ENVIRONMENTAL SERVICES

ENGINEERING, CONSTRUCTION AND ENVIRONMENTAL ASPECTS OF ALTERNATIVE DESIGN MODES

SUBMISSION 4-1

DECEMBER, 1981

A000 4010

Foothills Pipe Lines (South Yukon) Ltd.

ENGINEERING, CONSTRUCTION AND ENVIRONMENTAL ASPECTS OF ALTERNATIVE DESIGN MODES

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DECEMBER, 1981

ADDENDUM TO THE ENVIRONMENTAL IMPACT STATEMENT FOR THE YUKON SECTION OF THE ALASKA HIGHWAY GAS PIPELINE

THE ALASKA HIGHWAY GAS PIPELINE PROJECT

Foothills Pipe Lines (South Yukon) Ltd.

WHITEHORSE:
308 STEELE STREET,
WHITEHORSE, N.W.T.,
Y1H 2C5

CALGARY:
1600 - 205 FIFTH AVENUE, S.W.,
CALGARY, ALBERTA
T2P 2V7

This document is one of a series of addenda prepared to meet information requirements placed on Foothills Pipe Lines (South Yukon) Ltd. by the Federal Environmental Assessment and Review Office. Addenda within the series are divided into seven sets of submissions dealing with separate subject areas:

1. Introduction to Addenda Submissions.

2. Project Description and Update for Addenda Submissions.

3. Alternative Routes.

4. Geotechnical, Hydrological, Design Mode and Revegetation Issues.

5. Fisheries, Wildlife and Scheduling Issues.

6. Issues Related to Pipeline Facilities.

7. Other Issues.

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1.0 INTRODUCTION

As part of the regulatory process involved with the application by Foothills Pipe Lines (South Yukon) Ltd. (the Project) to construct the Alaska Highway Gas Pipeline in Yukon Territory, an Environmental Impact Statement (EIS) was submitted to the Environmental Assessment and Review (EAR) Panel in 1979. That document presented a number of alternative approaches to pipe placement designed to overcome anticipated problems associated with permafrost conditions and the Project's plans to transmit gas at temperatures both above and below freezing. Pipe placement alternatives put forward were conceptual in nature and included four basic options:

1. Deeper ditch excavation to allow placement of the pipe within or upon soils not susceptible to changes brought about by freezing or thawing;

2. Deeper ditch excavation combined with subsequent partial filling of the ditch with material not susceptible to changes arising from freezing or thawing;

3. Placement of insulation around buried pipe to retard or prevent freezing or thawing of surrounding soils; and,

4. Placement of the pipe above ground within a gravel embankment in order to isolate the pipe from soils susceptible to changes brought about by freezing or thawing.

After review of the EIS, the EAR Panel requested more information with respect to alternative pipe placement modes. Specific requests for details of engineering design, location and materials required were made, as well as details of potential environmental impacts and planned mitigation measures. Subsequent review and clarification of information requirements by the Panel resulted in a request for "...information on design concepts for alternative modes and on the potential environmental impacts and mitigation measures..." that would be associated with them. An additional request to discuss the quantities of granular resources required for alternative approaches was also made, as well as confirmation that such supplies do exist.

This document has been prepared in response to the Panel's latter requests. It provides recent concepts developed by the Project regarding the use of alternative design modes (including a number of approaches not described in previous submissions), addresses potential environmental impacts on fish and wildlife, and describes mitigative measures planned. A separate section deals with granular requirements and the availability of this material.

2.0 DESCRIPTION OF ALTERNATIVE DESIGN MODES

The necessity for alternatives to the standard method of pipeline burial arises from the presence of intermittently frozen ground with varying degrees of ice content in western portions of the Yukon together with the plan to transport gas under both chilled (<0°C) and warm (>0°C) conditions. Present plans call for transmission of chilled gas to the first compressor station in Yukon Territory (STA-311, KP 64.7), at which point the gas temperature would be raised above 0°C and generally maintained above 0°C along the rest of the route. Alternative designs are required for both chilled and warm flow situations as variable soil characteristics and intermittent permafrost create conditions where buried chilled pipe may cause frost heaving in thawed (non-permafrost) sections; or, alternatively, buried warm pipe might cause thaw settlement in frozen (permafrost) sections.

Ten basic design approaches have been developed to overcome conditions in Yukon Territory, of which six may be considered unconventional alternatives. Two of the ten involve above grade installation. Table 4-1.1 lists both conventional and alternative designs and indicates potential for use in both warm and cold-flow situations.

Conventional designs include standard burial, burial using concrete weighting to overcome buoyancy and burial with the placement of select backfill material. Alternative designs involve burial deeper than normal to reach soil conditions not susceptible to the effects of freezing and thawing; a number of heat-traced configurations; and, above-grade placement of pipe within a gravel berm or a concrete cover. Each cold-flow design is illustrated by cross-sectional drawings (Figures 4-1.1 to 4-1.7). Comparable drawings for the warm-flow modes are presented in Appendix I. The latter is a pipeline design report included in its entirety with this submission in order to outline design approaches in detail.

Readers should note that pipe-placement designs are in some cases still being developed and geotechnical conditions that must be accommodated

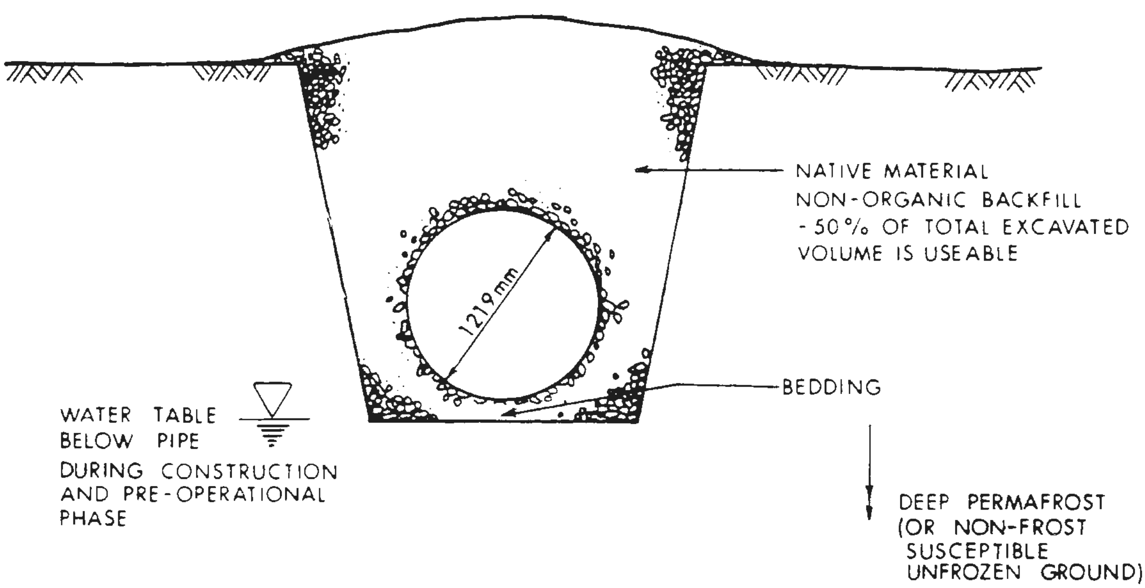
TABLE 4-1.1

PIPE PLACEMENT DESIGNS
DEVELOPED FOR USE IN YUKON TERRITORY

BELOW-GRADE DESIGNS	WARM FLOW	COLD FLOW
Conventional Designs		
Standard Burial	yes	yes
Saddle-Weighted Burial	yes	yes
Continuous-Weighted Burial	yes	no
Unweighted Burial	yes	no
Alternative Designs		
Deep Burial	yes	no
Buried Heat-Traced, Watercrossing	no	yes
Standard Burial, Heat-Traced, Insulated	no	yes
Road Crossing	no	yes
ABOVE-GRADE DESIGNS*		
Alternative Designs		
Embankment**	yes	yes
Concrete Restrained	yes	yes

*Both above-grade designs include a limited free span option used for crossing deep ravines or watercourses. In addition, free spans can be used to cross similarly difficult terrain from buried modes.

**Embankment design for warm flow includes an insulated gravel work and travelway. In cold flow situations, the travelway is not insulated, and the pad beneath the pipe may or may not be insulated.



NOTE DIMENSIONS AND SPECIFICATIONS WILL VARY WITH LOCAL OPERATING, PIPELINE GEOMETRY AND SOIL CONDITIONS.

PRELIMINARY

REV 81-06-25

MODE C1

Foothills Pipe Lines (South Yukon) Ltd.

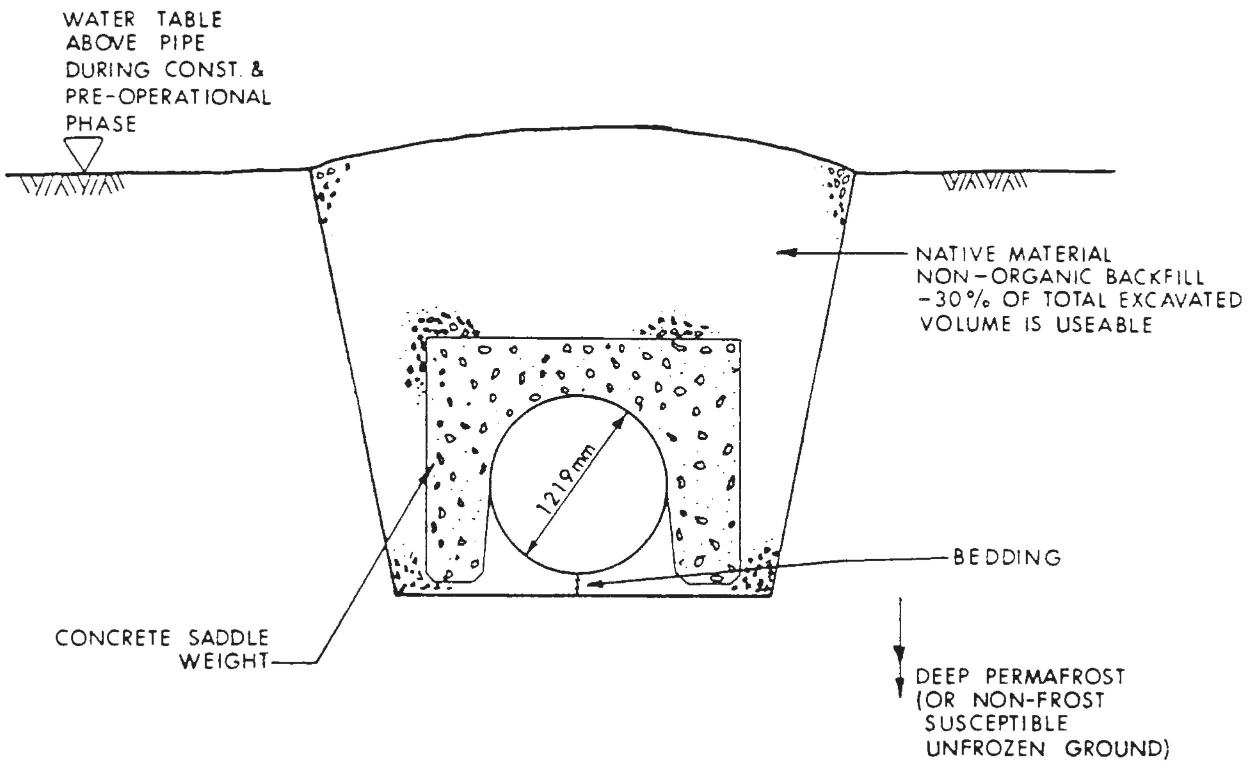
TITLE

THE ALASKA HIGHWAY GAS PIPELINE PROJECT

STANDARD BURIAL CHILLED PIPE

	DRAWN	CHECKED	APPROVED	APPROVED	SCALE N. T. S.	PREPARED BY YUKON PIPELINE DESIGN
BY	B. C.				FIGURE 4-1.1	
DATE	81 06 16	[illegible] 7				

A4 FORM 258



NOTE: DIMENSIONS AND SPECIFICATIONS WILL VARY WITH LOCAL OPERATING, PIPELINE GEOMETRY AND SOIL CONDITIONS.

PRELIMINARY

REV 81-06-25

MODE C2

Foothills Pipe Lines (South Yukon) Ltd.

TITLE

THE ALASKA HIGHWAY GAS PIPELINE PROJECT

SADDLE-WEIGHTED CHILLED PIPE

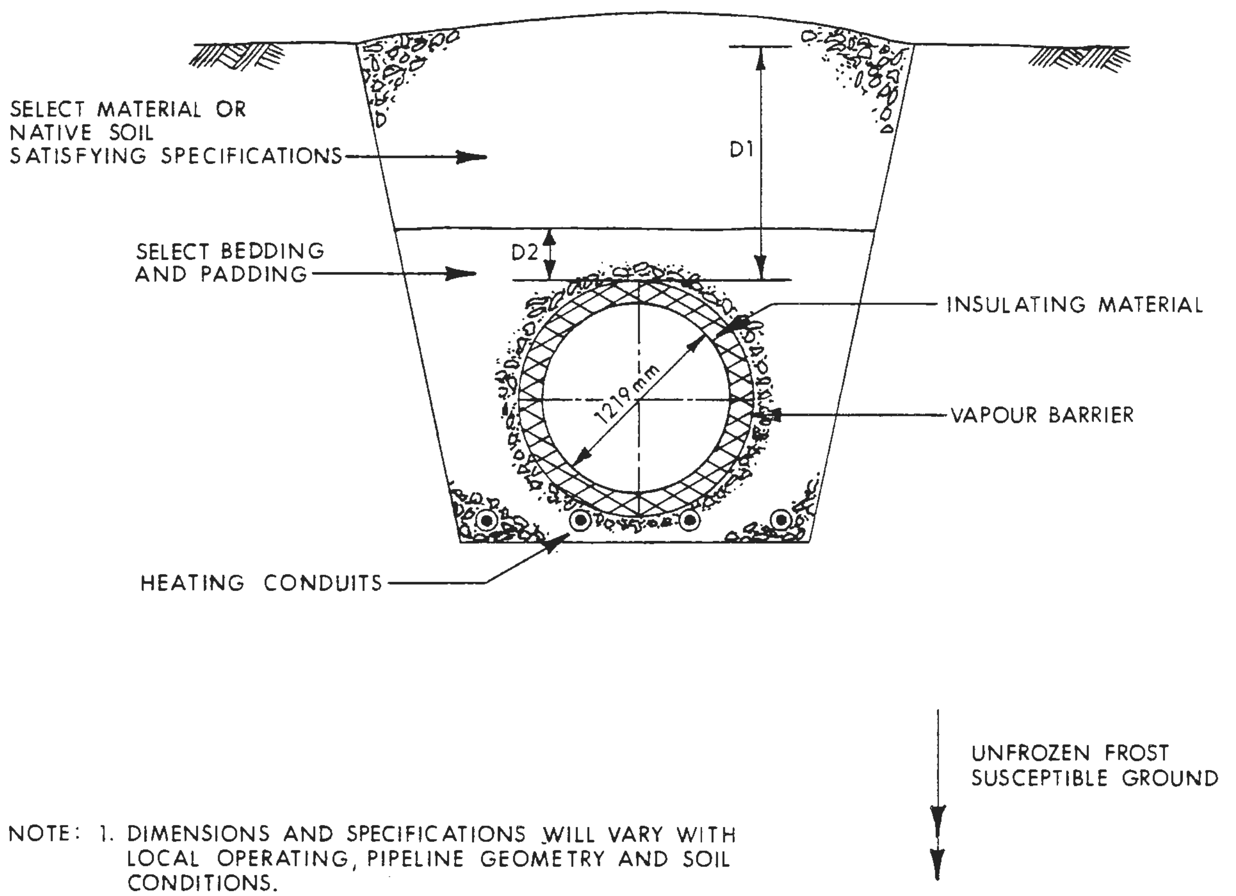
	DRAWN	CHECKED	APPROVED	APPROVED
BY	B. C.			
DATE	81 06 16	81 06 17		

SCALE N.T.S

PREPARED BY YUKON PIPELINE DESIGN

FIGURE 4-1.2

A4 FORM 250



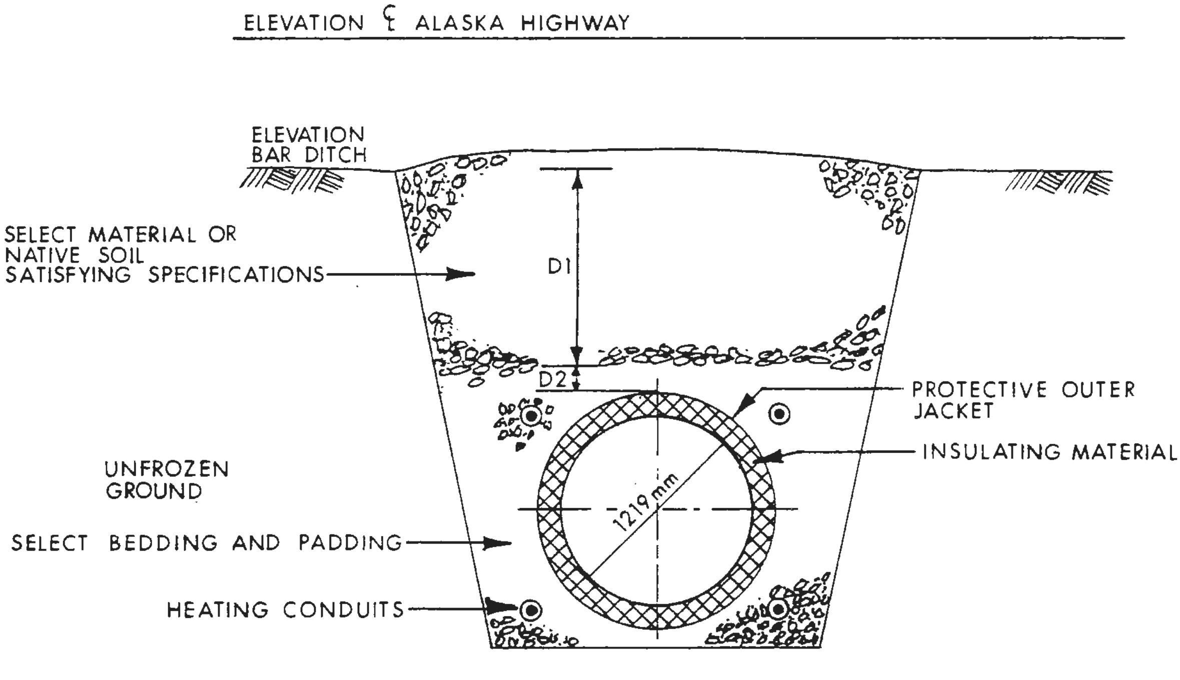
NOTE:
1. DIMENSIONS AND SPECIFICATIONS WILL VARY WITH LOCAL OPERATING, PIPELINE GEOMETRY AND SOIL CONDITIONS.
2. INSULATION OPTIONAL DEPENDING ON POWER SUPPLY AND THERMAL EFFICIENCY REQUIRED.
3. WRAP AROUND INSULATION MAY BE REPLACED WITH BOARD INSULATION ON DITCH BOTTOM AND SIDES.
4. D1 = 750mm MINIMUM WITH ADDITIONAL DEPTH WHERE REQUIRED FOR BUOYANCY CONTROL.

PRELIMINARY

MODE C3

Foothills Pipe Lines (South Yukon) Ltd.					TITLE: THE ALASKA HIGHWAY GAS PIPELINE PROJECT — STANDARD BURIAL-CHILLED PIPE WITH HEAT TRACING AND INSULATION
	DRAWN	CHECKED	APPROVED	APPROVED	SCALE N.T.S — PREPARED BY YUKON PIPELINE DESIGN
BY	R. STEELE	RPT			FIGURE 4-1.3
DATE	82 01 18	820119			

A4 FORM 258



NOTE: 1 DIMENSIONS AND SPECIFICATIONS WILL VARY WITH LOCAL OPERATING, PIPELINE GEOMETRY AND SOIL CONDITIONS.

2. D1 VARIES TO SUIT ROAD CROSSING SPECIFICATION.

PRELIMINARY

MODE C5

Foothills Pipe Lines (South Yukon) Ltd.

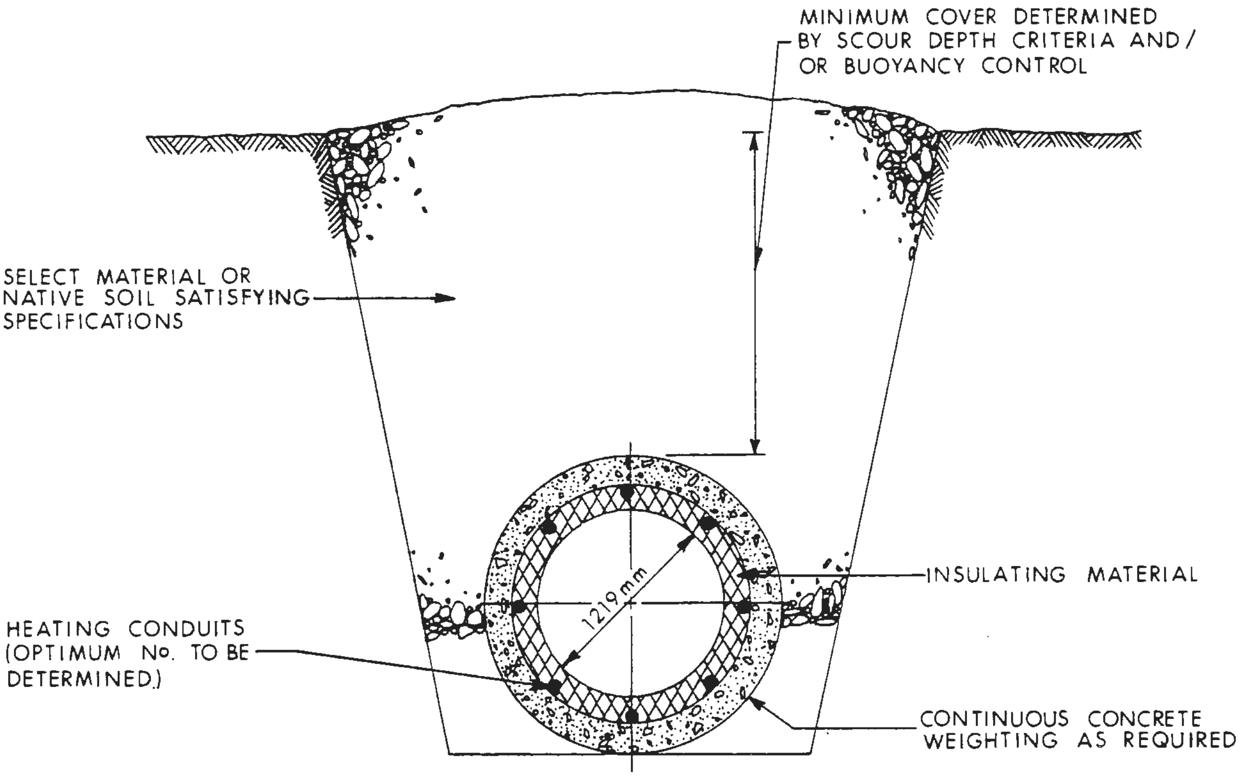
TITLE

THE ALASKA HIGHWAY GAS PIPELINE PROJECT

ROAD CROSSING-CHILLED PIPE

	DRAWN	CHECKED	APPROVED	APPROVED	SCALE N.T.S.	PREPARED BY YUKON PIPELINE DESIGN
BY	R. STEELE	[signature]			FIGURE 4-1.4	
DATE	82 01 20	82 01 21				

A4 FORM 258



NOTE: DIMENSIONS AND SPECIFICATIONS WILL VARY WITH LOCAL OPERATING, PIPELINE GEOMETRY AND SOIL CONDITIONS.

PRELIMINARY

MODE C6

Foothills Pipe Lines (South Yukon) Ltd.

TITLE

THE ALASKA HIGHWAY GAS PIPELINE PROJECT

BURIED HEAT-TRACED WATER CROSSING
CHILLED PIPE

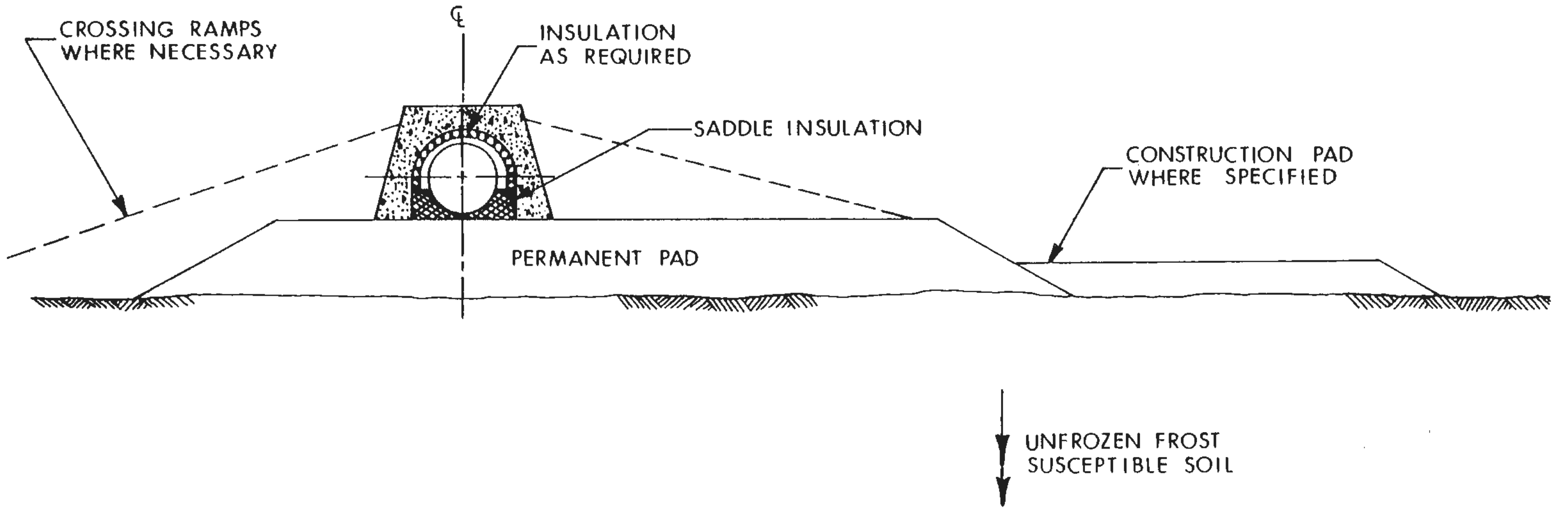
	DRAWN	CHECKED	APPROVED	APPROVED
BY	V. J. R.	RH		
DATE	81 01 18	820118		

SCALE N. T. S. PREPARED BY YUKON PIPELINE DESIGN

FIGURE 4-1.5

A4 FORM 258

A4 FORM 258



NOTES 1. DIMENSIONS AND SPECIFICATIONS ARE PRELIMINARY AND WILL VARY WITH LOCAL OPERATING, PIPE GEOMETRY AND SOIL CONDITIONS.

MODE C7

PRELIMINARY

Foothills Pipe Lines (South Yukon) Ltd.

	DRAWN	CHECKED	APPROVED	APPROVED
BY	V.J.R.	RT		
DATE	82 01 15	820118		

TITLE
THE ALASKA HIGHWAY GAS PIPELINE PROJECT

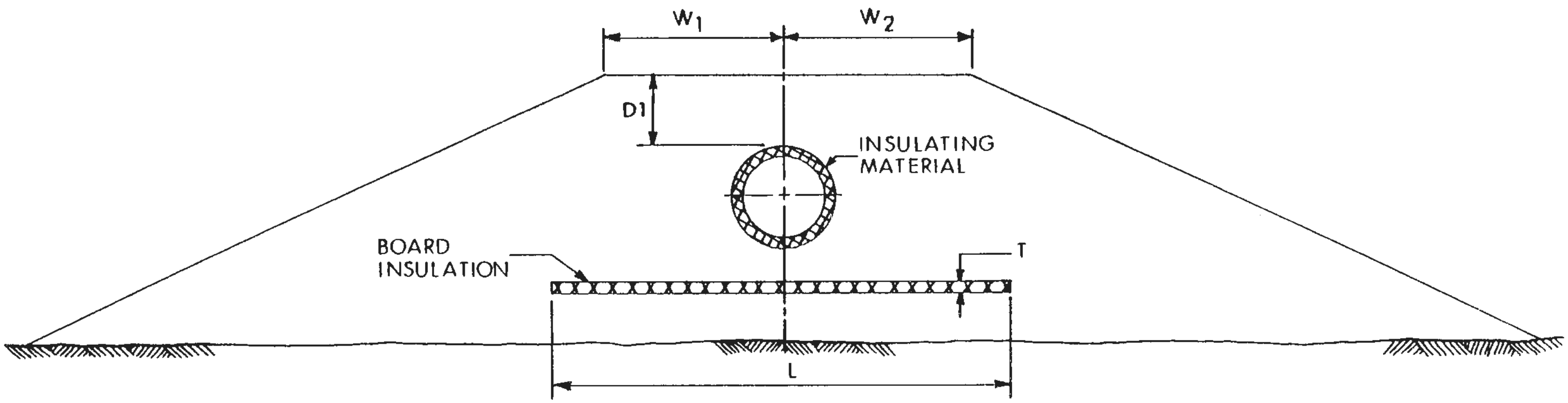
CONCRETE - RESTRAINED
CHILLED PIPE

SCALE N.T.S.

PREPARED BY YUKON PIPELINE DESIGN

FIGURE 4-1.6

A4 FORM 258



NOTES 1. THE GRANULAR EMBANKMENT FOR ABOVE GROUND PIPE PLACEMENT CHILLED FLOW WILL BE FURTHER ANALYSED IF REQUIRED.

2. D1 = 750 mm MINIMUM

MODE C8

PRELIMINARY

DATE	BY	
82 01 15	V.J.R.	DRAWN
820118	[illegible]	CHECKED
		APPROVED
		APPROVED

Foothills Pipe Lines (South Yukon) Ltd.

TITLE
THE ALASKA HIGHWAY GAS PIPELINE PROJECT

EMBANKMENT
CHILLED PIPE

SCALE N.T.S.

PREPARED BY YUKON PIPELINE DESIGN

FIGURE 4-1.7

by specific designs are still being evaluated. This continuing work will undoubtedly cause refinements in the designs presented. It is also worth noting that warm-flow designs have developed in advance of those for cold flow. As a result, designs for warm flow are essentially final and a comprehensive description of factors considered in design development can be presented (Appendix I). Similar documentation of design development for approaches taken to deal with cold flow is not available at the time of writing but is currently being prepared.

The selection of particular designs for use along specific sections of the pipeline will be dependent upon geotechnical conditions encountered and other design requirements (Appendix I). While final mode assignment is a relatively complex undertaking which is part of final design, preliminary assignment of each mode is an on-going and often-repeated exercise during the design process. Differentiation between burial and above-grade sections has, however, become generally established. As a result the locations of above-grade modes based on Project Plans in late fall, 1981 have been mapped for planning purposes and for this submission. Figure 4-1.8 shows the location of above and below-grade mode assignments at an approximate scale of 1:1,000,000. The approximate locations of above-grade mode assignments have also been summarized in tabular form, and may be found in Table 4-1.2.

