeska Pipeline, in conjunction with necessary microwave spurs to respective compressor and metering stations, will provide the communication channels to the required locations.

Between Delta Junction and Alaska/Yukon Border Metering Station, a microwave system will be constructed by R.C.A. Alaska in accordance with Alyeska communication system construction standards, to provide a backbone system for the required channels serving locations in this area.

A dedicated group of 48 channels will be reserved on both backbone systems for Applicants' exclusive use. Adequate voice channels will be provided to interconnect Fairbanks Control Center, the four (4) District Offices, fifteen (15) compressor stations and three (3) metering stations on a dial selective basis. Dual channels will connect the Control Center with all compressor and metering stations on a dial selective basis. Dual channels will connect the Control Center with all compressor and metering station for use with Supervisory Control and Data Acquisition System. Three (3) voice channels will be provided for an auto-selective mobile radio system linking all mobile units with the Control Center and/or respective District Offices. In this system, a mobile user will automatically be switched to one of three channels for direct dial to desired office. Full duplex service is furnished by this system instead of the conventional half-duplex service usually provided.

Mobile radio base stations will be provided and maintained by R.C.A. Alaska while mobile units will be provided by Applicant.

5.2 SUPERVISORY CONTROL AND DATA ACQUISITION

Control objectives are to provide 1) Compressor capacity control, 2) Custody transfer quality metering facilities, and 3) System flow control.

These basic requirements will be satisfied by installing 1) a programmable station controller at each of fifteen (15) compressor stations, and 2) a computerized Supervisory Control and Data Acquisition (SCADA) System with Master Control located at Fairbanks and capable of routinely accessing Remote Terminal Units (RTU) located at each of fifteen (15) compressor stations and three (3) metering stations.

Station Programmable Controller

As previously stated in Station Design, the programmable station controller located at each compressor station is to be powered by an uninterruptable power system, and provide

1. Reliable automatic local control through use of conventional electronic instrumentation with set point adjustment of the station variable made manually or remotely through the supervisory control system.

2. Continued station operation under dynamic local control in the event of a communications failure between the Master Control Unit and the station.

3. Interlocked control circuit for each compressor so that subsequent required actions will be permitted only if all previously required actions have been satisfactorily performed in the intended sequence.

4. Necessary interlocks to prevent indiscriminate resetting of critical alarm and/or restarting of compressors, etc.

5. Independent emergency shut-down system for each control circuit which will automatically shutdown and isolate the respective controlled device from the station so as to protect personnel from any possible harzard and to minimize possible damage to equipment.

Supervisory Control and Data Acquisition System

The Supervisory Control and Data Acquisition (SCADA) System will consist of a Master Control Station, eighteen (18) Remote Terminal Units (RTU), and provide

1. Dual mini-computers at Master Control each having minimum expandable memory of 48K 16-bit words.

2. Additional bulk storage of 1.2 Megawords each computer.

3. Dual modems and redundant power supplies at each location.

4. Hardware consisting of three color CRT Displays, one logging and two input/output typewriters with card readers, Master Station Panel, Operator's Control Panel and Programmer's keyboard.

5. Routine capability of serially addressing each RTU requesting process data/status and providing commands as needed.

6. Routine logging, alarm scanning, engineering calculations in addition to basic supervisory tasks.

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EXHIBIT Z2-6

CONSTRUCTION PLAN

Alcan Pipeline Company
Docket No. CP76-
Exhibit Z2-6
Hearing Exhibit No.___

CONSTRUCTION PLAN INDEX

6.0 CONSTRUCTION PLAN

The following section details the Applicant's proposed construction plan, and the resources necessary to ensure efficient construction of the Alcan Pipeline system.

6.1 Construction Concept

The Applicant's construction concept is based upon a conventional construction program for civil and pipeline operations. Conventional construction practices and techniques will be utilized for most construction activities; where conventional operations must be modified for physical difficulties or environmental concerns, these modifications will be based upon successful construction techniques established during construction of the Alyeska project, or by construction experience on other northern projects.

Construction concepts, resources and schedules presented herein for the Alcan pipeline system have been shaped by the presence of existing facilities, by the history of construction in the pipeline corridor, and by the topography traversed by the pipeline route.

The construction program for the Alcan Pipeline system has been developed by giving full consideration to the following factors:

a. The Alcan Pipeline route will parallel the Alyeska Oil Pipeline or haul road from Prudhoe Bay to Delta Junction, a distance of 539 miles, and will parallel the Alcan highway and utilize the Haines Pipeline right-of-way from Delta Junction to the Alaska-Yukon border, a distance of 192 miles.

b. Use of the Alyeska work pad and haul road will make summer construction possible on that portion of the system paralleling the Alyeska Oil Pipeline.

c. Construction on that portion of the line from Delta Junction to the Alaska-Yukon border would, for the most part, be conventional summer conconstruction.

d. Construction support facilities - i.e., borrow pits, roads, camps, pipe yards, communications facilities, etc. are in place over the greatest part of the proposed route.

Construction of the Alcan system would be enhanced by experience gained from prior construction of the Alyeska Pipeline System. The construction of the Alyeska project has demonstrated that the construction requirements and costs of a major program in an area not serviced by transportation and communications systems are enormous. The extremely costly and complex civil construction and service facility installation programs and logistics requirements of the Alyeska pipeline serve to illustrate the scale of operations necessary for the construction of a large diameter pipeline in frontier areas. However, the Alcan pipeline project cannot be typified as a frontier-area construction project; on that portion of the Alcan route from Prudhoe Bay to Delta Junction, the construction program will benefit from the prior development of the Alyeska system. Both design and construction of the system on this portion of the route will utilize engineering data and civil and support infrastructure resulting from the Alyeska design and construction programs, including the following:

a. Construction of the Alyeska project has generated substantial field data necessary for design and construction planning of the Alcan system over the major part of the pipeline route, which can be made available to the successful applicant. This data includes the detailed geotechnical, environmental and archeological field work generated by Alyeska construction and provides a level of detail of design information which will make further extensive geotechnical and environmental field programs unnecessary.

b. The timing of the Alyeska project in relation to the Alcan project is such that existing temporary construction facilities can be made available for construction of the Alcan Pipeline. These facilities include construction camps, pipeyards, staging areas and borrow pits. Construction equipment utilized for Alyeska construction would be in place and available for Alcan construction.

c. Permanent Alyeska facilities would also be of considerable benefit in construction of the Alcan pipeline system, and in relatively lower system costs. These facilities include existing communications systems for contractor and project management use during construction; the haul road for ease of construction movement and logistics; and the Alyeska pipeline work pad, a great percentage of which could be used in Alcan pipeline construction.

d. Alyeska has found it necessary to modify normal construction procedures to provide for government guidelines and environmental restrictions applying to pipeline construction. The construction of Alyeska has resulted in established inspection procedures, a familiarity with the terrain traversed by Alyeska, an understanding and appreciation of the environmental constraints which must be applied to the construction of an arctic pipeline, and an understanding of the construction requirements and priorities of pipeline contractors.

e. A gravel work pad concept is proposed for Alcan system pipeline construction, and scheduling of the Alcan project has been designed to approximate that of the Alyeska pipeline system. Since a gravel work pad concept is presently being used in Alyeska construction, there are few new factors to be taken into account by engineers, contractors, and government authorities.

f. Use of a gravel work pad allows constructions from March through November. Also, if the winter is mild, a continuation of the construction schedule is available up to the Christmas Holiday period. This construction season has several definite advantages over construction during the coldest winter months in Alaska. These include greatly increased productivity of men and machines, avoidance of the uncertainties of working in the winter darkness, and the difficulties and uncertainties of snow road construction, avoidance of weather shutdowns due to white-outs, high North Slope winds and extreme cold. Another major advantage would be in the utilization of construction techniques implemented on the construction of the Alyeska line. Contractors on the Alyeska project have established construction procedures and practices which will be directly applicable to the construction of the Alcan Pipeline system. Costs of the Alcan project are very predictable, since construction will utilize these proven techniques.

On that portion of the line from Delta Junction to the Alaska-Yukon border, the Alcan Pipeline system will traverse terrain which is well suited to pipeline construction; the surficial geology, for the most part, consists of well-drained granular soils, with low or no ice content. Muskeg areas are intermittent, and comprise less than 15 percent of this portion of the route. Work pad and rip rap requirements in this area will not be a major construction or cost item. This portion of the pipeline would be installed in a well-established construction corridor, and construction access and communications will present no difficulties. An extensive construction history is available for this portion of the Alcan route. This history includes construction of the Alcan highway, the Canol pipeline, and the Haines military products pipeline. It is proposed that the Haines products line right-of-way would be used for the construction of the Alcan system, as a means of lessening environmental impact. Investigations of the history of construction from Delta Junction to the Alaska-Yukon border have indicated that construction could be accomplished primarily through the use of conventional pipeline construction techniques during the summer months. Logistics requirements will present few difficulties.

In summary, although the Alcan Pipeline system construction will be difficult in comparison to pipeline construction in the continguous United States, the Alcan project is inherently a predictable construction project. The Applicant has structured a construction plan based upon the following major concepts:

a. Using existing Alyeska facilities to the greatest possible extent.

b. Summer pipeline construction through the use of the Alyeska work pad concept.

c. Using established Alyeska construction techniques where applicable.

Costs and construction timetables of the Alcan Pipeline system are reliable. Transportation systems and logistics patterns are well established. Movements of men and materials will not be subject to the uncertainties normally encountered by construction projects in frontier areas. Construction of the system will use proven, established Arctic construction techniques; examination of the pipe production requirements, terrain, existing construction facilities, manpower and resource availability, ease of logistics, and lack of a requirement for extensive new construction support facilities has led the Applicant to structure a construction program spanning only three years prior to the first flow of gas. Because of the use of established Alyeska construction techniques and the work experience of contractors in Alaska, a form of competitive bidding is anticipated, and contractors will share responsibility for failures or successes in cost management.

6.2 Construction Schedule

The construction schedule proposed for the Alcan Pipeline system will span three years prior to the initial flow of gas. The first year will be devoted to the movements of materials and equipment, civil construction, and support facility construction. These programs will continue into the second year of construction. Pipeline construction will commence in the second construction year, and will be completed in the third year. Compressor station construction will commence with site development, performed by the civil construction crews. An individual station will be constructed over a 14-month period, and the overall station construction schedule will be timed to the requirements of the project volume buildup. Meter station facilities, operating and maintenance facilities and communications systems facilities will be completed prior to system startup. The project construction schedule is illustrated in drawing APC S9-1.

6.2.1 Civil Construction Program

Civil construction crews will commence operations in the first year of construction, and will be responsible for the following major areas over the construction period:

a. Mobilization and preparation for construction of existing pipeyards, access roads, borrow pits, camps, and staging areas.

b. Development of sites and access roads for new camps and pipeyards on the section of the line from Delta Junction to the Alaska-Yukon border.

c. Location and development of new borrow pits where required.

d. Gravel crushing and washing plant installation.

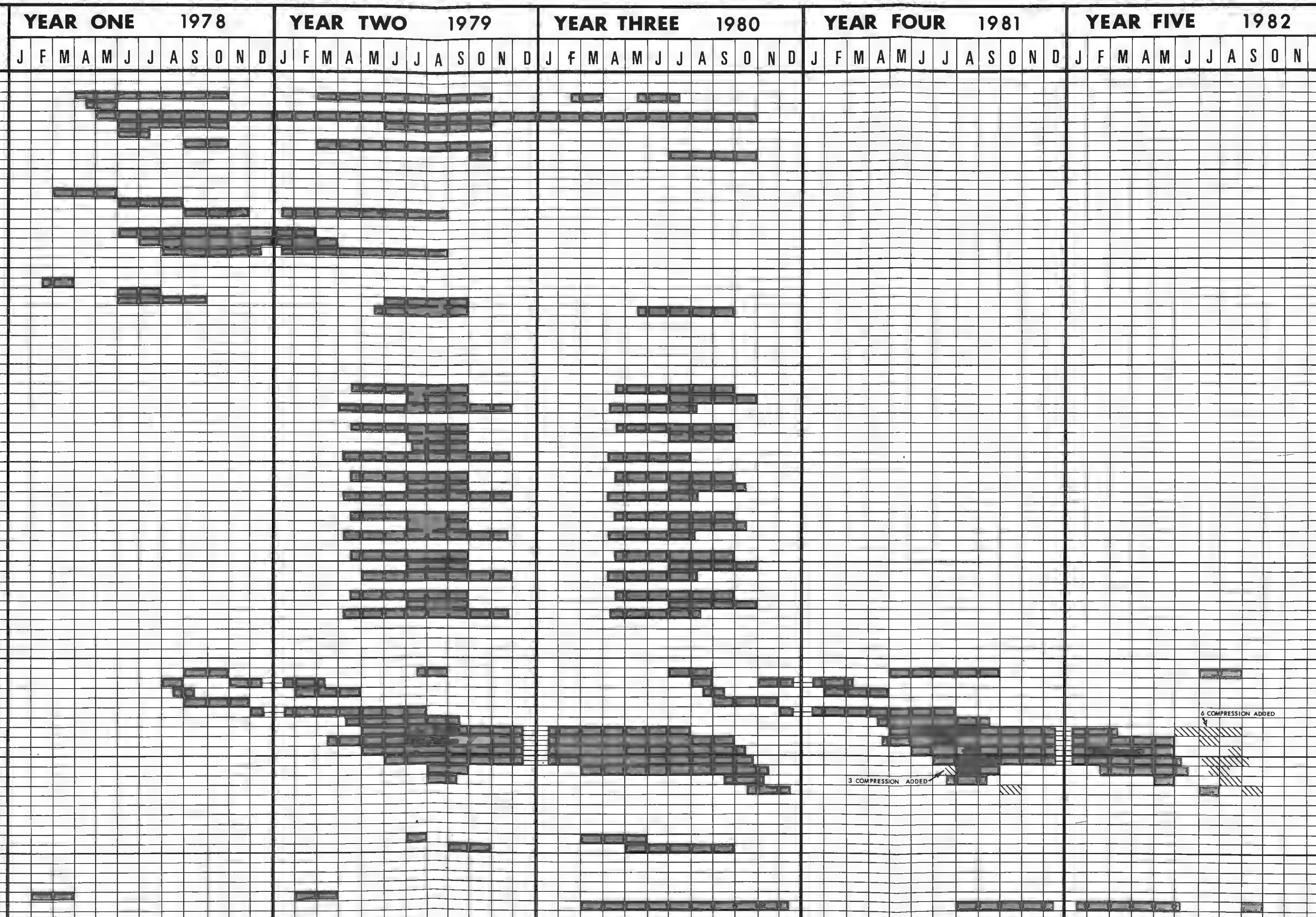
e. Site development and access road construction.

f. Stockpiling of material for select backfill, concrete weights, foundations aggregate and top dressing.

CONSTRUCTION SCHEDULE ALCAN PIPELINE COMPANY

ALCAN PIPELINE COMPANY
DOCKET NO. CP76 ______
EXHIBIT Z2-6
HEARING EXHIBIT NO. ______
PAGE 6

	COMMENTS
CIVIL CONSTRUCTION —	
WORK PAD EXTENSION, CLEARING & GRADING INCL.	
CAMPSITES	
ACCESS ROADS	5% CONSTRUCT, 95% MAINTAIN
STATION SITES AND O&M FACILITIES SITES	
PIPEYARDS	
MATERIAL PROCESSING	
REVEGETATION	
PIPE MOVEMENT —	
PRUDHOE BAY PORT OF ENTRY	
– MANUFACTURE	
– SHIP TO PRUDHOE BAY	DOUBLE-JOINT AT PRUDHOE BAY
– DISTRIBUTE TO PIPEYARDS	
VALDEZ PORT OF ENTRY	
– MANUFACTURE PIPE	
– SHIP TO VALDEZ	DOUBLE-JOINT AT VALDEZ
– DISTRIBUTE TO PIPEYARDS	AND FAIRBANKS
SPECIAL CONTRACTS —	
CAMP MOBILIZATION – ALYESKA FACILITIES	
CAMP INSTALLATION – SPREAD 6	
WEIGHT CASTING	
AERIAL CROSSING CONSTRUCTION	
PIPELINE CONSTRUCTION —	
SPREAD ONE – MP 00.0 TO MP 125	
– PIPELINE CONSTRUCTION PERIOD	
– TESTING	
– RIVER CROSSINGS	
SPREAD TWO – MP 125.0 TO MP 225.5	
– PIPELINE CONSTRUCTION PERIOD	
– ATIGUN PASS CONSTRUCTION	
– TESTING	
– RIVER CROSSINGS	
SPREAD THREE – MP 225.5 TO MP 352.5	
– PIPELINE CONSTRUCTION PERIOD	
– TESTING	
– RIVER CROSSINGS	
SPREAD FOUR – MP 352.5 TO MP 470.0	
– PIPELINE CONSTRUCTION PERIOD	
– TESTING	
– RIVER CROSSINGS	
SPREAD FIVE – MP 470.0 TO MP 600.0	
– PIPELINE CONSTRUCTION PERIOD	
– TESTING	
– RIVER CROSSINGS	
SPREAD SIX – MP 600.0 TO MP 731.4	
– PIPELINE CONSTRUCTION PERIOD	
– TESTING	
– RIVER CROSSINGS	
COMPRESSOR STATION CONSTRUCTION —	
– SITE WORK	
– MOBILIZE MATERIAL AND EQUIPMENT	
– RECEIVE AND SHAKEDOWN MATERIALS	
– EXCAVATIONS AND PILINGS	
– FOUNDATIONS	
– BUILDINGS	
– EQUIPMENT AND VESSELS	
– PIPING, VALVES & FITTINGS	
– ELECTRICAL	
– INSTRUMENTATION	
– INSULATE AND PAINT	
– TESTING	
– START UP AND COMMISSION	
METER STATION CONSTRUCTION —	
– MOBILIZE MATERIALS AND EQUIPMENT	
– INSTALLATION – ALL ACTIVITIES	
COMMUNICATIONS & CONTROL SYSTEMS —	
– CONSTRUCTION COMMUNICATIONS	TEMPORARY
– PERMANENT COMMUNICATION & CONTROL SYSTEM	
OPERATING AND MAINTENANCE FACILITIES —	
– CIVIL CONSTRUCTION (PADS, ETC.)	
– MOBILIZE MATERIALS (HAPPY VALLEY & PROSPECT)	
– INSTALLATION – ALL ACTIVITIES	



GULF INTERSTATE ENGINEERING COMPANY

Alcan Pipeline Company

CONSTRUCTION SCHEDULE

DRWN. —	SCALE —	DATE JUNE 1976
APPRVD.	DRWG. NO. APC-S9-1	REV. NO.