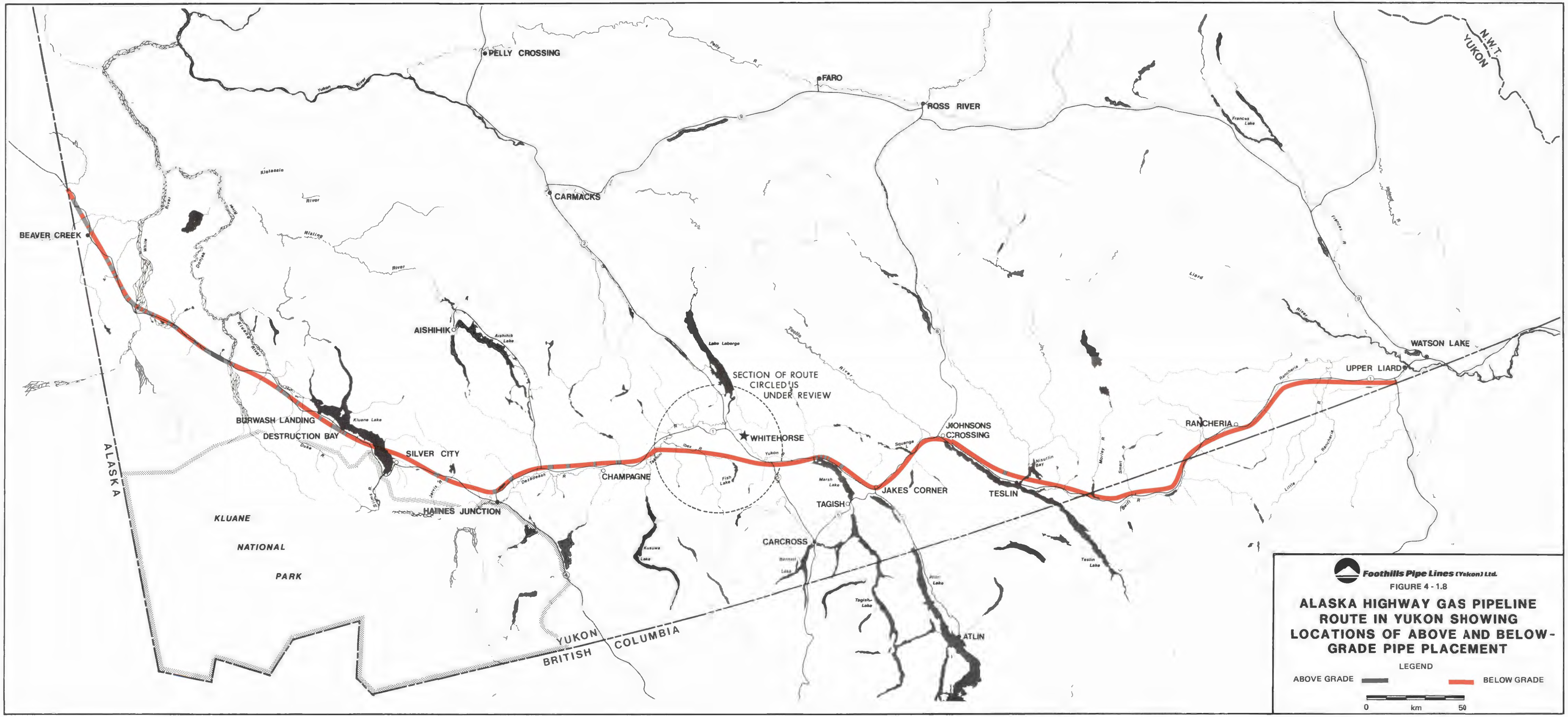


FIGURE 4 - 1.8

ALASKA HIGHWAY GAS PIPELINE ROUTE IN YUKON SHOWING LOCATIONS OF ABOVE AND BELOW-GRADE PIPE PLACEMENT

TABLE 4-1.2

APPROXIMATE LOCATIONS OF
ABOVE-GRADE PIPE PLACEMENT IN YUKON TERRITORY
(assuming cold flow to Station 311)

Location (KP)	Length (km)	Location (KP)	Length (km)
7.3 - 15.4	8.1	163.3 - 167.4	4.1
17.9 - 21.2	3.3	188.6 - 190.1	1.5
22.6 - 24.2	1.6	197.3 - 200.8	3.5
39.4 - 40.2	0.8	201.5 - 202.3	0.8
42.5 - 44.1	1.6	257.8 - 258.4	0.6
54.6 - 54.8	0.2	265.8 - 265.9	0.1
59.1 - 59.3	0.2	287.4 - 288.5	1.1
60.9 - 61.1	0.2	299.2 - 300.0	0.8
66.5 - 70.5	4.0	315.0 - 315.5	0.5
71.2 - 72.3	1.1	333.3 - 334.5	2.2
73.3 - 74.9	1.6	347.7 - 347.9	0.2
76.7 - 79.9	3.2	358.3 - 358.6	0.3
82.4 - 83.0	0.6	359.2 - 359.6	0.4
92.8 - 94.6	1.8	466.3 - 466.5	0.2
96.6 - 98.8	2.2	466.6 - 466.7	0.1
109.2 - 109.7	0.5	467.1 - 468.0	0.9
114.2 - 116.3	2.1	468.5 - 469.3	0.8
116.4 - 126.0	9.6	470.8 - 471.1	0.3
126.3 - 129.6	3.3	476.9 - 477.3	0.4
131.4 - 131.6	0.2	579.4 - 579.6	0.2
158.6 - 160.4	1.8		

3.0 ENVIRONMENTAL ASSESSMENT OF ALTERNATIVE PIPE PLACEMENT MODES

The implications of using the various alternative pipe placement designs, with regard to fish and wildlife, vary depending upon the particular mode being used, the location of use and the presence or absence of fish or wildlife populations. This assessment deals with the general concepts of below-grade and above-grade modes and the associated concerns related to fish and wildlife populations. In dealing with the specific impacts of these two types of pipe placement, emphasis has been placed on the concrete-restrained mode when discussing above-grade design. This approach has been taken for the following reasons:

1. The Project presently considers the concrete-restrained mode to be the best solution to the engineering problems encountered where above-grade design is required for frost heave and thaw settlement problems; and,

2. Of the two above-grade designs, the concrete-restrained mode poses greater problems for ensuring wildlife movement across the right-of-way. The passage of wildlife is the most serious fish or wildlife concern associated with above-grade designs; therefore, the concrete-restrained mode would require the greatest mitigatory efforts and assessment of the impact of that mode represents the most conservative approach.

3.1 ASSESSMENT OF BURIED MODES

The alternative designs which involve burial of the pipe (deep burial, buried heat-traced watercrossings, standard burial heat-traced insulated, road crossing) are all comparable to standard burial in terms of potential effects on fish and wildlife populations. Concerns regarding standard burial of the pipe primarily involve the disturbance caused during construction of the pipeline; post-construction concerns are relatively minor, and generally involve stabilization and reclamation measures. The concerns regarding construction of the standard burial mode have been addressed in a number of documents prepared by the Project and should be consulted for a discussion of associated problems and solutions (e.g., Submission 5-2: The Development of Construction Schedules in Relation to Fisheries and Wildlife Issues). Those concerns and mitigative measures apply to all locations where below-grade designs are specified (see Figure 4-1.8).

3.2 ASSESSMENT OF ABOVE-GRADE MODES

The two above-grade pipe placement modes involve substantial above-ground structures. In an unmodified form both modes could present an impediment to animal movement across the pipeline in terrestrial areas although the extent to which the embankment mode would impede movement would be slight. If extended to watercourses with inadequate planning, both above-grade modes could impede water flow and possibly fish movement.

3.2.1 Assessment of Effects on Fish

General Concerns and Approach to Impact Mitigation

In terms of possible effects upon aquatic resources there is little difference between the embankment or concrete-restrained pipe placement modes. Both modes involve the installation of a gravel pad. The fact that in one instance the pipe is covered with gravel, while in the other the pipe is covered with concrete makes no significant difference with respect to impact upon aquatic systems.

A convenient way to assess potential effects of the above-grade modes on fish is to consider the effects of highway construction on fish populations. The above-grade mode essentially consists of a gravel pad which supports the pipe and provides a trafficable surface for access along the right-of-way. The typical width of the gravel pad will be approximately 27 m from toe-to-toe (see Figure 4-1.6). However, if an above-grade mode is used when crossing a stream or river, the traffic bearing portion of the gravel pad would not be retained, which would leave a pad width of approximately 18 m (see Figure 4-1.6). The dimensions provided here are approximate, and will vary with site-specific conditions.

The primary concern for fish resources in relation to the above-grade modes involves the manner in which water is conveyed across the right-of-way. Culverts will typically be used for this purpose due to their relatively low cost and minimal maintenance requirements. In general, there are five major areas of concern in relation to the placement of a culvert in a fish-bearing watercourse and problems which may be encountered by fish in traversing the structure: water velocity; water depth; elevated outlets; debris accumulation; and, icing. Briefly, these factors are of concern for the following reasons: 1) water velocity may be a barrier to fish movement if the velocity exceeds the swimming capability of the fish; 2) if the depth of water in the culvert does not completely cover the gills of the fish, oxygen exchange may be hampered which affects the stamina of the fish, and if the body of the fish is not completely submerged the efficiency of swimming movements are reduced; 3) an elevated culvert outlet creates a physical barrier to fish movement, not unlike a waterfall; 4) debris accumulation at the culvert inlet may also create a barrier to fish movement; and, 5) icing is a potential problem where a combination of the shaded condition in the culvert and the heat transfer characteristics of metal culverts causes an extensive build-up of ice in the structure. This icing may result in damming of the watercourse, restricting or preventing downstream flow in the winter, or cause ponding and overflow conditions in the spring. The consequences may range from jeopardizing fish overwintering habitat, to the creation of a barrier to fish movement in the spring.

In addition to potential problems fish may encounter in traversing a culvert, the placement of a culvert instream also results in loss of aquatic habitat. The concerns regarding habitat loss encompass both the actual location of the culvert itself, and any effects modification of the hydraulic conditions of the watercourse may have on stream morphology at the culvert inlet and in downstream reaches. Of significance here is the type of habitat in the region (e.g., spawning area, nursery area) and the degree of utilization of this habitat by the fish fauna in the watercourse. There may also be some loss in primary and secondary productivity at the actual location of the culvert installation. However, when the width of the right-of-way is considered in relation to the length of the stream, such a loss is insignificant.

The consequences of above-grade construction must be assessed from two perspectives: 1) on the basis of the timing of instream construction activities; and, 2) the type of structure used to facilitate the movement of water across the above-grade pipe. The concerns regarding timing of construction on the fisheries resources are similar to those posed by conventional pipeline burial, although the degree of concern regarding above-grade construction is less due to the lack of instream trenching. Nevertheless, during above-grade construction there will be an increase in suspended sediment concentrations in creek waters. The degree of concern regarding the increase in suspended sediment loads will depend on the fish fauna which use the watercourse, the time of year when the suspended sediment loads are created, and the proximity of sensitive fish habitat (if any) to the pipeline crossing location. The primary mitigative method that would be used to avoid potential impacts resulting from above-grade construction activities is that of timing construction activities to coincide with the least-sensitive period of time for the fish fauna in each watercourse. This is the same strategy used by the Project to mitigate potential impacts on fish populations during conventional pipeline construction.

The concern for the fisheries resource in relation to the type of structure used to facilitate stream or river discharge across the right-of-way are wide in scope, and contingent upon many factors including the aspects of habitat utilization by fish, the type of structure installed, and the configuration of the water passage structure subsequent to construction. At worst case, a permanent blockage of fish movement in a stream could result in a complete loss of fish production from areas upstream of the structure.

A number of mitigative approaches will be used to ameliorate potential adverse impacts on fish populations at watercrossings where an above-grade pipe-placement mode is employed. One means of mitigation will be through the use of a free span (unsupported length of pipe). This method of stream crossing is one which has a number of advantages from an engineering and construction viewpoint and which is part of the design approach to crossing small streams when utilizing an above-grade mode. The use of this technique will in most cases be restricted to small watercourses, as a feasible free-span distance without additional design modification is in the order of 20 m, which would be a bank-to-bank distance. Preliminary indications are that distances of at least 30 m may be achieved through specialized design of the free span. On larger watercourses, openings in the gravel pad, using free span, would be provided where the design flow for the watercourse is greater than 4 m^3/s. Free spans, when used at streams supporting fish will ensure uninterrupted passage of fish across the right-of-way.

Where a free span is not employed, facilitation of water flow and movement will be achieved through the use of culverts designed on a site-specific basis. The following specifications for culvert installation will be employed to avoid the previously-identified concerns in fish-bearing watercourses.

1. Water Velocity: Culverts will be designed to achieve an average maximum cross-sectional water velocity of 0.9 m/s, which may only be exceeded for 3 consecutive days during the annual flood, or 7 consecutive days for a flood with a recurrence interval of 1 in 50 years. If necessary, the design will include a selected region in the culvert wherein water

velocities meet these criteria. Culvert lengths in these cases will be kept to a minimum, but would be in the range of 18 m.

2. Water Depth: Culverts will be designed to maintain a minimum water depth of 0.2 m at any point in the culvert during periods of low flow, if there is a requirement for fish passage during the low-flow period.

3. Water Surface Profile: Culvert gradients will be kept as close to the normal stream gradient as conditions permit. Culverts will be installed with a constant slope throughout, except where settlement is anticipated. Any sudden drop in the water surface profile at any point within culvert influence will not exceed 0.3 m. If closed-bottom culverts are used in fish-bearing watercourses, culvert inverts will be laid a minimum of 0.15 m below the normal streambed elevation.

4. Culvert Shapes and Installation: There are two culvert types presently being actively considered for use should any fish-bearing watercourses be crossed by above-grade pipe. These are the bottomless arch culvert, and the concrete box culvert. In both instances normal stream gradient and substrate would be retained to assist in minimizing any increase in water velocity within the structure, ensuring ambient water levels during periods of low flow, and maintaining the normal water surface profile. As a component of the Project's protection plan with regard to any type of culvert installation, rip-rap and/or end flanges will be placed at both the culvert inlet and outlet to prevent erosion and scour. Rip-rap at the ends of the culverts will extend approximately two culvert diameters downstream of the outlet. Culverts will not be positioned in a manner such that discharges would be directed at potentially unstable

banks; if such positioning is unavoidable, bank protection will be employed. While the possible use of circular steel culverts has not been abandoned, it would appear that maintenance of required water velocity (number one above) will in most cases not be possible within these structures.

5. Maintenance: Surveillance of any culverting structure in above-grade sections will be part of pipeline operation and will entail cleaning culverts to ensure they are free of debris and ice during periods of heavy run-off. In addition, appropriate measures will be employed for de-icing of culverts if icing problems lead to restriction of flow in fish-bearing watercourses, the creation of impassable obstacles, or the damming of any such watercourse.

In light of the proposed mitigation measures, it is anticipated that the above-grade modes of construction may be used at watercrossings without residual impacts on the fishery resource, as construction will be conducted during the time-period which is least-sensitive for fish, and fish passage will be facilitated at all watercrossings for the life of the pipeline.

Site-specific Assessment and Impact Mitigation

The locations of areas where above-grade pipe placement is currently under consideration are presented in Table 4-1.2. Within these above-grade sections, seven fish-bearing watercourses are crossed by the pipeline route. These creeks are listed in Table 4-1.3; also included in this table are the watercourse widths, the important species of fish which use these watercourses, and the various aspects of the life cycle of these fish which are found in the vicinity of the proposed pipeline crossings.

It is apparent from an examination of Table 4-1.3 that all fish-bearing watercourses crossed by above-grade pipe are small creeks, which

TABLE 4-1.3

CURRENT LOCATIONS, WIDTHS AND UTILIZATION BY FISH OF FISH-BEARING WATERCOURSES CROSSED BY THE ABOVE-GRADE MODE

Watercourse	KP	Width (m)	Important Fish Present[1]	Use of Habitat by Fish[2]
Mirror Creek	7.4	10.0	A.G.	c,d,e,f
Snag Creek	13.8	16.0	A.G.	c,d,f
unnamed creek	61.0	1.5	A.G.	a,b,c,d,e
Long's Creek	93.4	7.0	A.G.	c,d,e
			L.W.F.	c,e
Wolf Creek	94.3	8.0	A.G.	c,d,e
			L.W.F.	c,e
unnamed creek	124.6	<1.0	A.G.	d
Greyling Creek	477.2	3.6	Ci.S.	c,f
			A.G.	c,d,e,f
			L.W.F.	e,f,
			N.P.	d,e,f
			Burbot	d,f

[1]Ci.S. = chinook salmon; A.G. = Arctic grayling; L.W.F. = lake whitefish; N.P. = northern pike.

[2]a = spawning migration; b = spawning; c = nursery (young-of-the-year); d = rearing (immatures other than underyearlings); e = summer (adults); f = overwintering.

may be crossed by a free span of pipe. This crossing technique will be used at all of the watercourses indicated, which removes any concern for impairment of fish movement in these watercourses, as well as the majority of concern for the downstream effects of instream construction activities.

3.2.2 Assessment of Effects on Wildlife

General Concerns and Approach to Impact Mitigation

This assessment section has been developed assuming that the concrete-restrained mode will be used exclusively (or nearly so) in areas requiring above-grade construction. Given the 2 m height and near vertical side slopes of the concrete-restraining weights the unmodified structure will present a continuous and effective barrier to animal movement. In comparison, the use of an above-grade embankment would introduce a continuous but negotiable structure with 2 1/2:1 side slopes requiring reduced mitigative alteration.

Species of mammals which undertake regular movements either within their home range or between seasonal ranges would be susceptible to impact if unmodified concrete-restrained sections of pipeline were to cross their movement corridors. Of the mammal species identified as a concern in the Northern Pipeline Agency's terms and conditions[1], ungulates (woodland caribou, Dall's sheep, moose, elk, mule deer) and the larger carnivores (wolf, red fox, coyote, grizzly bear) are sufficiently mobile that encounters with above-grade concrete-restrained pipe are probable. Given the near-continuous distribution of smaller mammals (e.g., squirrel, marten, fisher) along the pipeline route, it is probable that the territories of these animals would also be encountered.

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1. Northern Pipeline Agency. 1980. Northern Pipeline Socio-economic and Environmental Terms and Conditions for the Yukon Territory (Draft).

For ungulates, seasonal migrations between ranges undertaken each year enable animals to exploit their resource base optimally. These migrations often take place in restricted corridors. Disruption of such movements may cause large scale population declines, since range relocation is not usually possible. Similarly, alienation of even a portion of an important ungulate seasonal habitat (e.g., winter range) can lead to overgrazing and range degradation within the accessible portion of the habitat and an eventual population decline on that range.

Larger carnivores occupying defended territories of 10's or 100's of square kilometres would also likely experience negative impacts if prevented from continuing normal movements. The concern in this case is related to the theory that the size of any carnivore's territory represents the area necessary to sustain the animal. Any diminution in territory size as a consequence of restricted access could have a negative effect either by reducing resources available to the animal or by forcing it into competition with animals in neighbouring territories. In view of the relatively small numbers of these larger carnivores and the total size of their ranges, lengthy sections of concrete-restrained pipe could impinge upon a relatively large fraction of the total number of territories within a given region and therefore be of substantive concern.

Smaller animals would also be affected by a physical barrier to movement within their territories. However, any such impact would be relatively insignificant, occurring only in the immediate vicinity of the pipeline. While modifications in the size or shape of territories similar to those outlined for larger animals would take place in the immediate vicinity of the barrier, this would not result in noticeable declines in the abundance of such small mammals. Being relatively numerous and having small territories, above-grade sections of pipe would encounter an insignificant fraction of the total number of territories within a given region.

Information on the behavioral responses to the previously described small mammals and carnivores to physical and/or visual barriers is virtually non-existent. However, ungulate behavior observed in response to such barriers has been documented in a number of situations. This information has been thoroughly reviewed[2], and the mitigatory measures presented in following sections are largely based on this literature.

Three major options to allow crossing by animals can be considered where animal movements are required at the location of above-grade pipe installation. These are: 1) underpasses, which would be available at the locations of free spans over stream channels or ravines; 2) overpasses, such a gravel ramps; or, 3) on-grade crossing sites, such as buried sections of pipeline. Relevant literature suggests that ungulates demonstrate a preference for on-grade crossing sites. However, while such sites would likely be most effective at maintaining cross right-of-way movements, it must be recognized that the thaw-unstable conditions which necessitated the use of the above-grade mode also limit the areas where on-grade crossings can be safely constructed. Consequently, where geotechnical conditions prevent the use of on-grade crossing sites, alternative ramp structures enlarged sufficiently to approximate on-grade situations have been developed. Smaller crossing structures have also been developed for those wildlife species which have a less severe requirement for crossing and which may be less reserved in using crossing structures. Free spans are also discussed below as effective options in allowing free animal passage across the concrete-restrained mode. Design specifications for all structures are presented below together with guidelines for frequency of use.

A. DESIGN SPECIFICATIONS

1) Ungulate Crossing Facilities

Ungulate crossing facilities will be placed in areas known to be migratory corridors, and in areas known to support high seasonal concentrations of ungulates.

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2. Shank, C.C. 1979. Human-related behavioral disturbance to northern large mammals: a bibliography and review. Prepared for Foothills Pipe Lines (South Yukon) Ltd., Calgary. 228 pp.

a) Ramp in cut-and-fill situations - ramps which extend from the uphill side of the right-of-way across the above-grade structure in a continuous, uninterrupted slope which closely matches the natural topography. These ramps will be fan-shaped on either side of the concrete mode. Ramp width at the top of the concrete-restraining weights will not be less than 25 m. Ramps will be revegetated.

b) Enlarged free spans - free spans with not less than 3 m of ground-to-pipeline clearance for a minimum distance of 20 m.

c) Large flat-land ramps - fan-shaped structures extending over the concrete mode located in relatively flat areas with an apex width of 25 m and side slopes not exceeding 5:1. These ramps will be revegetated.

2) Standard Crossing Facilities

These structures will be used together with and not as substitutes for the ungulate structures described above.

a) Standard ramps - fan-shaped ramps 10 m in width at their apex with side slopes not exceeding 4:1. These ramps will be revegetated.

b) Standard spans - free spans with not less than 2 m of ground-to-pipeline clearance for a minimum distance of 10 m.

B. FREQUENCY OF CROSSING STRUCTURE INSTALLATION

The frequency of crossing facilities will vary depending upon the kinds of animals involved, the kind and degree of area use by animals and the length of above-grade concrete restraint involved.

The frequency of ungulate crossing facilities will vary, depending upon the importance of the habitat encountered at the locations of above-grade construction. Three basic habitat types have been identified in this regard:

Type 1 - those sections of the pipeline route which cross known migration corridors or encounter high winter concentrations of ungulates with some associated cross-corridor movement.

Type 2 - those sections of the pipeline which encounter or approach seasonally high concentrations of ungulates with the possibility for cross-corridor movement.

Type 3 - all remaining sections of the pipeline.

Standard crossing facilities will be constructed along any concrete-restrained section of pipe and between ungulate crossing structures to ensure that crossing opportunities of some kind occur at intervals of not more than 330 m.

For Sections of Concrete-restrained Mode Exceeding 1 km in Length

Type 1 Areas

i) Ungulate crossing structures will occur at a frequency of two per kilometre.

ii) Between ungulate crossing facilities, one standard facility (standard ramp or span) will be constructed so that crossing opportunities (ungulate plus standard) occur at least every 330 m.

Type 2 Areas

i) Ungulate crossing facilities will occur at a frequency of one per kilometre.

ii) Between ungulate crossing facilities, standard facilities will be constructed so that crossing opportunities (ungulate plus standard) occur every 330 m.

Type 3 Areas

i) Three standard crossing facilities will be provided per kilometre.

For Sections of the Concrete-restrained Mode Extending 500 to 1000 m in Length

Type 1 Areas

i) One ungulate and one standard crossing facility will be provided.

Type 2 Areas

i) Two standard facilities will be provided.

Type 3 Areas

i) One standard facility will be provided.

For Sections of the Concrete-restrained Mode Extending Less Than 500 m in Length

No crossing facilities will be constructed at these locations.

Site-specific Assessment and Impact Mitigation

Table 4-1.4 shows the concerns and mitigative requirements which have been identified for wildlife for each section of above-grade mode. The locations of areas where the above-grade mode is currently under consideration are listed in Table 4-1.2, and illustrated in Figure 4-1.8.

Of the 41 locations where the above-grade mode is currently under consideration, 13 involve a length of less than 500 m, and are therefore considered to pose no significant obstacle to wildlife movement. These locations are not addressed in Table 4-1.4. Of the remaining 28 locations, 21 are planned for locations where no concentrations of important wildlife species have been documented; nevertheless, the possibility of obstructions during occasional crossing attempts by wildlife exists, and standard crossing facilities are proposed as a means of preventing blockage of movements. The remaining seven locations occur in areas where concentrations of important wildlife species are known to occur. More detailed and intensive impact mitigation is proposed at these locations (see Table 4-1.4).

TABLE 4-1.4

CURRENT LOCATIONS AND LENGTH OF ABOVE-GRADE MODE IN EXCESS OF 500 m, AND CONCERNS AND IMPACT MITIGATION FOR IMPORTANT SPECIES OF WILDLIFE

KP	Length of Above-grade Mode (km)		
7.3-15.4	8.1	Concern:	Possible blockage of cross-right-of-way movements by mammals. No known concentrations of important wildlife species.
		Impact Mitigation:	Standard crossing facilities (spans, ramps) to be constructed approximately every 330 m.
17.9-21.2	3.3	Concern:	Possible blockage of cross-right-of-way movements by mammals. No known concentrations of important wildlife species.
		Impact Mitigation:	Standard crossing facilities (spans, ramps) to be constructed approximately every 330 m.
22.6-24.2	1.6	Concern:	Possible blockage of cross-right-of-way movements by mammals. No known concentrations of important wildlife species.
		Impact Mitigation:	Standard crossing facilities (spans, ramps) to be constructed approximately every 330 m.
39.4-40.2	0.8	Concern:	Possible blockage of cross-right-of-way movements by mammals. No known concentrations of important wildlife species.
		Impact Mitigation:	Standard crossing facilities (spans, ramps) to be constructed approximately every 330 m.

Table 4-1.4 Continued

KP	Length of Above-grade Mode (km)		
42.5-44.1	1.6	Concern:	Possible blockage of cross-right-of-way movements by mammals. No known concentrations of important wildlife species.
		Impact Mitigation:	Standard crossing facilities (spans, ramps) to be constructed approximately every 330 m.
66.5-70.5	4.0	Concern:	Possible blockage of cross-right-of-way movements by mammals. No known concentrations of important wildlife species.
		Impact Mitigation:	Standard crossing facilities (spans, ramps) to be constructed approximately every 330 m.
71.2-72.3	1.1	Concern:	Possible blockage of cross-right-of-way movements by mammals. No known concentrations of important wildlife species.
		Impact Mitigation:	Standard crossing facilities (spans, ramps) to be constructed approximately every 330 m.
73.3-74.9	1.6	Concern:	Possible blockage of cross-right-of-way movements by mammals. No known concentrations of important wildlife species.
		Impact Mitigation:	Standard crossing facilities (spans, ramps) to be constructed approximately every 330 m.

Table 4-1.4 Continued

KP	Length of Above-grade Mode (km)		
76.7-79.9	3.2	Concern:	Possible blockage of cross-right-of-way movements by mammals. No known concentrations of important wildlife species.
		Impact Mitigation:	Standard crossing facilities (spans, ramps) to be constructed approximately every 330 m.
82.4-83.0	0.6	Concern:	Adjacent to moose spring-summer range. Some blockage of cross-right-of-way movement possible.
		Impact Mitigation:	One ungulate crossing to be constructed within above-grade
92.8-94.6	1.8	Concern:	Adjacent to moose spring-summer range. Some blockage of cross-right-of-way movement possible.
		Impact Mitigation:	Five crossing ramps to be constructed within above-grade section (two ungulate crossings, three standard crossings).
96.6-98.8	2.2	Concern:	Possible blockage of cross-right-of-way movements by mammals. No known concentrations of important wildlife species.
		Impact Mitigation:	Standard crossing facilities (spans, ramps) to be constructed approximately every 330 m.
109.2-109.7	0.5	Concern:	Possible blockage of cross-right-of-way movements by mammals. No known concentrations of important wildlife species.

Table 4-1.4 Continued

KP	Length of Above-grade Mode (km)		
		Impact Mitigation:	Standard crossing facilities (spans, ramps) to be constructed approximately every 330 m.
114.2-116.3	2.1	Concern:	Adjacent to moose spring-summer range. Some blockage of cross-right-of-way movement possible.
		Impact Mitigation:	Six crossing ramps to be constructed (two ungulate crossings, four standard crossings).
116.4-126.0	9.6	Concern:	Portion of this section adjacent to moose spring-summer range. Some blockage of cross-right-of-way movement possible. General concern for blockage of movements along remaining portion.
		Impact Mitigation:	Twenty-nine crossing ramps to be constructed (four ungulate crossings, 25 standard crossings).
126.3-129.6	3.3	Concern:	Portion of this section adjacent to moose spring-summer range. Some blockage of cross-right-of-way movement possible. General concern for blockage of movements along remaining portion.
		Impact Mitigation:	Nine crossing ramps to be constructed (two ungulate crossings, seven standard crossings).
158.6-160.4	1.8	Concern:	Caribou migration corridor. Blockage of seasonal migration possible.

Table 4-1.4 Continued

KP	Length of Above-grade Mode (km)		
		Impact Mitigation:	Six ramps to be constructed (three ungulate crossings, three standard crossings).
163.3-167.4	4.1	Concern:	Caribou migration corridor. Blockage of seasonal migration possible.
			Fifteen ramps to be constructed (seven ungulate crossings, eight standard crossings).
188.6-190.1	1.5	Concern:	Possible blockage of cross-right-of-way movements by mammals. No known concentrations of important wildlife species.
		Impact Mitigation:	Standard crossing facilities (spans, ramps) to be constructed approximately every 330 m.
197.3-200.8	3.5	Concern:	Possible blockage of cross-right-of-way movements by mammals. No known concentrations of important wildlife species.
		Impact Mitigation:	Standard crossing facilities (spans, ramps) to be constructed approximately every 330 m.
201.5-202.3	0.8	Concern:	Possible blockage of cross-right-of-way movements by mammals. No known concentrations of important wildlife species.
		Impact Mitigation:	Standard crossing facilities (spans, ramps) to be constructed approximately every 330 m.

Table 4-1.4 Continued

KP	Length of Above-grade Mode (km)		
257.8-258.4	0.6	Concern:	Possible blockage of cross-right-of-way movements by mammals. No known concentrations of important wildlife species.
		Impact Mitigation:	Standard crossing facilities (spans, ramps) to be constructed approximately every 330 m.
287.4-288.5	1.1	Concern:	Possible blockage of cross-right-of-way movements by mammals. No known concentrations of important wildlife species.
		Impact Mitigation:	Standard crossing facilities (spans, ramps) to be constructed approximately every 330 m.
299.2-300.0	0.8	Concern:	Possible blockage of cross-right-of-way movements by mammals. No known concentrations of important wildlife species.
		Impact Mitigation:	Standard crossing facilities (spans, ramps) to be constructed approximately every 330 m.
315.0-315.5	0.5	Concern:	Possible blockage of cross-right-of-way movements by mammals. No known concentrations of important wildlife species.
		Impact Mitigation:	Standard crossing facilities (spans, ramps) to be constructed approximately every 330 m.

Table 4-1.4 Continued

KP	Length of Above-grade Mode (km)		
333.3-334.5	1.2	Concern:	Possible blockage of cross-right-of-way movements by mammals. No known concentrations of important wildlife species.
		Impact Mitigation:	Standard crossing facilities (spans, ramps) to be constructed approximately every 330 m.
467.1-468.0	0.9	Concern:	Possible blockage of cross-right-of-way movements by mammals. No known concentrations of important wildlife species.
		Impact Mitigation:	Standard crossing facilities (spans, ramps) to be constructed approximately every 330 m.
468.5-469.3	0.8	Concern:	Possible blockage of cross-right-of-way movements by mammals. No known concentrations of important wildlife species.
		Impact Mitigation:	Standard crossing facilities (spans, ramps) to be constructed approximately every 330 m.

4.0 GRANULAR MATERIAL REQUIREMENTS

Gravel requirements for the above-grade concrete-restrained mode are approximately 37.5 m^3/lineal m, with 36.2 m^3/lineal m required for work pad and 1.3 m^3/lineal m for concrete retraints. Over the 67 km of above-grade construction, assuming it is all concrete-restrained, 2.5 x 10^6 m^3 of granular material would be required (Table 4-1.5). Preliminary field investigations of gravel sources within 1 km of the Alaska Highway and/or the pipeline indicate that in the sections of pipeline where the above-grade modes will likely be used, in excess of 43.9 x 10^6 m^3 of granular material is readily available (Table 4-1.5). It is apparent that the available sources of granular material in close proximity to the pipeline route or Alaska Highway exceed the requirements that would be realized by the construction of 67 km of concrete-restrained mode.

TABLE 4-1.5

TOTAL LENGTHS OF ABOVE-GRADE MODE, BY CONSTRUCTION SECTION, MATERIAL REQUIREMENTS FOR CONSTRUCTION OF THE CONCRETE-RESTRAINED MODE, AND THE ESTIMATED QUANTITY OF GRANULAR MATERIAL AVAILABLE

Section Number	Kilometre Post From	Kilometre Post To	Spread Length (km)	Total Length Above-Grade (km)	Above-Grade Material Requirement (m^3)[1]	Available Material (x 10^6 m^3)[2]
1	0	55	55	15.6	585,000	4.68
2	55	110	55	15.4	557,500	4.18
3	110	165	55	18.7	701,250	2.27
4	165	220	55	8.2	307,500	>5.54
5	226	300	74	2.6	97,500	>6.23
6	300	378	78	3.6	135,000	>3.14
8	452	537	85	2.7	101,250	>10.22
9	537	598	61	0.2	7,500	>7.68

[1]Material requirements based on the estimate of 37.5 m^3/lineal m for construction of the concrete-restrained mode.

[2]Gravel sources which have been identified within 1 km of the Alaska Highway or the pipeline route.

5.0 SUMMARY AND CONCLUSIONS

This submission has reviewed the types and locations of alternative pipe placement modes which are currently planned or available to the Project for use in areas of potential frost heave or thaw settlement. From an environmental impact perspective, the conclusion is that all alternative modes which involve burial will pose environmental problems that are no different than those created by the conventional buried mode. The submission has therefore concentrated on alternative modes which involve above-grade pipe placement and in particular the concrete-restrained mode. Potentially, significant environmental impacts to fish and wildlife resources could occur in the absence of impact mitigation; however, for fish resources, all fish-bearing watercourses where an above-grade mode is necessary are sufficiently narrow to allow construction of a free span for the crossing. This removes virtually all of the concern for fish inhabiting the watercourses in question with regard to the effects of instream construction activities as well as those that might arise during operation. For wildlife, concerns related to obstruction of movements by highly-mobile species (particularly ungulates) arise as a result of above-grade concrete-restrained pipe placement. The majority of locations where the above-grade mode is necessary either will not prevent animal movement by virtue of their short length (less than 500 m), or do not occur in locations known to harbor concentrations of wildlife. Eight locations involve animal movement corridors or areas of wildlife concentration where an impact could occur. Review of existing information on the behavior of wildlife when crossing linear facilities such as pipelines has led to the adoption of specific design features to mitigate impacts at these locations. The Project anticipates that wildlife, specifically ungulates, will use the crossing structures provided, and that minimal obstruction of movement will occur.

CLIENT: **FOOTHILLS PIPE LINES (SOUTH YUKON) LTD.**

THE ALASKA HIGHWAY GAS PIPELINE PROJECT

BASIS OF THE PERMAFROST PIPELINE DESIGN FOR WARM FLOW

REVISION 0: 1981 December 4

ENGINEER: **YUKON PIPELINE DESIGN JOINT VENTURE (YPD)**

ASSOCIATED-KELLOGG LTD.
PETROTECH LAVALIN INC.
CANUCK ENGINEERING LTD.
MONENCO PIPELINE CONSULTANTS LTD.

1001 East Tower, Fifth Avenue Place 425 First Street S.W.
Calgary, Alberta T2P 3L8
Telephone 237-1422

PREPARED BY: J. Price
A. Pare
S. McKeown
D. Harron
N. Surtees

APPROVED BY: J. Price

PROFESSIONAL ENGINEER ALBERTA
P. St. J. PRICE

YPD PERMIT STAMP:

THE ASSOCIATION OF PROFESSIONAL ENGINEERS, GEOLOGISTS and GEOPHYSICISTS OF ALBERTA
PERMIT NUMBER
Yukon Pipeline Design Joint Venture (YPD)

YUKON PIPELINE DESIGN JOINT VENTURE (YPD)

ASSOCIATED-PULLMAN KELLOGG LTD. PETROTECH LAVALIN INC.
CANUCK ENGINEERING LTD. MONENCO PIPELINE CONSULTANTS LIMITED

1001 425 1ST STREET S.W CALGARY, ALTA T2P 3L8 TEL 237 1422

FOOTHILLS PIPE LINES (SOUTH YUKON) LTD.
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APPENDICES

1.0 EXECUTIVE SUMMARY

The report gives the basis and overview of the permafrost design being developed for the warm flow sections of the pipeline in the Yukon.

The detailed and final design will require integration of the work of the various disciplines, companies and consultants involved in the design. The report defines the design objectives and basic criteria and discusses the coordinated approach being followed in the design process. The design process requires a terrain analysis and the identification of permafrost problems that need to be mitigated by the selection of appropriate construction modes. Operation of the warm pipeline and construction related activities on the right-of-way will affect the thermal regime with consequent effects on right-of-way stability, pipeline integrity and the environment.

The permafrost design integrates the pipeline design with the right-of-way stability and construction zone designs in order to satisfy the basic objectives of pipeline integrity, mitigation of environmental impacts and minimum cost.

In the pipeline design two basic design concepts have been developed to mitigate problems related to thawing permafrost. These are buried restrained modes and abovegrade restrained modes. The buried restrained modes are essentially conventional pipeline design methods with some additional select material to compensate for losses in material quantities and strengths due to the nature of thawing permafrost. Depending on the local soil conditions the buried modes will alter the thermal regime by developing a thaw-bulb up to 20 m deep and 35 m wide, after 30 years of service. This requires consideration of right-of-way settlements, pipeline stability problems, differential settlements of the pipe, drainage and erosion control and static and seismic slope and thaw-bulb stability problems. These problems will be mitigated by initial design and construction and by monitoring and maintenance during operation of the pipeline. The abovegrade restrained modes include insulated pipe in an insulated embankment and pipe restrained by linked concrete weights resting on an insulated bearing pad. The abovegrade modes will be used in unstable soil areas or soils with an excessive settlement potential. These modes will have a minimal effect in the thermal regime provided proper drainage control measures are adopted. Aerial surveillance, periodic checks of pipe elevations and surface maintenance may be required in some areas during operation of the system. Maintenance requirements are expected to be minimal for the abovegrade modes.

The right-of-way stability and construction zone design will satisfy pipe integrity and environmental constraints and specifications for grading, trenching, right-of-way preparation, disposition of unsuitable spoil, and temporary work pads and right-of-way restoration. Site specific erosion and drainage control measures have been developed. These will limit erosion and loss of overburden, prevent ponding and consequent degradation of underlying permafrost, prevent icings from blocking cross drainage and prevent washouts which could cause instability of the pipeline. Static and seismic slope stability of all slopes traversed by the pipeline and static and seismic stability of thaw-plugs on slopes paralleled by the pipeline will be checked and protective design measures incorporated where necessary as recommended by geotechnical and earthquake consultants.

The pipeline design, the right-of-way stability and construction zone designs will be integrated on a site specific basis during the detailed and final design stages. Throughout this report environmental concerns have been considered to be an integral part of pipeline design and as such they have been incorporated into the conceptual design in the appropriate subject areas. The basic approach will be that design solutions to engineering problems will deal with most long term environmental concerns. Where this is not possible, site specific environmental concerns will be identified and resolved at the detailed design stage.

2.0 INTRODUCTION

2.1 PURPOSE AND SCOPE

The warm flow sections (operated above 0°C) of the Alaska Highway Gas Pipeline will pass through discontinuous permafrost and areas of relatively high earthquake risk. The purpose of this report is to provide an overview of the discontinuous permafrost design being developed for the warm flow sections of the pipeline. The report deals with the pipeline civil design and related terrain and construction problems and does not include the compressor station, gas hydraulics and metallurgical aspects of the overall design.

The report gives a summary of the basis of the pipeline design including the right-of-way and construction zone design being developed to satisfy the basic objectives of pipeline integrity and mitigation of adverse environmental impacts.

2.2 DESIGN PROBLEMS

The operating warm pipeline buried in permafrost will develop a thaw-bulb up to about 20 m deep and 35 m wide, after 30 years of service. The nature of some of the permafrost soils in the Yukon is that they consist of ice-rich peat and organic silts near the surface, and deeper strata with varying amounts of ice content. Soils lose strength after thawing and some of the soils encountered in the Yukon would offer little restraint for the pipeline. Such soils are referred to in this report as unstable soils. An unstable soil is defined as an initially unfrozen or a thawed soil which will not provide sufficient resistance to restrain, or limit movements of a particular size and geometrical configuration of the pipeline operating at a specified maximum temperature differential and gas pressure. Both stable and unstable soils after thawing could consolidate and settle causing the right-of-way surface and the pipeline to settle excessively if appropriate mitigative designs and remedial maintenance procedures are not used in a particular area. Thawing of ice-rich slopes require special consideration of pipeline stability and differential movements, static and seismic slope stability, thaw-bulb stability, solifluction and erosion and drainage control and may require the development of site specific designs to mitigate these problems.

The pipeline route in some areas will pass in the proximity of the Shakwak and Dalton segments of the Denali fault system which is characterized by high seismicity. The permafrost design problems associated with seismic activity and ground shaking are pipeline stability, seismic slope stability and ground movements, thaw-bulb stability, seismic liquefaction and fault movements. No active faults have been identified and fault movements are no longer considered a design problem. The seismic ground motions will be considered in the development and selection of the pipeline designs.

During construction of the pipeline, right-of-way disturbance due to construction traffic, clearing, grading, trenching, backfilling and restoration could lead to thermal degradation and subsequent loss of pipeline integrity.

Right-of-way and construction zone designs will be developed to integrate with the pipeline design by development of right-of-way preparation procedures, by development of grading and trenching constraints, by using appropriate mitigative designs for erosion and drainage control, for slope stability, for thaw-bulb stability, by acceptable disposal of unsuitable spoil and restoration. The degree to which design successfully addresses the aspects of pipeline integrity, thermal degradation, erosion and drainage control and construction sequencing will assist to minimize environmental impacts.

2.3 REGULATIONS

The pipeline design will be in accordance with the National Energy Board Act Gas Pipeline Regulations, Registration SOR/74-233; and the Northern Pipeline Act. The design and construction will be in compliance with CSA Standard Z184-M1979, and the Engineering Orders and Environmental Terms and Conditions (1980) issued by the Northern Pipeline Agency.

2.4 BASIC DESIGN CRITERIA

The basic design criteria consistent with good engineering practice and the regulations are that a safe and relatively maintenance free pipeline be built to avoid adverse environmental impacts and minimize capital costs. The design criteria that will ensure pipeline integrity are summarized in the structural design criteria report in Appendix A.

Pipeline construction modes will be selected along the route so that the structural design criteria and guidelines are satisfied for the site specific geotechnical, topographic, terrain, and pipeline operating conditions. Right-of-way and construction zone design procedures and specifications will be established so that environmental and pipeline integrity constraints are satisfied.

The Socio-economic and Environmental Terms and Conditions (revised draft, October 1980) and subsequent guidelines will be taken into account in the engineering design to satisfy engineering design requirements as specified in Order No. NP-MO-1-79. Minimization of engineering associated environmental impacts are consistent with engineering design for pipeline integrity.

2.5 DESIGN APPROACH

A flow diagram is given in Figure 2.5.1 outlining the design logic. The basic design objectives are pipeline integrity, mitigation of environmental impacts and minimum cost.

A terrain analysis has been undertaken over the last five years and is continuing using geotechnical borehole data, terrain typing, geological data, geophysical explorations and air photo interpretations. The information from these investigations are summarized on the Geotechnical Atlas in the computer data bank and in the slope catalog which are continuously being updated.

The pipeline is being designed using the latest available terrain data. Data gathering will continue and during construction, additional information obtained may require changes to the final design which will be made in accordance with the design criteria and guidelines developed for the project.

Pipeline design problems and associated right-of-way and construction zone design problems have been identified for the warm flow sections of the pipeline using the terrain analysis together with geothermal predictions of the effects of the warm pipeline, of right-of-way disturbance and of ponding and related drainage measures on the thermal regime. The pipeline design, right-of-way and construction zone design are parallel activities in the design logic which are integrated at the detailed site specific design stage.

The pipeline design involves the co-ordinated efforts of geotechnical, structural, pipeline, civil, construction, environmental and geothermal disciplines. Alternative construction modes have been developed to mitigate the various design problems. Mode selections for varying terrain conditions will be made based on the information on the Geotechnical Atlas, geotechnical predictions of thaw settlements and soil strength properties, and the structural design criteria and guidelines. A full scale test facility has been constructed at Quill Creek to gain construction and engineering experience and to test thermal effects of a number of construction modes and procedures.

The right-of-way and construction zone design involves the co-ordinated efforts of the construction, civil, hydraulics and hydrology, geothermal, structural, geotechnical and environmental disciplines. Typical drainage and erosion control design measures have been developed and thermal effects of ponding and right-of-way disturbance are being studied. Specifications are being developed for right-of-way preparation, grading and trenching, disposition of unsuitable spoil, right-of-way stability, temporary workpads, temporary and permanent access roads, drainage and erosion control and post construction right-of-way restoration and revegetation. In the detailed design phase the pipeline design and right-of-way and construction zone design will be integrated and detailed designs will be checked for compliance with all design and environmental constraints and revised on a site specific basis if necessary.

The detailed design will then be reviewed by Foothills and government officials.

After approval, construction will proceed and the as-built survey will be undertaken.

3.0 BASIC DESIGN DATA

3.1 INTRODUCTION

This chapter gives a brief description of the terrain analysis and geotechical data collected by Foothills Pipe Lines (South Yukon) Ltd. and summarizes the basic pipeline design and construction zone design problems. The basis of the pipeline design is outlined in Chapter 4 and of the right-of-way stability and construction zone design is outlined in Chapter 5.

3.2 TERRAIN ANALYSIS

Subsurface profiles and descriptions of terrain types crossed by the pipeline right-of-way and accessory descriptions of soil types, textures, thermal states, ice contents, slopes and drainage were developed by consultants. The profiles and descriptions define the terrain types crossed by the pipeline and are an aid toward assessing problems related to permafrost, drainage control, slope stability, excavation and construction.

The profiles and accessory descriptions of the terrain types were constructed from assessments of geotechnical data, field programs, drill hole data and air-photo interpretations using the modified Geological Survey of Canada system of terrain typing.

The route selection was made by Foothills using the results of the terrain analysis, local topography and local geotechnical conditions in combination with environmental, sociological and construction input.

3.3 GEOTECHNICAL DATA

Considerable geotechnical data have been collected since 1976 by Foothills and their consultants. This effort has included nine drilling programs to determine subsurface soil conditions, and six geophysical programs to help delineate depth and extent of permafrost. This information is summarized in the Geotechnical Atlas. A computerized data bank in which all the detailed information is stored has been developed and a slope catalog has been prepared describing the characteristics of the slopes along the route. The Geotechnical Atlas, data bank and slope catalog are continuously being updated as new information is obtained.

Many design conditions can be evaluated only by joint consideration of the geotechnical conditions, geothermal analysis of the change in the thermal regime induced by the construction and operation of the pipeline, anticipated earthquake activity and the structural design guidelines. Geotechnical studies have been undertaken to determine thaw settlement potential in various soil conditions and terrain types, to determine soil strength characteristics after thawing, and to evaluate erodibility characteristics of surficial soils.

Geotechnical parameters are being developed by geotechnical consultants for use in the structural analysis and development of design guidelines discussed in Chapter 4. These parameters include bearing strengths and load deformation characteristics of the various soil types and the potential for differential settlements along the route. A detailed description of the soil properties required to analyze each design configuration and develop design guidelines is provided in subsequent sections of this chapter.

3.4 GEOTHERMAL DATA

An operating warm pipeline buried in permafrost will develop a thaw-bulb which will vary in size depending on the pipe temperature and local soil conditions. The maximum thaw-bulb is predicted to be 20 m deep and 35 m wide after 30 years of service. This will cause thaw settlements of the buried pipeline and the right-of-way surface in some of the permafrost soils along the route. Geothermal predictions are being done by consultants on all the buried configurations on flat and sloping terrain to determine the extent of thawing. The results of these analyses are used by the geotechnical consultants to predict the amount of thaw settlement that will potentially occur in various terrain types and soil strata.

In the restrained abovegrade modes, insulation will be used in the construction pads and around the pipe when necessary. Geothermal analyses are being performed to verify alternative geometrical configurations of the aboveground modes and determine insulation requirements so that thaw penetration under the pipeline and construction pad will be limited to acceptable amounts. Geothermal analyses are also being undertaken to optimize insulation thickness and configurations and to determine pipe wall temperatures for the restrained above grade configurations during shut-downs. Thermal effects of right-of-way disturbance and drainage control measures are also being analyzed.

The soil thermal and geotechnical properties developed by the consultants and required for the geothermal calculations include conductivity, water content, dry density, excess ice content and specific heat of the soils and thermal properties of the insulation. The thermal properties are obtained from published data and the Geotechnical Atlas, drill hole logs and the data bank. Surface meteorolocial data and water and snow accumulations are estimated from published sources and by analysis for a particular region and topography and their effects are included in the overall geothermal predictions.

The Quill Creek test facility has been constructed and is extensively instrumented with thermistors so that accuracy of geothermal predictions can be checked against field measurements.

3.5 EARTHQUAKE CONDITIONS

The Shakwak and Dalton segments of the Denali Fault Systems through which the pipeline route passes are characterized by high seismicity. The earthquake induced ground movements and loading conditions considered in the pipeline design include ground velocity, acceleration and displacement, seismic liquefaction, and transverse and longitudinal movements of thawing ice-rich slopes traversed or paralleled by the pipeline. No active faults have been identified at this time and fault movements are not considered a design problem. Areas along the route with a seismic liquefaction potential have been identified by the geotechnical consultants.

The related seismic slope stability, and thaw-bulb stability design problems, are considered in the right-of-way stability and construction zone design basis in Chapter 5.

3.6 ENVIRONMENTAL CONSIDERATIONS

Environmental considerations for the pipeline design are integrated in the right-of-way and construction zone design outlined in Chapter 5. Concerns identified from The Socio-economic and Environmental Terms and Conditions (Northern Pipeline Agency; revised draft October 1980) include the following:

a) Drainage, Erosion Control and Revegetation;
b) Wildlife;
c) Fisheries;
d) Special Interest Areas;
e) Clearing;
f) Blasting;
g) Roads and Other Facilities.

These environmental concerns will be used as a check-list to ensure that the design and/or construction procedures adequately address the environmental requirements.

3.7 DESIGN PROBLEMS

The pipeline design problems for the warm flow sections have been separated into two categories: 1) those related to pipeline integrity; 2) and those related to right-of-way stability, construction zone preparation and restoration, and erosion and drainage control.

3.7.1 Pipeline Integrity and Stability

The modes of structural damage which will affect the integrity of the pipeline and the stress, strain and stability criteria to prevent this damage are discussed in the report on the structural design criteria for the buried pipeline (Appendix A). Structural analysis procedures have been developed to analyze the pipeline response due to specified operating and soil conditions. A reconciliation of the results of these analyses with the structural design criteria forms the basis for determining guidelines for pipeline integrity. The construction modes discussed in Chapter 4 are developed using these guidelines.

The design problems related to pipeline integrity in permafrost as a result of earthquake activity and warm pipeline operating loads are:

a) Loss of soil restraint due to thawing ground or seismic liquefaction;

b) overall structural instability due to loss of lateral or verical soil restraint or liquefaction; particularly at horizontal or vertical changes of alignment;

c) differential movements of the pipe due to soil settlements or slope movements.

3.7.2 Right-of-way Stability and Construction Zone

The treatment of the right-of-way and construction zone is important both for its interaction with the construction modes and for environmental impacts. The basic criteria used in the right-of-way and construction zone design are to assure stability, provide for effective drainage and erosion control, and to protect the environment.

The main design problems related to the right-of-way stability and construction zone design in permafrost as a result of earthquake activity and the changes in thermal regime caused by the warm pipeline are:

a) Right-of-way preparation, and trenching and disposition of unsuitable or excess spoil;

b) erosion and drainage control and ponding;

c) settlements of the right-of-way due to thermal degradation caused by the warm pipeline, by ponding and by surface disturbance;

d) static and seismic slope stability on thawing slopes;

e) static and seismic thaw-bulb stability;

f) right-of-way restoration and revegetation.

4.0 PIPELINE INTEGRITY AND STABILITY AND CONSTRUCTION MODES

4.1 INTRODUCTION

This chapter presents the design basis and procedures that will be used for selection of the construction modes and maintenance procedures developed for the warm sections of the pipeline. The basic design philosophy is that appropriate construction modes will be selected for terrain types and subsoil conditions along the alignment taking into account local soil conditions, topography, thermal effects and pipeline integrity and stability constraints. During construction of the pipeline, local geotechnical and terrain conditions identified during the right-of-way preparation and trenching operations may dictate changes to the design and these will be made in accordance with the design manual.

Two basic construction mode concepts have been developed for the permafrost design in the Yukon. These are buried restrained systems and abovegrade restrained systems. Pipeline stability and integrity for the buried construction modes will be sensitive to loss of soil strength due to thawing and thermal degradation causing settlements. Adequate soil restraint will be provided and elevations or deformations of the buried pipeline will be monitored during operation in some permafrost areas where these thaw sensitive construction modes are implemented. The pipeline would be buried only where predicted settlements will be less than a specified allowable value and pipe movements will be monitored at sufficient intervals and frequency to audit differential pipe movements with time and identify trends to the pipe deformation design limits. Remedial maintenance procedures will be implemented to prevent unacceptable damage to the pipeline if the deformation design limits are approached during pipeline operation.

The abovegrade restrained construction modes will be used in unstable soil areas and in areas where predicted settlements will be greater than the specified allowable value. These modes are being designed to minimize thaw penetration in most areas thus largely eliminating thaw settlement problems. Aerial surveillance would be used to monitor effects of the abovegrade restrained modes on the terrain and maintenance requirements would be implemented where necessary.

The basic criteria for selection of alternative construction modes will be predicted settlement potential and allowable pipeline settlements, soil restraint requirements for structural stability, availability of borrow materials, and capital costs. Hydrological considerations and wildlife activity will also influence mode selection.

4.2 DESIGN BASIS AND GUIDELINES

4.2.1 Insulation Design

Insulation will be provided where necessary around the pipeline and within construction pads to eliminate or limit thaw penetration; and around the pipe in some specialized designs to reduce heat flux for heat tracing or refrigeration applications.

A general specification for pipeline and laydown of flat board insulation is being prepared. Included in this specification will be the required properties for insulating materials and for protective outer shells when required for insulation around the pipe.

Specifications for mechancial strength, ductility at a full range of ambient and operating temperatures, water permeability, long term insulating properties, long term durability, abrasive resistance, ease of application, availability and serviceability are being developed.

Contact has been made with a number of suppliers and once the specification is complete it will be sent to various manufacturers and suppliers for their proposals. Case histories of insulation performance and manufacturers and suppliers feedback will be used to choose suitable insulating procedures, materials and protective outer jackets for particular requirements. Where necessary tests will be performed to check suitability of the materials selected.

4.2.2 Pipeline Integrity and Stability

Soils lose strength after thawing and some of the soils encountered in the Yukon would offer little restraint for the pipeline and are referred to as unstable soils. Similar unstable soil conditions will exist in some frozen or unfrozen muskeg or low lying swampy areas. An unstable soil is defined as a soil which will not provide sufficient resistance to restrain or limit movements of a particular size and geometrical configuration of the pipeline operating at a specified maximum temperature differential and gas pressure. Both stable and unstable soils could consolidate after thawing causing the right-of-way surface to settle and the pipeline to lose support if appropriate mitigative designs and remedial maintenance procedures are not used in problem areas. Seismic activity, liquefaction potential and thawing of ice-rich slopes will require development of site specific designs in some areas to prevent excessive slope movements, loss of support, slope instability, and thaw-bulb instability. Erosion and drainage control measures will be developed to limit ponding and consequent thermal degradation to help prevent slope instability, to limit erosion and prevent loss of support to the pipeline as a result of washouts. Slope stability and erosion and drainage control measures are discussed in Chapter 5.

The structural design criteria which are the basis for determining design guidelines for the selection between alternate construction modes in any area are summarized in the report on "The Structural Design Criteria for Restrained Pipeline" which is included in Appendix A. The relevant modes of structural damage which are considered in the pipeline design:

a) Overall structural instability of the pipeline due to insufficient restraint or loss of support;

b) wrinkling, excessive tension or denting due to transverse differential movements of the pipe, longitudinal drag on the pipe, or bearing pressures;

c) excessive ovalling or denting due to overburden loads;

d) low temperature tensile failure.

Structural analysis procedures have been developed to analyse the response of the pipeline to the various loading conditions configurations and soil conditions that will be encountered. A reconciliation of the results of the analyses for various soil conditions forms the basis for determining design guidelines to protect against the various modes of damage, for selection of appropriate construction modes and defining constraints on the operating system.

4.2.2.1 Structural Stability

After the pipeline goes into operation a large axial compressive force will be developed in the restrained pipeline by temperature differentials and by gas pressure. The pipeline will behave as a beam-column as a result of this axial compressive load, requiring consideration of overall stability of the pipeline in unstable soil areas. Of particular concern are changes of alignment, such as bends, where the axial force develops a transverse component which must be counteracted by soil resistance.

The conditions affecting overall stability of the buried pipeline will be the pipe size, the positive temperature differential, the pipe geometry in a particular area, the weight of the pipe and attached weights, if any, and the soil resistance available to restrain the pipeline.

A positive temperature differential is defined as the difference between the maximum operating temperature of the flowing gas and the reference temperature. The reference temperature is defined as the temperature of the pipe steel when the pipeline is installed and restrained with zero longitudinal thermal stress. The reference temperature will normally be at or near ambient air temperatures at the time of construction.

A buried pipeline is restrained primarily by uplift resistance and lateral and downward soil bearing resistance. Soil friction plays a minor role in restraining buried pipelines except at unanchored transitions to a flexible unrestrained configuration or at unanchored block valves where different pressures and temperatures will develop on either side of the valves during blowdowns. If insufficient uplift resistance or bearing resistance exists at a particular location overall structural instability could cause the pipeline to buckle out of the ground, to buckle sideways or to buckle downward into settling soils at changes of alignment such as at over, side and sagbends respectively. Bouyancy, liquefaction, loss of support and washout effects could also cause straight pipeline to buckle out of the ground.

At a high positive temperature differential structural instability could lead to large deflections and excessive bending of the line causing wrinkling or tensile rupture before thermal stresses in the pipe are released. At low positive temperature differentials pipe movement may relieve thermal stresses prior to the occurrence of unacceptable structural damage. Structural instability is a sudden phenomenon and impending instability cannot be practically monitored hence an essential requirement incorporated into the pipeline design is that sufficient soil restraint will be provided and maintained around buried sections of the pipeline. Where necessary this may involve using select backfill, by burying the pipe in stable soil and by remedial maintenance in areas where thawing and consolidation of permafrost causes slumping of select backfill.

In restrained abovegrade configurations sufficient select cover or concrete weighting and bearing ramps will be provided to prevent instability.

4.2.2.2 Ground Movements

Differential movements of the pipeline would be caused by thaw settlements or transverse slope movements. These movements will develop compressive and tensile bending strains in the pipe wall which must be limited in the design criteria to prevent wrinkling or longitudinal tensile failure. Soil reactions will be imposed on the pipe in certain regions and the design criteria limit ovalling and circumferential stresses to prevent denting. In permafrost areas and unstable soil areas, differential movements of the pipeline will be monitored at sufficient intervals and frequency to identify trends to the stress and strain limits at which time remedial maintenance measures would be implemented. Slope movements will be limited by design and slope instability prevented by adequate factors of safety and implementation of proper erosion and drainage control measures.

In areas where the pipeline parallels a slope, longitudinal slope movements, thaw-bulb instability or solifluction would stretch the pipe in the upper region and compress it in the lower region. This could lead to tensile failure, wrinkling or denting in the overbend and sagbend areas. Pipeline damage will be avoided by adequate factors of safety against thaw-bulb instability and limiting movements by design and provision of adequate erosion and drainage control.

4.2.2.3 Overburden Loads

In areas where the pipeline is deeply buried or traffic loads at road crossings must be considered, soil compaction or other support will be specified so that the pipe does not oval excessively and does not dent.

4.2.3 Structural Analysis

Membrane stresses caused by gas pressure, temperature differential and ground shaking caused by earthquakes (excluding massive ground movements) are analyzed using standard elastic analysis procedures. A reconciliation of the results of these analyses with the stress constraints in the structural design criteria form the basis for establishing maximum allowable limits for temperature differentials in each of the earthquake zones.

Combined membrane stresses, primary bending stresses and bending strains caused by loss of support, ground movements and instability for specific structural configurations are analyzed using nonlinear analyses procedures. The PIPLIN computer program is used for most of these analyses. This is a special purpose program for stress and deformation analysis of cross-country pipelines, either above ground or buried. The program considers the effects of internal pressure, thermal expansion, gravity load, soil settlement, soil deformation, fault movement, soil creep and frost heave. Several nonlinear aspects of behaviour are considered, including yield of the pipe steel, large displacement effects, nonlinear support, and nonlinear creep and frost heave. Applications of the computer program for the Yukon Pipeline Design include: sidebend analysis of restrained pipe with nonlinear longitudinal and transverse soil restraint; overbend analysis of restrained pipe with lift-off and nonlinear longitudinal soil restraint; sagbend analysis with nonlinear longitudinal and vertical soil restraint; loss of soil support over short lengths over which the pipe will safely bridge; settlements or excavation of trench bottom with arbitrary settlement profile over long lengths with nonlinear soil properties and analysis of ditch profiles that the pipe will conform to without the application of external force. The computer program has been developed, improved and extensively tested over the last nine years. Geotechnical parameters required as input to these analyses include effective weight of various soils and select material; sideway load-deformation relationships and ultimate bearing resistance of ditch sides in various soil types; vertical load deformation relationships of soil underneath the pipe; consolidation and settlement potential of various soil types and longitudinal shear resistance between the pipe and various soil types.

A reconciliation of the results of the structural analysis of the various design configurations with the stress and strain limits defined in the structural design criteria provides the basis for determining guidelines for soil restraint requirements and settlement limitations which will assure the stability and integrity of the pipeline.

In areas where flexibility is provided the flexibility analyses will be done using PIPANL or other suitable systems if PIPLIN is not suitable. PIPANL is a special purpose program for stress analysis of cross-country pipelines and station piping, either aboveground or buried. The program performs static load analyses and response spectrum earthquake analyses of three-dimensional piping systems subjected to internal pressure, thermal expansion, gravity load and soil or support settlement. Branches and loops are permitted. Non-linear properties of several types may be specified for the supports. The pipe itself is assumed to remain elastic and large displacement effects are not considered. Applications of the program may be at transitions to scraper traps, movements of unanchored block valves during blowdowns, and flexibility of attached piping at scraper traps and block valves.

4.2.4 Design Configurations and Guidelines

A reconciliation of the results of structural analysis of the various design configurations, using the various operating conditions and soil types where applicable, with the stress and strain limitations in the structural design criteria determines design guidelines for pipeline integrity and stability. A brief outline of the design guidelines for each design configuration follows. Numerical values for parameters referred to in the guidelines which will be used to determine ditch dimensions, embankment dimensions, overburden and soil restraint requirements and pipe movement constraints will be provided in the detailed design documentation.

4.2.4.1 Temperature Differentials

Discharge temperatures at compressor stations will be controlled so that the maximum allowable differentials are not exceeded and minimum flowing gas temperatures in the warm flow sections of the pipeline do not fall below 0°C for extended periods.

4.2.4.2 Overbend Stability

The overbend analyses for buried modes, embankments or concrete weighted modes require the specification of uplift resistance, longitudinal shear resistance, pipe size, bend angle, radius of curvature, temperature differential and gas pressure. The design configurations are illustrated on Figure 4.2.4.2. The results of parametric analyses are used to determine the required uplift resistance for given temperature differentials, bend angles and gas pressures to restrain the pipeline and prevent:

a) Overall instability of the pipe;

b) wrinkling or excessive tension;

c) excessive deflection of the bend apex which could lead to loss of select overburden in buried modes and embankment or tipping of the concrete weights in the concrete restrained mode.

The depth of burial, or the size of concrete weights, will be determined from the required uplift resistance at specific locations.

4.2.4.3 Sidebend Stability

The design configurations for sidebends including buried embankments and concrete weighted sidebends are illustrated on Figure 4.2.4.3. The sidebend analyses require the specification of bearing capacity of the ditch side and load deformation properties of the soils, longitudinal shear resistance, pipe size, bend angle, radius of curvature, temperature differential and gas pressure. The results of parametric analyses are used to determine the required ditch wall bearing resistance and soil stiffness for given temperature differentials, bend angles and gas pressures to restrain the pipeline and prevent:

a) Overall instability of the pipeline;

b) wrinkling or excessive tension;

c) excessive lateral deflections of the bend apex which could lead to the pipeline pushing out of the select overburden zone in the buried modes, damaging the select fill on the loaded side of the embankment, or pushing the concrete weights off the construction pad.

The required bearing resistance and soil stiffness to restrain the pipeline will be determined from the results of these parametric analyses.

In the buried modes in permafrost the pipeline will be buried in stable soils which will provide the required bearing resistance and soil stiffness. If specific soil types at normal burial depths will not provide the required restraint, they will be classified as unstable soils and the pipeline will be buried deeper in accessible stable soils, or a wider ditch with a select backfill and compacted bearing pad will be provided, or a combination of deeper burial and a bearing pad will be used depending on local conditions.

The width of the crest of the embankment mode will be increased and compacted as required to provide the necessary sideway restraint at sidebends in the embankment mode.

A ramp constructed from compacted select material to provide the necessary sideway restraint will be provided at sidebends in the concrete restrained mode.

4.2.4.4 Sagbend Stability

The sagbend configuration is illustrated on Figure 4.2.4.4. The vertical bearing restraint offered by the ditch bottom in unfrozen soils will normally increase with increasing downward deflections of the bend apex hence instability will not normally be a problem at sagbends.

If settlements occur, however, there will be a tendency for the sagbend to buckle into the settlement profile. Hence differential settlements will normally control the design of buried sagbends in thawing permafrost. Significant thawing and settlements will normally not occur under the abovegrade embankment or concrete restrained modes.

Differential settlements of the buried modes are discussed later.

4.2.4.5 Straight Pipeline Stability

Instability of buried pipelines, particularly at changes in alignment, can occur as a result of insufficient soil bearing or uplift resistance to restrain the pipeline in the ground. Instability can also be triggered in straight sections of the pipeline by loss of soil support due to washouts, seismic liquefaction, settlements, buoyant loadings in combination with loss of soil restraint, etc. Some typical configurations are illustrated in Figure 4.2.4.5.

The structural analyses of loss of support are used to determine safe free span lengths over which the pipeline will safely bridge for a given pipe size, temperature differential, gas pressure, primary gravity load and buoyancy load. A reconciliation of these analyses with the design criteria will ensure:

a) Overall stability of the pipe

b) combined membrane and bending stresses below the yield strength of the steel.

The design philosophy is to provide continuous support and restraint to the pipeline in accordance with the codes and regulations and with good engineering practice. Loss of support or acceptable span lengths are therefore not generally a design consideration.

The safe free span lengths for specific conditions will be used to specify the spacing of soil stabilization or special supports for remedial maintenance measures in areas where loss of support or excessive differential settlements occur. These considerations are discussed subsequently.

4.2.4.6 Loss of Support and Differential Movements

Loss of support as a result of thawing permafrost or earthquakes could be caused by ground settlements, washouts and thermal erosion, slope movements or instability, etc. These design problems are created by the unique nature of thawing permafrost and distinguish the pipeline design for warm flow in the Yukon from conventional pipelines in non-permafrost areas. Loss of support and excessive differential movements are mitigated by providing adequate restraint to stabilize the pipeline, by providing site specific drainage and erosion control to prevent thermal erosion and washouts, and by providing adequate protection against static or seismic slope instability. The erosion and drainage design and the slope stability design are integral parts of the overall design for pipeline integrity and are discussed in Chapter 5.

The loss of support, differential settlements and transverse differential slope movement configurations are illustrated in Figures 4.2.4.6A and 4.2.4.6B. If loss of support or transverse slope movements occur over a length less than or equal to the safe free span length discussed in the previous section the pipe will bridge the loss of support span as shown in Figure 4.2.4.6A. For span lengths somewhat greater than the safe free span length the pipe will deform or will buckle into the loss of support profile as shown in Figure 4.2.4.6B provided adequate overburden exists. The resulting differential movements of the pipe are restricted in the design criteria to prevent:

a) Excessive compressive strains which could cause wrinkling;

b) excessive tensile strains which could cause tensile rupture;

c) excessive soil reactions which could cause denting.