The existing transportation corridors paralleling the entire route will be used to maximum advantage for an early mobilization of civil construction crews to accommodate pipeline, compressor station and other permanent facility construction schedules. Civil construction work will be done in the milder temperatures of April, May, June, July, August, September and October, with only road and equipment maintenance in the remaining colder months. In order to take advantage of the long hours of daylight of the summer months, a two-shift operation can be maintained. Most civil construction assignments will be spread over two major construction years. The system will be divided into six sections, compatible with pipeline spread assignments. Civil construction and pipeline construction will be performed by the same contractor. Civil construction schedules and requirements will be similar in all sections, with the exceptions of section six and a portion of section five, south of Delta Junction. Civil construction crews will not construct an extensive workpad in this area. Site development will be required for two new construction camps, and several new pipeyards on this portion of the route. A general description of the work requirements for the civil crews follows:

<u>First Construction Year - 1978</u>

a. New pipeyards where required will be developed immediately after breakup in order to allow for early pipe deliveries.

b. The construction of two new camp sites, required in Section 6, will be undertaken in April and May.

c. The few access roads required to new facilities will be constructed early in the year in order to establish the necessary access to the work sites. Maintenance on all system access roads will be carried out on a regular basis during the construction months with only snowplowing in the winter months.

d. Further development of existing borrow pits and clearing and grading will allow approximately 60 percent of the Alyeska work pad extension to be completed.

e. Site development work for maintenance facilities and the first compressor station sites will be completed with the exception of any grading necessary to accommodate the final configuration and the backfill for structures.

f. It is planned to make about 30 per cent of the select pipe backfill and all the concrete aggregates this year. Sufficient backfill will be available in well-drained stockpiles for pipeline sections to be completed early in 1979.

Second Construction Year - 1979

a. Grading work will be completed for the individual stations except for the final landscaping configuration and the revegetation.

b. Meter station sites will be developed during the second year.

c. Road maintenance and snow plowing will be continued on a regular basis.

d. The work pad extension and any additional excavation will be completed by midseason in order to give the pipeline spreads full access to the project.

e. Late in the season, restoring and revegetating the right-of-way and borrow pits will start in the areas where construction has been completed.

f. Remaining granular material required for pipe bedding and station top dressing will be placed in well drained stockpiles for future use.

Third Construction Year - 1980, to End of Project

a. Road maintenance and snow plowing will be continued on a regular basis until project completion.

b. Restoration and reseeding operations will take place in the late summer and fall months of each construction year until completion of the project and restoration is accomplished.

6.2.2 Support Facilities and Services

To provide for construction crew accommodation and materials handling, installation of new temporary support buildings and services facilities (camps, warehousing) will be completed by specialists early in the first construction year. Catering and camp maintenance will be a continuing construction requirement, contracted to camp specialists.

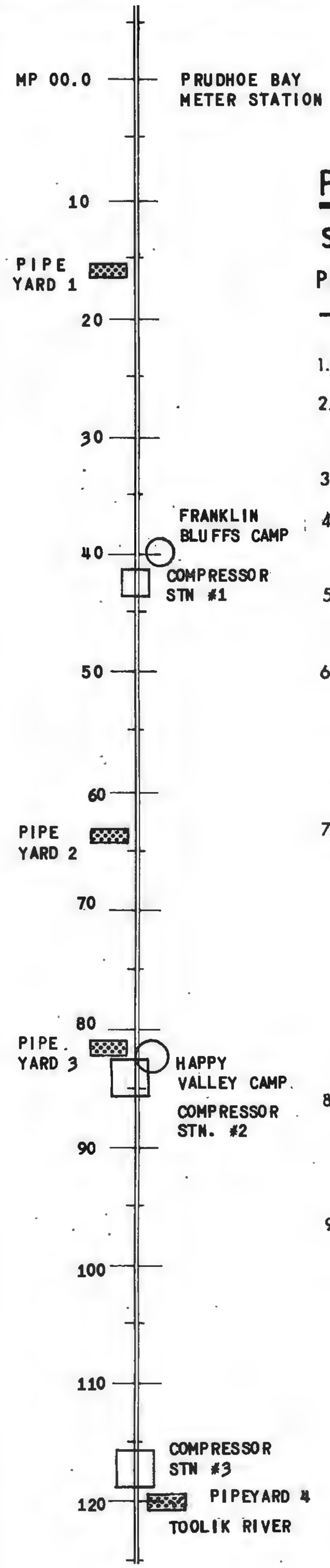
6.2.3. Mainline Construction

All project activities are dependent to a large degree on pipeline construction operations. Construction of the mainline will require six pipeline construction spreads working during the second and third construction years, 1979 and 1980. The spread assignments have been based on our evaluation of terrain, working season, production rates, manpower and equipment requirements, access, and support facilities requirements. A major consideration in the selection of spread lengths is the existing support and civil infrastructure of the Alyeska system. Spread assignments on that portion of the route from Prudhoe Bay to Delta Junction would be very similar to those of the Alyeska project. Existing camp locations and pipeyard locations are therefore compatible with the chosen spread lengths.

Spread assignments will be as follows:

Spread	Milepost		to Milepost	Spread Length
1	00	(Prudhoe Bay)	125 (Toolik R)	125 Mi.
2	125	to	225.5 (Minnie Cr)	100.5 Mi.
3	225.5	to	352.5 (Yukon R)	127 Mi.
4	352.5	to	470 (Moose Cr)	117.5 Mi.
5	470	to	600	130 Mi.
6	600	to	731.4 (Border)	131.4

The pipeline will parallel the Alyeska system from Prudhoe Bay to Delta Junction, a distance of 538.8 miles. Spread 5 will, therefore, use the work pad concept for approximately half of the spread construction. The remainder of spread 5 and all the spread 6 will utilize conventional summer construction technology; some work pad will be required over this portion of the route, with the exception of some muskeg areas, where rip rap and/or pad would be utilized. Drawing APC R9-2 outlines the pipeline construction sequence and spread assignments, and Drawings APC S9-3 through APC S9-8 detail the construction requirements of the six spreads. Pipeline construction schedule is illustrated on the overall project schedule, Drawing APC S9-1. This drawing also outlines the proposed river crossing construction and the Atigun Pass crossing.



PIPELINE CONSTRUCTION

SPREAD NO. 1

PRUDHOE BAY (MP 00.0) TO TOOLIK RIVER (MP 125.0)

1. LENGTH: 125 MILES - 660,000 FEET
2. PRODUCTION RATE: 50 JOINTS/DAY AVERAGE
3. CONSTRUCTION SEASON: APRIL THRU SEPTEMBER
4. CONSTRUCTION PER SEASON: 1979 - APPROX. 63 MILES
   1980 - REMAINDER OF 125 MILES
5. MAJOR RIVER CROSSINGS: REFER TO ROUTE SHEET
   APC-B9-1 TO APC-B9-5
6. SPECIAL CONSTRUCTION:
   - Haul Road Crossings: ROUTE SHEETS APC-B9-1 TO APC-B9-5
   - Alcan Hwy Crossings: ROUTE SHEETS APC-B9-1 TO APC-B9-5
7. STATIONS & APPURTENANCES:

COMPRESSOR STN. No.	1	M.P.	43.5
	2	M.P.	83.7
	3	M.P.	118.6

   METER STATIONS: MP 00.0
   BLOCK VALVE ASSEMBLIES: 5 REQU'D
8. PIPELINE CONSTRUCTION PEAK DIRECT LABOR: 693
   COMPRESSOR STATION - CONSTRUCTION PEAK DIRECT LABOR: 407
9. TERRAIN DESCRIPTION: REFER TO ROUTE SHEETS
   APC-B9-1 TO APC-B9-5

GULF INTERSTATE ENGINEERING COMPANY		
Alcan Pipeline Company		
SPREAD 1 - CONSTRUCTION		
DRWN.	SCALE —	DATE June 1976
APPRVD.	DRWG. NO. APC-S9-3	REV. NO.

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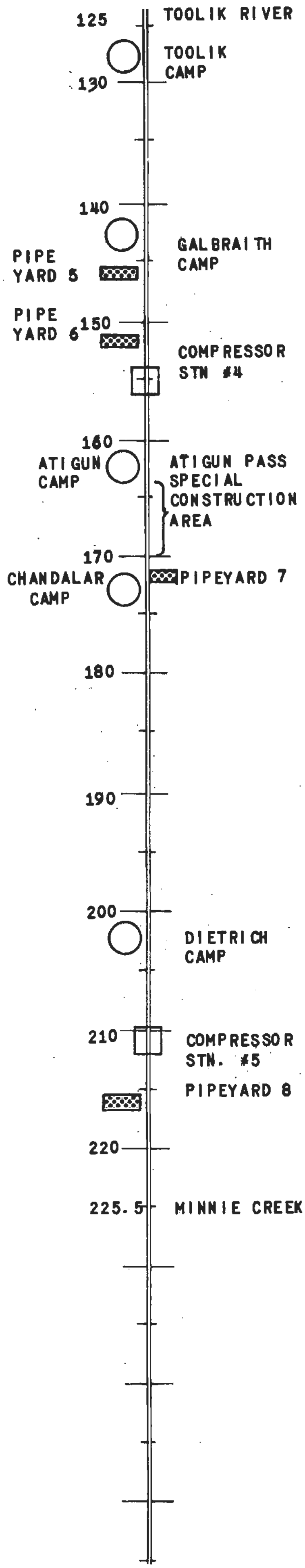

PIPELINE CONSTRUCTION

SPREAD NO. 2

TOOLIK RIVER (MP 125.0) TO MINNIE CREEK (MP 225.5)

1. LENGTH: 100.5 MILES– 530,600 FEET
2. PRODUCTION RATE: 50 JOINTS / DAY AVERAGE
3. CONSTRUCTION SEASON: APRIL THRU SEPTEMBER
4. CONSTRUCTION PER SEASON: 1979 – APPROX 50 MILES
   1980 – BALANCE OF 100.5 MILES
5. MAJOR RIVER CROSSINGS: REFER TO ROUTE SHEETS APC-B9-5 TO APC-B9-8
6. SPECIAL CONSTRUCTION:
   Haul Road Crossings ROUTE SHEETS APC-B9-5 TO APC-B9-8
   Alcan Hwy Crossings ROUTE SHEETS APC-B9-5 TO APC-B9-8
7. STATIONS & APPURTENANCES:
   COMPRESSOR STN. No. 4 M.P. 157.7
   5 M.P. 210.8
   ______ M.P. ______
   METER STATIONS ______
   BLOCK VALVE ASSEMBLIES 3 REQU'D
8. PIPELINE CONSTRUCTION PEAK DIRECT LABOR 693
   COMPRESSOR STATION - CONSTRUCTION PEAK DIRECT LABOR 258
9. TERRAIN DESCRIPTION: REFER TO ROUTE SHEETS APC-B9-5 TO APC-B9-8

GULF INTERSTATE ENGINEERING COMPANY		
Alcan Pipeline Company		
SPREAD 2 - CONSTRUCTION		
DRWN.	SCALE ——	DATE June 1976
APPRVD.	DRWG. NO. APC-S9-4	REV. NO.

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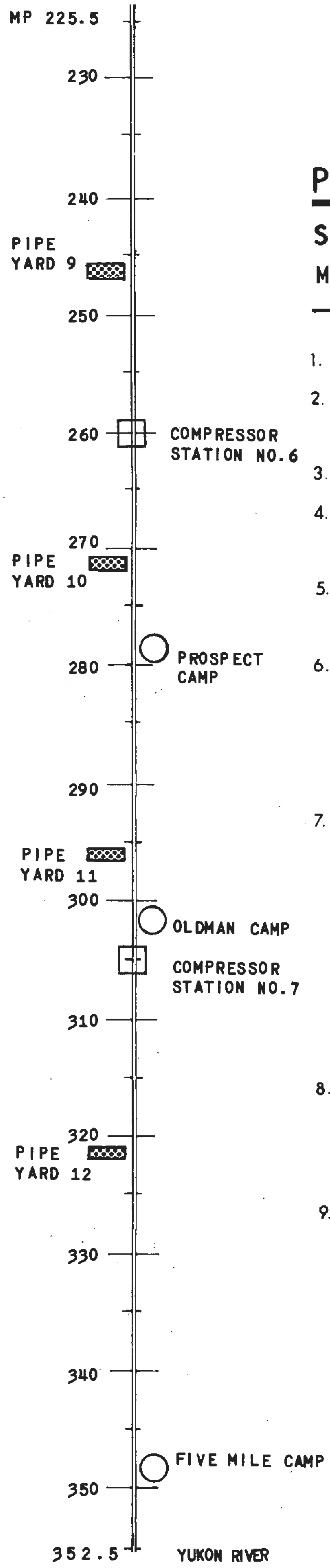

PIPELINE CONSTRUCTION

SPREAD NO. 3

MINNIE CREEK (mp 225.5) TO YUKON RIVER (mp 352.5)

1. LENGTH: 127 MILES - 670,600 FEET
2. PRODUCTION RATE: 50 JOINTS /DAY AVERAGE
3. CONSTRUCTION SEASON: APRIL THRU SEPTEMBER
4. CONSTRUCTION PER SEASON: 1979 - APPROX. 63 MILES
   1980 - REMAINDER OF 127 MILES
5. MAJOR RIVER CROSSINGS: REFER TO ROUTE SHEET APC-B9-8 TO APC-B9-12
6. SPECIAL CONSTRUCTION:
   - Haul Road Crossings: ROUTE SHEETS B9-8 TO B9-12
   - Alcan Hwy Crossings: ROUTE SHEETS B9-8 TO B9-12
7. STATIONS & APPURTENANCES:
   - COMPRESSOR STN. No. 6 M.P. 261.9
   - 7 M.P. 305.9
   - M.P.
   - METER STATIONS: NONE
   - BLOCK VALVE ASSEMBLIES 6 REQU'D
8. PIPELINE CONSTRUCTION PEAK DIRECT LABOR ______________ 693

   COMPRESSOR STATION - CONSTRUCTION PEAK DIRECT LABOR ______________ 258
9. TERRAIN DESCRIPTION: REFER TO ROUTE SHEETS APC-B9-8 TO APC-B9-12

GULF INTERSTATE ENGINEERING COMPANY		
Alcan Pipeline Company		
SPREAD 3-CONSTRUCTION		
DRWN.	SCALE —	DATE June 1976
APPRVD.	DRWG. NO. APC-S9-5	REV. NO.