Design guidelines for safe differential design movements and design maximum movements are determined in the structural analyses for parametric variations in temperature differentials, soil bearing stiffnesses and overburden loadings.

The buried pipeline will be monitored in thawing permafrost and remedial maintenance procedures will be implemented when the allowable design settlement or movement is reached. Maintenance procedures will involve the provision of stabilized soil supports at a spacing equal to or less than the safe free span lengths discussed in Section 4.2.4.5.

4.2.4.7 Longitudinal Slope Movements

Longitudinal slope movements on ice-rich slopes paralleling the pipeline alignment could be caused by solifluction, static slumping of the thaw-bulb and static or seismic slope instability. The design configuration is illustrated in Figure 4.2.4.7. When ice rich slopes cannot be avoided by route re-alignment these movements will be limited by mitigative static and seismic slope stability designs and by erosion and drainage control to prevent:

a) Erosion and loss of overburden which could lead to overall instability in the vicinity of the overbend;

b) denting in the overbend or sagbend areas;

c) wrinkling in areas where compressive strains are developed;

d) tensile rupture in areas where tensile strains are developed.

Surveillance of slopes and remedial maintenance will be implemented where necessary.

4.2.4.8 Pipe Stiffness and Ditch Profiles

The standards require that the pipeline conform to the ditch profile without the application of external force as illustrated in Figure 4.2.4.8. On cross-country sections this requirement will normally be satisfied by using cold field bends or hot-bends so that the pipe is bent to the ditch profile.

Ditch profiles will be determined in areas where it is not possible to use field bends so that:

a) The pipe will conform to the profile without the application of external force;

b) ditch profile curvatures are less than the wrinkling curvature.

4.2.4.9 Ovalling Due to Overburden Loading

Overburden loadings and soil bearing reactions will cause the pipeline to oval or to dent as illustrated in Figure 4.2.4.9. Select bedding will be provided on all uneven ditch bottoms to avoid concentrated soil reactions and denting. In areas where the pipeline is deeply buried controlled compaction will be specified to prevent excessive ovalling or denting. At road crossings controlled compaction and burial depths will be specified to limit ovalling and circumferential stresses in the casing at cased crossings or in the carrier pipe at uncased crossings and also to prevent settlement of the road surface.

4.3 CONSTRUCTION MODES

The burial construction modes developed to mitigate design problems and assure integrity of the system are designated as follows:

Mode 1 Standard Burial Warm Pipe
Mode 2 Saddle Weighted Warm Pipe
Mode 3 Continuous Weighted Warm Pipe
Mode 4 Unweighted Burial Warm Pipe
Mode 5 Deep Burial Warm Pipe

Stability and integrity of these buried modes will be sensitive to thawing permafrost and settlements. The pipeline will only be buried in frozen soils which are stable after thawing. The thawed soil must provide sufficient resistance to restrain the pipeline and the predicted settlement must be less than the allowable design differential settlements. One of the abovegrade modes will be used where these conditions cannot be complied with. The buried pipeline in permafrost areas will be monitored at sufficient frequency and interval to identify trends to the design deformation limits for the pipeline. If deformation limits are reached in specific areas remedial maintenance procedures would be implemented to support the pipeline and stop settlements or ground movements by stabilizing the soil or providing special supports.

An overfill will be provided over the buried pipeline to compensate for overburden depth that may be lost by consolidation and slumping of the backfill and surrounding permafrost. This overfill will be regularly maintained to assure minimum burial depths and soil restraint during operation of the system.

The abovegrade construction modes will largely eliminate thermal degradation, settlements and stability problems provided adequate site specific erosion and drainage control measures are implemented to prevent thermal erosion, ponding or washouts. These control measures are discussed in Chapter 5. The abovegrade construction modes are designated as:

Mode 6 Insulated Embankment
Mode 7 Concrete Restrained

Surveillance and maintenance of erosion and control measures for abovegrade modes will be required during operation to preserve the thermal regime and prevent settlements or loss of support.

Transitions from buried modes to abovegrade modes are designated as:

Mode 8 Burial to Embankment or Concrete Restrained Transition

Special site specific design such as road crossings and river crossings are designated as:

Mode 9 Special Designs

A description of each construction mode follows.

4.3.1 Mode 1 - Standard Burial Warm Pipe

This mode will be used in dry, well drained, stable soils with the water table below the pipe as illustrated in Figure 4.3.1. Pipe settlement will be estimated and it must be less than the acceptable criteria. The minimum depth of cover, D_1, will be determined based on the required uplift resistance to stabilize the pipeline and the density and strength of the backfill. The quality of the native material will be determined during the detailed design and it will be deemed either as acceptable or select material will be specified. The minimum depth of cover will be specified accordingly and indicated on the design alignment sheets. A compensating initial overfill will be provided in order to prevent formation of a depression over the pipe should some settlement occur. Filter cloths may be provided as required to help maintain select material around the pipe.

At field bends additional overburden, deeper burial and/or bearing pads will be provided as required to restrain the pipeline.

4.3.2 Mode 2 - Saddle Weighted Warm Pipe

Concrete saddle weights will be used in some areas to provide negative buoyancy to the pipeline in areas where the water table may rise above the pipe. The mode is illustrated in Figure 4.3.2. In these areas the pipeline will be buried in stable soil with an estimated settlement potential less than the maximum allowable. The required uplift resistance and soil restraint will be provided to restrain straight segments and field bends by providing adequate depth of burial and/or bearing pads. The overfill will be provided and maintained to compensate for slumping and consolidation. Filter cloths will be provided as required to help maintain select material around the pipe.

4.3.3 Mode 3 - Continuous Weighted Warm Pipe

Pipe weighted with a continuous concrete coating or with precast bolt on weights is illustrated in Figure 4.3.3 and will be used at river crossings, some stream crossings and perhaps some muskeg areas. The pipeline will be buried in stable soils with an estimated settlement potential less than the allowable as described for Modes 1 and 2.

4.3.4 Mode 4 - Unweighted Burial Warm Pipe

This mode is illustrated in Figure 4.3.4 and will be specified in initially frozen areas where stable soil is accessible at pipe depth but a significant surface layer of ice-rich material suggests that the water table could be at the ground surface after thawing. The extra depth of cover over Mode 1 reflects the reduced buoyant weight of the backfill material. The minimum depth of burial specified will provide adequate uplift resistance to restrain the pipeline and to provide buoyancy control without the need for concrete weights. Other soil restraint specifications will be the same as described for Mode 2.

4.3.5 Mode 5 - Deep Burial Warm Pipe

This mode is illustrated in Figure 4.3.5 and will be used in areas where stable soils are accessible at greater depths than those for the previous four modes. This mode is actually the limiting case of Mode 4 with the maximum depth of burial limited by construction equipment capabilities as discussed in Chapter 5.

In areas where stable soils are not accessible and estimated settlements could be greater than the maximum allowable one of the aboveground construction modes will be used. Mode assignments will also be based on mimimum costs if a number of alternatives are suitable for specific areas.

4.3.6 Mode 6 - Insulated Embankment Warm Flow

The embankment designs on flat terrain and cut-fill situations are illustrated in Figures 4.3.6 A and 4.3.6 B. Side-cut and overlay configurations on slopes are not illustrated but special drainage control will be provided for these geometrical configurations. The embankment design will eliminate or limit thaw penetration and consequent settlements provided adequate drainage is provided. Choice between the embankment and the concrete restrained mode, and other suitable alternatives, will be made on the basis of minimum costs, and other site specific constraints.

The embankment mode will be located on the upslope side of cut-fill configurations where possible to help minimize drainage and thermal erosion problems. When this is not possible for construction reasons special cross drainage facilities will be designed.

4.3.7 Mode 7 - Concrete Restrained Warm Flow

The concrete restrained mode is illustrated in Figures 4.3.7 A and 4.3.7 B for flat terrain and cut-fill sections respectively. Side-cut and overlay configurations on slopes are not illustrated but will require special drainage control to prevent thermal erosion and permafrost regression. The concrete restrained mode will eliminate or limit thawing and settlements provided, ponding and thermal erosion are prevented. Limited thaw penetration may occur in the vicinity of the edges of the bearing pad and settlements of the edges of the pads and preservation of drainage will be achieved by surveillance and maintenance.

The mode consists of keyed linked concrete weights with the required weight to stabilize and restrain the line. Bearing ramps will be provided at sidebends where necessary to restrain sideway movements. Wildlife crossings will be provided where required for wildlife migration routes. In areas where continuous wildlife crossings are required the embankment mode (4.3.6) or a modified form of concrete restrained mode would be used or a special deep burial design may be developed. Trail and minor road crossings will also be provided where necessary.

The concrete restrained mode will be located on the upslope side of cut-fill configurations where possible as discussed for the embankment mode.

4.3.8 Mode 8 - Burial to Embankment or Concrete Restrained Transitions

The transition mode is illustrated in Figure 4.3.8. The lengths of the transitions will depend on the bend angles specified for a particular area. The depth of burial required to restrain the overbend region will depend on the temperature differential, pipe size and bend angle and will increase for increasing bend angles.

4.3.9 Special Designs

Due to the site specific nature of this mode, these designs are not illustrated. They include road crossings, river crossings, and liquefaction on flat terrain. Designs for seismic liquefaction in unfrozen ground in flat terrain will be done on site specific basis and could include the embankment modes, burial with a large overburden load, special supports or route selection.

4.3.10 Remedial Maintenance

In areas where thaw settlements or slope movements occur and monitoring indicates that the deformation design limits for the pipeline are being approached remedial maintenance will be implemented to stop further settlements. One alternative being studied and illustrated in Figure 4.3.9 will be to thaw out the permafrost intermittently with steam injection to the maximum estimated thaw depth and to stabilize the sub-soil with high pressure low slump grout injection. These soil stabilized areas would be spaced at the maximum free span length discussed in Section 4.2.4.5. Alternatively other types of supports spaced at the same maximum free span lengths may be considered if necessary.

5.0 RIGHT-OF-WAY STABILITY AND CONSTRUCTION ZONE DESIGN

5.1 INTRODUCTION

The construction methods addressed in this chapter include construction scheduling, right-of-way preparation (clearing, grading, etc.), temporary and permanent workpad design, trenching, disposal of spoil, right-of-way restoration, and permanent access roads. The project objective is to construct the pipeline in as economical and efficient a manner as possible while mitigating both temporary and permanent environmental impacts and maintaining the long term integrity of the pipeline.

The design basis outlined here will provide that the effects of the construction procedures used will not cause locally unacceptable conditions and that the construction procedures will conform to the environmental terms and conditions. These construction procedures will minimize terrain disturbance and will provide a stable right-of-way during the construction period. After construction activities have ceased the disturbed areas will be permanently restored to a finished cross section suitable for the application of permanent erosion control, restoration of natural drainage and revegetation.

The design basis for the design of drainage and erosion control measures for warm flow are outlined.

Should further analysis indicate special concerns that are not addressed as part of the scope of this report, engineering designs will be established as required to ensure an acceptable design of each drainage and erosion control facility.

The site specific detailed design will include the detailed drawings and specifications for construction using the design basis presented in this section as a guideline for design.

Construction of the pipeline will result in some changes to the natural state of slopes intersected by the pipeline right-of-way. These changes include geometrical (resulting from cuts and fills on sideslopes), thermal (due to deeper thaw penetration), or environmental (such as changes in drainage and groundwater regimes).

Slope stability studies will be undertaken to ensure that the pipeline system, the right-of-way, and all other activities associated with the construction and operation of the pipeline will not be subjected to detrimental slope movements nor cause movements that will have adverse effects on the environment. In order to meet these objectives the design process includes a compilation of the slope catalogue along the route, a classification of the slopes that will be affected by the pipeline alignment, a development of design criteria and the relevant input parameters to the analytical studies, the results of analytical analyses, and a development of mitigative measures that may be employed to enhance the stability of slopes. In addition, seismic slope stability and liquefaction studies will be performed for each significant slope along the route. State-of-the-art analytical procedures will be used to assess these slopes and mitigative measures will be recommended for slopes that do not meet the required safety criteria.

5.2 BASIS OF CONSTRUCTION ZONE DESIGN GUIDELINES

5.2.1 Scheduling

The scheduling of the pipeline construction will be dictated by economic considerations, construction requirements, and environmental constraints. Economic requirements are beyond the scope of this report. It is considered generally preferable that construction of buried pipelines in permafrost be done during the winter season. This is due to a number of reasons including the constructibility of access roads and workpads, stability of the trench walls, stability of the spoil material, and minimizing the disturbance to the surface soil layers. Construction of abovegrade modes could be done in the summer provided a construction pad is constructed. Environmental constraints to scheduling may include the imposition of "timing windows" so construction will not interfere with critical habitat utilization by important fish and wildlife species.

5.2.2 Right-of-Way Preparation

Right-of-way preparation includes clearing, grubbing, stripping, and grading of the right-of-way in order to create a surface suitable for construction of the pipeline.

The areas to be cleared will be the minimum required for efficient construction operations. All clearing will be in accordance with the objectives of the Environmental Terms and Conditions and its associated Guidelines. Hand clearing methods will be used in sensitive terrain and in conjunction with co-ordinated timing prior to construction at designated river and stream banks and valley walls. Hand clearing may also be required at the top of some cuts in areas of significant cross slopes.

Grubbing will be required along the trench line whenever the pipe will be in a buried mode. It may also be performed in areas under the trench spoil pile where no grading will be done (i.e., areas of minimal cross slope). Grubbing will be done in association with grading in areas of significant cutting of all mode designs. Grubbing will not be performed beneath ice aggregate roads, temporary gravel workpads and travel lanes or permanent insulated workpads.

Rough grading of the hummocky terrain in areas of low cross slopes will be performed. The graded material will be wasted off the right-of-way or used in right-of-way reclamation and thermal barriers at the toes of the workpad. The graded material will not be used to fill in hollows of the hummocky terrain.

Conventional cut-fill grading techniques will be used in seasonally frozen areas and thaw stable permafrost. Some stripping of surficial organic layers may be necessary in order that the fill sections be constructed of stable materials and founded on sufficiently competent soil.

Greater quantities of right-of-way grading will be required in areas where there is a significant cross slope and also in areas of significant slopes parallel to the right-of-way. Right-of-way protection may be required in all areas where unstable soils are exposed. All permanent fills will be constructed of thaw stable soils that can be compacted to a reasonable density under winter conditions.

Design configurations in sideslope areas will be such that the amounts of cut and fill are minimized while maintaining a stable right-of-way and pipe environment and adequate construction work space. Cut slopes will be designed such that thawing does not lead to instability resulting in detrimental effects to the right-of-way, the pipe, and the environment.

5.2.3 Workpad Design

Workpad design and construction will be in accordance with the proposed usage, the environmental terms and conditions, the availability of material, the nature of the terrain, and the degree of permanence of the pad.

Permanent workpads will be constructed in all areas where aboveground pipe modes are called for. These pads will be insulated for the warm flow sections of the pipe. These pads will be designed primarily on geothermal design considerations in order to minimize thaw under the pads and hence the associated settlement. Permanent drainage facilities requiring a minimum of maintenance will be constructed where necessary. Temporary workpads will be constructed from either gravel or ice and snow. Depending on the degree of permanence required, the gravel pads may be supplemented by insulation or filter cloths. Temporary workpads and travel lanes in areas of relatively stable terrain for one winter season need have only enough gravel to assure trafficability, create a level surface, and prevent exposure of a significant number of terrain high spots. Following abandonment of these pads, the gravel will be contoured to restore natural drainage and eliminate any ponding situations that may arise. In areas where workpads and travel lanes are to be constructed on disturbed thaw unstable terrain (as in a graded cut), a greater thickness of the workpad gravel may be required for post construction right-of-way protection from thaw degradation.

Snow and ice roads can be constructed in areas where these materials are readily available. Care will be taken that both the mining and placement of these materials will not have adverse effects on surficial soil layers. These pads will not be used after thawing becomes advanced in the spring. Testing on the construction and performance of ice roads under Yukon conditions was performed in the winter of 1981 at the Quill Creek Test Site.

While it is generally preferred that the workpad be constructed when the ground is frozen, construction scheduling and efficiency concerns may result in some summer construction. A number of summer construction alternatives are presently being considered including gravel pads of varying thickness, insulated gravel pads, and pads on filter cloth. The selection of the appropriate mode will depend on the thickness of the active layer, the strength of the upper thawed layer, the amount of traffic expected on the pad, and the degree of performance required. Test sections of potential summer workpad designs have been constructed at the Quill Creek Test Site. The performance of various design alternatives is presently being observed and evaluated.

5.2.4 Trenching Constraints

The maximum depth and dimensions of the pipeline trench are constrained by the equipment used. The maximum depth obtainable using presently existing wheeled ditchers is about 2.5 m. While the maximum depth that a conventional backhoe (e.g. Cat 245) can excavate is in the order of 10 m, the manufacturers recommend that a shorter stick be used when excavating permafrost which effectively limits the excavation depth to 6 m. In unfrozen areas, excavation to depths of up to 10 m is possible but progress is very slow. The wheeled ditcher generally excavates a cleaner trench than the backhoe particularly if blasting is used in conjunction with the latter. More bedding, padding, and select backfill material will be required if the excavation method is blasting and backhoe instead of using a wheeled ditcher.

The performance of the ditching alternatives was observed at the Quill Creek Test Site in February 1981. Preliminary observations of excavation rates in permafrost include:

Wheeled Ditcher:	Peat - 2.1 m deep trench - 240 m/10 h shift
	Gravel - 2.5 deep trench - 110 m/10 h shift (33 m/3 h)
Backhoe Excavation:	Peat + Gravel - 2.4 m deep trench - 22 m/10 h shift
Blasting + Backhoe Excavation:	Peat + Gravel - 5.2 m deep trench - 45 m/10 h shift

While these rates are indicative of the excavation rates for the different alternatives, they are dependent on terrain conditions, weather, machinery, downtime and many other factors. A complete report on the trenching excavation tests is presently being prepared by consultants to Foothills.

5.2.5 Disposition of Spoil

There will be four classes of spoil material generated in the construction of the pipeline. These include:

a) Trees, brush and other wood material;
b) Stripped organic material;
c) Trench spoil;
d) Right-of-way grading spoil.

Disposal of trees, brush, and other wood material will be in accordance with good pipeline practice and the applicable regulatory ordinances. Disposal methods will include burning of the material (on rocks or sleds in permafrost terrain), chipping or mulching. Disposal operations will be conducted in a manner such that debris will not enter a watercourse. Wood chips and mulch may be spread evenly over the right-of-way where their insulating properties can be used to impede or reduce thaw degradation.

Stripped organic material will be spread over the right-of-way and used as insulating barriers at the sides of the workpad and over the granular trench backfill.

The texture of the trench spoil materials will depend upon the excavation method. The wheeled ditcher spoil will be primarily broken down into small particle sizes while blasting and backhoe excavation may result in very large blocks of spoil material. The majority of the wheeled ditcher spoil will be placed back in the trench and excess used as a berm over the trench. Large blocks of material obtained from backhoe and/or blasting excavation techniques may not be used as trench backfill, will be either broken down or removed to designated spoil disposal areas.

In areas where significant right-of-way grading is required (e.g. cross slopes), large amounts of spoil from cuts may be generated. While some of this material may be suitable for fill construction, it is anticipated that in many areas it will not. If the cut material is ice-rich or fine grained, it must be wasted in designated spoil areas. Trenching spoil may also be wasted in a similar manner if it is considered to have a detrimental impact on the right-of-way protection.

5.2.6 Right-of-Way Restoration

Erosion control measures will be implemented as quickly as possible after disturbance of permafrost areas so as to forestall thermal degradation, slope failure, and ground subsidence. All temporary workpads and access roads will be regraded in order to encourage the re-establishment of natural drainage systems and temporary drainage measures such as culverts will be removed wherever possible. Regrading and the spreading of spoil and organic material on the right-of-way will be done in a manner to satisfy revegetation requirements.

5.2.7 Access Roads

Permanent access roads will be necessary to compressor stations, intermediate blockvalves, and perhaps to some areas of the right-of-way. Access roads will be designed based on local soil conditions, trafficability objectives, the availability of suitable construction materials, and the time of construction. The road designs will be consistent with good engineering practice and current practices being adopted in Yukon to adapt to local conditions. The access roads will be constructed of granular materials. The thickness of the gravel will vary with the shear strength of the soil, the design wheel loading and road usage, and whether measures such as riprapping (with wood), filter cloth, or insulation board are employed.

5.3 DESCRIPTION OF CONSTRUCTION ZONE DESIGN MEASURES

5.3.1 Right-of-Way Preparation

Clearing and rough leveling of the right-of-way will be as described in the Design Basis portion of this section. Trees will be either burned, mulched, or used as corduroy material beneath workpads and access roads. The feasibility of the latter alternative is presently being evaluated and a test section of this type of construction is being monitored at the Quill Creek Test Site. Other right-of-way preparation and reclamation techniques are also presently being observed and monitored at Quill Creek.

Rough grading of hummocks and stripping of organic surface layers in thaw unstable terrain under temporary workpads or access roads may be done in areas where its effect on the thermal regime will be minimal. It may also be performed in areas where the upper (active layer) zone of soil is considered very compressible. The disturbance to the thermal regime will be minimal provided that:

a) The thickness of the organic soil is at least two times the active layer depth;

b) the excavation is done by blading and not by ripping;

c) the soil (peat) under the stripped surface is not allowed to melt before placement of gravel workpad or access road.

Right-of-way preparation in areas of level terrain will be minimized. Travel on the right-of-way will be restricted to the workpads and access roads or to designated areas that will be restored after construction.

Cut slopes will be designed such that thawing does not lead to slope instability. Slopes may be cut vertically and allowed to self-heal or they may be cut at a design slope and in some areas protected with gravel blankets, gravel buttresses or peat blankets. These techniques are presently being observed at the Quill Creek Test Site. All major slope cuts (greater than 5 m in height) will be designed on a site specific basis. Cut slopes in granular thaw stable soils will be cut back to a stable angle during grading.

5.3.2 Workpad Design

The design of the workpad will be a function of the trafficability objectives, the degree of permanence required, geotechnical conditions, environmental conditions, drainage conditions, the availability of pad construction material and the season of the construction.

5.3.2.1 Trafficability Objectives/Degree of Permanence

For aboveground modes, the workpad will be designed on the basis of pipeline integrity. The pad dimensions will reflect the results of geothermal modelling and mechanical constraints such as minimum cover over the board insulation. The basic design constraint is that an unacceptable amount of thaw will not occur under the workpad leading to the pipeline settlement.

Summertime construction will require the use of an end dumped pioneer fill over the cleared undisturbed right-of-way. This fill will be sufficiently thick to carry heavy construction equipment and also to allow for any displacement of the embankment materials down into the active layer soils. The use of filter cloth or log riprapping may be beneficial in satisfying the latter requirement. Stripping of the organic layer (when feasible) may be another alternative to inhibit the downward migration of the granular fill particles.

Insulated workpads may also be required in areas where high trafficability standards are required. These pads will be less affected by seasonal freeze thaw cycles and hence will be less prone to deterioration with time. These pads would be recommended in poor soils areas where extended usage through a number of thaw seasons is required and where the costs of a thicker granular pad are outweighed by a thinner insulated gravel pad.

Workpads and travel lanes constructed for use in below grade modes during one winter season only will be constructed to much less stringent requirements. In thaw stable areas, these pads can be just the graded and grubbed right-of-way with minimal surface preparation. In areas where the surficial soils are thaw unstable, workpads constructed of ice aggregate or uninsulated gravel will be considered in order to protect the right-of-way during subsequent thaw seasons. Travel lanes will be constructed to similar standards for both above and below grade modes.

Thicker workpads and travel lanes may be necessary in summer construction areas where soil conditions are poor. These pads may be supplemented with filter cloth and other reinforcement techniques.

5.3.2.2 Geotechnical Conditions

The geotechnical conditions are particularly important in the assessment of workpad performance during thaw seasons and in the assessment of the long term performance of the right-of-way and its interaction on the pipeline.

The important parameters to be considered are the thawed shear strength of the soil and its thaw settlement characteristics. The latter will be evaluated in conjunction with a geothermal assessment of thaw depth under the gravel pad. A series of thermistor observations are currently being recorded at the Quill Creek Test Site in order to aid in the geothermal modelling of thaw profiles beneath various workpad configurations.

The soil strength will be assessed on the moisture content/gradation/density characteristics of the soil type as extrapolated for the terrain unit.

The use of log riprapping (or corduroy) and filter cloth beneath the workpad embankment will be considered in some summer construction areas. The application of filter cloth to a thawed surface (or one that potentially may thaw) will reduce the gravel requirements by up to one third.

5.3.2.3 Environmental Considerations

Erosion and drainage design measures for environmental concerns along the right-of-way and the workpads are addressed in the Drainage and Erosion Control segment of this report.

5.3.2.4 Availability of Material

Select granular materials will be used for both workpad construction and pipe backfill. This material will be obtained from designated borrow pits. Crushing and/or screening operations may be necessary at some pits in order to process material suitable for pipe bedding and the workpad surface course.

The borrow material for the workpads will be coarse grained well graded material with specified limits of fines. Finer materials will be used for pipe bedding and padding. In areas of winter construction, the material used must be low in ice/moisture content and capable of being properly placed and compacted.

The location and operation of borrow pits will be consistant with applicable regulatory ordinances. When it is necessary to utilize borrow sources located within a flood plain, dykes and other works will be used to ensure that the natural stream or river course is maintained.

5.3.3 Permanent Access Roads

Permanent access roads will be designed with reference to the relevant sections of ENVIRONMENTAL DESIGN FOR NORTHERN ROAD DEVELOPMENTS (Environment Canada Report EP S 8-EC-76-3). Whenever practicable an undisturbed buffer zone at least 100 m wide will be maintained between the pipeline right-of-way and roads and water bodies.

Permanent access road design will be similar to that described for workpads. These roads will by definition be constructed to last through continuous freeze-thaw cycles and hence the thawed properties of the subgrade soils will be a major factor in the roadway design. The assessment of the subgrade soils will be as described in the workpad design section. The use of filter cloth, insulation, or rip-rapping (corduroy) will be evaluated especially in areas of particulary weak subgrade soils or where good quality granular material is expensive or difficult to obtain. Drainage design measures will be as described in the Drainage and Erosion Control portion of this report.

5.3.4 Right-of-Way Restoration

Thawing of initially frozen ground could cause quite substantial settlement of the right-of-way for an eventual distance of about 20 m or more on either side of the pipe. Access may be necessary in some areas to maintain the right- of-way as it thaws and settles. An initial overfill is provided on the buried construction modes to allow for settlements and sideway consolidation of the ditch wall and to maintain minimum depths of overburden.

Erosion control procedures for the right-of-way are described in the Drainage and Erosion Control section of this report.

5.4 BASIS OF DESIGN OF DRAINAGE AND EROSION CONTROL DESIGN

In D & E control design, environmental concerns have been considered to be an integral part of the design and as such they have been incorporated into the design criteria in the appropriate subject areas. Right-of-way vegetation and temporary control measures are not considered within the scope of this section.

In the following sections the rationale and design criteria for specific D & E control measures are explained. In Section 5.5, natural and engineering parameters, which must be considered in the assignment of D & E control measures, are identified and their significance discussed. In Section 5.6, conditions requiring D & E control are identified and related control measures are presented. In Appendix "B", design criteria for the proposed D & E control measures are presented.

The design criteria of the D & E control measures are developed to maintain the integrity of the pipeline, and to minimize terrain disturbance and adverse environmental impacts in compliance with various governmental regulations. However, some maintenance of D & E control measures will be required, especially during the early years of operation.

5.5 DESIGN PARAMETERS

Parameters which must be considered in the assignment of D & E control measures are included in this section. They are grouped into natural parameters and engineering parameters.

5.5.1 Natural Parameters

Natural parameters are those characteristics along the route which are defined by existing (preconstruction) conditions. Significant natural parameters are hydrological, geotechnical topographical and environmental. The D & E control design is intended to re-establish natural drainage patterns which may be altered during construction of the pipeline.

5.5.1.1 Hydrological

D & E control facilities must accommodate the intensity and volume of design flows which are encountered at the pipeline right-of-way. Flows are identified as; active layer (groundwater flow), non- concentrated (overland flow), and concentrated flow (either with or without a defined channel). Aufeis, a condition of surface ice buildup, can be of significance to design in areas of abovegrade construction.

Hydrological parameters are assessed by the Hydraulic Consultants on the basis of regional frequency analysis and by the "rational" and related methods (Northwest Hydraulic Consultants Ltd. (NHCL), August 1978; Inland Waters Directorate (IWD), December 1978). Design flow values having a return period in the order of 100 years are generated. Aufeis conditions are predicted on the basis of field survey information and by conditions along the Alaska Highway. Hydrological parameters used in the design for abovegrade mode are a kilometre-by-kilometre account of the nature, orientation, and intensity of design peak flows, plus comments pertaining to any special features.

5.5.1.2 Geotechnical

Geotechnical parameters of significance to the design of D & E control facilities are the type and the erodibility of soils and slope stability.

Geotechnical parameters are assessed by the Geotechnical Consultants on the basis of available terrain mapping and borehole data. The analysis of terrain erodibility is made in conjunction with the sensitivity classification of the Geological Survey of Canada (GSC).

The primary geotechnical parameter affecting D & E control design is the terrain erodibility index (TEI, scale 2 to 10). The TEI is compiled as the summation of a Soil Erodibility Index (scale 1 to 3) a Topographic Index (scale 1 to 3) and a Thermal Erosion Index (scale 0 to 4) all determined for bare soils.

5.5.1.3 Topographical

Topographical parameters of significance to the design of D & E control facilities are the slopes, both parallel and perpendicular to the right-of-way, and the definition (shape, size, slope orientation, elevation) of gullies and streams along the pipeline right-of-way. The topographical data source for the design is 1:10 000 scale photogrametrical mapping with spot elevation and 3 metre contour intervals and field topographical survey notes. Drainage facilities are located and sized in accordance with topographical information giving due consideration to the hydrological and geotechnical parameters previously discussed. Field inspection is required for confirmation of these parameters for areas of abovegrade construction where culverts are to be installed. The exact placement, location, elevation and grade of culverts will be determined prior to construction after the right-of-way is cleared.

5.5.1.4 Environmental

An important environmental consideration at stream crossings, where D & E control facilites are planned, is the presence or absence of certain fish and the site specific activities of fish, if present.

With respect to right-of-way revegetation the D & E control design assumes that revegetation is a longterm enhancement measure and therefore will not be considered in D & E control design. Detail of revegetation measures are outlined in a document entitled "Revegetation Plan" (Foothills, 1981).

5.5.2 Engineering Parameters

The engineering parameters considered in the D & E control design are the pipeline route, construction mode, right-of-way preparation and borrow/spoil material.

5.5.2.1 Pipeline Route

The pipeline route selection is not within the scope of this report. However, the route has been selected considering D & E control.

A pipeline right-of-way 40 metres (m) wide is located within a 240 m wide first right-of-way and depending on the direction of construction the pipeline is located 26 m from the north or the south boundary of the 40 m right-of-way. The limits of any terrain disturbance should be confined to the 40 m right-of-way. The work area will be either north or south of the pipeline, depending on the direction of construction. The direction of construction should be such that the work area is most often on the downslope side of the pipeline.

Locations of features and facilities along the route are identified by kilometre post (KP) established during the survey of the reference line.

5.5.2.2 Construction Modes

Allocations of construction modes are made primarily on the basis of structural geotechnical and geothermal considerations. The selection of the construction mode is not within the scope of this report, however, the D & E control concerns are considered in the construction mode selection. For the purposes of D & E control design, the construction modes are grouped into two main categories, buried mode and abovegrade restrained mode.

Except for the minor effects of grading, the buried mode (as used in conventional pipeline construction) has little impact on natural drainage patterns. Streams are essentially restored to their natural conditions, and active layer or groundwater flow is preserved. In overland sections of the route where no flow concentrations exist, mound breaks are provided to allow the discharge of flow intercepted by the backfill mound. Should a section of the backfill mound wash out, the consequences are not expected to be severe. Two buried mode conditions of potential consequence and hence of concern to the D & E control design are:

a) Surface flows parallel to the pipeline which could cause erosion of the disturbed right-of-way;

b) groundwater flow within the pipeline trench which could induce channelization of the trench and settlement.

Solutions proposed for these conditions are respectively:

a) Surface protection with coarse material fill where on-site materials are expected to erode;

b) pipeline trench plugs.

The abovegrade restrained mode is similar to a highway, and D & E control problems are treated in a manner compatible with accepted practices. This mode affects drainage patterns by restricting cross drainage to installed facilities. D & E control design for this mode will ensure:

a) That water is able to cross the pipeline right-of-way;

b) that parallel and cross drainage facilities are not subject to erosion.

An embankment opening is proposed as a special abovegrade measure where large peak flows are expected, and where predicted aufeis conditions could possibly obstruct culvert facilities.

The abovegrade restrained "cut-fill" mode would be used only for sections where the negative slope perpendicular to the route is greater than 15%, with a vertical cut depth of at least 2 m, and no major concentrations of flow exist. In this mode, overland and active layer flow could pass freely over the pipeline and workpad.

5.5.2.3 Right-of-way Preparation

Grading of the natural topography will be confined primarily within the right-of-way. Parallel grading will minimize curvature of the pipeline and perpendicular grading will provide a relatively level working surface. Grading includes cut, cut-fill and fill configurations.