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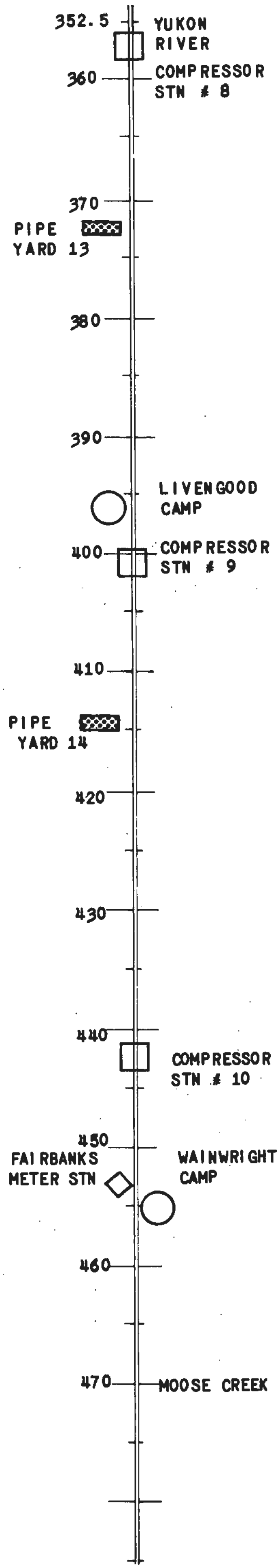


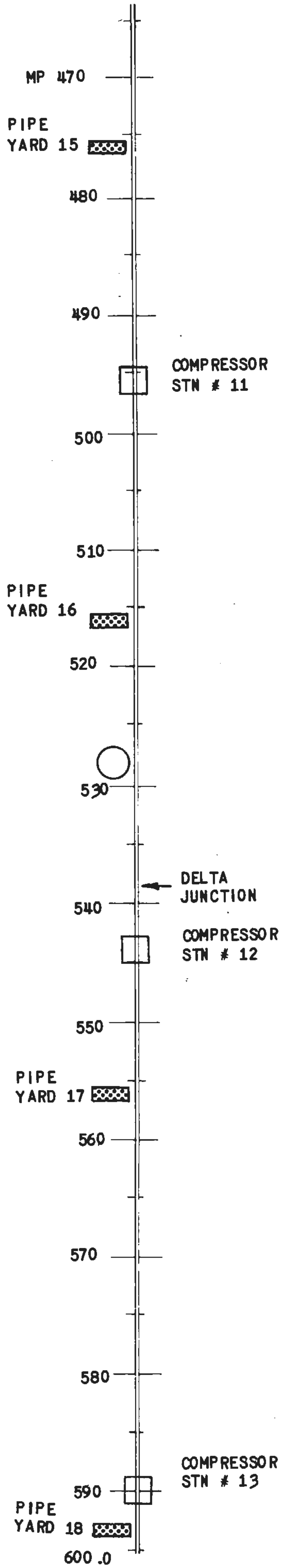
PIPELINE CONSTRUCTION

SPREAD NO. 4

YUKON RIVER (MP 352.5) TO MOOSE CREEK (MP 470.0)

1. LENGTH: 117.5 MILES - 620,400 FEET
2. PRODUCTION RATE: 50 JOINTS / DAY AVERAGE
3. CONSTRUCTION SEASON: APRIL THRU SEPTEMBER
4. CONSTRUCTION PER SEASON: 1979 - APPROX. 59 MILES
   1980 - REMAINDER OF 117.5 MILES
5. MAJOR RIVER CROSSINGS: REFER TO ROUTE SHEET APC-B9-12 TO APC-B9-16
6. SPECIAL CONSTRUCTION:
   Haul Road Crossings ROUTE SHEETS APC-B9-12 TO APC-B9-16
   Alcan Hwy Crossings ROUTE SHEETS APC-B9-12 TO APC-B9-16
7. STATIONS & APPURTENANCES:
   COMPRESSOR STN. No. 8 M.P. 355.0
   9 M.P. 400.7
   10 M.P. 442.6
   METER STATIONS NONE
   BLOCK VALVE ASSEMBLIES 5 REQU'D
8. PIPELINE CONSTRUCTION PEAK DIRECT LABOR 693
   COMPRESSOR STATION - CONSTRUCTION PEAK DIRECT LABOR 387
9. TERRAIN DESCRIPTION: REFER TO ROUTE SHEETS APC-B9-12 TO APC-B9-16

GULF INTERSTATE ENGINEERING COMPANY		
Alcan Pipeline Company		
SPREAD 4 - CONSTRUCTION		
DRWN.	SCALE —	DATE June 1976
APPRVD.	DRWG. NO. APC-S9-6	REV. NO.



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PIPELINE CONSTRUCTION

SPREAD NO. 5

MOOSE CREEK (MP 470.0) TO MP 600.0

1. LENGTH: 130 MILES - 686,400 FEET
2. PRODUCTION RATE: 50 JOINTS/DAY AVERAGE
3. CONSTRUCTION SEASON: APRIL THRU SEPTEMBER
4. CONSTRUCTION PER SEASON: 1979 - APPROX. 65 MILES
   1980 - REMAINDER OF 130 MILES
5. MAJOR RIVER CROSSINGS: REFER TO ROUTE SHEETS APC-B9-16 TO APC-B9-21
6. SPECIAL CONSTRUCTION:
   Haul Road Crossings ROUTE SHEET APC-B9-16 TO APC-B9-21
   Alcan Hwy Crossings ROUTE SHEET APC-B9-16 TO APC-B9-21
7. STATIONS & APPURTENANCES:

COMPRESSOR STN. No.	11	M.P.	497.4
	12	M.P.	543.6
	13	M.P.	590.3

   METER STATIONS ________
   BLOCK VALVE ASSEMBLIES 5 REQU'D
8. PIPELINE CONSTRUCTION PEAK DIRECT LABOR ---------- 693
   COMPRESSOR STATION - CONSTRUCTION PEAK DIRECT LABOR ---------- 387
9. TERRAIN DESCRIPTION: REFER TO ROUTE SHEETS APC-B9-16 TO APC-B9-21

GULF INTERSTATE ENGINEERING COMPANY		
Alcan Pipeline Company		
SPREAD 5 - CONSTRUCTION		
DRWN.	SCALE ——	DATE June 1976
APPRVD.	DRWG. NO. APC-S9-7	REV. NO.

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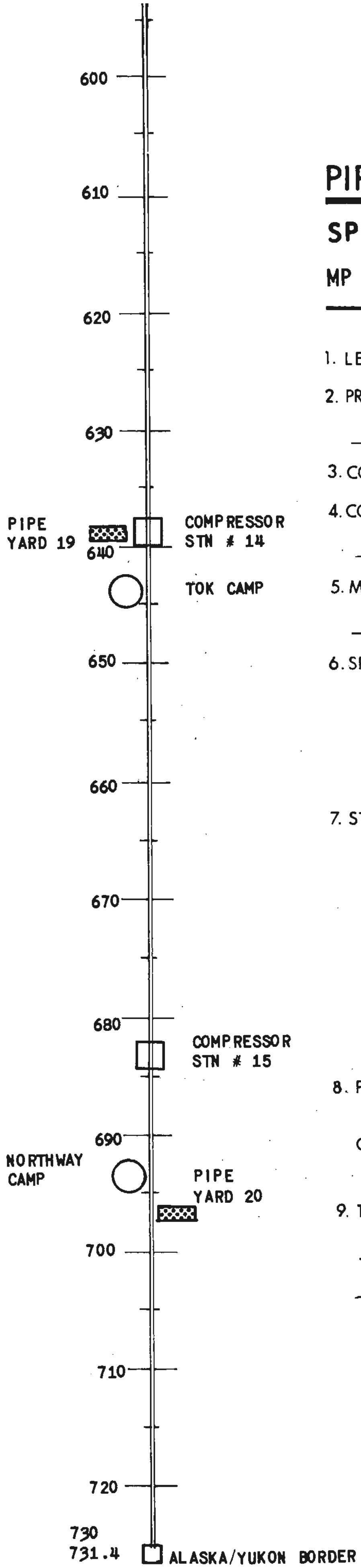

PIPELINE CONSTRUCTION

SPREAD NO. 6

MP 600.0 TO ALASKA/YUKON BORDER (MP 731.4)

1. LENGTH: 131.4 MILES 693 800 FEET
2. PRODUCTION RATE: 50 JOINTS / DAY AVERAGE
3. CONSTRUCTION SEASON: APRIL THRU SEPTEMBER
4. CONSTRUCTION PER SEASON: 1979 – APPROX. 65 MILES
   1980 – REMAINDER OF 131.4 MILES
5. MAJOR RIVER CROSSINGS: REFER TO ROUTE SHEET
   APC-B9-21 TO APC-B9-25
6. SPECIAL CONSTRUCTION:
   Haul Road Crossings: ROUTE SHEETS APC-B9-21 TO APC-B9-25
   Alcan Hwy Crossings: ROUTE SHEETS APC-B9-21 TO APC-B9-25
7. STATIONS & APPURTENANCES:

COMPRESSOR STN. No.		M.P.
	14	639.4
	15	684.1

   METER STATIONS: MP 731.4
   BLOCK VALVE ASSEMBLIES: 6 REQU'D
8. PIPELINE CONSTRUCTION PEAK DIRECT LABOR 693
   COMPRESSOR STATION - CONSTRUCTION PEAK DIRECT LABOR 258
9. TERRAIN DESCRIPTION: REFER TO ROUTE SHEETS
   APC-B9-21 TO APC-B9-25

GULF INTERSTATE ENGINEERING COMPANY		
Alcan Pipeline Company		
SPREAD 6– CONSTRUCTION		
DRWN.	SCALE —	DATE June 1976
APPRVD.	DRWG. NO. APC-S9-8	REV. NO.

6.2.4 Compressor Stations

A fully operative compressor station contains equipment to both compress and refrigerate the gas; equipment to control and monitor the flow; buildings to house operating personnel and equipment; and auxiliary systems for electrical power, heating, communications, automation, and instrumentation, fire fighting and waste disposal.

The objective of maintaining gas refrigeration to prevent thawing of frozen ground dictates that some stations, in the initial system gas build-up stages, require gas chilling only. This means that, although the main gas compressors will be set at a later date, the major portion of the station equipment must be in place for the chilling operation. The civil infrastructure, access roads, and station pad sites will be constructed in advance of the station construction phase. Upon completion of a station work pad site and receipt of material and equipment delivered through the logistics system, station construction will begin.

In establishing the overall schedule for the construction of the stations, the following factors were taken into consideration:

a. The required start-up date for each full or partial station.

b. Utilization of the available work days in a season.

Pipeline hydraulic and geothermal analyses indicate that stations 4, 5, 7, 8, 9, 11, 12, 13 and 15 will require the chilling portion of the station be operative for the first year of pipeline operation at 1.2 BCFD inlet. That is, these stations will be completed except for the main gas compressor package. Stations 2, 6, 10 and 14 require both compression and chilling for the first year. Compression packages will be added to stations 4, 8, and 12 for the second operating year, volumes of 1.6 BCFD inlet. For full operations at 2.4 BCFD inlet during the third operating year, stations 1 and 3 will require both chilling and compression installation, and stations 5, 7, 9, 11, 13 and 15 will require the addition of compression. All stations will be fully developed by 1983. Drawing APC S9-9 shows the station build up by chiller/compressor units. The overall station construction schedule, by operation, is illustrated in Drawing APC S9-1.

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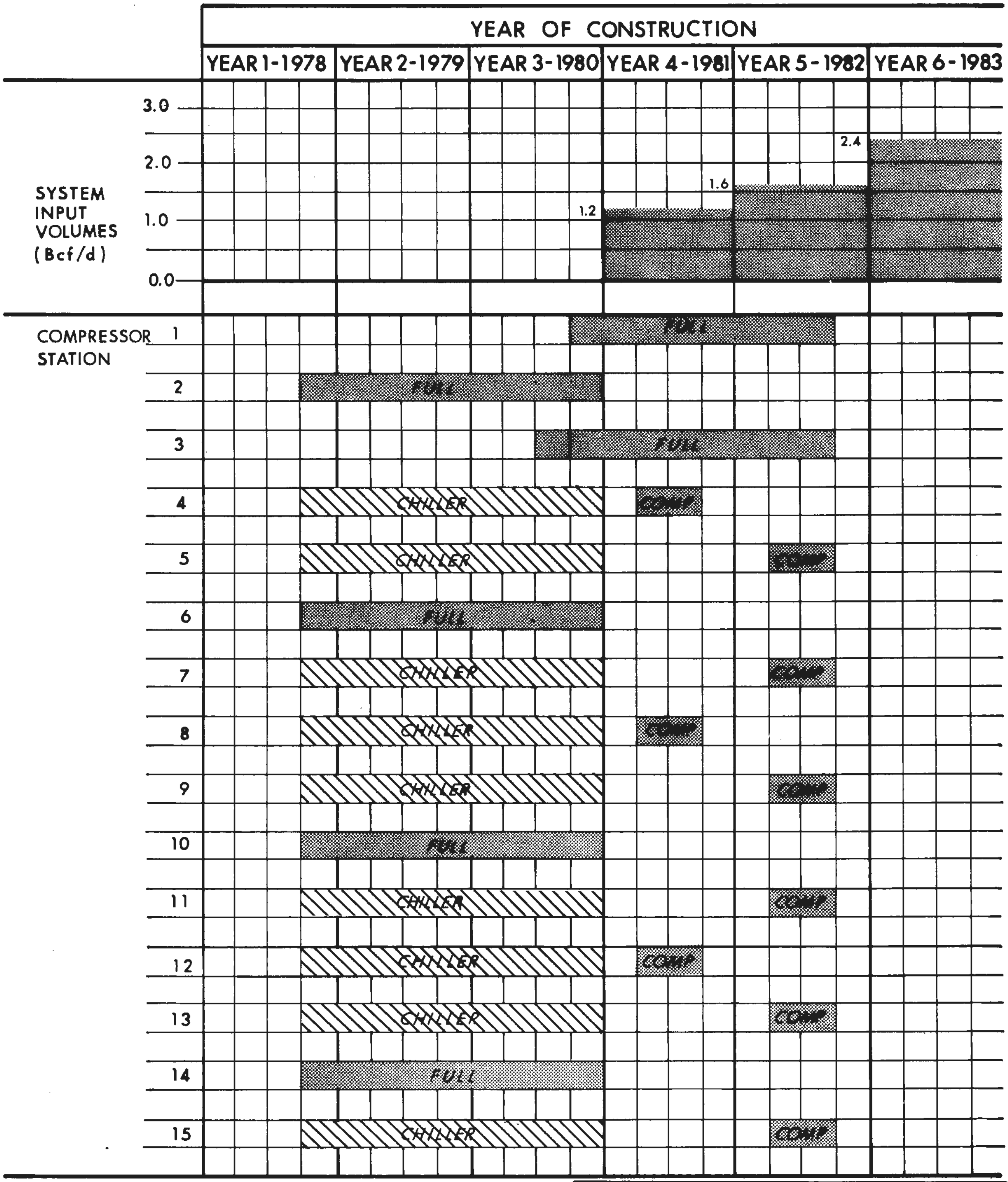

GULF INTERSTATE ENGINEERING COMPANY

Alcan Pipeline Company

STATION CONSTRUCTION

DRWN. ——	SCALE ——	DATE June 1976
APPRVD.	DRWG. NO. APC-S9-9	REV. NO.

6.2.5 Meter Stations

The three meter stations, one at Prudhoe, one community gas service meter at Fairbanks and the Alaska/Yukon border meter station near Scottie's Creek are scheduled to be constructed prior to the first year of pipeline operation. The schedule is illustrated on Drawing APC S9-1.

6.2.6 Operating and Maintenance Facilities

The O & M facilities for the Alcan system are described in Section 7.0 of this exhibit. Construction scheduling for the district O & M headquarters is illustrated in Drawing APC S9-1. O & M facilities will be essentially complete prior to start-up of the system.

6.2.7 Communications and Control System

The installation of temporary communications facilities for construction will not be a major construction requirement, as sophisticated communications systems exist along the pipeline route. Camp and field communications will be connected in the first months of the project. The installation of permanent facilities, including the central control system at Fairbanks will be completed prior to the initial flow of gas. Scheduling is outlined on Drawing APC S9-1.

6.3 Construction Procedures

The construction procedures proposed for construction of the Alcan Pipeline system consist of conventional construction techniques, or techniques modified for Arctic construction. Established and successful construction practices now being utilized on the Alyeska project will be implemented for Alcan system construction. The proposed construction procedures have been developed through a review of Alyeska construction practices, discussions with contractors now working on the Alyeska project, and on recommendations of Alyeska contractors and other contractors with significant northern construction experience. The Alyeska project has served as a training or proving ground for arctic construction labor and techniques. Extensive review of Alyeska experience and of the proposed winter construction plans of other pipeline applicants indicates that emphasis must be placed on using established and predictable techniques. Any attempt to construct a frontier-area pipeline using unproven practices will result in cost-plus contractual arrangements with contractors, high initial training period construction costs, a lack of project time & cost control and a high probability of encountering the escalating and compounding costs which have recently impacted several large construction projects in North America. It is important that the relationship of construction practices and contractor control to project cost be understood before selection of a mode of construction or construction plan. A sound basic construction plan is an important factor in the control of costs. Frontier construction plans are inherently labor or labor - associated cost-intensive. The number of people working on a project affect:

a. Support services costs (i.e. campsites, catering, transport, etc.)

b. Logistic requirements

c. Effective project control and completion schedule

Once embarked on a major construction project, construction cannot be suspended while new construction techniques are developed to contend with unforeseen problems. Recent history suggests that when this type of problem occurs on large projects with many interacting construction groups, an attempt is made to solve the problem with more people and more equipment, using the same unsuccessful construction techniques. When a sequential series of pipeline operations is involved, this "solution" can be disastrous. More men and equipment working on a pipeline right-of-way results in lower production; costs increase, and the project may be delayed. When construction utilizes a marginal seasonal "window" for the installation period, projects can be easily delayed for a year or several years by failure to achieve expected production rates. It is primarily this concern which has caused the Applicant to reject suggested winter pipeline construction practices as uncertain and impractical, and to base the construction plan and techniques on proven summer constuction practices. Winter construction seasons are still available for use as contingent seasons to maintain schedule.