In cut configurations, all surface flow intercepted by the right-of-way will be channelized and will flow parallel to the pipeline until cross drainage is possible. This condition is potentially severe for D & E control design because:

a) Some flow occurs on exposed bare soils which are susceptible to erosion;

b) the cut section intercepts flow which would not normally flow in the direction of the pipeline, thereby creating a higher discharge than would be experienced under natural conditions;

c) cut situations frequently occur at steep slopes, creating a potential watercourse along the cut.

Appropriate measures to control this condition are outlined in Section 5.6.2.

In cut-fill configurations, steep cut slopes with exposed native material may experience some erosion due to overland and seepage flow. Flows will be contained upslope of the pipeline until being directed to and drained off by some cross drainage facility. Should the longitudinal slope be greater than the cross slope of the right-of-way, flow may remain within the right-of-way rather than drain off towards undisturbed terrain. Appropriate measures to control this condition are outlined in Section 5.6.3.

In fill configurations, flow could be intercepted by the fill material and could flow beside the workpad over undisturbed terrain until reaching a culvert. Culverts should be located in natural depressions or other appropriate locations.

5.5.2.4 Spoil and Borrow Material

Unsuitable spoil material consists of that material excavated which is unsuitable for use as backfill or other application.

D & E control design recommends that unsuitable spoil material be disposed off the right-of-way.

Borrow materials are selected to meet construction standards. Since pit-run borrow materials will frequently be used for construction, the criteria for D & E controls will be to maximize the use of this borrow material, and minimize the need for processed borrow material.

5.5.3 Regulations

The design and construction of the pipeline right-of-way drainage and erosion control facilities will be in compliance with the National Energy Board Act, Gas Pipeline Regulations, the Northern Pipeline Act, the Engineering Orders and The Socio-economic and Environmental Terms and Conditions (Northern Pipeline Agency; revised draft October, 1980) and related guidelines issued by the Northern Pipeline Agency.

5.6 DRAINAGE AND EROSION CONDITIONS AND RELATED CONTROL MEASURES

This section outlines conditions requiring drainage and erosion control, and introduces the remedial measures which are proposed for them.

5.6.1 Interception of Active Layer and Non-Concentrated Overland Flow

Active layer and non-concentrated overland flow is defined for situations wherever there is an absence of creeks, gullies, or shallow swales having some definable contributing drainage basin. Overland flow can be expected during the spring time snowmelt period, while the ground is frozen. During summer periods, most rainfall runoff will flow in the subsurface active layer.

In below grade mode, the overland flow will be intercepted by the backfill mound and will be drained longitudinally to the nearest backfill mound break. In this mode, the active layer flow may be intercepted by the backfill material in the trench, depending on the relative permeabilities of the native and the backfill materials. On steep longitudinal slopes, trench plugs may be installed to control flow within the trench.

In the abovegrade mode the overland flow will be intercepted by the workpad and will be drained longitudinally to the nearest cross drainage facility. In this mode, the active layer under the workpad will be frozen, therefore ground water flow will be forced to the surface upstream of the workpad and will be drained as surface drainage.

5.6.2 Longitudinal Drainage of Intercepted Flow

Water intercepted by the pipeline right-of-way will flow along the pipeline right-of-way until a cross drainage facility is reached. Surface water will flow as contained surface drainage. Where the line is buried, longitudinal subsurface drainage may also occur within the pipeline trench and will be controlled by trench plugs. When encountering a shallow depression, where neither longitudinal nor cross drainage is provided, water may pond until it evaporates, drains by subsurface flow or is provided drainage through maintenance activities.

Cut slopes are a concern to the D & E control design in permafrost areas. These cut slopes will generally be cut vertically during construction, and will slump during the following seasons as shown in Figure 5.6.2. Slumping slopes may only be a problem if the slump material were to enter longitudinal drainage courses, blocking the drainage course or resulting in siltation of natural drainage courses.

Potential problems from cut slopes will be avoided by specifying a maximum allowable vertical cut. Five metres is the anticipated maximum vertical cut in consideration of D & E control on the basis of right-of-way geometry and anticipated repose angles for slumped material.

5.6.2.1 Surface Drainage

In the buried mode, erosion will be controlled by frequent mound breaks and related diversion dikes to divert flow off the right-of-way as shown on the drawing 2-00-02-00-TP-0050.

For cases other than total right-of-way cut, the diversion dikes are extended into undisturbed terrain to ensure that bare soils are not subjected to erosion.

In the abovegrade restrained mode, potential longitudinal erosion will be controlled by ditch checks (see drawing 2-00-02-00-TP-0053) or coarse material protection.

5.6.2.2 Subsurface Drainage

Longitudinal subsurface drainage is applicable only to the buried mode of construction and potential problems can be controlled by proper design and construction of trench plugs, as shown on the drawing 2-00-02-00-TP-0051. Subsurface drainage through the pipeline trench will occur when the trench backfill material permeability and longitudinal slope provide a drainage path superior to natural conditions.

Potential problems associated with this flow through the trench include:

a) Stability failure of material within the trench due to saturation;

b) washout of pipe bedding material;

c) initiation of concentrated flow, whereby water channelizes within the pipeline trench;

d) warming the flowing groundwater thus transporting unwanted thermal effects beyond that region normally affected by the heat of the buried pipe.

To mitigate these problems, trench plugs should be considered:

a) At cross drainages occurring where the longitudinal pipeline slope is greater than 10%;

b) at the approaches to a river when significant groundwater flow is expected in the trench.

Trench plugs are designed to help water to flow towards the surface where it can be diverted off the right-of-way by diversion dikes.

5.6.3 Cross Drainage of Intercepted Flow

Cross drainage refers to water passage across the pipeline right-of-way. Cross drainage facilities for intercepted flow impose a localized concentration of flow downstream of the right-of-way greater than that which would occur naturally. Facilities are designed and spaced such that no adverse effects on native terrain are induced. D & E control design applied to this condition is relative to construction mode:

a) Buried mode;
b) abovegrade restrained mode;
c) abovegrade restrained "cut-fill" mode.

5.6.3.1 Buried Mode

In the buried mode of construction, cross drainage of intercepted flow will be provided by mound breaks, which are simply gaps in the backfill mound. Exposed surface materials at mound breaks should be sufficiently coarse to withstand anticipated flow velocities. Mound breaks occur at natural depressions and are spaced relative to longitudinal slope along the right-of-way. Diversion dikes should be provided where specified to divert flow onto undisturbed terrain. Trench plugs cannot function properly unless constructed with mound breaks and diversion dikes, thus providing the surface drainage necessary to prevent groundwater from re-entering the pipeline trench.

Mound breaks, related diversion dike and trench plug location are shown on the drawing 2-00-02-00-TP-0050.

5.6.3.2 Abovegrade Restrained Mode

In the abovegrade restrained mode of construction, cross drainage of intercepted flow will be provided by culverts. Culverts will normally be located in natural depressions approximately on natural grade. For ease of maintenance a minimum 600 mm culvert size will be used. Special inlet treatment should not be required, but outlet treatment may be required to dissipate erosive energy downstream of the culvert.

The drawing 2-00-02-00-TP-0054 shows a typical transition from longitudinal flow passage in a ditch section to a culvert facility and the typical culvert installation details.

5.6.3.3 Abovegrade Restrained "Cut-Fill" Mode

In the abovegrade restrained "cut-fill" mode of construction, there should be limited intercepted flow. Non-concentrated flow will be dispersed by grading of the workpad surface to slope perpendicular to the right-of-way to provide cross drainage.

Figure 5.6.3.3A shows the abovegrade restrained "cut-fill" mode transition to the abovegrade restrained mode and Figure 5.6.3.3B shows typical cross sections of the abovegrade restrained "cut-fill" mode.

5.6.4 Cross Drainage of Concentrated Flow

Concentrated flow conditions are encountered when the pipeline right-of-way crosses rivers, creeks and intermittent waterways. Most large rivers, and creeks are treated as special design crossings. Special D & E control conditions are addressed on a site specific basis.

5.6.4.1 Buried Mode

In the buried mode of construction, cross drainage of concentrated flows will be accommodated by restoration of drainage channels and, where appropriate, floodplains, or waterways, to their preconstruction geometry. These restorations will include, as appropriate:

a) Restoration of intermittent drainage courses (swale, gully) to their approximate natural geometry and slope;

b) restoration of the waterway channels to their approximate natural geometry based on top width and maximum depth;

c) provision of constant channel bed slope to match the natural channel bed(s) upstream and downstream of the disturbed area;

d) provision of channel bed and bank material which is of equal or greater coarseness than the native channel material;

e) provision of coarse material fill as a surface treatment in floodplain regions where disturbed native materials may be easily eroded.

5.6.4.2 Abovegrade Restrained Mode

In the abovegrade restrained mode of construction, cross drainage of concentrated flow will be provided by culvert facilities or embankment openings. Culvert facilities as shown on the drawing 2-00-02-00-TP-54, must be designed on a site specific basis with consideration given to design flow, upstream storage capacity, channel characteristics and fish habitat.

D & E control measures which may be required with a culvert include:

a) Outlet treatment in the form of a premanufactured culvert end section or coarse material to dissipate energy at the culvert outlet;

b) inlet treatment in the form of a premanufactured culvert end section or coarse material to provide a smooth flow transition into the culvert and prevent erosion at the entrance;

c) guide banks upstream of the culvert in larger streams to ensure that flow does not impinge on the embankment away from the culvert;

d) channelization to permit flow from the culvert to join the natural stream or vice versa. Channelization, where required, should preferrably be located downstream from the culvert. Channelization would only apply where the skew angle between the creek and right-of-way is greater than 45 degrees.

For streams having a design flow greater than 4 m^3/s, or severe aufeis conditions, culvert facilites may be replaced by an embankment opening as shown on the drawing 2-00-02-00-TP-0052. The embankment opening consists of a free span segment of pipeline supported at both ends by embankment workpad "abutments". The "abutments" will be protected to a level necessary to ensure their integrity during design flood conditions. Restoration of the stream channels should be completed as per the requirements for a buried pipeline. Guide banks and channelization as above could apply to the embankment opening as well.

5.6.4.3 Abovegrade Restrained "Cut-Fill" Mode

The above grade "cut-fill" mode will not be used in areas of concentrated cross drainage.

5.6.5 Special Hydraulic Conditions

Four special hydraulic conditions are: intensive overland flow; concentrated flow parallel to the right-of-way; aufeis; and wave action. These conditions are avoided as much as possible when the route is selected and when the construction modes are assigned, therefore they should be rarely encountered along the pipeline route.

5.6.5.1 Intensive Overland Flow

Intensive overland flow becomes a problem only when associated with the aboveground restrained mode of construction. In these conditions, sufficient erosion protection of the upstream side of the workpad should be provided between cross drainage facilities.

5.6.5.2 Concentrated Flow Parallel to the Right-of-way

Concentrated flow parallel to the right-of-way could occur for a short section. This condition would create some problems independent of construction mode as design flows would be substantially greater than that for the standard longitudinal drainage facilities (section 3.2).

Proposed solutions to this condition are:

a) Enhancement of standard measures (ditches, diversion dikes) by providing surface armoring material;

b) sheltering of the right-of-way by channelization or construction of levees to keep concentrated flow away from the disturbed right-of-way surface.

5.6.5.3 Aufeis

Aufeis is a condition of surface ice buildup as groundwater flow becomes exposed to the air and freezes (Van Everdingen, 1978). Aufeis conditions present significant problems in the abovegrade restrained mode of construction when there is sufficient aufeis developed to obstruct culvert facilities to the extent that they can not pass design flows. Where these conditions occur, an embankment opening, as described in Section 5.6.4.2 is used.

5.6.5.4 Wave Action

Wave action may be encountered if the aboveground restrained mode is routed through or beside any large ponds. Proposed measures for this condition will be the provision of riprap on slopes exposed to wave action.

5.6.6 Thermal Erosion

Some thermal erosion and thermal degradation will be experienced along the right-of-way due to thawing of ice-rich material. Thermal effects may be caused by:

a) Physical exposure of ice-rich material (cut slopes);

b) loss of surface insulation due to removal of or damage to vegetation, introduction of non-vegetated fill or ponding of water;

c) heat from warm pipeline.

The D & E control measures are only one component of the design procedure for control of thermal degradation. The proposed D & E control design criteria acknowledge thermal erosion such that;

a) Material originating from thawing cut slopes should not enter drainage courses;

b) D & E control measures will minimize ponding of water which might contribute to thermal degradation.

c) D & E control measures will minimize thermal transfer associated with water movement by confining water to D & E control facilities.

5.6.7 Maintenance

Some maintenance of D & E control facilities will be required, especially during the early years of operation. In the event of failure of a D & E control facility, field judgement will be required to determine the cause of failure and assess the need for some higher level of protection.

Anticipated maintenance includes:

a) Drainage of water ponded in shallow depressions, using ditches or by backfilling the depressions;

b) removal of sediment or debris from parallel and cross drainage facilities;

c) de-icing of culverts;

d) stabilization of cut slopes;

e) repairing or upgrading culverts, diversion dikes or other facilities adversely affected by settlement;

f) repairing or upgrading of erosion controls where erosion occurs.

5.7 BASIS OF SLOPE STABILITY DESIGN

A catalogue is presently being prepared of slopes along the pipeline route in the Yukon for all slopes greater than 14% which intersect the pipeline route. The slopes are identified by a slope number and located by kilometre post. Each slope is classified by length, direction of slope (longitudinal or transverse), slope angle (both average and maximum), and slope height. The subsurface stratigraphy is evaluated on the basis of terrain typing and borehole results and groundwater conditions are estimated (where possible). Finally, a preliminary geotechnical assessment is made delineating potential design problems associated with each slope and the required analyses that must be undertaken.

Subsequent to the compilation of a slope catalogue, a full stability evaluation of all catalogued slopes is being undertaken by consultants. The effect of disturbance to the thermal regime of the slope due to both construction activities and pipeline operations will be made for each frozen slope and the consequences of this disturbance will be evaluated.

The analytical assessment of each slope will examine the geothermal regime (frozen or unfrozen slope), material properties (soil or rock strength), and the proposed post-construction slope geometry. The slopes will be examined from both a static and seismic point of view and areas of liquefaction potential will be noted in order that appropriate design measures can be implemented. The effect of the thaw plug around the pipeline will be evaluated both for longitudinal and transverse slopes as will the effect of potential soil movement on the pipeline stability and integrity.

Minimum allowable factors of safety and maximum slope movements will be specified and the slopes will be designed to these criteria. The minimum allowable factor of safety will be different for the static and dynamic analyses with the latter being a lower value. Mitigative slope design measures will be proposed in areas where slopes do not meet these criteria.

5.7.1 Description of Design Measures

The basic input needed for the design of the slopes are topography, shear strengths of the soil and rock formations, groundwater conditions in the slopes, expected thermal regime, and earthquake motions adopted as design criteria.

The slope geometry and the subsurface stratigraphy have a large bearing on the type of failure. In permafrost areas, thaw fronts will provide constraints to potential failure surfaces and may result in wedge or infinite-slope failures being most critical. In thawed areas, weak soil layers and the depth to bedrock may affect a potential failure surface and hence the factor of safety. Large critical slopes on the pipeline route will be designed on a site specific basis due to these considerations.

The shear strength parameters used in the slope analyses will be based on the results of laboratory tests on soil samples where applicable test results are available. Although shear strength testing is desirable, it is often difficult to obtain undisturbed samples of many soil units. Hence correlation of soil index, density and gradation properties with tests in similar materials may also be required in many instances in order to estimate the relevant soil parameters. This is particularly evident in frozen soils with a significant coarse fraction where undisturbed sampling is very difficult. However, these soils have a well defined range of shear strength parameters, and the level of confidence in assignment of parameters is high.

The parameters affecting the groundwater regime of a slope include the hydrology of the area, drainage conditions, permeability, and thaw-consolidation pore water pressures induced by thawing permafrost soils. Most fine grained permafrost soils are considered to be saturated on thawing with the excess pore pressure generation being a function of the ratio of the rate of advance of the thaw front to the coefficient of consolidation of the soil. Altered groundwater conditions in a slope resulting from a change in the thermal regime often exert the most important impact in the reduction of stability of a slope where the soils are fine grained and enhibit poor drainage characteristics.

In South Yukon the soils are relatively free draining and do not maintain significant excess pore pressure during moderate rates of thaw experienced in the field.

Geothermal analyses will be based on the final cut-fill configuration of the right-of-way and will include the thaw-bulb around the pipeline. Potential disturbance of the right-of-way will be considered in areas where this is considered possible.

For earthquake loading, the design input parameters will include the earthquake acceleration, duration, and response spectrum. Liquefaction potential will be principally based on soil grainsize, groundwater conditions, soil density, and overburden pressure. Dynamic shear tests may be performed in critical locations if the soil conditions warrant them.

5.7.2 Methods of Analysis

Static methods of analysis will be performed on all frozen, thawing and unfrozen slopes. Frozen and thawing slopes will be analyzed with respect to thaw-bulb stability, infinite slope stability and cut slope stability. Unfrozen slopes will be analyzed by traditional failure surface analyses which take into account weak soil layers and the bedrock configurations. Dynamic methods of analysis will include both the pseudostatic analysis and permanent slope displacement computations, where required.

5.7.3 Remedial Measures

In areas of potential concern due to slope stability problems, mitigative measures may be necessary in order to assure the pipeline integrity. For frozen or thawing slopes, these would include:

a) Pipeline right-of-way re-route;
b) measures to limit or prevent thaw (i.e. insulation or peat covers);
c) regrading;
d) gravel surcharge load on the thawing slope;
e) restraining structures;
f) groundwater control and drainage.

A number of these measures are currently being tested and monitored at the Quill Creek Test Site.

For areas of thawed slopes, the following mitigative measures will be considered:

a) Pipeline right-of-way re-route;
b) regrading/excavation and filling;
c) groundwater control and drainage;
d) restraining structures.

In addition, slopes will be monitored for movement in areas of potential concern and further mitigative measures will be undertaken if unacceptable slope movement is found to occur.

6.0 FINAL DESIGN

6.1 SITE SPECIFIC AND INTEGRATED DESIGN

The pipeline design, the right-of-way stability and construction zone designs will be integrated on a site specific basis during the detailed and final design stages. Revisions to construction mode assignments as required for drainage slope stability and pipe integrity will be incorportated.

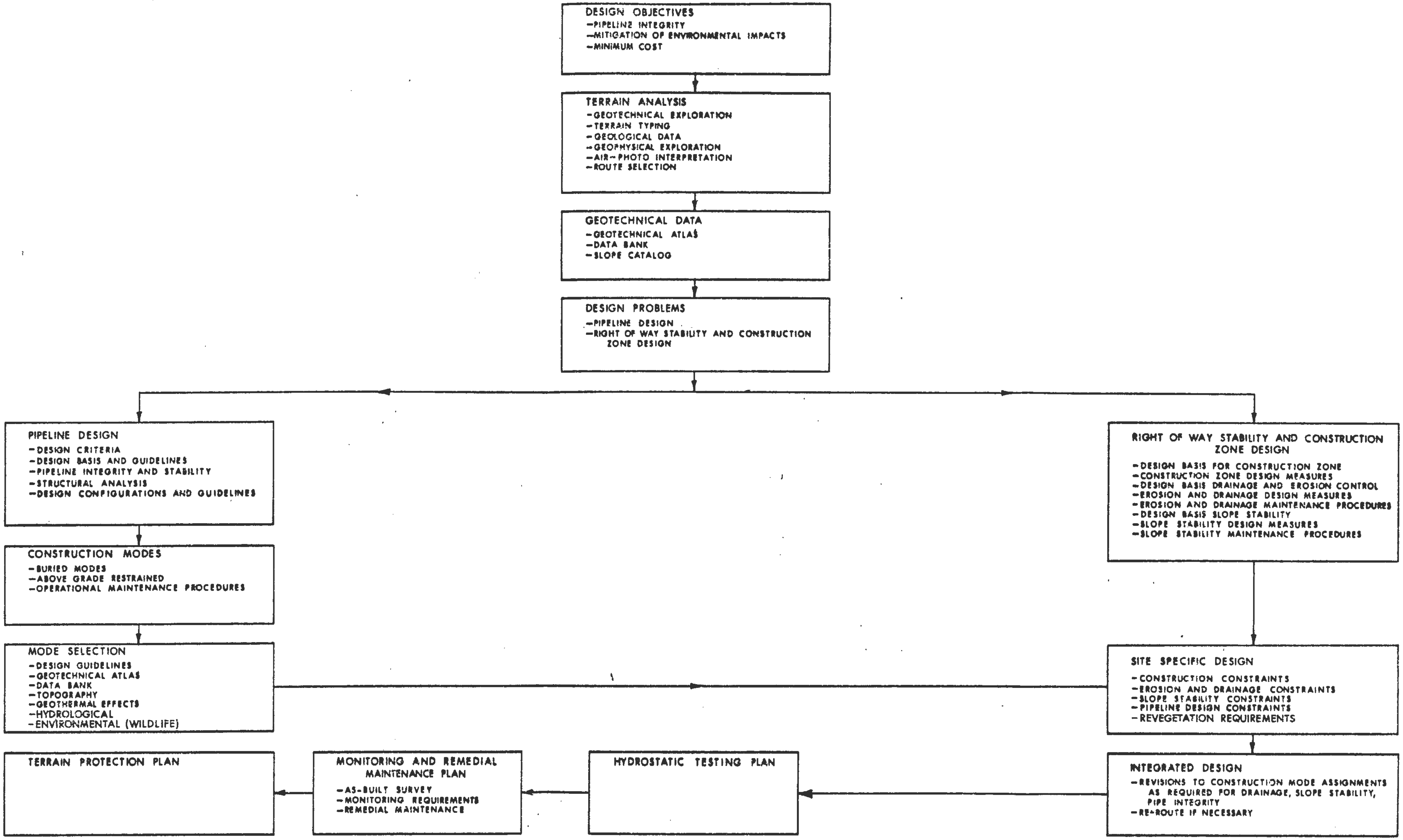
6.2 HYDROSTATIC TESTING PLAN

In accordance with the National Energy Board Act and the Gas Pipeline Regulations, Part III, Field Pressure testing the pipeline will be hydrostatically tested under water as the test medium.

A hydrostatic testing plan detailing test section locations and associated test procedure requirements will be developed and presented with the pipeline specifications.

6.3 MONITORING AND REMEDIAL MAINTENANCE

The safe range of pipe movements for settlements will be determined in the stress analysis and reconciliation with the design criteria. Monitoring of the pipeline will be undertaken in unstable soil areas. A monitoring and Remedial Maintenance plan will be developed detailing, necessary measurement intervals, methods and frequency of measurements to identify trends toward critical stress in accordance with NEB Regulations, and remedial maintenance procedures to be implemented as required.



GENERAL NOTES	REFERENCE DRAWING		MICROFILM RECORD		REVISIONS						NORTHERN PIPELINE AGENCY
	DRAWING NO.	TITLE	FILE NO.	DATE	NO.	DESCRIPTION	DATE	BY	CHKD.	APPR.	

ENGINEERING RECORDS	
DRAWN BY G. Y.	DATE 81 05 01
CHECKED BY	DATE 81 05 01
DRAFTING SUPERVISOR	DATE 81-05-04
ENGINEER	DATE 81-05-04

APPROVALS

SCALE

Foothills Pipe Lines (South Yukon) Ltd.

THE ALASKA HIGHWAY GAS PIPELINE PROJECT

PIPELINE DESIGN LOGIC

FIGURE 2.5.1

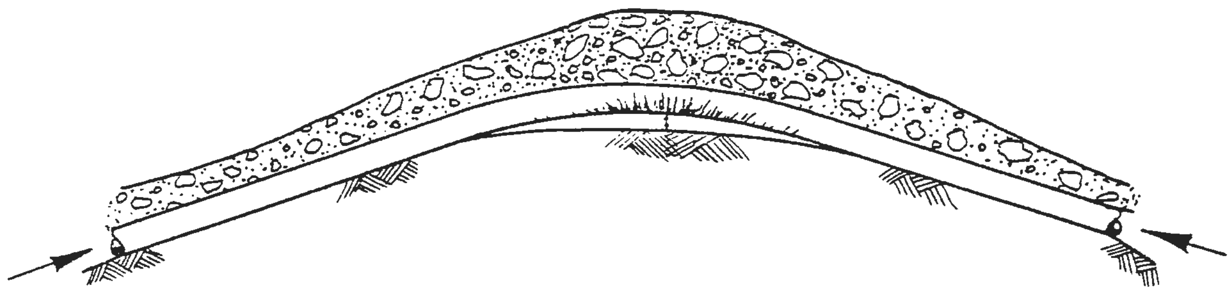
PREPARED BY

YUKON PIPELINE DESIGN JOINT VENTURE

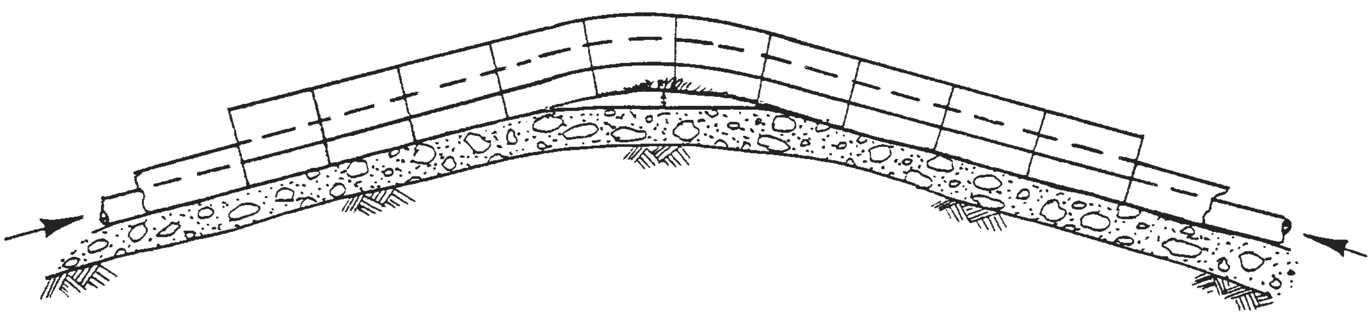
APK CANUCK MONENCO PETROTECH

NON	ZONE	FACILITY	NO	DWG TYPE	DRAWING NO.	REV

METRIC A2, FORM 260 AUG.80



BURIED OR EMBANKMENT OVERBEND



RESTRAINED CONCRETE WEIGHTED OVERBEND

Foothills Pipe Lines (South Yukon) Ltd.

TITLE

THE ALASKA HIGHWAY GAS PIPELINE PROJECT

OVERBEND STABILITY

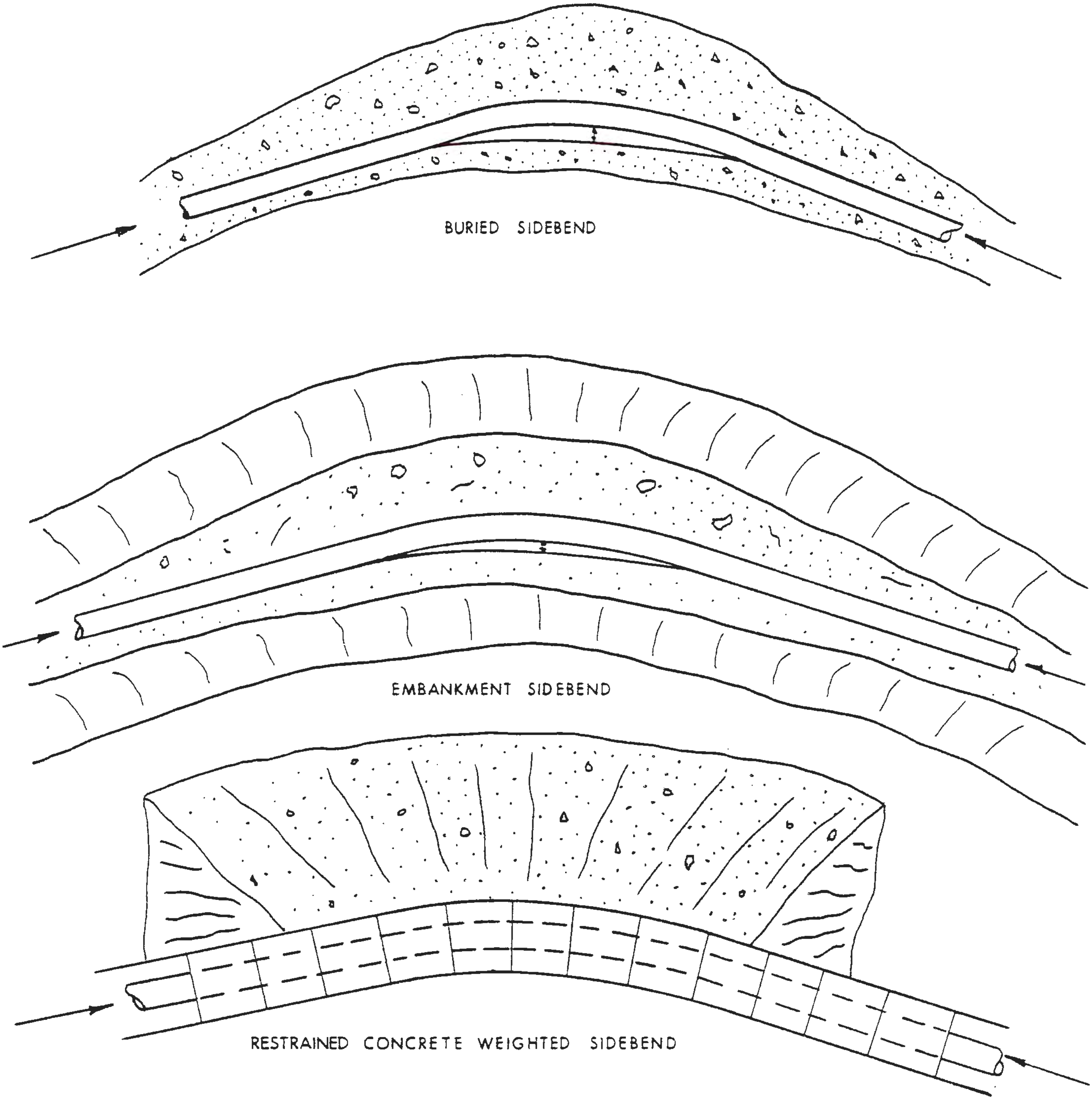
	DRAWN	CHECKED	APPROVED	APPROVED
BY	L. S.			
DATE	81 04 15	810416	81-05-04	

SCALE NONE

PREPARED BY YUKON PIPELINE DESIGN

FIGURE 4.2 4.2

A4 FORM 258



Foothills Pipe Lines (South Yukon) Ltd.

TITLE
THE ALASKA HIGHWAY GAS PIPELINE PROJECT

SIDEBEND STABILITY

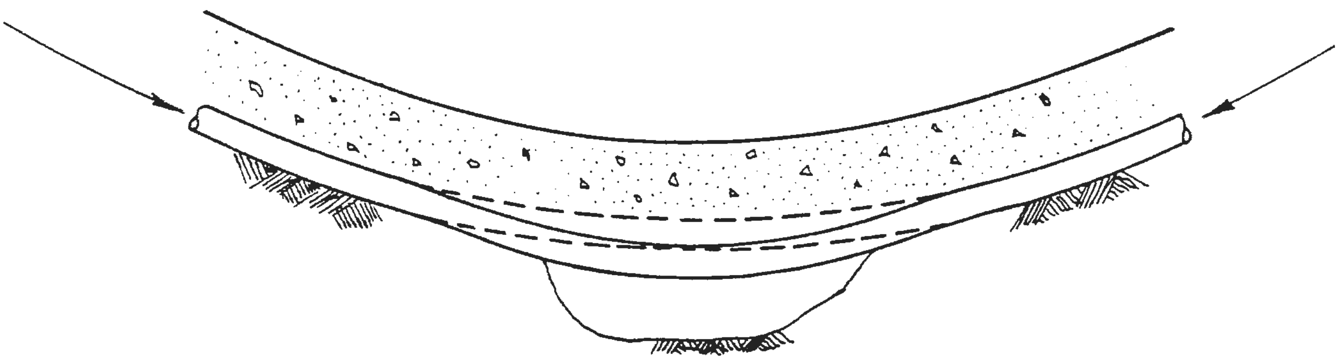
	DRAWN	CHECKED	APPROVED	APPROVED
BY	D. KELLAM	RPT	JP	
DATE	81 04 15	81 04 16	81-05-04	

SCALE NONE

PREPARED BY YUKON PIPELINE DESIGN

FIGURE 4.2.4.3

A4 FORM 258



Foothills Pipe Lines (South Yukon) Ltd.

TITLE

THE ALASKA HIGHWAY GAS PIPELINE PROJECT

SAGBEND STABILITY

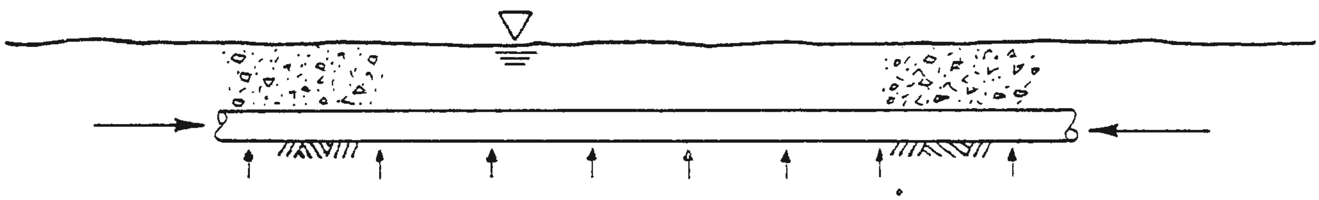
	DRAWN	CHECKED	APPROVED	APPROVED
BY	D. KELLAM	[illegible]	[illegible]	
DATE	81 04 14	81 04 16	81-05-04	

SCALE NONE

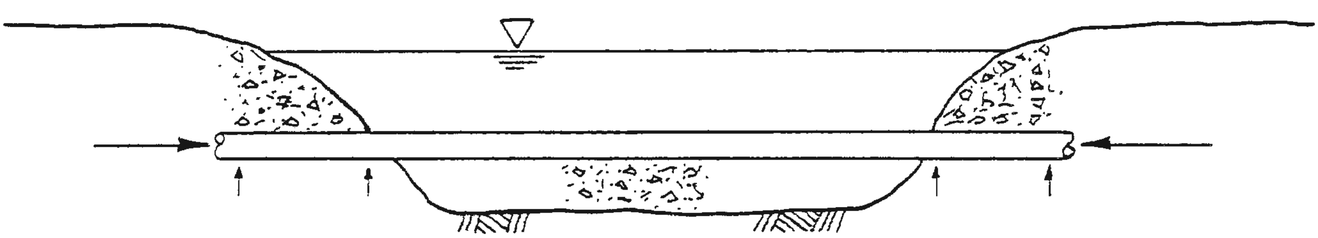
PREPARED BY YUKON PIPELINE DESIGN

FIGURE 4.2.4.4

A4 FORM 258



STRAIGHT PIPE STABILITY



LOSS OF OVERBURDEN

Foothills Pipe Lines (South Yukon) Ltd.

TITLE

THE ALASKA HIGHWAY GAS PIPELINE PROJECT

STRAIGHT PIPE STABILITY

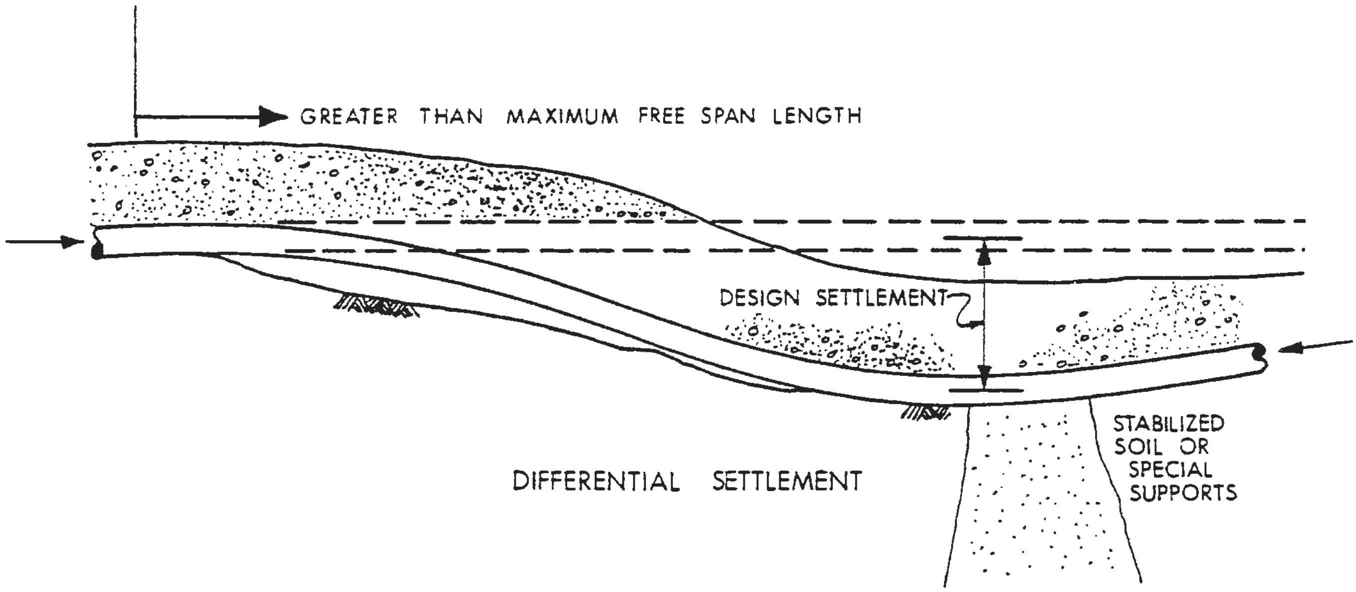
	DRAWN	CHECKED	APPROVED	APPROVED
BY	G. Y.	R.T.	H	
DATE	81 04 29	81 04 29	81-05-04	

SCALE N.T.S.

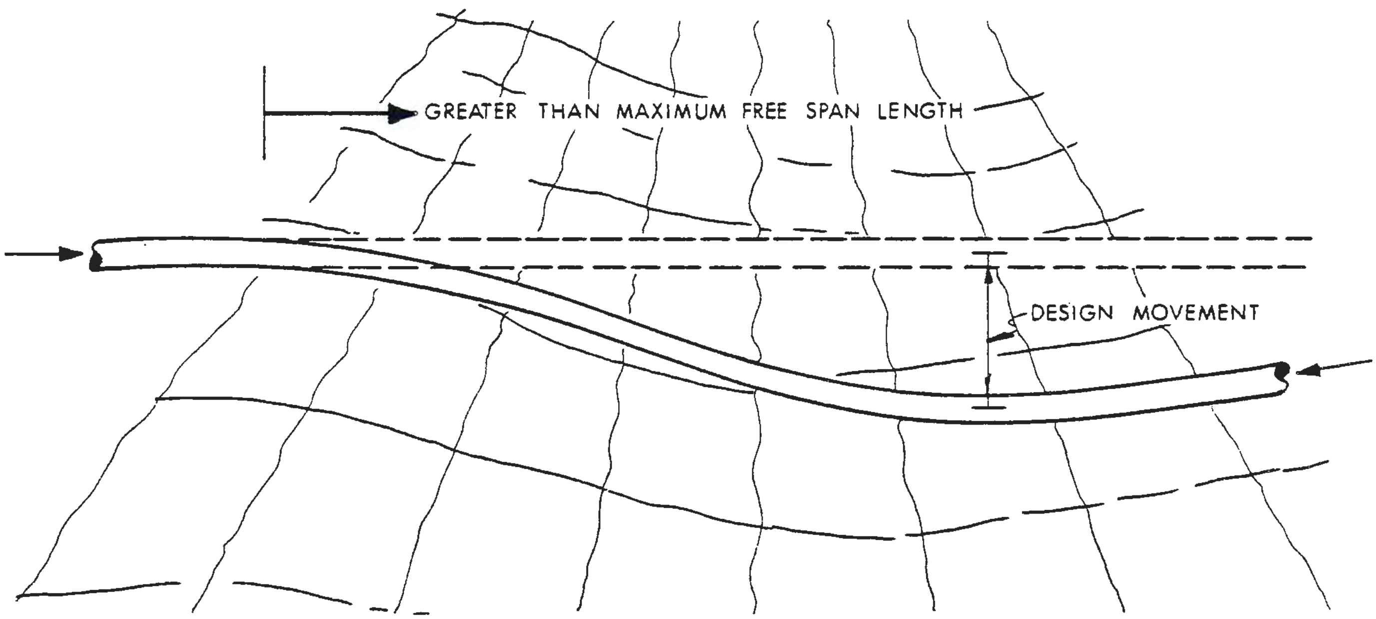
PREPARED BY YUKON PIPELINE DESIGN

FIGURE 4.2.4.5

A4 FORM 208



DIFFERENTIAL SETTLEMENT



TRANSVERSE DIFFERENTIAL SLOPE MOVEMENT

Foothills Pipe Lines [South Yukon] Ltd.

TITLE
THE ALASKA HIGHWAY GAS PIPELINE PROJECT

DIFFERENTIAL MOVEMENTS

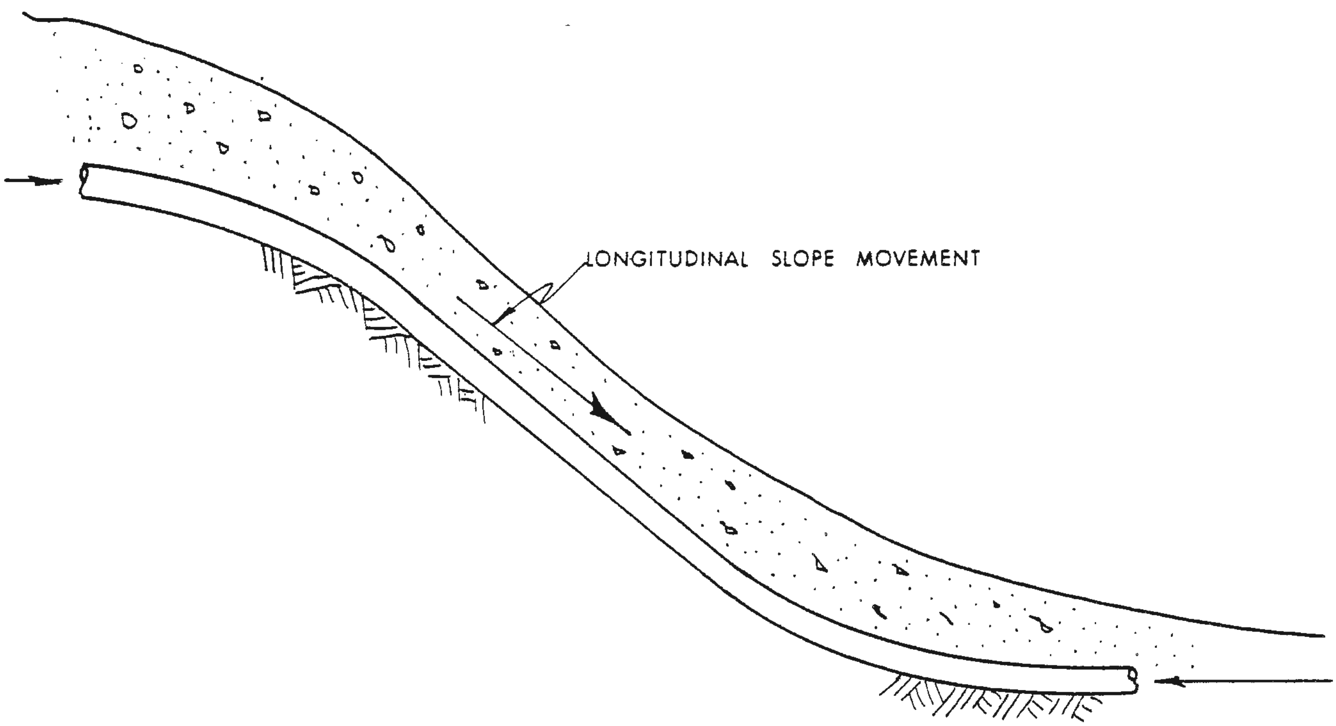
	DRAWN	CHECKED	APPROVED	APPROVED
BY	L.L.			
DATE	81-04-15	810416	81 05 04	

SCALE NONE

PREPARED BY YUKON PIPELINE DESIGN

FIGURE 4.2.4.6B

A4 FORM 258



Foothills Pipe Lines (South Yukon) Ltd.

TITLE
THE ALASKA HIGHWAY GAS PIPELINE PROJECT

LONGITUDINAL SLOPE MOVEMENT

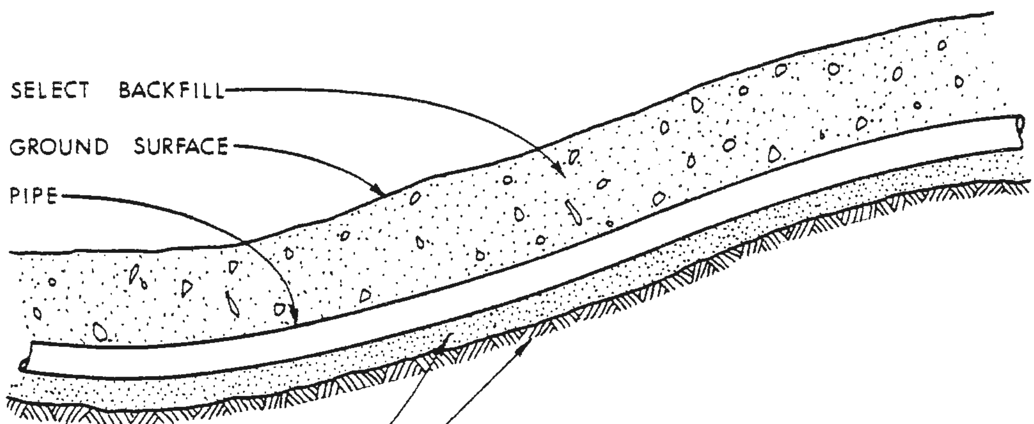
	DRAWN	CHECKED	APPROVED	APPROVED
BY	D. KELLAM	RPT	[illegible]	
DATE	81 04 14	81 04 16	81 05 04	

SCALE NONE

PREPARED BY YUKON PIPELINE DESIGN

FIGURE 4.2.4.7

A4 FORM 258



Foothills Pipe Lines (South Yukon) Ltd.

TITLE

THE ALASKA HIGHWAY GAS PIPELINE PROJECT

PIPE STIFFNESS AND DITCH PROFILE

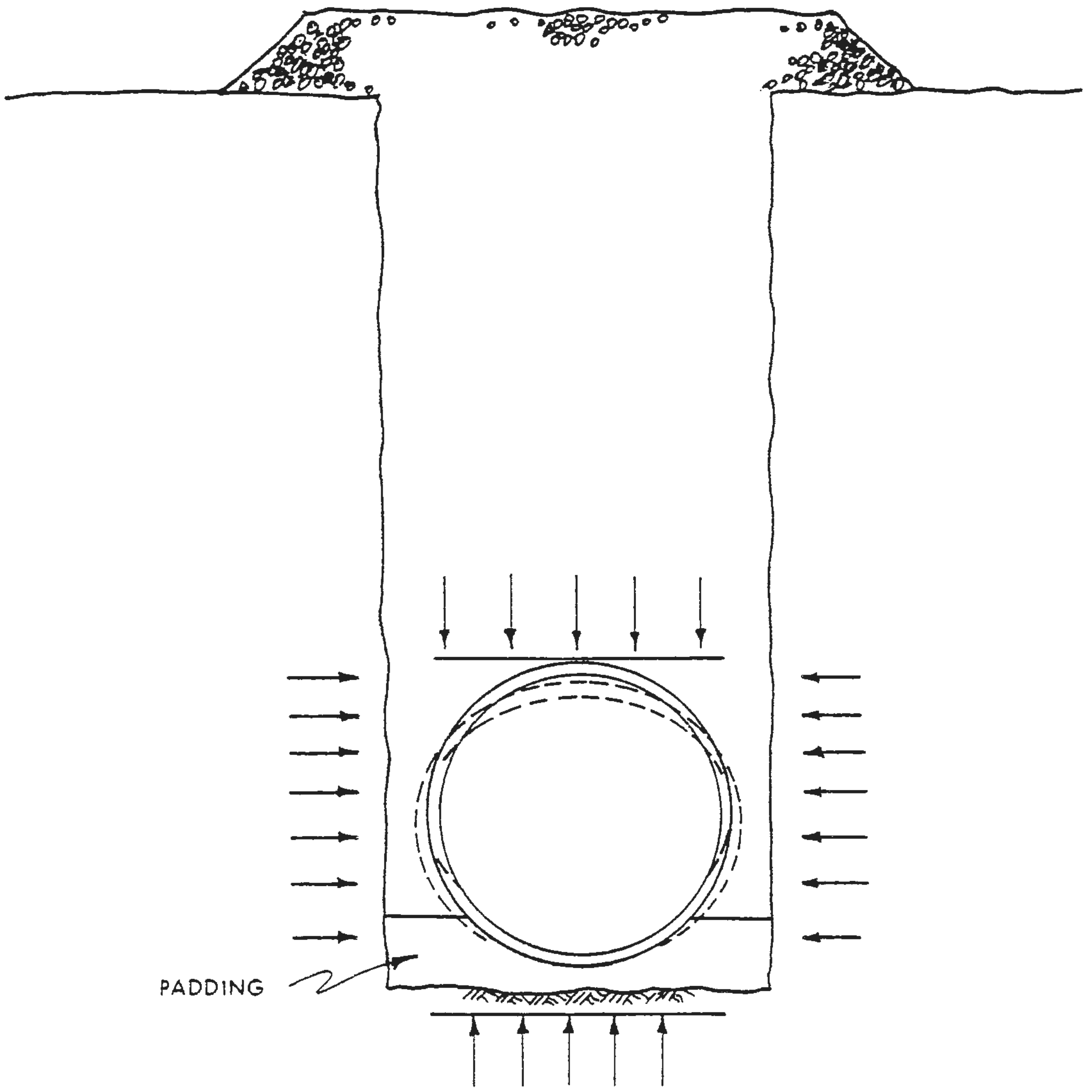
	DRAWN	CHECKED	APPROVED	APPROVED
BY	V. J. J.	A L A I		
DATE	81 07 27	810727	81 07 28	

SCALE NONE

PREPARED BY YUKON PIPELINE DESIGN

FIGURE 4.2.4.8

A4 FORM 256



Foothills Pipe Lines (South Yukon) Ltd.

TITLE
THE ALASKA HIGHWAY GAS PIPELINE PROJECT

OVALLING DUE TO
OVERBURDEN LOADING

	DRAWN	CHECKED	APPROVED	APPROVED
BY	A. M.	RFT	FP	
DATE	81 04 15	81 04 16	81 05 04	

SCALE NONE. PREPARED BY YUKON PIPELINE DESIGN

FIGURE 4.2.4.9

A4 FORM 258

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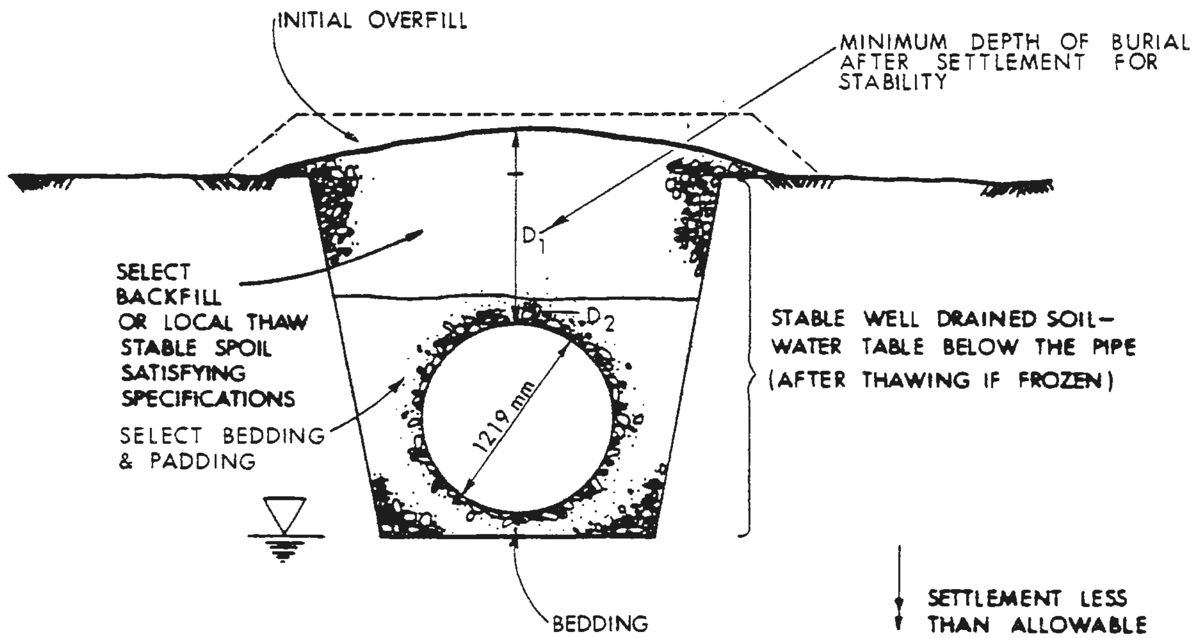
REV: 81 11 02



NOTE: DIMENSIONS AND SPECIFICATIONS WILL VARY WITH LOCAL OPERATING, PIPELINE GEOMETRY AND SOIL CONDITIONS.

Foothills Pipe Lines (South Yukon) Ltd.

TITLE
THE ALASKA HIGHWAY GAS PIPELINE PROJECT
MODE 1
STANDARD BURIAL WARM PIPE

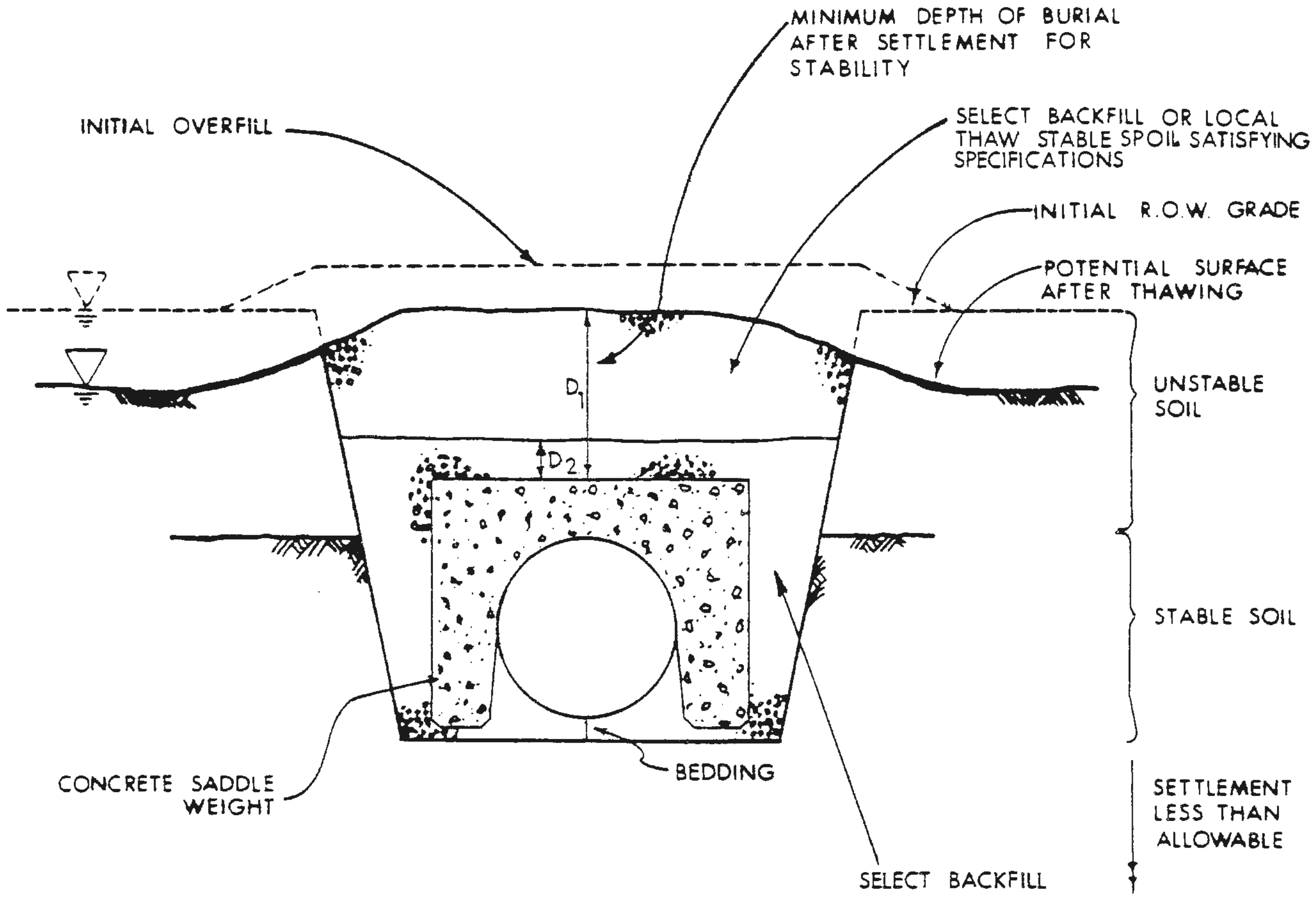
	DRAWN	CHECKED	APPROVED	APPROVED
BY	V.J.R.	RPT	[illegible]	
DATE	81 04 02	81 04 29	81-05-04	

SCALE N.T.S. PREPARED BY YUKON PIPELINE DESIGN

FIGURE 4.3.1.

A4 FORM 288

REV: 81 07 27
REV: 81 11 02



NOTE: DIMENSIONS AND SPECIFICATIONS WILL VARY WITH LOCAL OPERATING, PIPELINE GEOMETRY AND SOIL CONDITIONS.

Foothills Pipe Lines (South Yukon) Ltd.

TITLE
THE ALASKA HIGHWAY GAS PIPELINE PROJECT
MODE 2
SADDLE WEIGHTED WARM PIPE

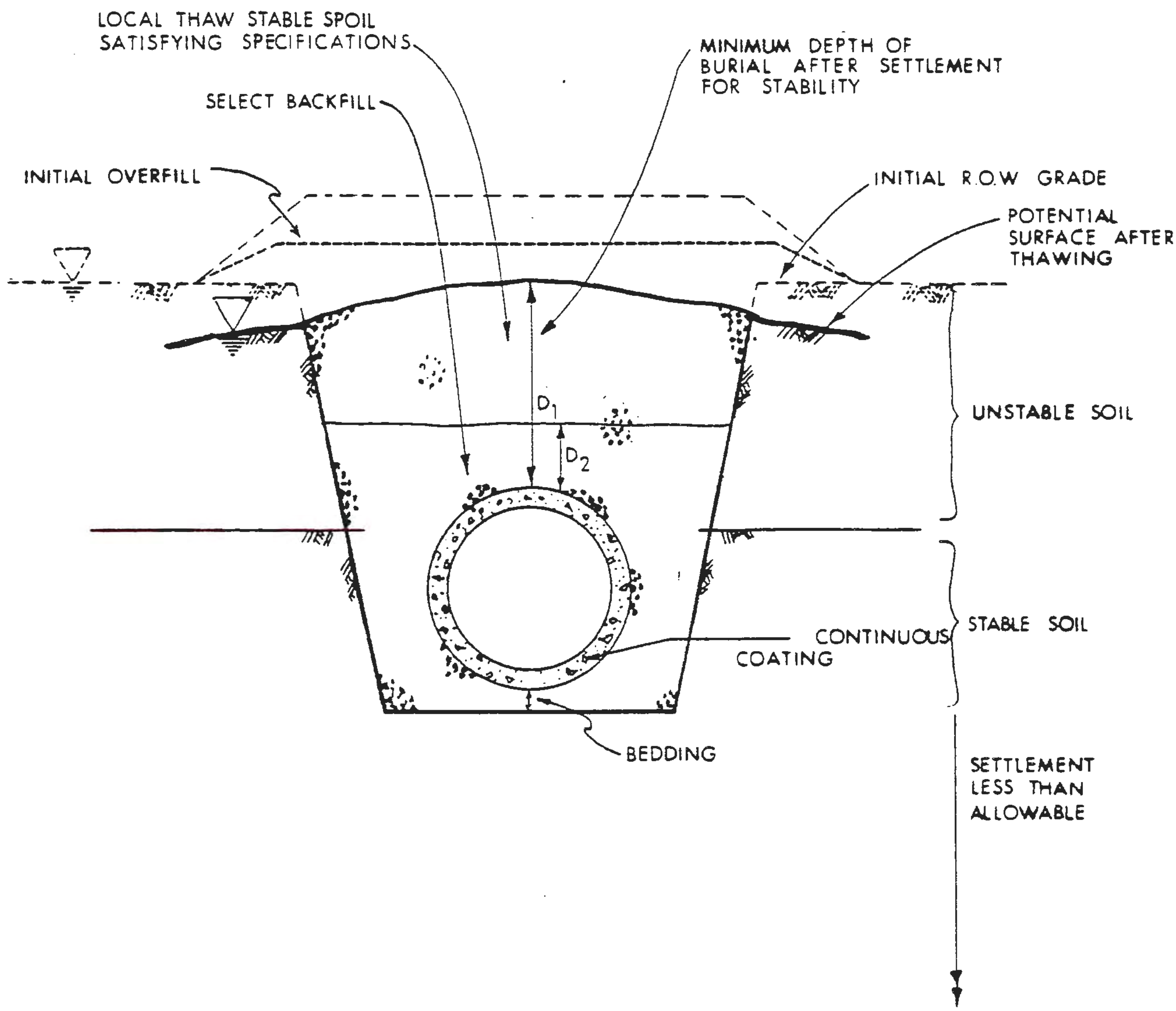
	DRAWN	CHECKED	APPROVED	APPROVED
BY	S. J. G.	[illegible]	[illegible]	
DATE	81 04 02	81 04 29	81-05-04	

SCALE N.T.S. PREPARED BY YUKON PIPELINE DESIGN

FIGURE 4.3.2.

A4 FORM 258

REV: 81 07 27
REV: 81 11 02



NOTE:
DIMENSIONS AND SPECIFICATIONS WILL VARY WITH LOCAL OPERATING, PIPE GEOMETRY AND SOIL CONDITIONS.

Foothills Pipe Lines (South Yukon) Ltd.

TITLE
THE ALASKA HIGHWAY GAS PIPELINE PROJECT
MODE 3
CONTINUOUS WEIGHTED
WARM PIPE

	DRAWN	CHECKED	APPROVED	APPROVED
BY	S.J.G.	RPT	[illegible]	
DATE	81 04 02	81 04 29	81-05 04	

SCALE N.T.S. PREPARED BY YUKON PIPELINE DESIGN

FIGURE 4.3.3.

A4 FORM 258

REV: 81 07 27
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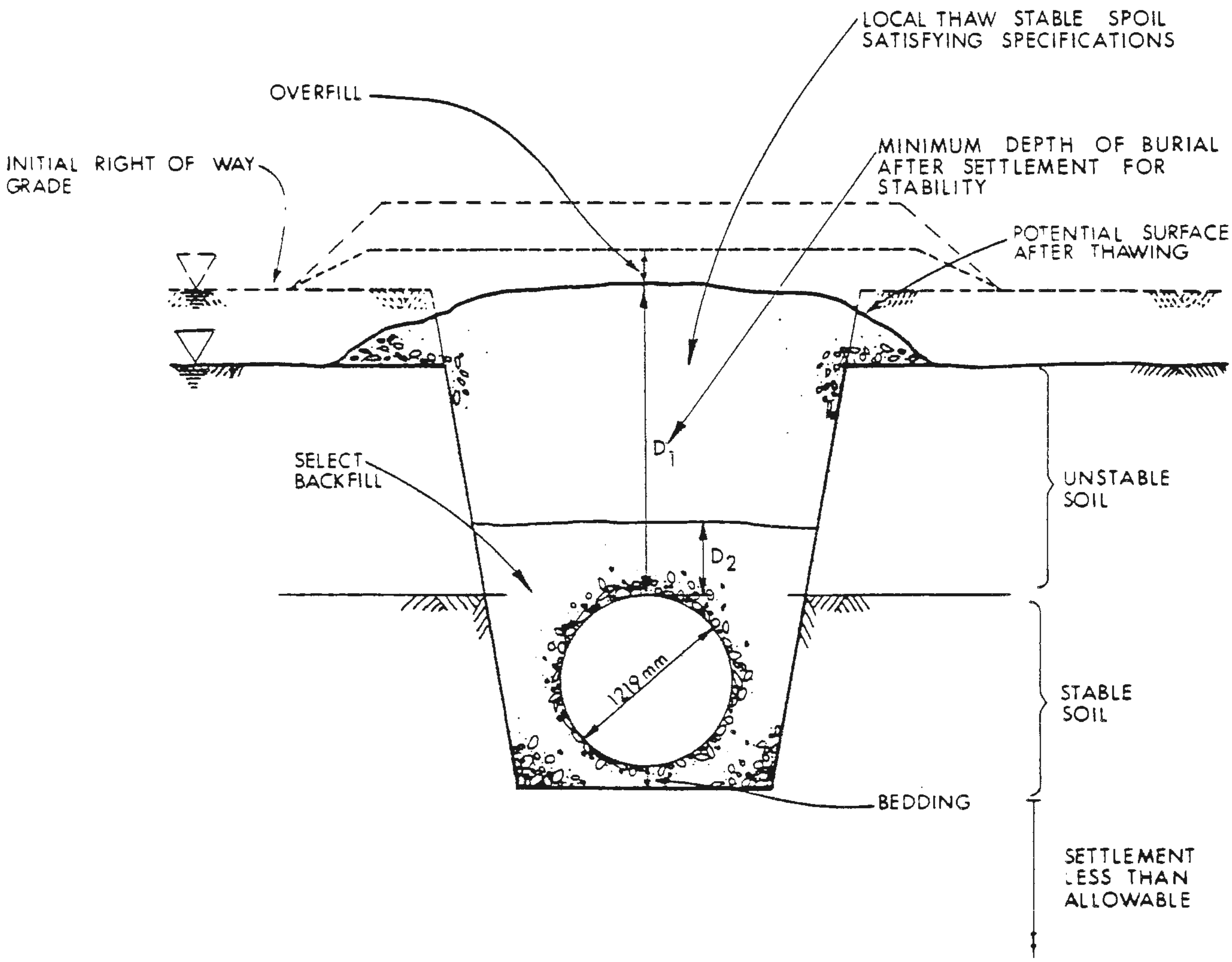


NOTE:
DIMENSIONS AND SPECIFICATIONS WILL VARY WITH LOCAL OPERATING PIPE GEOMETRY AND SOIL CONDITIONS

Foothills Pipe Lines (South Yukon) Ltd.