On that part of the route from Prudhoe Bay to Delta Junction, the Applicant proposes to utilize the Alyeska work pad and haul road for pipeline construction, with an extension where required to provide for equipment movement. Use of the work pad will make summer construction possible, and, through the use of an adjacent right-of-way, will limit environmental impacts. From Delta Junction to the Alaska-Yukon border, terrain will also allow summer construction. The construction procedures proposed by the Applicant will incorporate environmental guidelines developed for the Alyeska project where applicable; it is the intent of the Applicant to provide construction plans and practices which will ensure efficient and economical construction of the system, while minimizing the impact of construction on the environment.

Pipeline installation activities consist of a series of sequential operations. Where the Alcan pipeline parallels the Alyeska oil line or haul road, a work pad will be utilized for construction. From Dèlta Juntion to the Yukon border the Haines Product Pipeline right-of-way will be utilized. The pipeline construction operations would be similar for both segments. Clearing, grading and work pad construction on the system from Prudhoe Bay to the Yukon border would be accomplished by civil construction crews during the first year of construction.

6.3.1 Civil Construction Procedures

Civil construction requirements for the Alcan system are not extensive, due to the presence of the existing civil infrastructure installed for the Alyeska system, and due to the close proximity of the Alcan highway along the pipeline route from Delta Junction to the Alaska-Yukon border.

Construction equipment and methods used to establish the costs and schedule are what may be considered as North America standards, adapted where necessary for arctic construction. No specialized or unusual equipment or operations will be used in conjunction with the civil construction. The equipment that has been used in the development of cost estimates has been standardized to take full advantage of the skills previously acquired by workers in the area. This also gives a firm basis to both the costs and schedule because of the known operating costs and production capabilities of the equipment. Civil construction crews will be responsible for work pad extension, site development, borrow operations, material processing and road maintenance activities. A brief description of these operations follows:

a. Clearing and Grubbing

Clearing and grubbing performed by civil crews would be required for the following facilities:

new borrow pits
new access roads
new pipeyard sites
new campsites
station sites
O & M and meter station sites
Alyeska work pad extension as required

The construction area will be cleared of all trees, brush, and obstacles which would hinder construction operations. Conventional machine clearing methods will be used except in those areas classified as environmentally sensitive, where hand clearing will be required. In locations where a work pad is to be constructed, trees and brush will be cut off at a maximum height of 6 inches above ground surface. When cutting or grading is required, grubbing of stumps will be necessary. Timber will be disposed of in accordance with government regulations. Types of cover which will be encountered along the pipeline route are noted on the route maps, Drawings APC B9-1 through APC B9-25, Exhibit 22, Section 1.0.

b. Grading

Grading of the construction area will be kept to a minimum, and will be subject to erosion control specifications.

c. Borrow Development and Material Processing

Existing undepleted borrow pits will be used over the entire route, although it is anticipated that some additional quarries will be required to optimize haul distances in section three. A scraper operation will be used for fill material hauling in most pits. However, if a high percentage of oversize material is encountered, front-end loaders and off-highway trucks will be used, with a grizzly to scalp off the plus 6-inch materials.

Granular material required for select backfill, surfact cover and concrete aggregate will be crushed to specifications as required by primary jaws and secondary crushers operating in tandem; some select backfill will only require screening. This material will be stockpiled carefully to prevent consolidation due to freezing.

The knowledge generated by prior construction activities along the proposed Alcan pipeline route will be of considerable benefit in borrow pit development. An extensive borrow pit drilling and evaluation program will not be necessary, and it will be possible to plan construction to provide for efficient usage of borrow material with a minimum of waste.

d. Work Pad Construction

Work pad configurations are illustrated in Drawing APC S9-10 through S9-12 in Section 1.0 of this exhibit. Work pad specifications and construction methods will be compatible to those used in construction of the existing work pad. Materials will consist of well drained gravels in the upper embankment, placed on coarser fill material. In all of section one and part of section two, a thermal insulation barrier will be placed to minimize damage to permafrost. The work pad will be compacted and graded to provide for surface drainage.

Water courses will be handled on an individual basis with specific attention given to all related factors. Stream diversions will take place in advance of mainline construction.

e. Site Development

Construction requirements and procedures will be similar to those required for work pad construction.

f. Road Maintenance

Access roads and haul roads will be maintained on a regular basis.

g. Restoration and Revegetation

Restoration and revegetation of disturbed areas (including the pipeline construction area, campsites, pipe-yards, station sites) will commence as soon as practicable after construction. Erosion control and accommodation of natural drainage patterns will be a requirement of the clean-up activities. Excess or rejected spoil and fill material will be disposed of by approved methods. Borrow pits will be graded and contoured to conform to the surrounding area; topsoil will be restored and seeded. Seeding and fertiliz-ing methods will be based upon accepted methods on the Alyeska project.

6.3.2 <u>Pipeline Construction Procedures</u>

Pipeline construction operations will be accom-plished from May 15 to September 30, with the exception of clearing and grading, which will be scheduled for the winter preceeding pipelaying operations. Conventional summer construction techniques will be used for most of the pipe-line activities.

a. Clearing and Grading - Delta Junction to Alaska-Yukon Border

Clearing operations would be similar to those described for civil construction clearing. Grading crews will provide a continuous working area for pipelaying activities and equipment movement along the right-of-way. Grading will be kept to the minimum required to maintain the necessary pipeline production rates.

b. Ditch Excavation

The pipeline ditch will be a minimum of five feet wide and seven feet deep. Ditch production is extremely critical to the overall pipelaying production rates. In permafrost areas, the failure of the proposed "super ditchers" to meet expectations will necessitate the use of blasting techniques to be carried out ahead of the excavation. The drilling and blasting techniques will utilize diamond five patterns or modifications thereof, to break up material so that it can be excavated with backhoes. Track drills or twindrills will be used for boring holes for the explosive charges and charges will be matted. The blasting materials will be removed by backhoe.

In areas requiring blasting, or where there are irregularities in the bottom of the ditch, padding material will be placed in the ditch.

c. Stringing Pipe

Pipe will be double-jointed to 80-foot lengths, and placed in pipeyards prior to pipeline construction (see 6.5 Logistics). The pipeyards will primarily be those utilized for the Alyeska construction program. Stringing crews will haul pipe from the pipeyard and string it alongside the ditchline as required.

d. Materials Handling

Pipeline construction material, fuel, valves, fittings, pipeline coating, and equipment spare parts will be stored at the stockpile sites and haul sites as required. Materials will be stored and handled in accordance with manufacturers' specifications and government regulations.

e. Bending

Conventional bending machines will be employed to coldbend the pipe to fit the alignment and contour of the ditch. The degree of bend will conform to existing codes. Internal mandrils will be used to prevent out-of-roundness occurring during the bending operations.

f. Line-up and Weld

Line-up will be accomplished using internal line-up clamps except on tie-ins. Pipe ends will be cleaned and pre-heated as required. All welders will be required to qualify by tests using welding procedures approved by Applicant. Final selection of welding procedures will be made after the results of welding tests on pipe of the specified metallurgy.

g. Coating

The Applicant proposes to use continuous line travel tape coating over the ditch. The pipe will be cleaned, primed, wrapped and lowered-in. After the pipe has been coated, and prior to lower-in, the coating will be checked with a holiday detector.

h. Lower-in and Tie-in

Lowering-in will be conducted simultaneously with coating and wrapping.

There are two methods of lowering large-diameter pipe into the prepared ditch:

1. By the use of lower-in belts with the back side-booms leap-frogging the front booms. This method would be employed in choppy terrain or where conditions dictate short sections.

2. By the use of cradles with 1 or 2 catch-off tractors rigged up with lower-in belts. This method would be employed in level to rolling terrain, or where it is possible to lower long sections of pipe.

i. Weighting

Areas where weighting is required for buoyancy control will be determined by geotechnical and engineering investigations prior to construction, and by ditch inspection following excavation.

Pipeyards or compressor station sites will be utilized for weight-casting. Aggregate will be stockpiled by the civil construction crews. The weights will be cast using conventional concrete pouring techniques with reuseable forms.

j. Backfill

After placement of padding, the spoil material will be placed back into the ditch, and crowned over the center line of the ditch to provide for settlement. Local surface drainage is provided for by openings in the crown.

k. Cleaning and Gauging

After backfilling and initial tie-ins, and before testing, sections of the installed line will be gauged for roundness and cleared of any construction debris. This operation is accomplished by running two types of pipeline pigs through the pipeline. One is referred to as a standard cleaning pig or brush pig, and the other as a gauging pig.

These two pigs may be run simultaneously using compressed air as a propellant. Any buckles or egging of sufficient magnitude to stop the passing of the gauging pig will be cut out and replaced.

l. Testing

Water will be used for testing of the Alcan system. Testing procedures and pressures will be in accordance with part 192 of Title 49 of the Code of Federal Regulations, latest revision. Upon completion of the test, test section will be tied in by a final tie-in crew working with the testing crew.

m. River Crossings

Crossing pipe will be welded into sections on a prepared work pad area. The work pad, depending upon the geometry of the crossing (length, banks, profile), could be on one bank or the other, partly on the bank and partly bermed out into the river, or a flexiflote extension of a prepared bank.

After the pad method is chosen and the pad constructed, the pipe will be fabricated into manageable sections, coated and pre-tested. The trench will be excavated from the river bed with backhoes, clam shells, draglines, dredges or combinations of these machines, depending upon the physical characteristics of the river bed. A large river requires the use of river master winches as well as hold-back winches. Floats may be attached to the pipe to lessen the bottom drag. Some of the smaller stream crossings may be done by walking the pipe into the trench from the work pad, with the possible addition of a winch on the opposite bank. As each section is taken to the water's edge, the next section is welded onto its end and the procedure repeated until the crossing pipe emerges at the opposite bank.

Throughout the operation, the pipe will not be allowed to buckle and each tie-in weld is x-rayed and coated as it joins the continuous string.

The completed crossing will then be back-filled with the excavated spoil or other select material if the native spoil is not acceptable.

The cuts on the banks will be restored and stabilized as required to maintain the integrity of the pipe and minimize bank erosion.

n. Road, Rail and Foreign Pipeline Crossings

Where permitted, road crossings will be open cut. Road crossings where traffic must be allowed to pass will be bored; casing pipe will protect the carrier pipe as required.

Foreign pipeline crossings will be made in cooperation with the pipeline owner concerned. An adequate clearance will be maintained between pipelines.

6.3.3 Station Construction Procedures

The on-site station construction activities shown on Drawing APC S9-1 are a conventional sequence of events. The construction procedures and techniques used to complete each activity are conventional practices within the plant and station construction industry.

6.4 Construction Resource Requirements

Construction resources include the requirements for labor, equipment, construction materials, support facilities, and materials generated on site, such as fill, crushed gravel, concrete aggregate, rip rap and water.

6.4.1 Labor Requirements

The estimated construction labor requirements presented in this section are for the direct field construction and contractor administration of the Applicant's proposed system. They do not include allowances for government inspection requirements, or project management and administrative manpower. Requirements are tabulated by trade mix, and total project requirements for civil construction, pipeline installation and station construction are shown in graphical form on Drawing APC S9-13.

a. Civil Construction

Civil construction crews will perform the following functions:

- site development
- road construction and maintenance
- work pad extension
- material processing
- restoration and revegetation
- clearing and grading right-of-way

Peak civil construction, manpower requirements by year and by craft are given in Table 6.4.1.

b. Pipeline Construction

Estimates for pipeline construction labor do not include clearing and grading operations on that portion of the system paralleling the Alyeska system, as clearing and grading will be accomplished by civil construction crews prior to placing the workpad. Estimates include labor for the following pipeline operations:

Drilling and Blasting
Excavation
Hauling and Stringing
Bending
Line-up/Weld
Coat & Lower-in
Cathodic protection
Select backfill
Backfill
Tie-ins
Cleanup
Scraper traps & valves
Testing-pigging
Special construction
River crossings

Pipeline construction labor requirements are given in Table 6.4.1. The requirements shown are the peak requirements for years two and three of the construction project.

c. Compressor Station Construction

Construction of compressor stations would be timed to the volume build up on the system, and manpower requirements for station construction reflect the construction activity related to this build up. Peak manpower requirements will be reached in the fall of the second construction year, due to the early construction of chilling facilities on the system. Station manpower requirements are detailed by craft and by construction year on Table 6.4.2.

6.4.2 Equipment Requirements

Construction equipment requirements will peak during the second construction year. Equipment requirements for civil construction, and pipeline construction are given in Table 6.4.3. Peak station equipment requirements are shown in Table 6.4.4.

6.4.3 Borrow Requirements

The required quantities of borrow materials which will be used for construction are summarized in Table 6.4.5.

6.4.4. Construction Materials and Consumables

The quantities of construction materials, fuel and lubricants are summarized in section 6.5.

TABLE 6.4

PEAK LABOR REQUIREMENTS

CIVIL CONSTRUCTION

	1978	1979	1980	1981	1982
Foremen	71	59	6	7	7
Operators	968	835	112	15	15
Teamsters	207	180	34	10	10
Laborers	319	228	40	-	-
Sub-Total	1,565	1,301	192	32	32
Salaried Staff	192	186	66	2	2
Total	1,757	1,488	258	34	34

Note: Civil Construction operations include site development, access road construction and maintenance, work pad extension construction, material processing and revegetation.

TABLE 6.4.1

MANPOWER REQUIREMENT

PIPELINE CONSTRUCTION

	Spread No. 1	2	3	4	5	6	Total
Welders, Journeymen & Helpers	168	186	168	168	168	168	1,026
Operators, Mechanics & Apprentices	279	294	279	285	307	319	1,763
Teamsters (all classifications)	91	94	91	91	98	104	569
Labourers (all classifications)	205	216	205	211	248	272	1,357
Field Administration (all classifications)	20	20	20	20	20	20	120
SUBTOTAL	743	790	743	755	821	863	4,715
Contractors--Administration							
Fairbanks	59	59	59	59	59	59	354
TOTAL	802	849	802	814	880	992	5,069

TABLE 6.4.2

MANPOWER REQUIREMENT

STATION CONSTRUCTION

Classification	Peak Direct Labor Requirements 1978	1979	1980	1981	1982
Building Crafts	468	850	140	96	52
Pipe Fitters	-	315	315	23	23
Millwrights and Boiler Makers	-	175	175	70	30
Electricians	-	165	165	25	23
Total	468	1505	795	212	128

Note: Building crafts include Laborers, Teamsters, Operators, Concrete Finishers, Ironmakers, Sheetmetal Mechanics, Painters.

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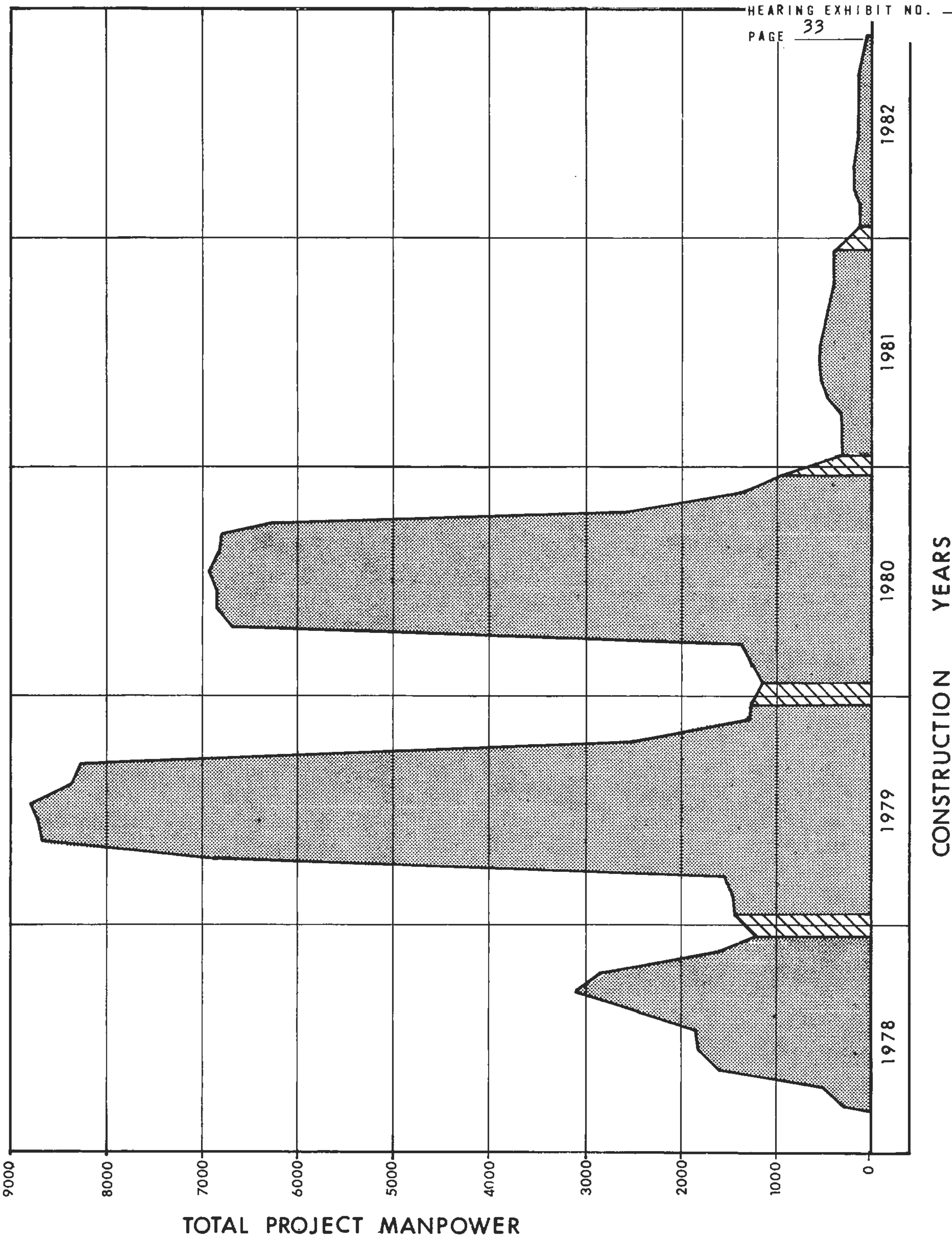

GULF INTERSTATE ENGINEERING COMPANY		
Alcan Pipeline Company		
PROJECT MANPOWER		
DRWN.	SCALE ——	DATE JUNE 1976
APPRVD.	DRWG. NO. APC-S9-13	REV. NO.

TABLE 6.4.3

MAJOR EQUIPMENT REQUIREMENTS

PIPELINE AND CIVIL CONSTRUCTION

Equipment	Spread No. 1	2	3	4	5	6	Total
Pipelayers							
Model 594	4	8	4	4	4	4	28
Model 583	25	25	25	25	25	25	125
Model 572	12	12	12	12	12	7	67
Model 571	1	1	1	1	1	1	6
Dozers							
Model D9	4	5	5	5	5	5	29
Model D8	20	23	20	26	27	25	141
Model D7	2	2	2	2	2	2	12
Model D6	8	8	8	8	8	11	51
Model 350	5	5	5	5	5	5	30
Mobile Crane							
60 ton	2	2	2	2	2	2	12
Backhoes							
2½ c.y.	15	16	15	15	15	14	90
Drag Line & Clam.							
4½ c.y.	2	2	2	2	-	-	8
1½ c.y.	10	11	10	10	11	16	68
3/4 c.y.	1	1	1	1	1	1	6
Motor Patrol							
Model (Cat #14)	8	8	8	8	8	6	54
Off Hi-Way Trucks							
Model Cat #769	28	28	28	28	29	25	166
Model Cat #773	18	9	9	9	-	-	45
Compressors							
1600 CFM	4	4	4	4	4	4	24
1200 CFM	10	12	10	10	10	10	62
800 CFM	2	4	4	4	1	-	15
175 CFM	2	2	2	2	2	1	11
125 CFM	5	6	5	5	5	5	31
Rock Drills							
Twin Drills	10	10	10	10	10	10	60
Air Tracs	2	6	4	4	1	-	17
641 Scraper	-	9	9	9	6	6	39
631 Waterwagon	2	2	2	2	1	1	10

TABLE 6.4.3 (cont'd)

MAJOR EQUIPMENT REQUIREMENTS

PIPELINE AND CIVIL CONSTRUCTION

Equipment	Spread No. 1	2	3	4	5	6	Total
15-ton High Crane	1	1	1	1	1	1	6
30-ton High Crane	1	1	1	1	1	1	6
Jaw Crusher	1	1	1	1	1	-	5
Belt Loader	1	1	1	1	1	-	5
Crushing Plant	1	1	1	1	1	1	6
Raygo 400 Compactor	4	4	4	4	3	2	25
Bomag 90 Compactor	1	1	1	1	1	1	6
15 KW light plant	20	20	20	20	14	10	104
500 KW generator	3	3	3	3	3	3	18
Front End Loaders							
Cat 988	6	6	6	6	4	4	32
Cat 977	2	2	2	2	3	4	15
Cat 992	2	2	2	2	-	-	8
Skidders							
Tree-Farmer	4	4	4	4	6	6	28
Welders							
Quad Welder	2	3	2	2	2	2	13
Weld. Machine	31	31	31	31	31	31	186
Utility Rigs	20	20	20	20	18	16	114
Specialized Equipment							
42-inch Bend Machine	1	1	1	1	1	1	6
Line-up Clamp	2	2	2	2	2	2	12
Mandrel	2	2	2	2	2	2	12
Line Heaters	6	8	6	6	6	6	38
Cl. Machine	1	1	1	1	1	1	6
Comb. Wrap. Machine	1	1	1	1	1	1	6
End. Prep. Machine	5	6	5	5	5	5	31
Pumps							
Six-inch Elliot	5	6	5	5	11	11	43
Ten-inch Diesel elec.	2	2	2	2	2	2	12

TABLE 6.4.3 (cont'd)

MAJOR EQUIPMENT REQUIREMENTS

PIPELINE AND CIVIL CONSTRUCTION

Equipment	Spread No. 1	2	3	4	5	6	Total
Trucks							
Truck tractor	22	22	22	22	24	24	136
Lo-boy	13	13	13	13	13	13	78
Hi-boy	12	12	12	12	14	12	74
Pole Trailer	9	9	9	9	9	9	54
Fuel Tanker	8	8	8	8	6	5	43
Service Truck	6	6	6	6	6	6	36
Buses							
32-passenger	27	29	27	27	27	27	164
20-passenger	5	5	5	5	5	5	30
Winch and Bed Trucks							
Single axle	10	11	10	10	9	11	61
Tandem axle	5	5	5	5	6	5	31
Oilfield bed	5	5	5	5	5	5	30
Skid Truck	1	1	1	1	1	1	6
Tire Truck	3	3	3	3	3	3	18
Mech. Rigs	30	30	30	30	29	28	117
Sedans & P.U.'s	108	111	108	108	113	99	647
Pitman Truck	6	6	6	6	4	3	31

TABLE 6.4.4

MAJOR EQUIPMENT REQUIREMENTS

STATION CONSTRUCION

Equipment Type	Typical Pieces per Station Site	Total Peak Equipment Requirement - 1979
250 CFM Air Compressor	2	26
100 KW Diesel/Electric Generator Set	2	26
3/8 yard Backhoe	1	13
D6 Dozer	1	13
3-ton Hi-Lift	1	13
25-ton Mobile Crane (rubber)	1	13
Pettibone or #14 Grove Crane	1	13
50-ton mobile crane (rubber)	1	13
150-ton mobile crane (rubber)	1	4
75-ton Low-boy trailer	1	4
Tandem tractor truck	1	4
5-ton flat bed truck	1	13
16S Concrete Batcher	1	13
Power Concrete Buggies	2	26
Crew cabs	4	52
#12 Motor Grader	1	6
Compactors	10	130
Portable Generator Sets	4	52
Power Trowel	2	26
Master Heaters	6	78
Snowmobiles	2	26

TABLE 6.4.4 (cont'd)

MAJOR EQUIPMENT REQUIREMENTS, STATION CONSTRUCTION..CONT'd

Equipment Type	Typical Pieces per Station Site	Total Peak Equipment Requirement-1979
Concrete Vibrators	4	52
400-A Diesel Welders	2	26
300-A Electric Welders	10	130
Fuel Truck	1	13
Water Tank Truck	1	13
Gradall	1	13
1-Yard Front-End Loader, Wheeled	1	13
Fire Truck	1	13
Scaffold	100 Sections	1300 Sectior
5000 gal Fuel Tanks	2	26

TABLE 6.4.5

BORROW MATERIAL REQUIREMENTS

1. PIPELINE CONSTRUCTION			
a. Work Pad Extension			
Granular Borrow		5,638,000	
Rock Borrow (Quarry)		288,000	
	Pad Subtotal	5,926,000	
b. Backfill - Crushed and Select		3,642,000	
c. Access Roads		115,000	
	Pipeline Total	9,683,000	cubic yards
2. OTHER			
a. Compressor Stations -			
Borrow fill material		1,170,000	
Crushed top dress		62,000	
Concrete aggregate		55,000	
Topsoil		26,000	
Compressor Station Subtotal		1,313,000	
b. Meter Stations		15,000	
c. Campsites		120,000	
d. Pipeyards		120,000	
e. Operating and Maintenance Facilities		80,000	
	Total	1,648,000	cubic yards
3. TOTAL BORROW REQUIREMENTS		11,331,000	cubic yards

6.5 LOGISTICS

6.5.1 Introduction

Construction of the Alaskan section of the Alcan Pipeline will require large quantities of materials, both for the pipeline facilities, and for the actual construction operations. The total material requirements over the five-year construction period, from permit receipt through to completion of the pipeline system, will require some 1,100,000 tons of materials and supplies. Approximately 70 percent of the total tonnage is accounted for by line pipe and fuel.

Logistics for the project have been based on obtaining all permanent equipment for the pipeline and stations outside Alaska. Consumable materials and supplies, including food and fuel will be obtained from Alaskan suppliers to the extent of their capabilities. The applicant has discussed with suppliers their willingness to stock spare equipment parts and supplies and finds them amenable to this concept.

The transportation of equipment, manpower and materials will require a combination of the following modes of transportation; rail, truck, barge, container ship, ocean freighter, and both fixed wing and rotary aircraft.

In designing the logistics system, particular emphasis will be placed on materials movement through intermediate transfer points, to ensure efficient movements and unnecessary stockpiling at intermediate points. During the selection of transportation routes, staging areas, stockpile sites and right-of-way storage areas, full consideration has been given to utilizing the facilities that have been developed by or for Alyeska Pipeline Service Company.

6.5.2 Materials, Equipment and Supplies

Construction of the Alcan mainline will require just over one million tons of materials, equipment, and consumables. This total excludes granular materials, concrete aggregate and select backfill. The estimated tonnages for the major items and commodities are summarized in Table 6-5.

6.5.3 Elements of the Transportation System

This section outlines the location of the major staging areas and summarizes the transportation facilities and equipment that will be required to position materials on the right-of-way. The location of Alaskan staging areas and transportation routes is shown on Drawing APC S9-14.

The Applicant proposes to distribute equipment and materials by means of a two-tier distribution system, i.e., by assembly in staging areas and forwarding to stockpile sites along the right-of-way. The Alcan pipeline project will require three staging areas in Alaska. In keeping with the Applicants' intent of utilizing existing facilities to the maximum extent possible, it is proposed to employ the Prudhoe Bay-Fairbanks-Valdez facilities, which were established for the Alyeska project. In addition to these facilities, it will be necessary to acquire for limited periods of time warehouse space in Anchorage and Seward.

Stockpile sites will be established along the right-of-way; for the most part, these facilities will be located at campsites and at station sites. In addition to these stockpile sites, twenty pipe storage yards will be established for pipe storage prior to construction. The milepost location of camps, pipeyards, and compressor stations is given in Table 6.5.1.

The four basic transportation modes; rail, road, water and air will be employed in the movement of materials and equipment.

Rail - The facilities of the Alaska Railroad will be employed to a certain extent in the transportation of materials arriving at the ports of Anchorage, Seward and Whittier. A number of the rail shipments to Fairbanks will consist of lower 48 car ladings, which have been transported from Seattle to Alaska by means of barge trains. No major improvements or additions to the railroads fixed plant are anticipated.

Road - Extensive use will be made of the existing State highway system, the Alaska Highway, and the Alyeska haul road. The main function of highway transportation in the overall logistics planning is the delivery of materials and equipment from the three Alaskan staging areas to the stockpile sites on the right-of-way. In a number of cases, special permits will be required for certain equipment movements.

Water - The greater part of the pipeline materials will be transported to Alaska by means of ocean-going barges and ocean freighters, with a smaller quantity arriving by container ship. Water-borne freight will enter Alaska at

Prudhoe Bay, Seward and Valdez. Particular attention has been paid to scheduling the barge movement to Prudhoe Bay to ensure that the barges arrive off Point Barrow during the last week of July; in order to provide adequate time for the passage through the ice-covered waters off the North Slope of Alaska. In addition to utilizing the normal barge services between Washington and Alaska, the Applicant will consider time chartering a number of vessels to ensure adequate capacity during peak movement periods.

Air - The Applicant will make use of all air services operating from southern Alaska to communities and airfields adjacent to the right-of-way. Since the proposed right-of-way is readily accessible by existing highway systems, the Applicant does not propose to construct any new airstrips. The use of fixed wing aircraft will, in general, be limited to the movement of personnel and special equipment items to existing FAA airports. STOL aircraft will be employed extensively in ferrying personnel between FAA airports and airstrips adjacent to campsites. Helicopters will be used extensively in the early stages of the project, for the movement of survey, geotechnical and environmental crews. Once construction commences, helicopter requirements will be reduced.

6.5.4 Logistics Planning and Major Commodity Movements

This section outlines the manner in which the Applicant proposes to distribute key commodities and materials along the 731.4 mile right-of-way.

Line Pipe - Main line pipe will enter Alaska at Prudhoe Bay and Valdez by means of waterborne transportation. The Prudhoe Bay pipe will, subject to availability, enter Alaska by means of 400 x 100 foot barges, each capable of handling up to 13-1/2 miles of single jointed pipe. Tug and barge movements have been scheduled in accordance with both the mill projection schedule, and the limited open water season, thereby avoiding stockpiling at either pipe mills, or intermediate sites.

Line pipe for the North Slope section (some 173 miles) will arrive off Prudhoe Bay in early August 1978, where it will be lightered ashore and transferred to the Prudhoe Bay staging area. Double jointing will take place at the staging area. From this point double-jointed pipe will be trucked to the pipe yards. The trucking fleet will be sized to ensure that 50 percent of the pipe is delivered to the pipe yards prior to the start of pipeline construction in May 1979. Pipe deliveries will be completed during the summer of 1979.

Pipe for the balance of the line (MP173 to MP731.4) will be landed at Valdez by means of chartered vessels. Deliveries to Valdez will begin in May 1978 and finish in February 1979. A portion of the pipe will be double jointed in Valdez, while the balance will be trucked to Fairbanks for double jointing. From the Valdez and Fairbanks staging areas double jointed pipe will be trucked to the pipe yards along the right-of-way. As in the case of the Prudhoe Bay pipe. 50 percent of the pipe will be delivered to the pipe yards prior to the construction starting date.

Construction Equipment - Equipment for both the civil works and the pipeline contractors will be rigged up in Alaska and will then be trucked to the appropriate starting point on each spread.

Station Materials and Equipment - All station equipment will originate in the lower 48 and will be shipped to Alaska.

Fuel - The Applicant proposes to obtain fuel from Alaskan suppliers at established terminal facilities. Fuel suppliers will be responsible for delivery to their terminal sites. A fleet of tank trucks will be used to transport fuel from bulk terminals to tank farms along the right-of-way.

Miscellaneous materials - The Applicant proposes to purchase a large proportion of equipment, spares and miscellaneous items in Alaska. A large proportion of these materials will be loaded in containers at the major supply points in southern Alaska and trucked to the appropriate location on the right-of-way.

6.5.5 Logistics - Project Management

In order to achieve an efficient and orderly movement of equipment, materials and personnel, the Applicant proposes to establish a logistics group within its overall construction management organization. The essential task of the logistics group will be to schedule and supervise the movement of necessary materials and equipment to staging areas, and to distribute same in an efficient and economical manner to the various stockpile sites along the right-of-way. An additional function of the logistics group will be to provide security services at all major staging areas.