TITLE
THE ALASKA HIGHWAY GAS PIPELINE PROJECT
MODE 4
UNWEIGHTED BURIAL WARM PIPE

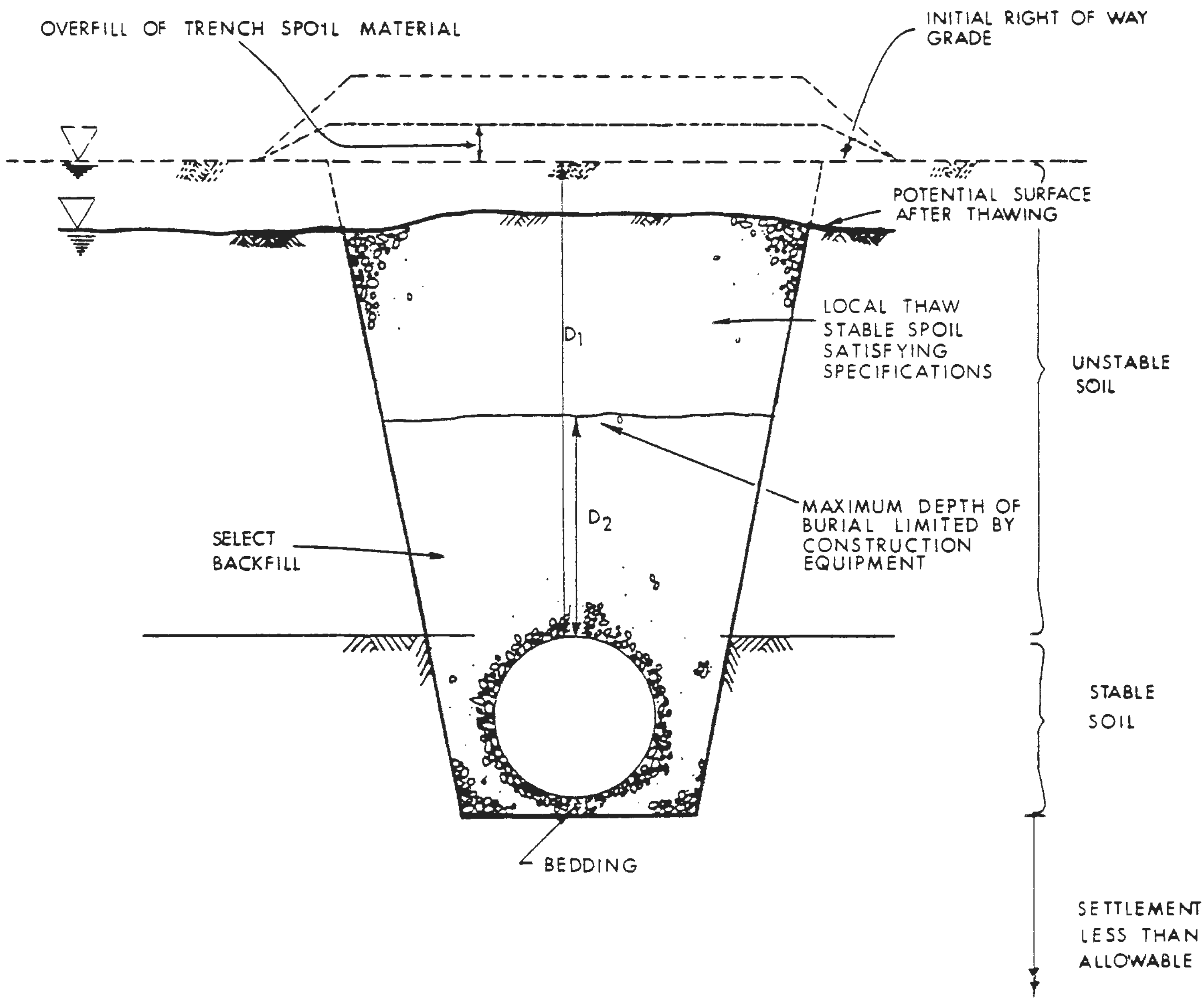
	DRAWN	CHECKED	APPROVED	APPROVED
BY	V. J. R.	RPT	gr	
DATE	81 04 02	81 04 29	81-05-04	

SCALE N.T.S. | PREPARED BY YUKON PIPELINE DESIGN

FIGURE 4.3.4.

A4 FORM 250

REV: 81 07 27
REV: 81 11 02



NOTE: DIMENSIONS AND SPECIFICATIONS WILL VARY WITH LOCAL OPERATING, PIPE GEOMETRY AND SOIL CONDITIONS.

Foothills Pipe Lines (South Yukon) Ltd.

TITLE
THE ALASKA HIGHWAY GAS PIPELINE PROJECT
MODE 5
DEEP BURIAL WARM PIPE

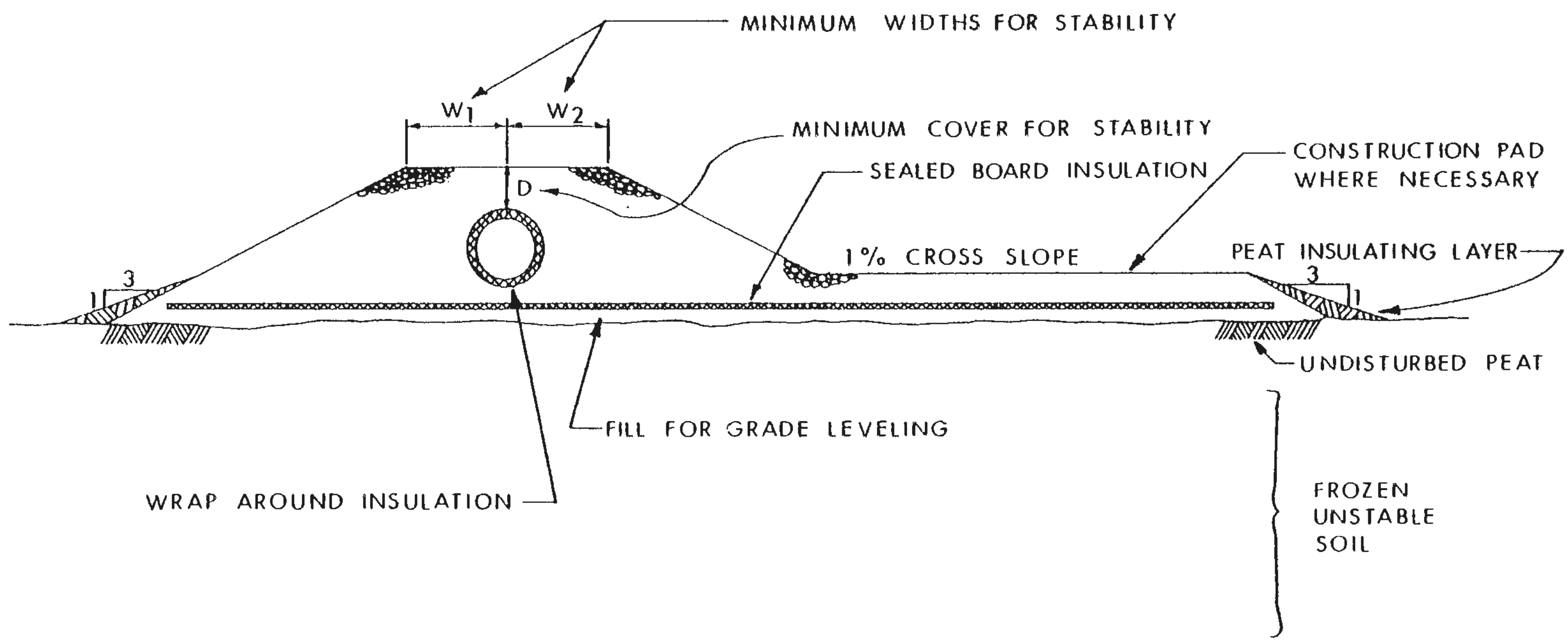
SCALE N.T.S. PREPARED BY YUKON PIPELINE DESIGN

	DRAWN	CHECKED	APPROVED	APPROVED
BY	T.A.O.	RPT	GN	
DATE	81 04 02	810429	81-05-04	

FIGURE 4.3.5.

A4 FORM 250

A4 FORM 250



NOTE: DIMENSIONS AND SPECIFICATIONS WILL VARY WITH LOCAL OPERATING PIPE GEOMETRY AND SOIL CONDITIONS.

Foothills Pipe Lines (South Yukon) Ltd.

REV: 81 07 27

	DRAWN	CHECKED	APPROVED	APPROVED
BY	G. Y.			
DATE	81 04 29	81 04 29	81-05-04	

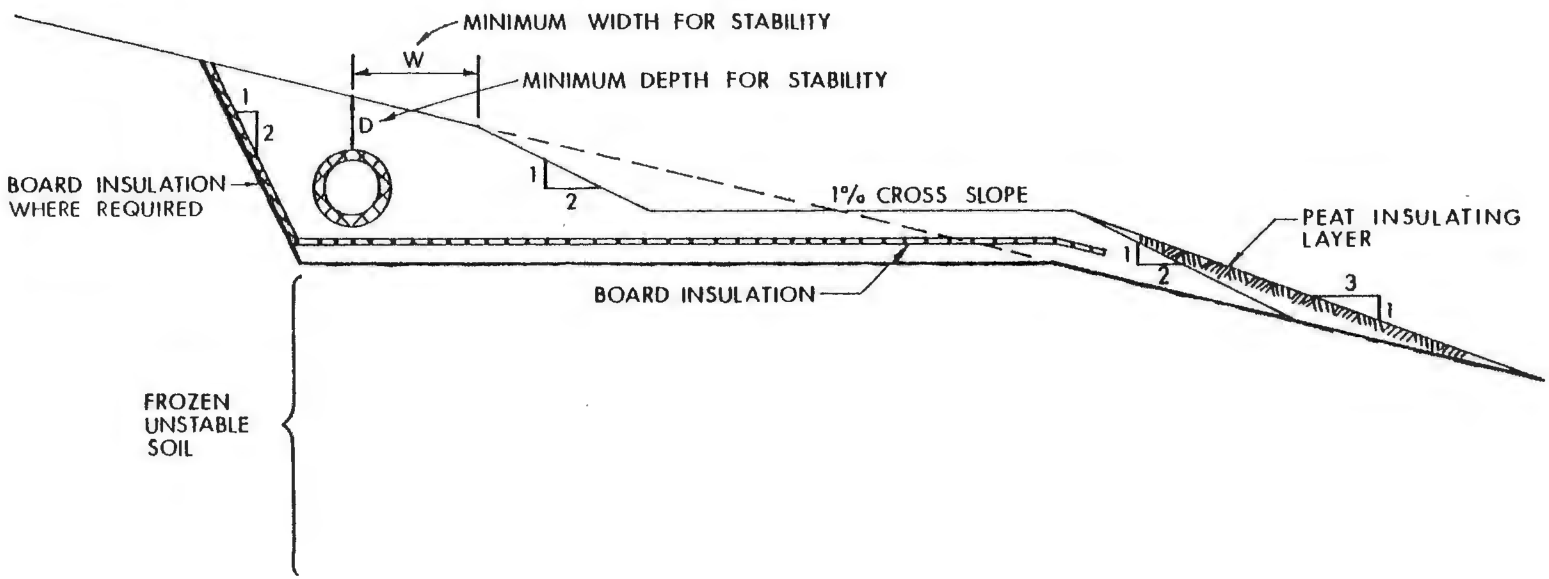
TITLE
THE ALASKA HIGHWAY GAS PIPELINE PROJECT
MODE 6
INSULATED EMBANKMENT
WARM FLOW

SCALE N.T.S.
PREPARED BY YUKON PIPELINE DESIGN

FIGURE 4.3.6A

A4 FORM 258

REV: 81 07 27



Foothills Pipe Lines (South Yukon) Ltd.

TITLE

THE ALASKA HIGHWAY GAS PIPELINE PROJECT

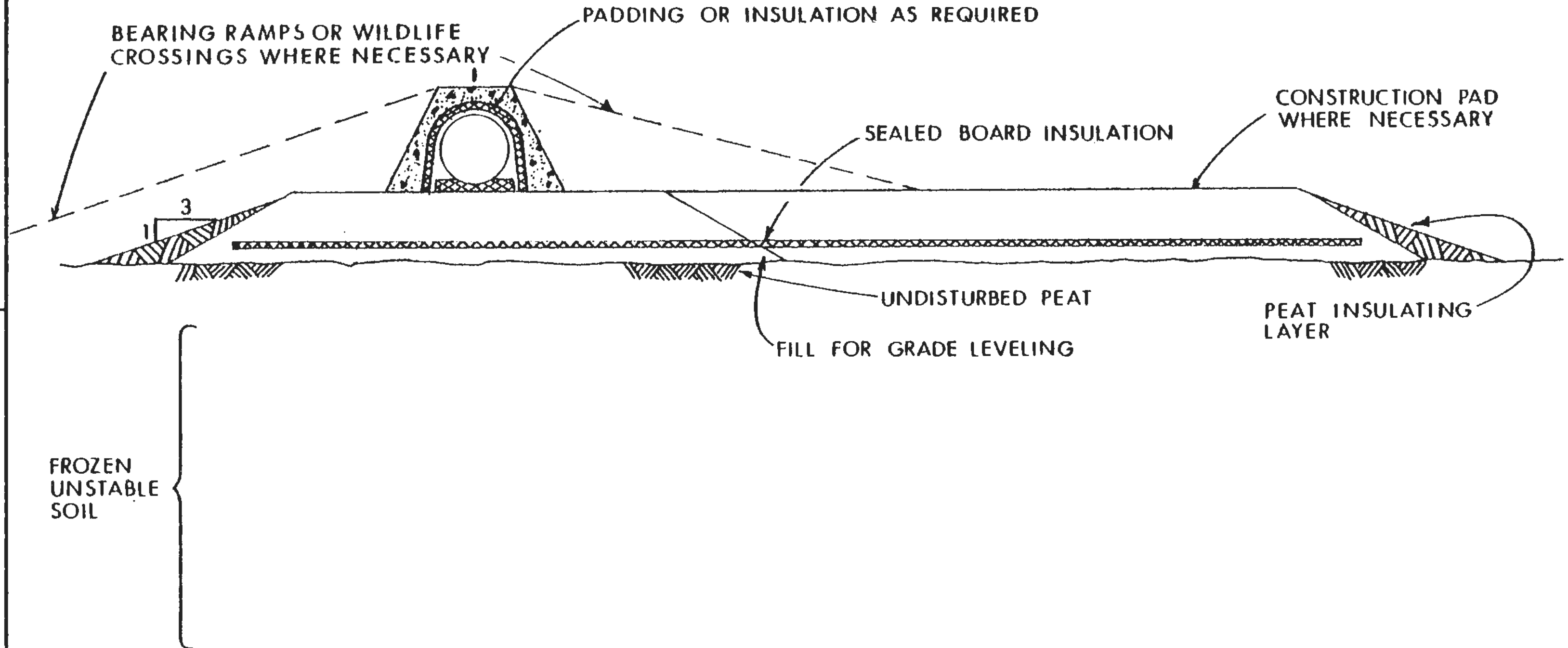
MODE 6
INSULATED EMBANKMENT
CUT-FILL SECTION

	DRAWN	CHECKED	APPROVED	APPROVED
BY	A. M.	RPJ	HJ	
DATE	81 04 29	81 04 29	81-05-04	

SCALE NTS

PREPARED BY YUKON PIPELINE DESIGN

FIGURE 4.3.6B



NOTE: DIMENSIONS AND SPECIFICATIONS WILL VARY WITH LOCAL OPERATING, PIPE GEOMETRY AND SOIL CONDITION

REV: 81 07 27

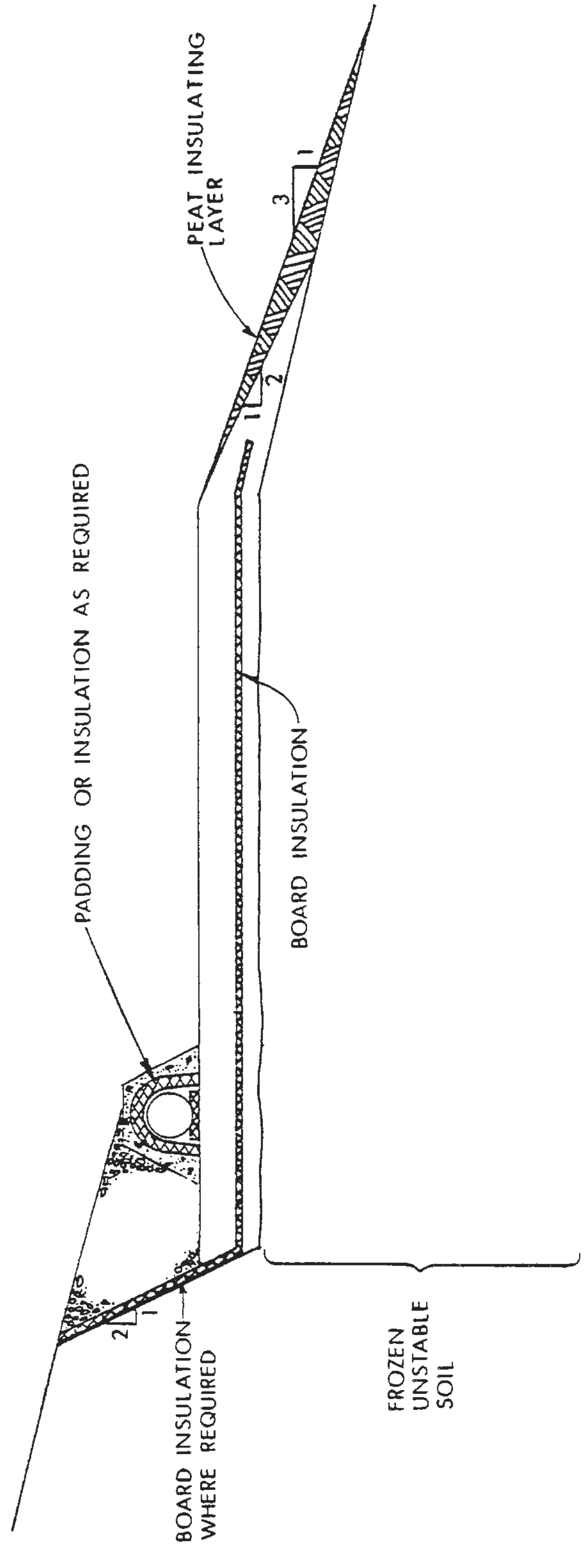
Foothills Pipe Lines (South Yukon) Ltd.

	DRAWN	CHECKED	APPROVED	APPROVED
BY	G. Y.	RPT		
DATE	81 04 29	81 04 30	81.05.04	

TITLE
THE ALASKA HIGHWAY GAS PIPELINE PROJECT
MODE 7
CONCRETE RESTRAINED

SCALE N.T.S. | PREPARED BY YUKON PIPELINE DESIGN

FIGURE 4.3.7A



REV: 81 07 27

Foothills Pipe Lines (South Yukon) Ltd.

TITLE

THE ALASKA HIGHWAY GAS PIPELINE PROJECT

MODE 7
CONCRETE RESTRAINED
CUT-FILL SECTION

	DRAWN	CHECKED	APPROVED	APPROVED
BY	S. J. G.	[illegible]	[illegible]	
DATE	81 04 30	810430	81-05-04	

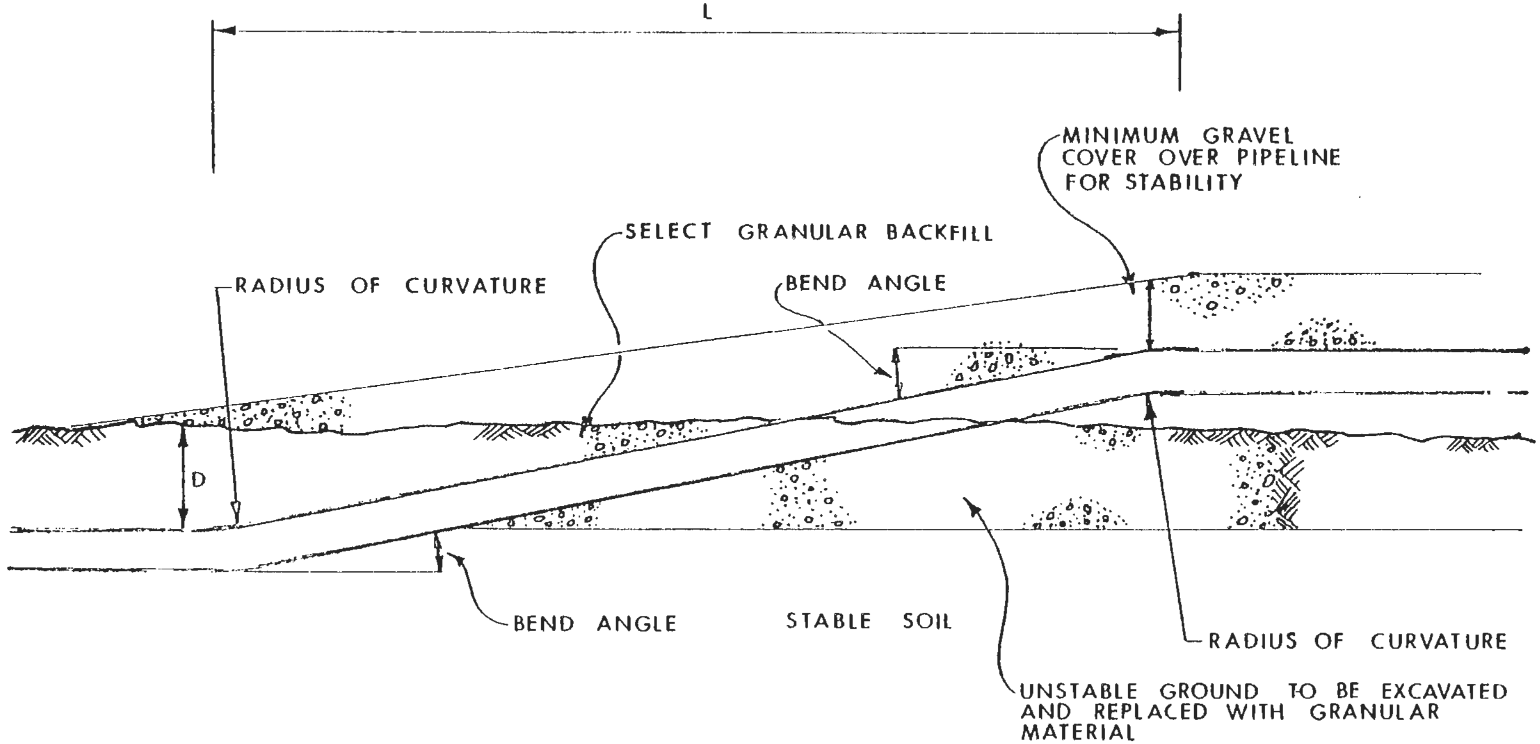
SCALE N.T.S.

PREPARED BY YUKON PIPELINE DESIGN

FIGURE 4.3.7B

A4 FORM 258

A4 FORM 25B



NOTES:

1. DIMENSIONS AND SPECIFICATIONS WILL VARY WITH LOCAL OPERATING, PIPELINE GEOMETRY AND SOIL CONDITIONS.
2. BEND ANGLES ARE EXAGGERATED.

Foothills Pipe Lines (South Yukon) Ltd.

	DRAWN	CHECKED	APPROVED	APPROVED
BY	L. S.	RP	gf	
DATE	81 04 30	81 04 30	81 05 04	

TITLE

THE ALASKA HIGHWAY GAS PIPELINE PROJECT

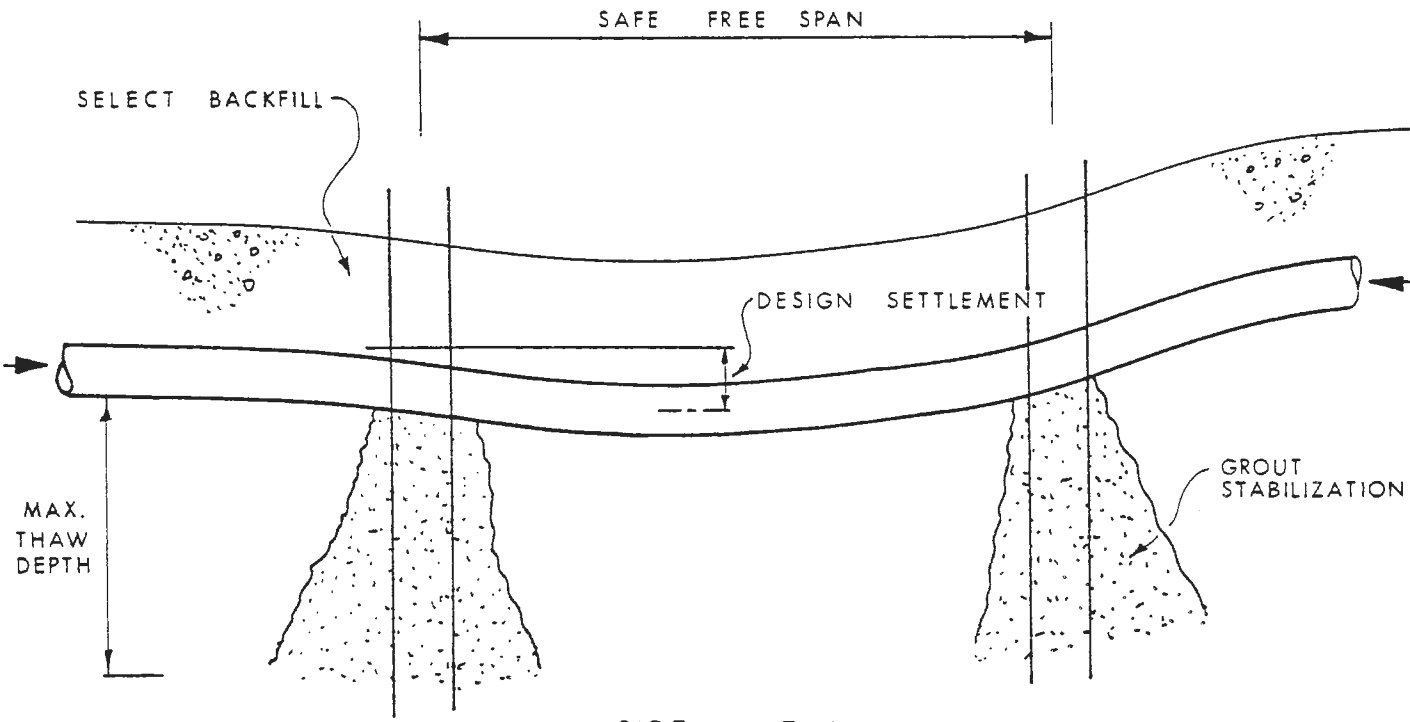
MODE 8

BURIAL TO EMBANKMENT OR RESTRAINED CONCRETE TRANSITION

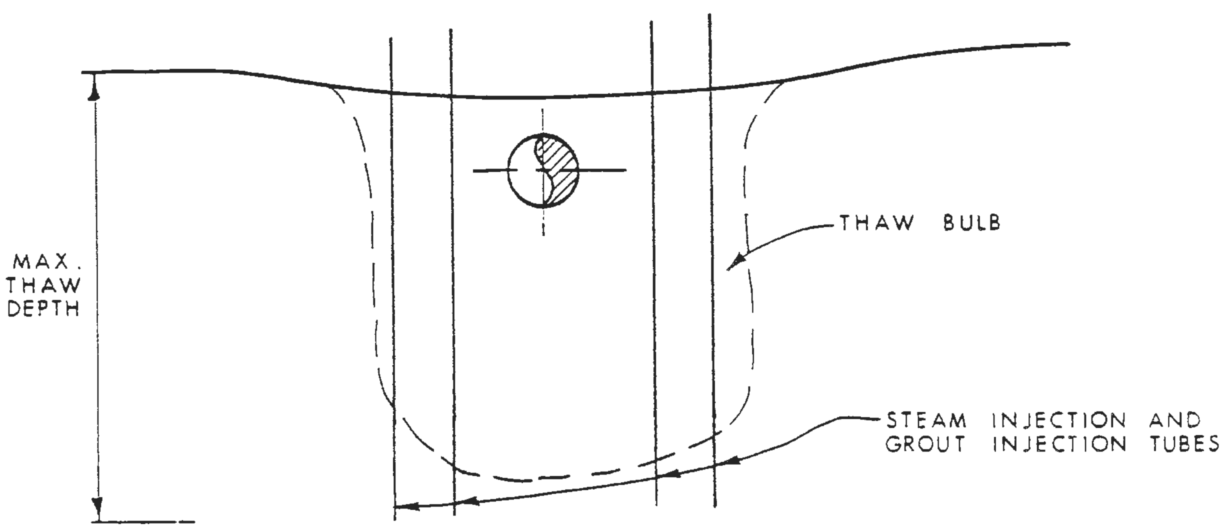
SCALE N. T. S.

PREPARED BY YUKON PIPELINE DESIGN

FIGURE 4.3.8.



SIDE VIEW



END VIEW

REV. 81 07 30

Foothills Pipe Lines (South Yukon) Ltd.

TITLE

HE ALASKA HIGHWAY GAS PIPELINE PROJECT

REMEDIAL MAINTENANCE

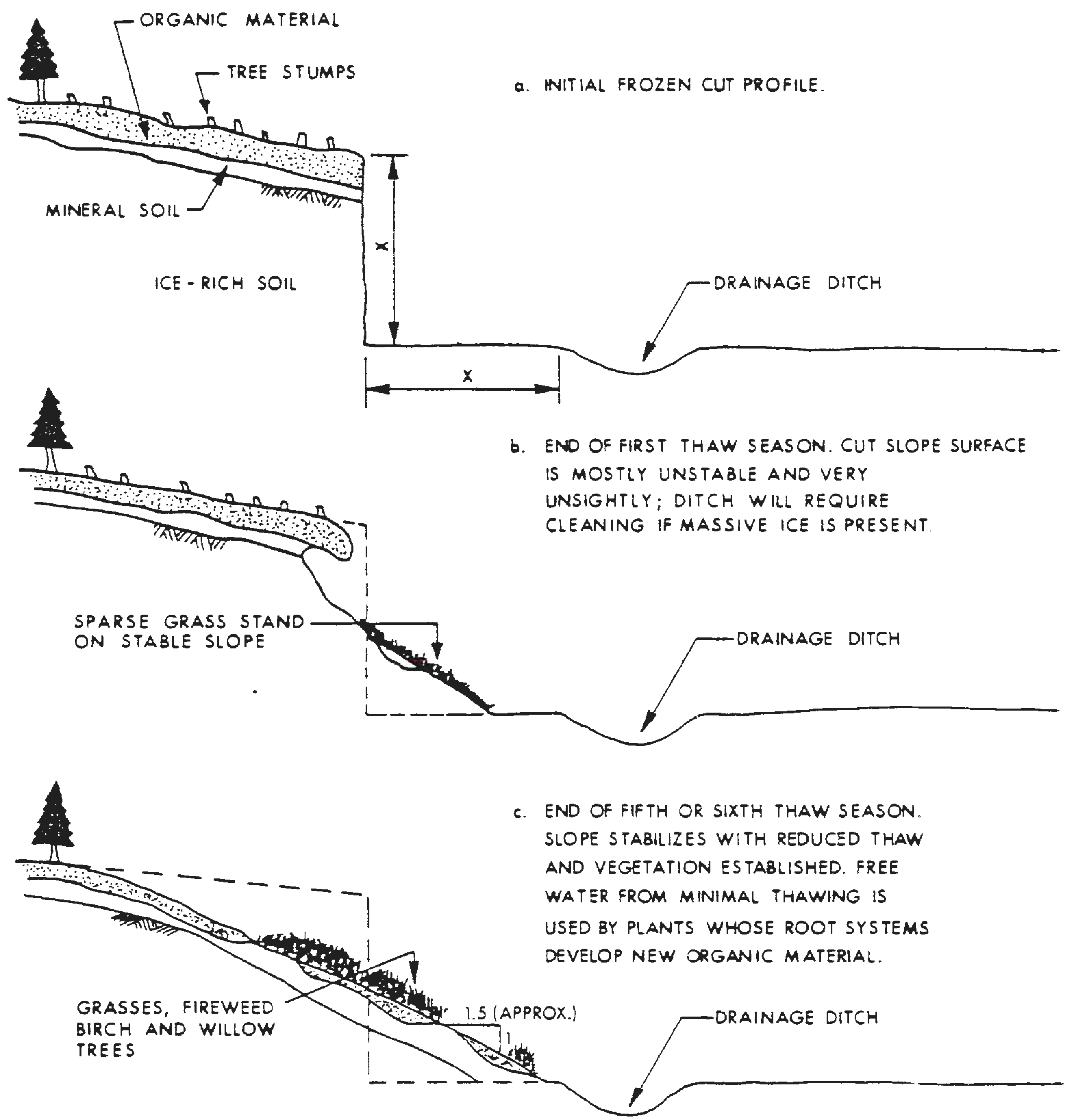
	DRAWN	CHECKED	APPROVED	APPROVED
BY	L.S.			
DATE	81 04 30	81 04 30	81-05-04	

SCALE N.T.S.

PREPARED BY YUKON PIPELINE DESIGN

FIGURE 4.3.9.

A4 FORM 250



(ADAPTED FROM BERG AND SMITH, 1976)

Foothills Pipe Lines (South Yukon) Ltd.