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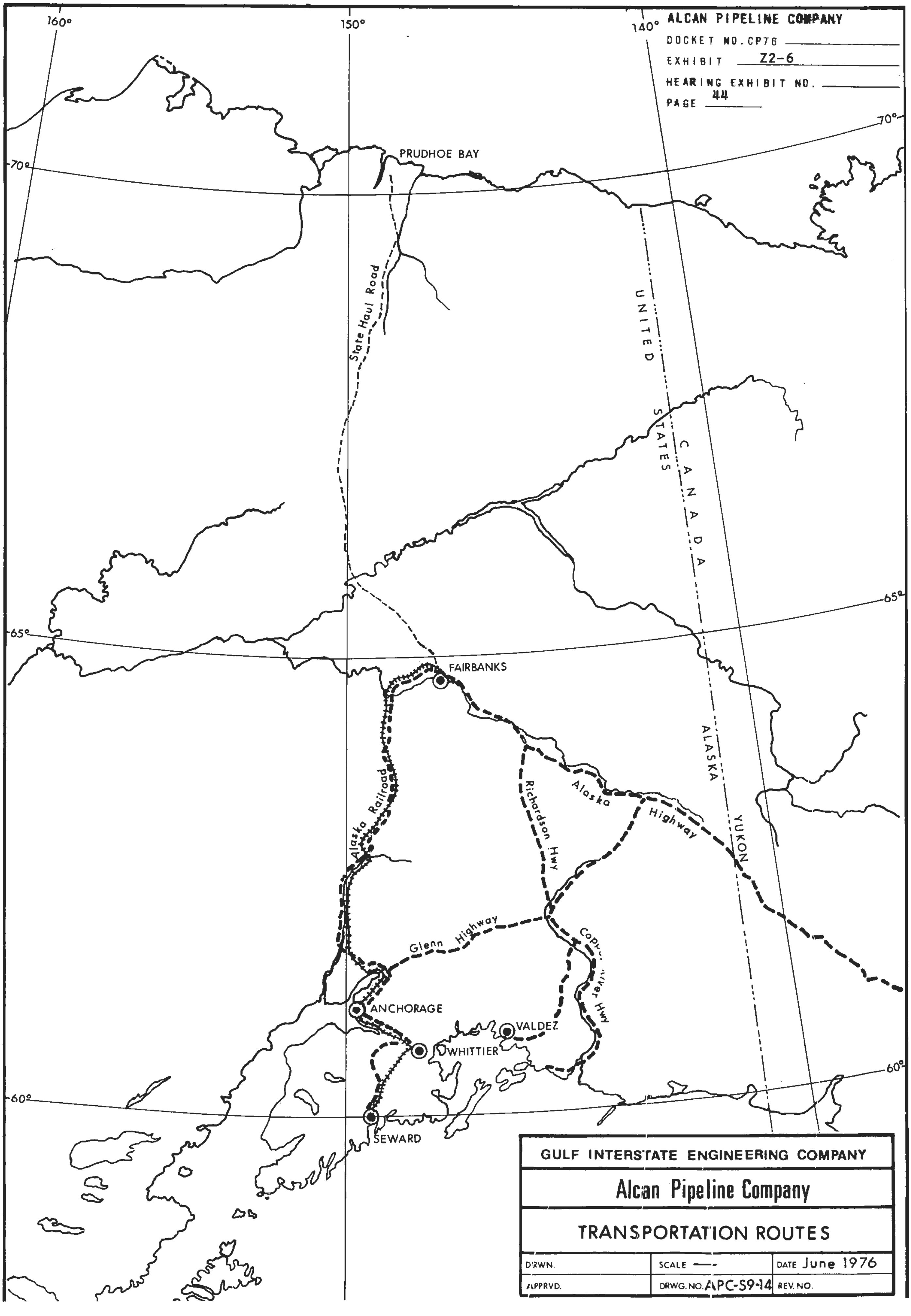

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Alcan Pipeline Company

TRANSPORTATION ROUTES

D'RWN.	SCALE —	DATE June 1976
APPRVD.	DRWG. NO. APC-S9-14	REV. NO.

TABLE 6.5
TONNAGE SUMMARY

42-inch Pipeline	Short Tons (1)
mainline pipe	513,000
coating materials	6,000
valves, fittings, stations connections, and scraper traps	6,000
miscellaneous pipeline materials	147,000
construction equipment & spare parts	61,000
fuel, lubricants & greases, including camp fuel	264,000
consumables	15,000
subtotal - pipeline	1,010,000
Stations	
15 compressor stations - materials	63,000
3 meter stations - materials	1,100
operating and maintenance facilities	4,900
fuel, lubricants and greases, including camp fuel	22,000
other consumables & miscellaneous items	7,000
Subtotal - Stations	98,000
TOTAL TONNAGE	1,108,000

NOTES: 1. All tonnage estimates have been rounded off for presentation purposes; actual tonnages have been employed in developing cost estimates.

TABLE 6.5.1
LOCATION OF STOCKPILE SITES

CAMPS		PIPEYARDS		COMPRESSOR STATIONS	
NAME	M.P.	NO.	M.P.	NO.	M.P.
Franklin Bluffs	39	1	17	1	43.5
Happy Valley	84	2	63	2	83.7
Toolik	130	3	82	3	118.6
Galbraith Lake	143	4	120	4	157.7
Atigun	162	5	147	5	210.8
Deitrich	203	6	151	6	261.9
Coldfoot	237	7	171	7	305.9
Prospect	277	8	216	8	355.0
Oldman	301	9	247	9	400.7
Five Mile	350	10	272	10	442.6
Livengood	398	11	296	11	497.4
Fairbanks (1)	452	12	324	12	543.6
Big Delta	528	13	374	13	590.3
Tok	643	14	416	14	639.4
Northway	692	15	476	15	684.1
		16	517		
		17	555		
		18	596		
		19	640		
		20	695		

NOTES: (1) Projected basis

The logistics planning and management group, along with appropriate support staff, i.e. accounting, data processing, personnel, etc. will be based in Fairbanks. In addition, it will be necessary to establish coordinating task forces at each of the three Alaskan staging areas. Local field coordination will be handled by teams of expediters and checkers operating from the major construction camps and compressor station sites.

6.6 PROJECT CONTROL

The objective of project management is to provide the overall project planning, coordination, and control of all aspects of a capital investment project to ensure successful completion of that project. A project management organization utilizes established management procedures in the areas of design coordination, project scheduling, construction coordination, cost control, and quality control and inspection services, with the intention of realizing efficient and effective construction. The project management group translates the objectives of the owner into a program of activities and provides control of the consultants and contractors responsible for the actual completion of these activities.

Effective project management on large projects is difficult to achieve due to the scale and complexity of operations which must be coordinated and monitored. Large-diameter pipeline construction in the Arctic is not only a large construction project, but a technically complex project requiring the successful coordination of many design and construction groups. Apart from the problems presented by weather and environment, proposed pipeline projects in these remote areas will typically require an extensive support facility and civil construction program. Infrastructure which exists in more densely populated areas, i.e. communications facilities, transportation systems, accommodation--must be provided for construction operations. The project management group must deal with very complex logistics and civil construction programs, and must interface with and report to various government bodies. Because of the complexity and scale of operations required, it is extremely important that the responsibility for the civil control and construction coordination for the various pipeline, civil station, and support facilities is shared by the contractors working on the project. The nature of typical frontier-area construction programs presents unusual conditions to a pipeline or civil contractor as compared to conventional construction projects. However, as noted earlier in this section, the Alcan Pipeline project will <u>not</u> be a typical frontier-area construction project. The Alcan Pipeline system construction will be easier to manage and control than frontier-area construction projects, due to the following considerations:

a. Existing civil infrastructure and service facilities reduce the scale of operations required.

b. Good communications systems exist along the route.

c. Good pipeline access and established logistics patterns.

d. Established government inspection procedures.

e. Established construction practices.

f. Summer construction.

Due to these considerations, it is suggested that it will be possible to enter into a contractual arrangement which will establish a high degree of responsibility for costs and schedules; project management will be much more effective than for frontier-area projects.

The project management group proposed by the Applicant will provide the reporting mechanisms to co-ordinate and monitor all aspects of construction of the Alcan Pipeline system. The project control program will be flexible enough to accept direction at any competent level. Contractors selected by the project management group will be responsible for performing the duties outlined in the individual contracts. The Applicant's project management group will use modern management techniques to maintain effective control over the project, and to monitor the proper allocation of project resources.

The project management group will co-ordinate the design, construction and logistics groups to ensure the schedules and programs of work are adhered to. Project management will be responsible for the following:

1. <u>Planning, Scheduling and Controlling</u> - of all operations for basic design and procurement to completion of construction.

2. Design Coordination - including design criteria, preparation of general design specifications and terms of reference.

3. Cost Control - preparation of preliminary estimates, budget estimates and cash flow forecasts, detailed cost estimates and cost control, cost reports with regularly updated forecasts of final costs.

4. Contract Administration and Purchasing - preparation of contractual documents and specifications invitations to bid, and aware of contracts.

5. Construction Management - supervision and coordination of the work of contractors and monitoring their progress in relation to the project schedule; determination of requirements for temporary facilities and site services and making arrangements for these services; receipt and custody of owner-supplied materials.

6. Quality Assurance - inspection of the quality of design and construction, and the methods and procedures used in executing the work. The Applicant's project management group will use stringent inspection procedures to monitor the installation of the pipeline and pipeline facilities to ensure integrity of the system. In addition, the Applicant will provide appropriate auditing of the inspection to insure compliance with the procedures.

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OPERATIONS AND MAINTENANCE PLAN

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OPERATIONS & MAINTENANCE PLAN INDEX

7.0 OPERATIONS AND MAINTENANCE PLAN

The following section details the Applicant's proposed operating and maintenance plan and the resources and facilities necessary to ensure the safe and efficient operation of the Alcan Pipeline system.

7.1 GENERAL CONCEPT

The Alcan Pipeline will be operated and maintained by the Applicants' staff. The Operation and Maintenance team will consist of 108 full time employees. The pipeline will always have multi-skilled personnel available to handle the normal day-to-day operations, scheduled major work, minor repairs, routine maintenance and contingency operations, as well as the normal painting, cleaning and upgrading of the pipeline system.

Support services such as catering, fuel and sewage hauling and rotational personnel transportation will be subcontracted to local businesses specializing in these types of support services.

The operations and maintenance organization is structured around four workable sized districts. Compressor stations and pipeline segments within each district will experience relatively common operational problems due to common terrain and climatic conditions.

The four districts are described on Table 7.1. Existing temporary construction camp facilities will be renovated to provide the necessary permanent district base facilities; therefore, only a small number of new facilities will be required.

The district bases and descriptions of the districts are outlined as follows:

7.1.1 Happy Valley District

This district covers the distance from Prudhoe Bay to Atigun Pass, a total pipeline mileage of approximately 163 miles. The District Staff will be responsible for the maintenance and operations of the compressor stations numbered one through three, plus the main gas receipt meter station at Prudhoe Bay. The district Base is positioned adjacent to Compressor Station 2 (C.S.2) at Pipeline Milepost 84. Locating this O&M facility at C.S.2 places it in relatively close proximity to the Sagwon Civil Airbase, which is a maintained airbase with complete facilities. Compressor Station Number 2 (C.S.2) is approximately 15 miles south of Sagwon and within one mile of the Happy Valley airstrip currently being used by Alyeska. This operations and maintenance district base will draw on the support utilities of Station 2; that is, the O&M facility will utilize the amenities of:

Power
Water
Water and Sewage facilities
Fuel Storage
Communications

The proposed site area and layout is designed to provide the facilities necessary to complete the Happy Valley District Base (see Figure 7.1.1).

7.1.2 Prospect District

District Number 2 will operate and maintain the Applicant's facilities installed between the Antigun Pass and the Yukon River; a total pipeline mileage of approximately 190 miles. There are four compressor stations within this district; compressor stations 4, 5, 6 and 7.

The maintenance facility itself is located at Compressor Station Number 6 (C.S.6), Pipeline Milepost 261.9.

The Prospect District O&M base is positioned approximately at the midpoint of the district, and approximately 10 miles north of the existing Prospect Creed Aerodrome. This location is 30 miles from the Evansville Civil Airport where there is complete flight services including a major vortac and radio beacon.

The Prospect District Base facility will rely on the support of the adjacent Compressor Station C.S.6. The site layout for this base is shown on Figure 7.1.2 and includes:

Equipment and Material Loading Dock and Ramp
Warehouse
Maintenance Shop
Equipment Laydown area
Living Complex
Office

There is no specific area allocated for pipe storage at the District bases; however, there is space available on the compressor station sites for pipe storage.

7.1.3 Fairbanks District

District Number 3 covers the distance from the Yukon River to the Tanana River crossing at Big Delta, a pipeline mileage of approximately 177 miles. In addition to the pipeline, this district is responsible for the O&M of compressor stations 8, 9, 10 and 11, plus the community gas service meter serving the community of Fairbanks. The operations and maintenance facility for the Fairbanks District is located at Compressor Station Number 10 (C.S.10), Pipeline Milepost 443. This O&M district base is within 15 miles of the city of Fairbanks, Alaska. Due to the proximity of Fairbanks, the living complex building is not required (see Figure 7.1.3). The remaining operations and maintenance buildings will receive support from the adjacent station.

7.1.4 Tanacross District

District Number 4 covers the segment of the Applicant's pipeline from the Tanana River Crossing at Big Delta to the Alaska/Yukon border, approximately 200 miles of pipeline. There are four compressor stations and one major meter station location within this District. The base itself is located at Compressor Station 14 (C.S.14), within five miles of Tanacross, Alaska.

There are major airport facilities at Tanacross, and the district base in approximately seven miles from the junction of the Alaska Highway and the highway to Valdez.

Just as the O&M site for the Fairbanks District Base is without a living complex, so is the one for the Tanacross District (see Figure 7.1.4). It has been assumed that the operating staff personnel could be housed in Tanacross and it is anticipated that any accomodations built in Tanacross will consist of two and three-bedroom single family dwellings, and/or one, two and three-bedroom apartments, in place of living complexes installed for the remote Operations Bases Happy Valley and Prospect.

7.2 NORMAL OPERATION PROCEDURES

7.2.1 Compressor Stations

The normal operation of the stations will be handled remotely from the dispatching office in Fairbanks, however there will be periodic operations and equipment checks, level settings, etc., that will be performed by

TABLE 7.1

OPERATION AND MAINTENANCE DISTRICTS

DISTRICT NUMBER	NAME	MILE POST		STATIONS		MILES OF PIPE
		From	To	Compressor	Meter	
1	Happy Valley	0	163	3	1	163
2	Prospect	163	353	4	0	190
3	Fairbanks	353	530	4	1	177
4	Tanacross	530	731	4	1	201

crews dispatched from the district bases as required. Regular major overhauls of all rotating equipment will be performed at intervals as recommended by the manufacturers.

7.2.2 Pipeline

Right-of-way and workpad maintenance, cathodic protection monitoring and environmental surveillance will be performed by Alcan personnel on a regularly scheduled basis.

7.2.3 Communications Equipment

The communications technicians will be responsible for checking and maintaining the communications equipment including radios and control equipment, and will be responsible for minor replacement and repairs but not for major repairs of this equipment.

7.3 CONTINGENCY OPERATIONS PROCEDURES

7.3.1 Compressor Stations

The major consideration as far as compressor station operation is concerned is a major rotating equipment component failure. The pipeline system can in an emergency continue to operate temporarily with a mainline turbine-compressor unit down. There will be repair personnel stationed at each maintenance base, and one comlete set of major components located at both the Fairbanks main base and the Happy Valley District base. These spares will be used to completely replace the malfunctioning component in the event that a major repair job is required. This contingency philosophy will allow a major rotating equipment repair to be completed in a relatively short period of time.

All other major components can be temporarily bypassed in the event of a failure.

7.3.2 Pipeline

The major consideration as far as pipeline operation is concerned is a large leak or pipeline break. Pipeline repair equipment has been classified as standby equipment, and will be located at the Happy Valley and Fairbanks district bases. A repair crew can be dispatched from the maintenance base closest to the line break and any additional personnel required flown in from the other Districts.

7.4 OPERATIONS AND MAINTENANCE EQUIPMENT AND MANPOWER

7.4.1 Assumptions

The operations and maintenance equipment requirements have been developed by giving full consideration to the following assumptions:

a. That the highway to Prudhoe Bay will be maintained by others, with some applicable charge to Applicant.

b. That subcontractors exist to handle the support services mentioned in Section 7.1.

7.4.2 Manpower

The operations and maintenance manpower requirements have been developed by adopting a multi-skill manning concept. That is, it has been assumed that by utilizing an efficient training, incentive and promotion program, certain classes of employees can perform effectively at several levels of job skills. This allows for a reduction in the total number of employees required and a flexible and efficient operations and maintenance staff.

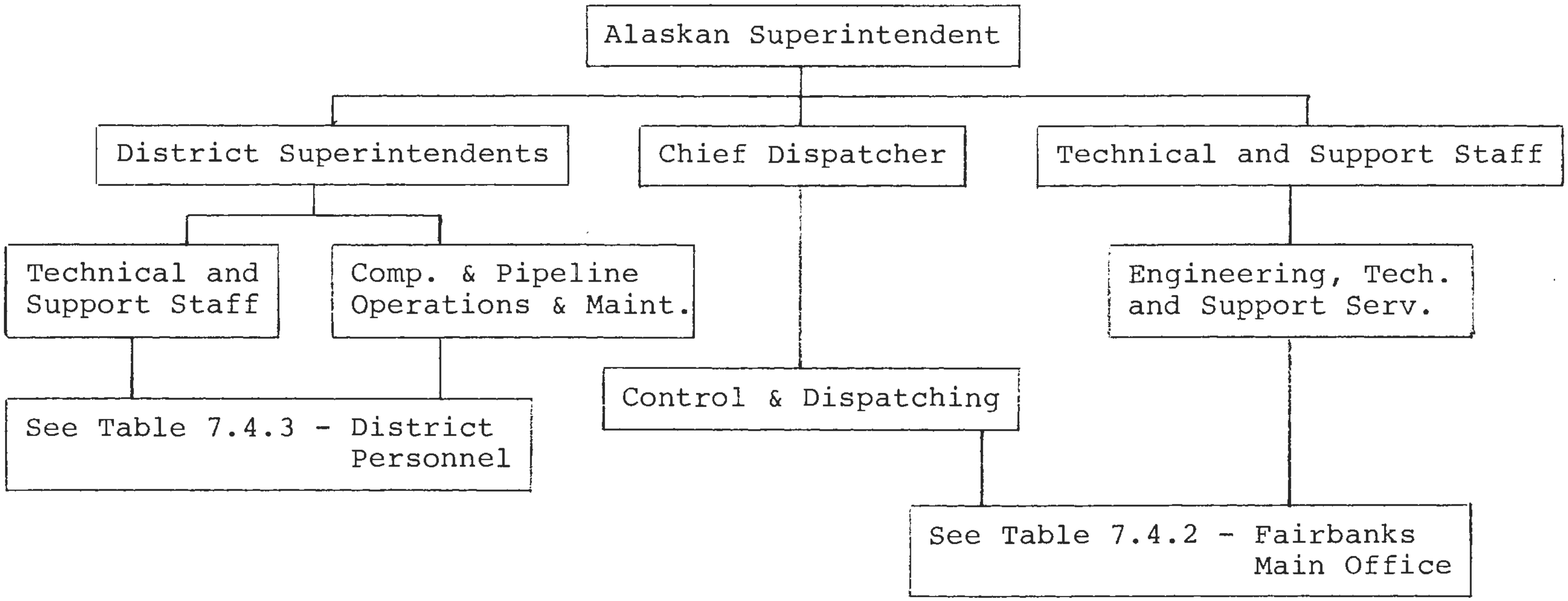
The staff organization chart is shown on Table 7.4.1. It can be seen from this organization chart that the District Bases are managed by a group of supervisors and engineers located in the main office of Fairbanks.

The main office group will utilize rented office space in Fairbanks. For complete manpower requirements, see Tables 7.4.2 and 7.4.3.

7.4.3 Equipment

The required complement of operations and maintenance equipment has been arrived at by giving due consideration to the necessity for the safe and efficient operation of a large diameter pipeline in a delicate and hostile environment. See Tables 7.4.4 and 7.4.5.

TABLE 7.4.1



Total Staff on Duty	74		Total Staff on Duty	22
Total Staff on Rotational	12		Total Staff on Rotational	0

Total Alcan Pipeline Company Alaskan Staff on Duty - 96
Rotational - 12

Total Permanent Staff - 108

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TABLE 7.4.2

FAIRBANKS MAIN OFFICE

Personnel by Job Description	No.
Alaskan Superintendent	1
Operations Engineer	1
Environmental Engineer	1
Communications Engineer	1
Safety Director	1
Tech. Service Technicians	2
Corrosion Technician	1
Draftsman	1
Chief Dispatch	1
Dispatchers	5
Programmer/Analyst	1
Right of Way/Land Man	1
Pilot	1
Clerks	2
Secretaries	2
Total on Duty	22

TABLE 7.4.3

DISTRICT PERSONNEL

Personnel by Job Description	BASE DISTRICT Happy Valley*	Prospect*	Fairbanks	Tanacross	Total
District Superintendent	1	1	1	1	4
Tech. Service Technicians	2	2	2	2	8
Corrosion Technician	1	1	1	1	4
Clerk	1	1	1	1	4
Foremen	2	2	2	2	8
Repairmen	3	3	3	3	12
Welders	1	1	1	1	4
Equipment Operators	3	3	5	3	14
Laborers	4	4	4	4	16
Total on Duty	18	18	20	18	74
Total Rotational	(6)	(6)	(0)	(0)	(12)

*All Happy Valley and Prospect personnel on rotational duty.

TABLE 7.4.4
ALCAN PIPELINE COMPANY
MAINTENANCE EQUIPMENT BY LOCATION
DISTRICT BASES

DESCRIPTION	HAPPY VALLEY	PROSPECT	FAIRBANKS	TANACROSS	TOTAL
5 Ton flatbed with cherry picker	1	1	1	1	4
Rubber Tired Backhoe	1	1	1	1	4
1 Ton Truck with welding Eqpt.	1	1	1	1	4
Personnel Trailer	1	1	1	1	4
Portable Power Generator	1	1	1	1	4
ATV	1	1	1	1	4
Snowmobiles, enclosed	2	2	2	2	8
Boat & Trailer	1	1	1	1	4
Emergency Equipment					
42" Pipe Carrier Trailer	1	0	1	0	2
Lowboys	2	0	2	0	4
Truck tractors	2	0	2	0	4
583 Pipe layer	2	0	2	0	4
D-7 Dozer	1	0	1	0	2
Combination Backhoe 1 1/4 yd.	2	0	2	0	4
TOTALS	19	9	19	9	56

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TABLE 7.4.5

ALCAN PIPELINE COMPANY

TRANSPORTATION EQUIPMENT BY LOCATION

DESCRIPTION	FAIRBANKS MAIN OFFICE	DISTRICT BASES Happy Valley	Prospect	Fairbanks	Tanacross	Total
1/2 ton Pick-Up Truck	4	3	3	3	3	16
3/4 ton 4x4 Pick-Up Truck	2	3	3	3	3	14
3/4 ton Crew Cabs	0	2	2	2	2	8
Automobiles	2	0	0	0	0	2
Aeroplane	1	0	0	0	0	1
Ambulance	0	1	1	1	1	4
TOTALS	9	9	9	9	9	45

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7.5 Tools and Spare Parts Inventory

In accordance with the normal and contingency operations philosophy described above, basic maintenance tools and spare parts will be located at each district base with major spare parts and contingency operation tools strategically located at the Happy Valley and Fairbanks District Bases. A list of major spare parts and tools is described below:

Mainline Compressor*:

Gas Generators (2), Power Turbine Rotors (2), Power Turbine Stators (2), Compressor Spare Bundle packages (2), Exhaust diffuser and inlet duct assembly (1) and other associated driver assembly and compressor unit miscellaneous spare parts.

Propane Compressors*:

Gas Producer Assemblies (2), Power Turbine Assemblies (2), and other spare parts for start system, fuel system, electrical system, lube system and engine system.

Power Generator Units*:

Gas Producer/Turbine assemblies (6) and other spare parts for start system, fuel system, electrical system, lube system and engine system.

* On Mainline compressor and Propane compressors, one complete set of spare parts will be located at Happy Valley District Base and the rest located at Fairbanks Main Depot. On power generating units, two sets will be located at Happy Valley with the rest being located at Fairbanks Main Depot.

Other major spare parts include: electric motors for propane condenser fans (45), condenser tube bundle packages (8), waste heat boiler (1), and adequate spare parts for various pumps, electrical switchgear, etc. Various valves, miscellaneous spare parts such as pressure gauges, oil filters, air filters, etc. will also be stocked.

Tools:

Various pipeline cleaning, safety and repair tools will include hydraulic bending machines (2), line up clamps, bevelling machines, cradles, sleeves, tongs, slings, ball pigs, etc. Technicians will be equipped with both stationary (shop) and mobil test equipment.

TABLE 7.6.1

ALCAN PIPELINE COMPANY

ESTIMATED ANNUAL PAYROLL
(1975 Dollars)

Job Description	Annual Salary	No.	Total Yearly
Alaskan Superintendent	$60,000	1	$ 60,000
District Superintendents	42,000	4	168,000
Engineers	36,000	3	108,000
Technicians	32,000	15	480,000
Chief Dispatcher	52,000	1	52,000
Dispatchers	36,000	5	180,000
Foremen	36,000	8	288,000
Repairmen	30,000	12	360,000
Welders	32,000	4	128,000
Equipment Operators	30,000	14	420,000
Laborers	26,000	16	416,000
Pilot	50,000	1	50,000
Right of Way/Landman	42,000	1	42,000
Programmer/Analyst	36,000	1	36,000
Safety Director	32,000	1	32,000
Draftsman	28,000	1	28,000
Clerks	28,000	6	168,000
Secretaries	20,000	2	40,000
Sub-Total		96	$3,056,000

Rotational Duty Employees 12 @ an average salary of

$31,000 each $ 372,000

Total Estimated Payroll $3,428,000

Rotational: (Per Dist.)

Dist. Supt.	1
Foremen	
Technicians	1
Eqpt. Oprs.	1
Repairmen	1
Laborers	2
Clerk	

TABLE 7.6.2

ALCAN PIPELINE COMPANY

OPERATING & MAINTENANCE COSTS
FOR 1981 OPERATIONS

DESCRIPTION	ESTIMATED COST			
	LABOR	SUB-CONTRACTS	MATERIALS	TOTAL
1) Land Use (B.L.M.)	-	-	-	$ 114,600
2) Comp. Station & Pipeline Maint. & Operation	$4,348,400	-	$5,271,200 a)	9,619,600
3) Gas Control	425,300	-	-	425,300
4) Supervision and Engineering	666,500	-	-	666,500
5) Repair & Operation of Transportation & Maint. Equipment	-	-	453,300	453,300
6) Communications	-	$ 833,400	-	833,400
7) Support Services (b)	-	611,000	-	611,000
8) Misc. Material, Labor & Rentals	272,000	30,600	286,200	1,938,800
Sub-Totals	$5,712,200	$1,475,000	$6,010,700	$14,662,500
Administrative & Gen Exp. (c)	2,856,100	-	601,000	3,457,200
Insurance (d)	-	-	-	4,113,100
Ad Valorem Taxes (e)	-	-	-	49,021,500
TOTALS	$8,568,300	$1,475,000	$6,611,800	$71,254,300

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TABLE 7.6.3

ALCAN PIPELINE COMPANY

OPERATING & MAINTENANCE COSTS
FOR 1982 OPERATIONS

DESCRIPTION	ESTIMATED COST			
	LABOR	SUB-CONTRACTS	MATERIALS	TOTAL
1) Land Use (B.L.M.)	-	-	-	$ 114,600
2) Comp. Station & Pipeline	$4,696,400	-	a) $6,292,600	10,989,000
3) Gas Control	459,400	-	-	459,400
4) Supervision and Engineering	719,900	-	-	719,900
5) Repair & Operation of Transportation & Maint. Equipment	-	-	485,000	485,000
6) Communications	-	867,000	-	867,000
7) Support Services (b)	-	635,600	-	635,600
8) Misc. Material, Labor & Rentals	293,800	31,800	338,900	2,014,500
Sub-Totals	$6,169,500	$1,534,400	$7,116,500	$16,285,000
Administrative & Gen. Exp.(c)	3,084,800	-	711,700	3,796,500
Insurance (d)	-	-	-	4,825,300
Ad Valorem Taxes	-	-	-	50,714,300
TOTALS	$9,254,300	$1,534,400	$7,828,200	$75,621,100

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TABLE 7.6.4

ALCAN PIPELINE COMPANY

OPERATING & MAINTENANCE COSTS
FOR 1983 OPERATIONS

DESCRIPTION	ESTIMATED COST			
	LABOR	SUB-CONTRACTS	MATERIALS	TOTAL
1) Land Use (B.L.M.)	-	-	-	$ 114,600
2) Comp. Station & Pipeline Maint. & Operation	$5,071,700	g) $2,368,400	a) $8,482,100	15,922,200
3) Gas Control	496,100	-	-	496,100
4) Supervision and Engineering	777,400	-	-	777,400
5) Repair & Operation of Transportation & Maint. Equip.	-	-	518,800	518,800
6) Communications	-	901,900	-	901,900
7) Support Services (b)	-	661,200	-	661,200
8) Misc. Material, Labor & Rentals	317,300	151,500	450,100	2,268,900
Sub-Totals	$6,662,500	$4,083,000	$9,451,000	$21,661,100
Administrative & Gen. Exp. (c)	3,331,300	-	945,100	4,276,400
Insurance (d)	-	-	-	5,227,800
Ad Valorem Taxes (e)	-	-	-	51,726,400
TOTALS	$9,993,800	$4,083,000	$10,396,100	$82,891,700

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NOTES:

a) Based on $10/HP/Yr. for 26,500 HP machine & $12/HP/Yr. for smaller machines.

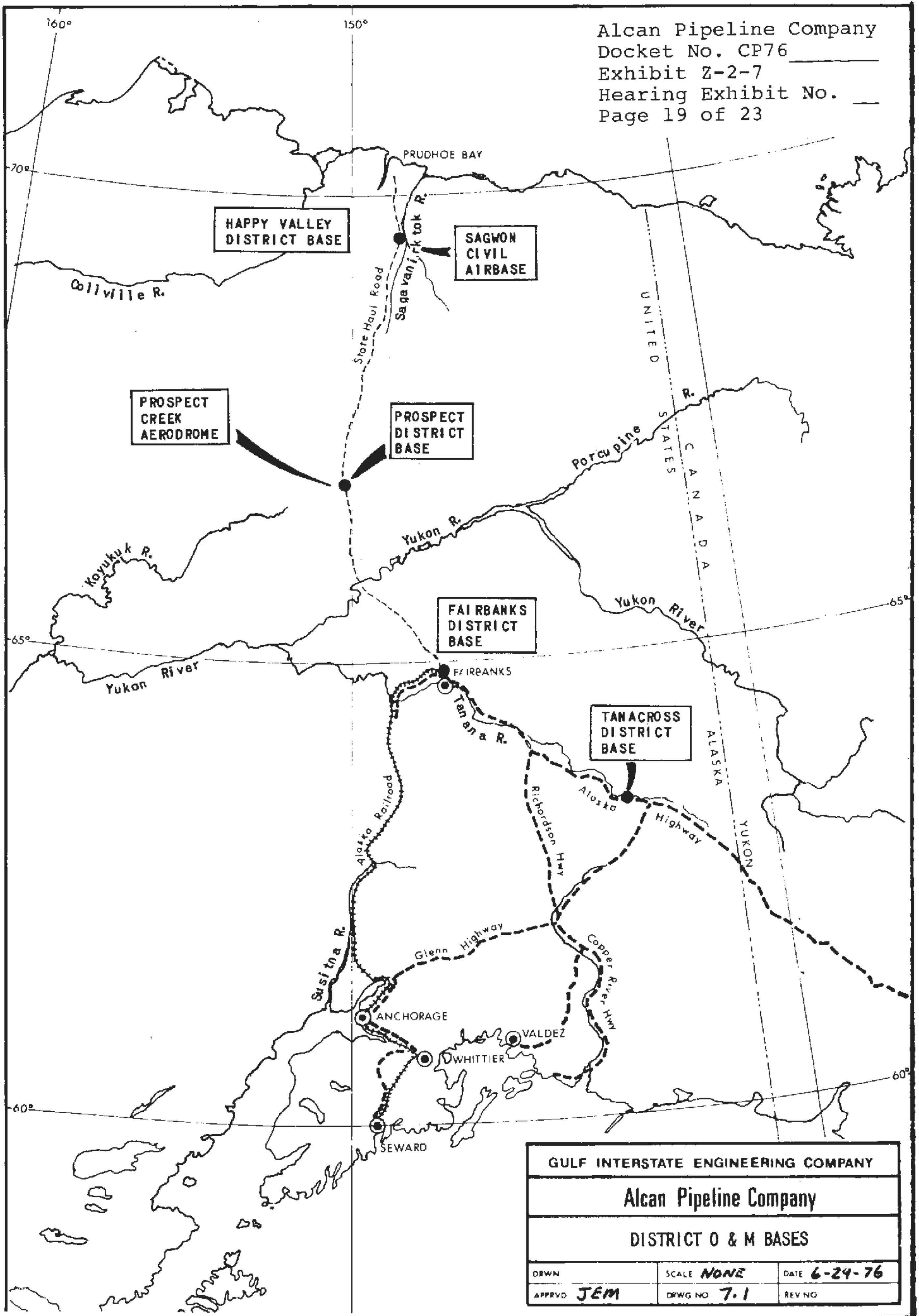
b) Includes fuel transport, sewage hauling and disposal, air transport and catering service. Catering service for Happy Valley and Prospect districts only.

c) At 50% for Labor and 10% for Material

d) At 1% of total cost of above ground structures, as completed.

e) At 2% of total investment cost

f) Based on 5 - 26500 HP Machine Overhauls per year
2 - 10000 HP Machine Overhauls per year
3 - 3830 HP Machine Overhauls per year
6 - 1180 HP Machine Overhauls per year



GULF INTERSTATE ENGINEERING COMPANY		
Alcan Pipeline Company		
DISTRICT O & M BASES		
DRWN	SCALE NONE	DATE 6-24-76
APPRVD JEM	DRWG NO 7.1	REV NO

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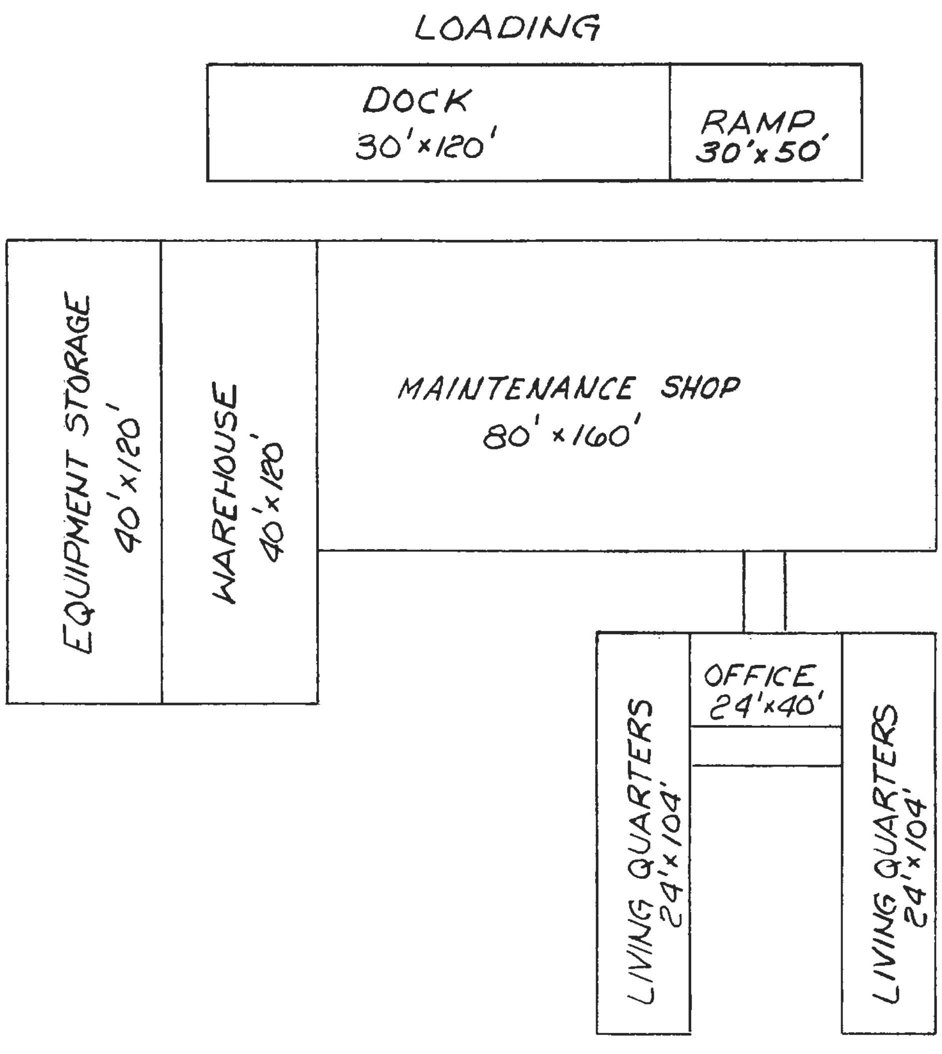

1 7/2/76

PRELIMINARY

GULF INTERSTATE ENGINEERING CO.	
ALCAN PIPELINE COMPANY	
DIST. BASE LAYOUT HAPPY VALLEY	
DATE 6/28/76	SCALE 1" = 50'-0"
DRAWN BY PRESLAR	APPROVED
CHECKED BY JEM	JOB NO 1198
APPROVED JEM	DRWG. NO. 7-4-2

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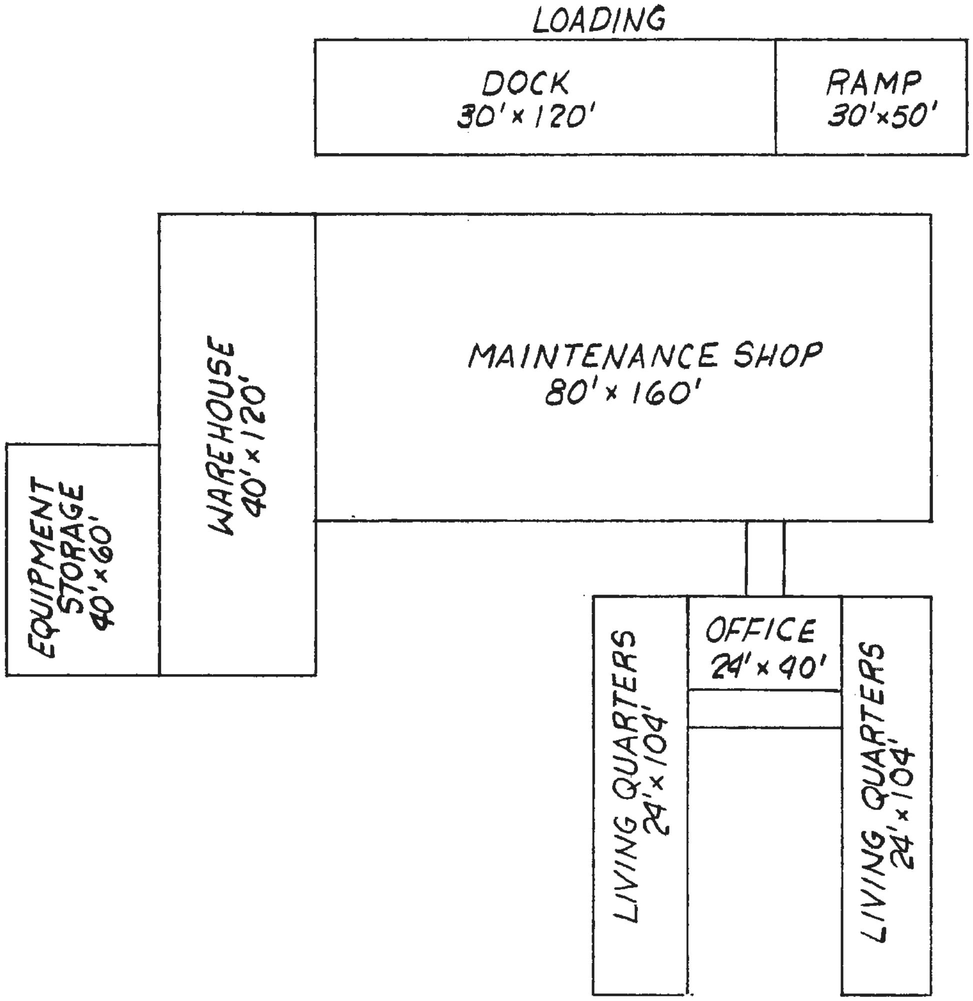

1 7/2/76

PRELIMINARY

GULF INTERSTATE ENGINEERING CO.	
ALCAN PIPELINE COMPANY	
DISTRICT BASE LAYOUT PROSPECT	
DATE 6/29/76	SCALE 1" = 50'
DRAWN BY D.R.B.	APPROVED
CHECKED BY JEM	JOB NO. 1198
APPROVED JEM	DRWG. NO. 7-4-3

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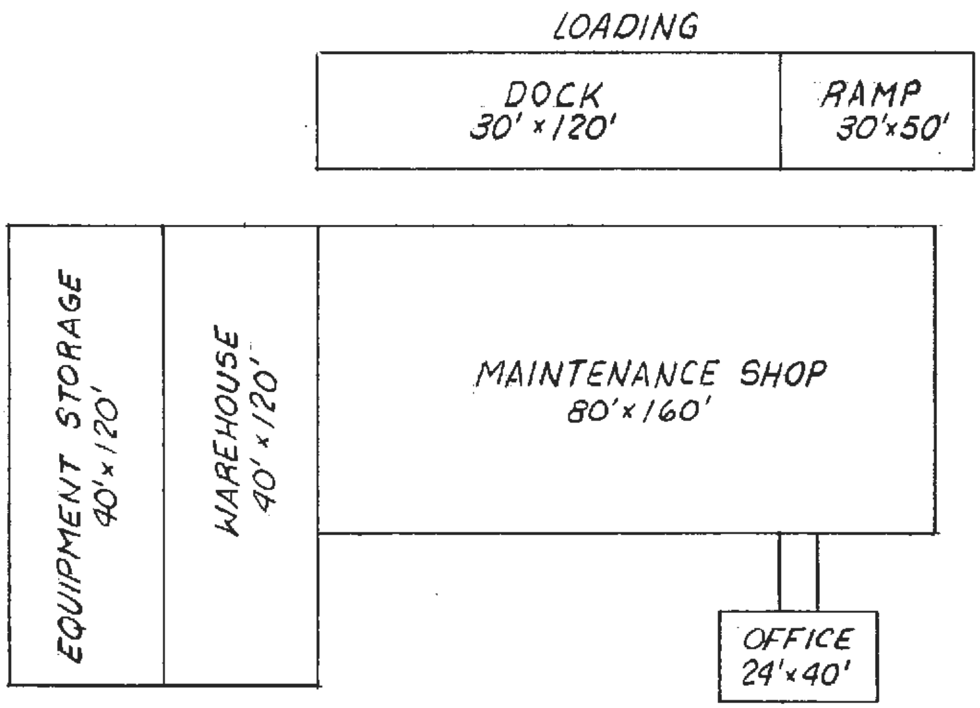


1 7/2/76

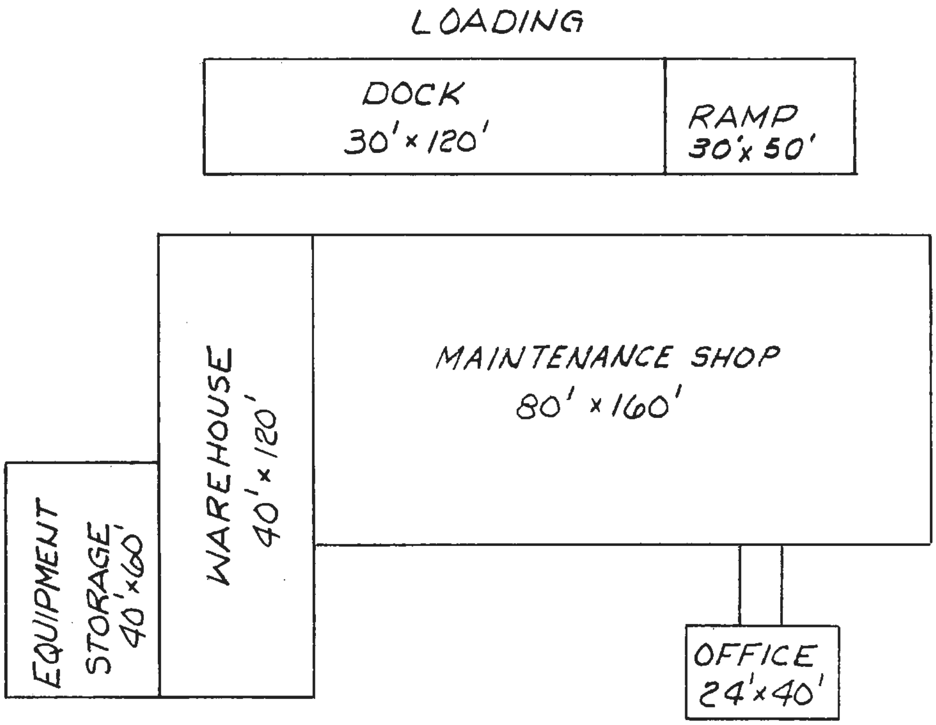
PRELIMINARY

GULF INTERSTATE ENGINEERING CO.

ALCAN PIPELINE COMPANY

DISTRICT BASE LAYOUT
FAIRBANKS

DATE 6/29/76	SCALE 1" = 50'
DRAWN BY D.R.B.	APPROVED
CHECKED BY JEM	JOB NO. 1198
APPROVED JEM	DRWG. NO. 7-4-4



PRELIMINARY

GULF INTERSTATE ENGINEERING CO.	
ALCAN PIPELINE COMPANY	
DIST. BASE LAYOUT TANACROSS	
DATE 6/28/76	SCALE 1" = 50'-0"
DRAWN BY PRESLAR	APPROVED
CHECKED BY JEM	JOB NO. 1198
APPROVED JEM	DRWG. NO. 7-4-5

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11.0 HAYNES RIGHT-OF-WAY

Following are five photographs taken along the Haynes right-of-way. They show the current status of a 30-year old right-of-way which will be used for the Alcan Project. There is no obvious degradation of the environment.

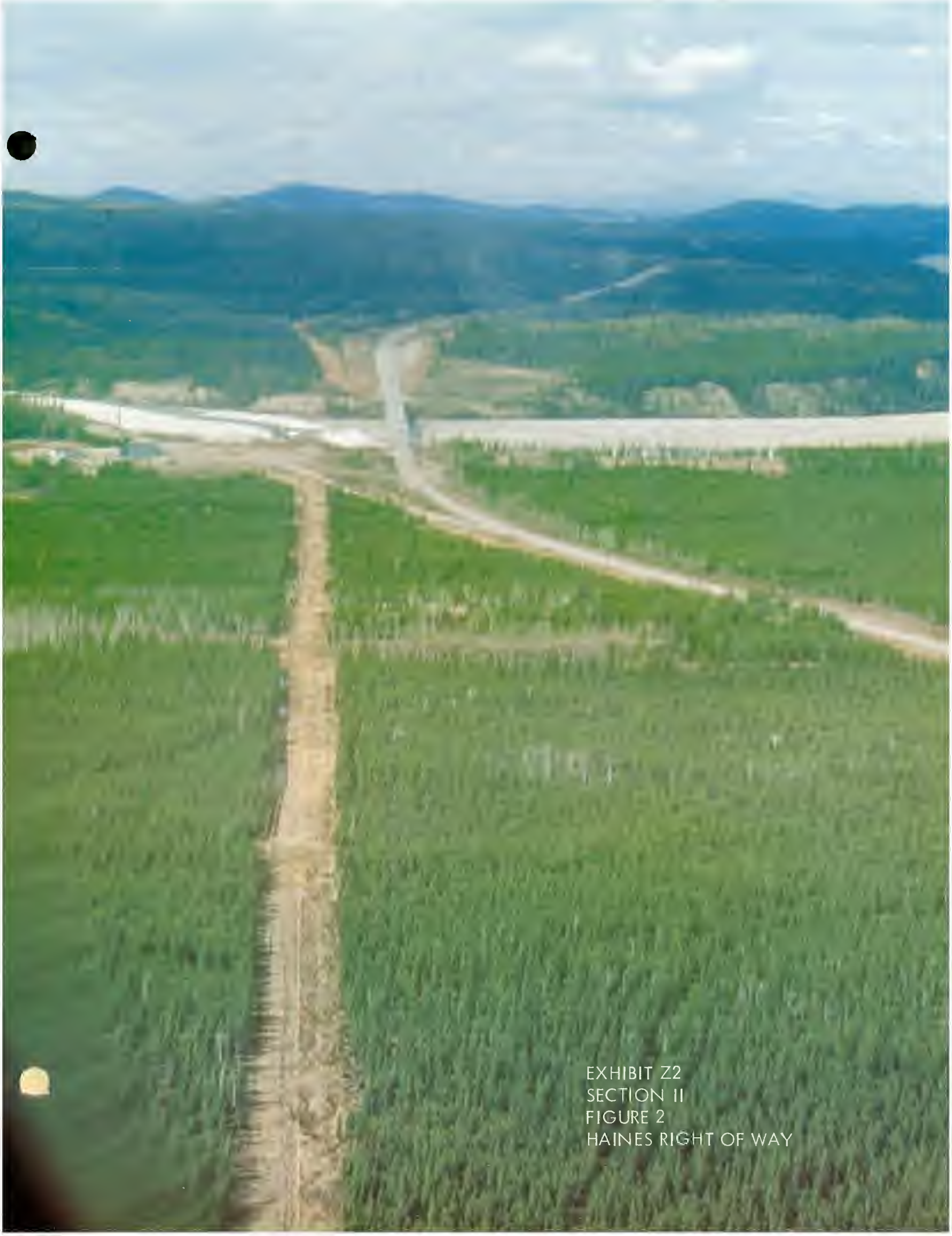

EXHIBIT Z2
SECTION II
FIGURE 2
HAINES RIGHT OF WAY

EXHIBIT Z2
SECTION II
FIGURE 3
HAINES RIGHT OF WAY

EXHIBIT 22
SECTION II
FIGURE [illegible]
HAINES RIGHT OF WAY

EXHIBIT Z2
SECTION II
FIGURE 5
PUMP STATION 3,
TANNACROSS