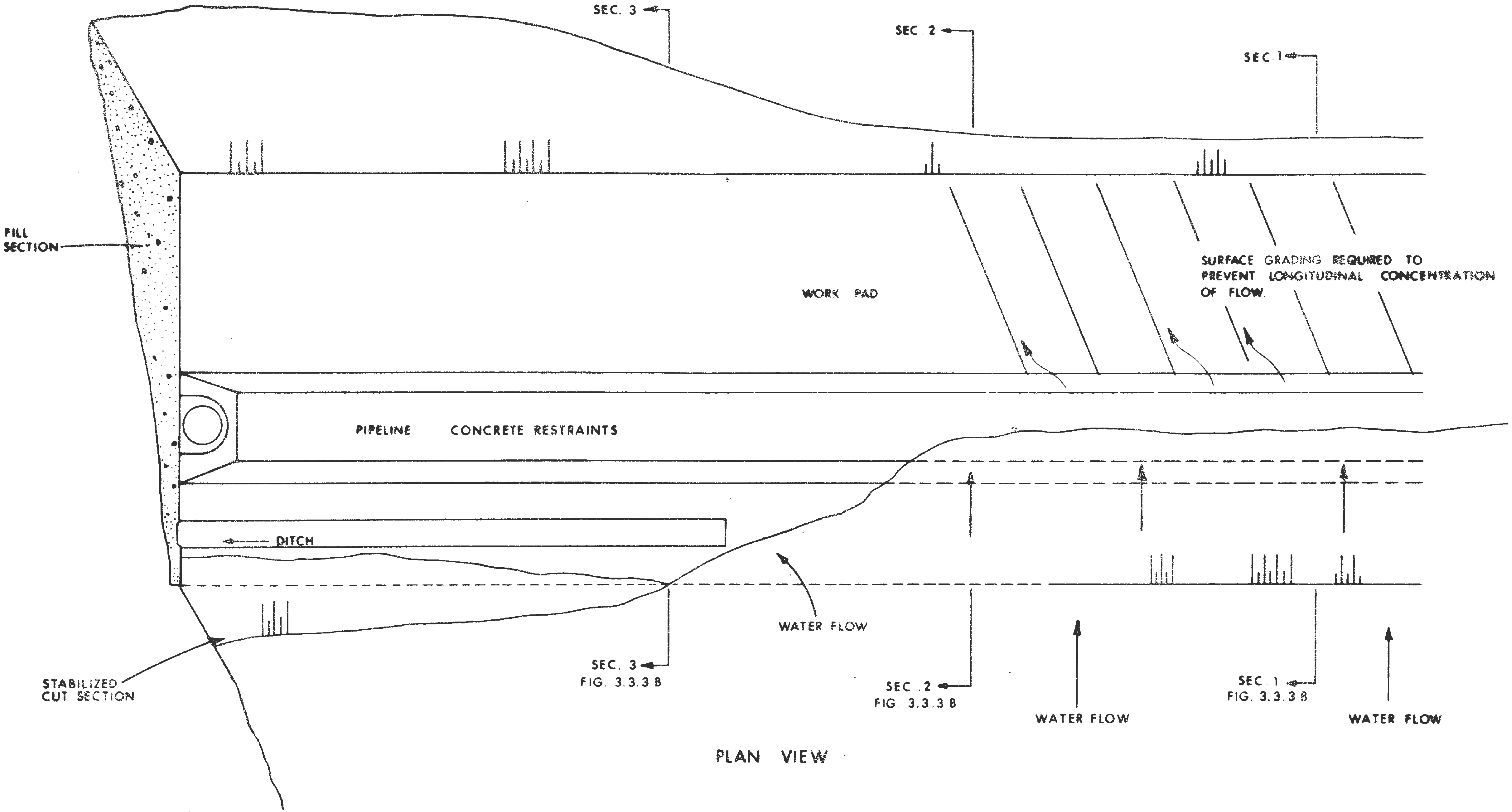
TITLE
THE ALASKA HIGHWAY GAS PIPELINE PROJECT

TYPICAL
CUT IN ICE - RICH SOILS

	DRAWN	CHECKED	APPROVED	APPROVED
BY	G. Y.	RPT	[illegible]	
DATE	81 09 17	810917	81 10 23	

SCALE N.T.S. PREPARED BY YUKON PIPELINE DESIGN

FIGURE 5.6.2



REVISIONS					
NO.		DATE	APPR.	BY	CHKD.

Foothills Pipe Lines (South Yukon) Ltd.

	DRAWN	CHECKED	APPROVED	APPROVED
BY	G. Y			
DATE	81 09 17	81.09.21	[illegible]	

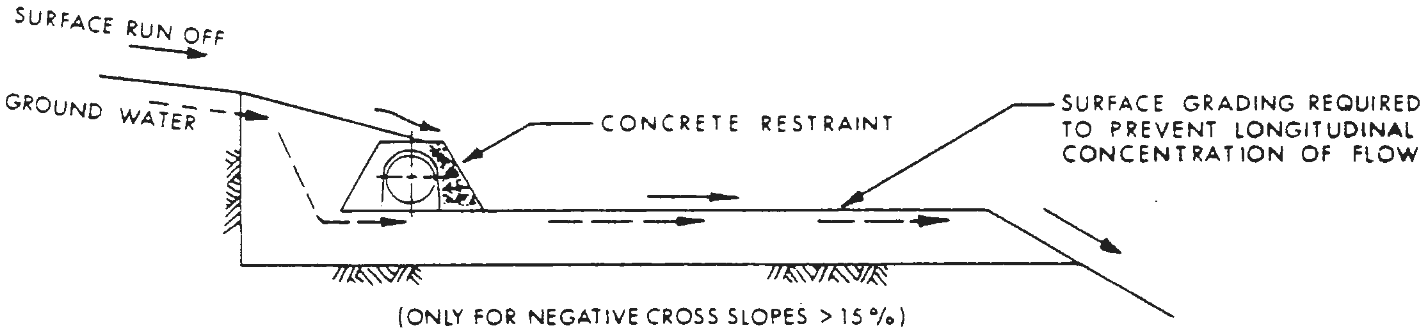
TITLE

THE ALASKA HIGHWAY GAS PIPELINE PROJECT

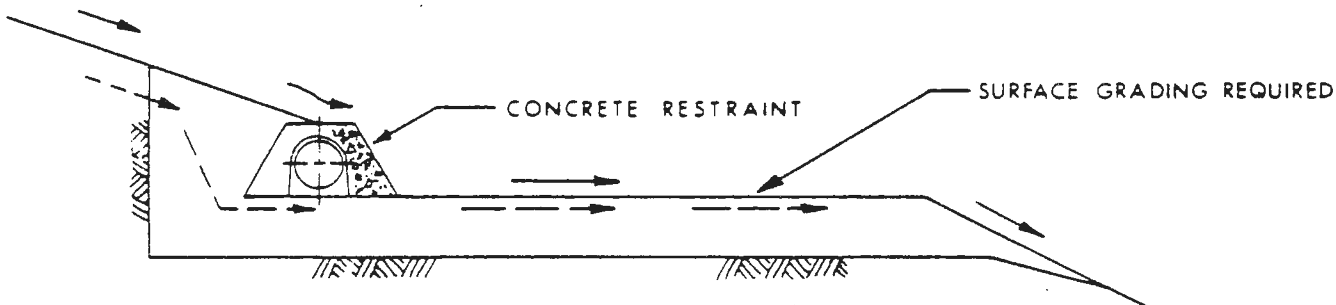
TYPICAL
DRAINAGE AND EROSION CONTROL
MEASURES FOR ABOVE GRADE
RESTRAINED CUT-FILL MODE

SCALE N.T.S PREPARED BY YUKON PIPELINE DESIGN

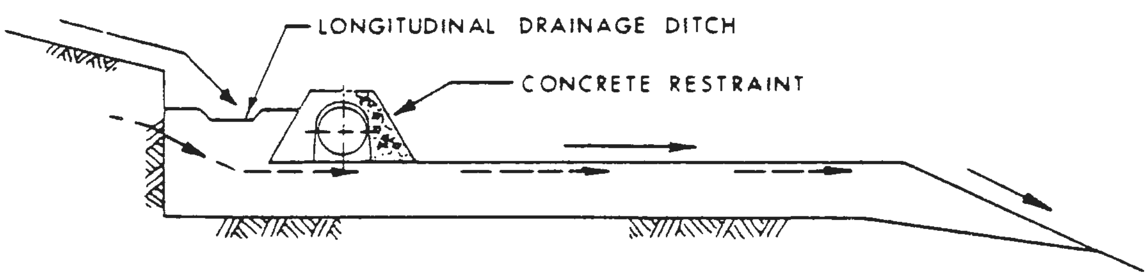
FIGURE 5.6.3.3 A



(ONLY FOR NEGATIVE CROSS SLOPES > 15 %)
SECTION 1



(ONLY FOR NEGATIVE CROSS SLOPES > 15 %)
SECTION 2



SECTION 3

NOTE: BOARD INSULATION NOT SHOWN ON THE SECTIONS FOR CLARITY OF DRAINAGE FLOW

Foothills Pipe Lines (South Yukon) Ltd.

TITLE

THE ALASKA HIGHWAY GAS PIPELINE PROJECT

TYPICAL
DRAINAGE AND EROSION CONTROL
MEASURES FOR ABOVE GRADE
RESTRAINED CUT-FILL MODE

	DRAWN	CHECKED	APPROVED	APPROVED
BY	G. Y.	[illegible]	[illegible]	
DATE	81 09 17	[illegible]	[illegible]	

SCALE N.T.S

PREPARED BY YUKON PIPELINE DESIGN

FIGURE 5.6.3.3 B

A4 FORM 258

APPENDIX A

STRUCTURAL DESIGN CRITERIA FOR THE RESTRAINED PIPELINE

CLIENT: **FOOTHILLS PIPE LINES (SOUTH YUKON) LTD.**

THE ALASKA HIGHWAY GAS PIPELINE PROJECT

STRUCTURAL DESIGN CRITERIA
FOR THE RESTRAINED PIPELINE

Revision 1 11 August 1981

ENGINEER: **YUKON PIPELINE DESIGN JOINT VENTURE (YPD)**

ASSOCIATED-KELLOGG LTD. PETROTECH LAVALIN INC.

CANUCK ENGINEERING LTD. MONENCO PIPELINE CONSULTANTS LTD.

1001 East Tower, Fifth Avenue Place 425 First Street S.W.
Calgary, Alberta T2P 3L8

Telephone 237-1422

PREPARED BY: P. St. J. Price, P.Eng.
T. Goss, P.Eng.

YPD PERMIT STAMP:

PROFESSIONAL ENGINEER
St. J. PRICE
ALBERTA

THE ASSOCIATION OF
PROFESSIONAL ENGINEERS,
GEOLOGISTS and GEOPHYSICISTS
OF ALBERTA
PERMIT NUMBER
P 3220
Yukon Pipeline Design
Joint Venture (YPD)

APPROVED BY: W.N. Wray, P.Eng.

PROFESSIONAL ENGINEER
WILLIAM N. WRAY
ALBERTA
22243
81-08-26

YUKON PIPELINE DESIGN JOINT VENTURE (YPD)

ASSOCIATED-PULLMAN KELLOGG LTD.
CANUCK ENGINEERING LTD.
PETROTECH LAVALIN INC.
MONENCO PIPELINE CONSULTANTS LIMITED

1001 425 1ST STREET S.W
CALGARY, ALTA T2P 3L8 TEL 237 1422

FOOTHILLS PIPE LINES (SOUTH YUKON) LTD.
DRAWING/DOCUMENT APPROVAL CHECK-LIST

TITLE	DRAWING/DOCUMENT NUMBER
STRUCTURAL DESIGN CRITERIA	R14
FOR THE RESTRAINED PIPELINE	
REVISION 1	

DOCUMENT APPROVAL CHECK-LIST

PIPELINE DESIGN

SENIOR MANAGER	81 08 26 DATE OF APPROVAL
MANAGER	81/08/17 DATE OF APPROVAL
SUPERVISOR	81/08/15 DATE OF APPROVAL

GEOTECHNICAL SERVICES

MANAGER	81/08/26 DATE OF APPROVAL

APPROVAL RECORD

DATE RECEIVED 81-08-12 DATE RETURNED 81-08-26

COMMENTS:

TABLE OF CONTENTS

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Table of Contents (continued)

STRUCTURAL DESIGN CRITERIA FOR RESTRAINED PIPELINE

1.0 INTRODUCTION

1.1 Purpose and Scope

The purpose of this report is to present the structural criteria developed to ensure integrity of the pipeline system. The criteria place limitations on combinations of stresses and strains to prevent the various modes of damage that will be prevented by design, construction and maintenance.

The report discusses the modes of structural damage protected against, the loading conditions, material properties of relevance for determining safe strains, the main analysis procedures used and the manner in which the stress analysis and reconciliation with the design criteria will be used to determine guidelines that will be incorporated into the pipeline design.

The strain criteria apply to the restrained buried and above grade systems which are subjected to substantial axial restraint and do not generally apply to unrestrained piping at compressor stations or elsewhere. Separate Design Criteria are being developed for unrestrained and partially unrestrained configurations.

1.2 Description of Design Conditions

The Alaska Highway Gas Pipeline in the Yukon Territory will pass through discontinuous permafrost and areas of relatively high earthquake risk. The flowing gas in the northwestern part of the pipeline route up to compressor station 311 in the Yukon (KP 64.2) is proposed to be chilled (operate below 0°C) and the flowing gas is proposed to be warm (operated above 0°C) downstream from compressor station 311.

Chilling the gas will freeze the pipeline into the permafrost. In unfrozen areas chilling could cause frost heave in frost susceptible soils. The design problems over the chilled section of the route are to develop designs which will eliminate heaving or will control heaving to acceptable amounts over the design life of the pipeline; to develop remedial control measures which will be used to arrest excessive heaving and assure structural integrity of the pipeline in problem areas during operation of the pipeline; and to develop monitoring methods and procedures which will be used to identify and observe pipe movements in unstable soil areas during operation of the pipeline and identify areas where remedial maintenance will be necessary. Delineation of the unfrozen frost heave susceptible areas along the route requiring special designs will be determined from the Geotechnical Atlas.

The warm section of the pipeline over the remainder of the route in the Yukon Territory will cause the permafrost areas to thaw. The nature of some of the permafrost soils in the Yukon is that they consist of ice-rich peat, organic silts and strata with excessive ice. After thawing, some of these soils would be unstable and would offer little restraint to the pipeline. Both stable and unstable soils after thawing could settle appreciably and the designs developed will assure stability of the pipeline and will avoid excessive settlements. Designs are also being developed for right-of-way stability and erosion and drainage control consistent with the requirements for pipeline integrity and the requirements of the Environmental Terms and Conditions. Geotechnical designs will be developed where necessary on a site specific basis for slope stability and thaw bulb stability on ice-rich slopes.

In the Shakwak and Dalton segments of the Denali Fault System which is characterized by high seismicity, the design problems in thawing ground will be seismic slope stability, thaw bulb stability on slopes, seismic liquefaction, pipeline stability and fault movements, if any active faults are crossed. No active faults have been identified at this time. Designs are being developed on a site specific basis for the seismic slope stability, thaw bulb stability, and seismic liquefaction conditions.

The design problems related to permafrost and seismic conditions over the warm section of the route are to develop designs which will eliminate or will limit differential movements of the pipeline in specific areas to acceptable amounts over the design life of the pipeline; to develop designs that will prevent overall instability of the pipeline in unstable ground or in ground with a liquefaction potential; to develop remedial control measures which will be used to limit excessive differential movements in problem areas during operation of the pipeline; and to develop monitoring methods with which to observe pipe movements during operation of the pipeline in order to identify areas where remedial maintenance will need to be implemented. Delineation of the permafrost areas along the route requiring special designs will be determined from the Geotechnical Atlas.

Designs, remedial control measures, and monitoring measures will be selected to assure structural integrity and safety of the pipeline, to be technically sound, practical and to mitigate adverse environmental impacts and to minimize capital and operating costs.

1.3 Basic Approach

Structural analyses of the pipeline response to combined operating loadings and differential frost heave, differential settlements, low soil restraint due to thawing, liquefaction or buoyancy effects, slope movements, fault movements, etc. determine the combined stresses and strains imposed on the pipeline and the conditions that could lead to damage or overall instability of the pipeline. A reconciliation of the results of these analyses with the stress, strain and stability criteria in this report provide the basis for determining design limitations and guidelines for the various loading conditions including maximum allowable temperature differentials, maximum allowable frost heave, maximum allowable settlements, soil support requirements for pipeline stability and field bend stability, etc., and design guidelines for the pipe movement monitoring system. Application of these design guidelines together with local geotechnical conditions and topography, geothermal effects, environmental and construction constraints and costs will enable appropriate construction modes to be selected along the route. The design criteria outlined in this report will prevent the various modes of structural failure or damage relevant to a buried pipeline that can be controlled by proper construction mode selection and by operations and maintenance.

The criteria outlined in this report are consistent with those used in the design and construction of the Western and Eastern Legs of the pipeline system in Alberta and South British Columbia, have been expanded to handle the special design problems in the discontinuous permafrost and earthquake prone areas in the Yukon Territory, and are therefore applicable to Zones 1 through 5. They are also consistent with the recommendations of the Northern Pipeline Agency summarized in the Position Paper on the Frost Heave Design Program (NPA, August 1979) and the Position Paper on the Differential Settlement, Structural

Stability, and Muskeg Design Program (NPA, February 1980). The criteria in this report apply to construction, pre-operation and operational loadings on restrained pipeline. Stress criteria for transportation, handling and stacking of pipe are documented elsewhere.

2.0 FAILURE DATA AND MODES OF STRUCTURAL DAMAGE

2.1 Failure Data

Research into the conditions that have resulted in disruptive failure of buried pipelines (Pipeline Research Committee of American Gas Association, November 1974; November 1969) has indicated the causes of most in-service incidents.

After a pipeline is placed in service, failures have occurred as a result of mechanical damage such as gouges and dents imposed during operation; environmental damage (such as corrosion); and by wrinkles, buckles, secondary loadings, sabotage, and internal combustion (Eiber, November 1974). Cathodic protection and pipe coating outerwrap will protect against environmental effects. The objectives of the metallurgical design include the provision of parent steel and welds with sufficient strength to withstand the nominal stresses and strains imposed on the pipeline, and with adequate toughness to prevent extension of sub-critical defects, to prevent unstable brittle fracture propagation and to control ductile fracture propagation (Maxey, November 1974; Kiefner, November 1969; Eiber, November 1969; Wilowski, Maxey and Eiber June 1977).

The structural design of the buried pipelne is concerned with the prevention or control of modes of damage such as overall instability, wrinkles, buckles, dents and tensile failures caused by combined primary and secondary stresses (Moschini, 1969) that can be controlled by design, construction, monitoring during operation and by maintenance.

2.2 Modes of Structural Damage

There are five modes of damage or failure associated with different combinations of loadings of relevance in the design of the buried gas transmission pipeline. Each of these depend on the type of stress or strain imposed by combined loadings at the time of failure. These modes of failure are overall instability (i.e. column buckling) local instability (i.e. wrinkling) longitudinal tensile rupture, circumferential tensile rupture, and denting. The criteria in Section 6 will protect against each of these modes of damage under normal operating and specified contingency conditions.

2.2.1 Overall Structural Instability

Overall instability would be caused by compression in the pipeline due to gas pressure, positive temperature differential and insufficient soil restraint to hold the pipe in the ground.

2.2.2 Wrinkling

Wrinkles could be caused by excessive longitudinal compressive strain in the pipe wall due to combinations of gas pressure, positive temperature differential, earthquake and compressive bending strains caused by differential movements and could also lead to fracture initiation if wrinkles develop to an advanced stage.

2.2.3 Longitudinal Fracture Initiation

Longitudinal fractures could be initiated by tensile hoop stress acting across a critical longitudinally oriented defect and could lead to ductile fracture propagation.

2.2.4 Circumferential Fracture Initiation

Circumferential fractures could be initiated by excessive longitudinal tensile strain acting across a circumferentially oriented defect in pipe steel or in girth welds and could lead to ductile fracture propogation.

2.2.5 Denting

Excessive ovalling or denting could be caused by excessive soil reactions or bearing pressures acting on the pipe and could hinder the passage of pigging devices or collapse the pipe under zero internal pressure conditions.

3.0 LOADING CONDITIONS

The main loading conditions of relevance in the pipeline design are those which can be controlled to prevent damage by design, by construction, by operations and by maintenance. These loadings include combinations of gas pressure, temperature differential, earthquake, weight of pipe plus other attachments, soil overburden, differential ground movement, buoyancy or liquefaction, and loss of ground support.

The loadings of interest could act independently or in combination and are classified into three groups. The first set will result from normal construction and operation of the pipeline and are designated as design loadings. The second will result from soil conditions and movements and are designated geotechnical loadings. The third could result from earthquake motions and are designated seismic loadings.

3.1 Design Loadings

Design loadings are determined by the system design and by ambient temperatures during installation. These loadings are essentially deterministic and include gas pressure, temperature differential, self weight of pipe and attachments and weight of gas or hydrostatic test medium.

3.1.1 Gas Pressure

For a given nominal outside diameter and yield strength of pipe, the required nominal wall thickness is determined according to applicable regulations, which in essence restrict the primary hoop stress to some level below the yield strength of the steel.

3.1.2 Temperature Differential

A temperature differential is defined as the difference between maximum or minimum operating temperature of the flowing gas and the reference temperature. The reference temperature is defined as the temperature of the pipe steel when the pipeline is installed in the ditch, and is restrained with zero longitudinal stress. The reference temperature will normally be at or near ambient temperatures at the time of installation of long lengths of pipeline. A positive temperature differential and gas pressure will develop an axial compressive force in the restrained pipeline requiring consideration of overall structural stability for some soil conditions particularly at field bends.

3.1.3 Hydrostatic Test Pressure

Test pressures required to prove strength are specified according to applicable regulations.

3.1.4 Dead Weight

Self-weight of pipe and attachments and weight of gas or test medium are deterministic loadings which for certain design conditions may need to be considered together with gas pressure and temperature differential to analyze stresses and strains caused by seismic and geotechnical loadings.

3.2 Geotechnical Loadings

Geotechnical loadings include differential soil movements, buoyant uplift and loss of ground support. Longitudinal strains which are additive to those developed by the design loadings will be developed by ground movements. The design criteria to be presented in Section 6 are based on a safe operating level and a maximum (critical) level for longitudinal strains. This forms the basis for determining the level of ground movements which would, in combination with design loadings, be permissable for the safe operation of the pipeline and those combinations which would cause critical combinations of stresses and strains which could lead to failure in one or more of the failure modes. The conditions are referred to as the "Design Condition" (e.g. Design Settlement) and the "Design Maximum Condition" (e.g. Design Maximum Settlement) respectively.

In those regions where thaw or frost susceptible soil conditions exist and monitoring and surveillance of the performance of the pipeline will be necessary, the stage when remedial maintenance should be undertaken will be determined by the "Design Condition" in accordance with the National Energy Board Gas Pipeline Regulation, subsection 71(2). The applicable regulation states:

> "In unstable soil areas, the company shall insure that particular attention is given by it to all sections of the pipeline where differential ground or pipe settlement or heaving is occurring and shall take measurements of the displacement at sufficient intervals and keep records of measurements so that trends toward critical stresses can be established and remedial action taken before combined stresses reach design limits of the pipeline".

The range between the "Design Condition and the "Design Maximum Condition" will enable the load factor against structural damage to be determined and, in conjunction with monitoring of pipe movements, will enable the time available in which to take remedial action to be estimated for site specific conditions during operation of the pipeline.

The geotechnical load conditions include differential soil settlement, static slope movements, differential frost heave, buoyant uplift, and overburden loads.

3.2.1 Differential Soil Settlement

This will result from thaw strain of the soil due to thermal regression of permafrost or frozen ground, loss of ground support due to thawing ground or due to erosion, or consolidation of thawing permafrost or unfrozen ground due to increased effective overburden pressure causing bending strains in the line.

3.2.2 Static Slope Stability and Slope Movements

Slope instability will be prevented by site specific geotechnical designs. Transverse movements of thawing ice rich slopes traversed by buried warm pipeline could occur causing bending strains or loss of support of the pipeline in these regions. Longitudinal thaw bulb movements or solifluction could also occur on slopes traversed or paralleled by the pipeline causing axial tension or compression in the pipeline.

3.2.3 Differential Frost Heave

This will be caused by ice segregation and by the water to ice phase change during freezing of unfrozen frost susceptible ground around the pipe as a result of the chilled gas flowing through the pipe, and will cause bending strains in the line. The potential for heaving of the pipe will exist in areas where gas temperatures will be maintained continuously below 0°C.

3.2.4 Buoyant Lift

This load will be caused by buoyant uplift whenever the pipe becomes partially or fully submerged in a water or saturated soil-water medium. This load is considered deterministic and spacing of concrete weights and anchors, etc., will be determined on the basis of this load and the applied design loads, such that stability is assured and combined stress levels are within allowable design levels, as required by NEB regulations.

3.2.5 Overburden Loads

Burial depths and select or non-select material backfill specifications will be determined so that overall pipeline stability particularly at overbends and sidebends is assured and so that excessive ovalling or denting does not occur.

3.3 Seismic Loadings

Seismic loadings are probabilistic and are ground motions and movements due to an earthquake. Travelling seismic waves will distort the ground and would impose longitudinal strains in the pipeline. The seismic motions which establish the strains are ground velocity, ground acceleration and velocity of transmission of seismic shear waves (Okamoto, 1973). Seismic ground motions could lead to slope instability, thaw bulb instability or liquefaction, or slope movements in certain areas.

Two levels of earthquake hazards are considered for the pipeline design in accordance with the recommendations of Dr. N. M. Newmark (Newmark Consulting Engineering Services, 1980). This concept of a dual earthquake design is in accordance with the principles developed for the design of nuclear reactor power plants (Newmark and Hall, 1969) and those being adopted for other structures and facilities (Newmark and Hall, 1973). The two design earthquakes are designated as a "Design Operating Earthquake" and a "Design Contingency Earthquake".The philosophy is that a pipeline would be designated to operate safely through a "Design Operating Earthquake" and to be allowed to suffer predefined damage as a result of a "Design Contingency Earthquake" using the same approach developed for the static ground movements in Section 3.2.

The "Design Condition" corresponds to ground movements caused by the Design Operating Earthquake and the "Design Maximum Condition" correspond to ground movements caused by the "Design Contingency Earthquake".

The seismic load conditions include ground strains caused by seismic motions, seismic slope stability and dynamic slope movements, seismic thaw bulb stability and movements, and seismic liquefaction.

3.3.1 Ground Strain

The seismic motions which establish ground strains are ground velocity, ground acceleration and velocity of transmission of seismic shear waves. The buried pipeline designs will be conservatively assumed to strain with the ground and to have nearly the same transient curvatures and longitudinal strains as the ground. (Newmark Consulting Engineering Services, 1980). For the above grade portions of the pipeline surface ground motions and displacements will be imparted through the construction pad under the line. For these construction modes the pipeline will be considered to behave as a structure in accordance with the recommendations of N. M. Newmark (Newmark Consulting Engineering Services, 1980).

3.3.2 Fault Movements

Vertical and horizontal displacements might occur where fault motions take place at well defined faults. No active well defined faults have been identified along the route.

3.3.3 Seismic Slope Stability and Dynamic Movements of Slopes

Earthquake designs will be implemented to assure that slope instability does not occur, especially with the buried warm pipeline on ice rich slopes. After several cycles of shaking, however, permanent displacements of a slope could occur causing differential bending strains or loss of support to the pipeline. In general transient displacements will not exceed about twice the maximum permanent displacement(Newmark Consulting Engineering Services, 1980). Seismic designs will be developed to assure thaw bulb stability on slopes traversed or paralleled by the pipeline. Transient and permanent displacements of the thaw bulb could occur causing axial tension or compression in the pipeline.

3.3.4 Seismic Liquefaction

An earthquake can cause some inundated sands or cohesionless soils to become "quick" or develop a liquefied condition which could cause buoyancy, pipeline instability or settlement conditions.

4.0 MATERIAL PROPERTIES

The important material properties which influence the ductile structural behaviour of a pipeline under applied loadings are the yield strength, the ductility and the relationship between stress and strain over the range that could be experienced by a particular system. From the point of view of the metallurgical design, the important properties are elongation, notch ductility and toughness.

The main failure modes of interest from a metallurgical point of view are longitudinal fracture initiation and ductile fracture propagation; brittle fracture propagation; and circumferential fracture initiation. Steel toughness, fracture initiation control and fracture propagation control are covered in the metallurgical design, the steel and weld specifications, and the Quality Assurance and Quality Control Programs.

In order to apply the design criteria that follow, it was necessary to establish the safe longitudinal tensile strains to prevent circumferential fracture, taking into account pipe temperatures, the properties of the pipe steel, the welding procedures used and the presence of metallurgical flaws or notches; and to establish the safe longitudinal compressive strains to prevent wrinkling under various operating conditions for the particular pipe sizes and specifications.

The welds are specified in the metallurgical design to withstand the maximum allowable longitudinal tensile strain defined in the structural criteria in the presence of a specified maximum allowable circumerential weld defect for the full range of operating and blowdown temperatures and pressures that will be experienced by the pipeline.

Wrinkling behaviour of pipelines is influenced mainly by internal pressure, the radius to wall thickness ratio and the relationship between stress and strain (Popov, Sharifi and Nagarajan, 1974). Full scale tests on the wrinkling behaviour of large diameter pipelines are described in the literature (Bouwkamp and Stephen, 1973), and analytical procedures to determine the compressive strains at which wrinkling could occur are available (Popov, Sharifi and Nagarajan. 1974; and Powell, Morris, Row, 1980). Analysis of wrinkling strains for the Alaska Highway Gas Pipeline are documented in the Structural Software Development Inc. Report (Powell, Morris, Row, 1980), and in addenda the Structural Software Development Inc. report which are presently being prepared.

5.0 ANALYSIS OF STRESSES AND STRAINS

The loadings discussed previously will impose nominal stresses and deformations in the pipeline. These can be calculated in a structural analysis using nominal specified dimensions. Internal pressure will impose a uniform hoop stress along the pipeline and a uniform longitudinal stress; temperature differentials and seismic motions will impose uniform longitudinal strains in the pipe. These stresses and strains will be uniformly distributed and symmetrical about the axis of the pipeline and are considered to be membrane stresses and strains. Longitudinal bending stresses and strains will be imposed by earth movements. Ovalling and denting caused by earth pressure on the pipeline will cause local circumferential bending stresses.

Combined membrane stresses due to design loadings are constrained within the elastic range of the steel and are calculated using simple elastic theories. A buried pipeline behaves as a beam-column and inelastic, nonlinear numerical analyses which account for large deflections, yielding and soil-pipe interaction are used to analyze deformations caused by combined design loadings and earth movements. The design criteria in the next section define the critical tensile and compressive strains that will be permitted. The numerical values of these strains depend on the pipe size, specification and operating conditions. The critical strains are used to determine "Design Conditions" and "Design Maximum Conditions" for earth movements from the results of parametric structural analyses and a reconciliation with the design criteria.

The computer programs used in the stress analysis include the PIPLIN and PIPANL computer programs (Copyright 1981).

6.0 STRUCTURAL DESIGN CRITERIA FOR BURIED PIPELINE

The design loadings, geotechnical loadings and seismic loadings will impose stresses and strains in the pipeline. The structural design criteria which place limitations on maximum allowable stresses and strains in the restrained pipeline are in accordance with the National Energy Board Act Gas Pipeline Regulations, Registration SOR/74-233, 10th April 1974, (as ammended); and the Northern Pipeline Act. The design and construction will be in compliance with CSA Standard Z184-M1979, and the Engineering Orders and Environmental Terms and Conditions issued by the Northern Pipeline Agency.

Combined hoop and longitudinal stresses, computed on an elastic basis, are limited to prevent excessive ductile demands on the steel. Longitudinal bending strains and curvature changes will be imposed by construction, settlement, frost heave, buoyant uplift, and movements at field bends. Curvature changes associated with bending are related to the maximum allowable longitudinal compressive and tensile strains in the pipe, including the longitudinal membrane strains. The maximum longitudinal compressive strains are limited to prevent wrinkling of the pipe and the maximum longitudinal tensile strains are limited to prevent excessive tension in the pipe wall. These strains are computed using an inelastic analysis. Ovalling of the pipe due to overburden or soil reactions are considered to prevent collapse or denting of the pipe under zero pressure conditions at deep burial depths, or due to differential movements respectively.

The maximum shear theory is adopted to predict the onset of yielding for combined stresses calculated on an elastic basis. This theory predicts that yielding will occur when the maximum shear stress at a point reaches the value of the maximum shear stress under tension.

The maximum shear stress is given by one-half the difference between the algebraically largest principal stress and the algebraically smallest principal stress at a given point in the pipe wall. Stress intensity is defined as twice the maximum shear stress. The criteria define allowable nominal stress and strain levels during operation of the pipeline. They also define maximum levels at which instability of the pipeline would be imminent or integrity or efficiency could be impaired.

6.1 Design Criteria

6.1.1 Membrane Stresses

6.1.1.1 Hoop Stress

Maximum possible Hoop stress levels due to gas pressure are used in the stress analysis. The maximum allowable operating pressure is based on the proof test pressure for a particular pipe size, wall thickness and specified minimum yield strength in CSA Standard Z184-M1979. The corresponding maximum possible hoop stress levels used in the stress analysis are as follows.

	Class Location	Maximum Stress
Maximum allowable hoop stress in line pipe sucessfully hydrotested to 1.0 of the specified minimum yield strength. (CSA Standard Z184-M1979 Table 6.5)	I	0.80 SMYS
	II	0.72 SMYS
	III	0.56 SMYS
	IV	0.44 SMYS

Maximum allowable hoop stress in line pipe sucessfully air tested to 0.90, 0.75, 0.50 and 0.40 of the specified minimum yield strength in class locations I, II, III and IV respectively. (CSA Standard Z184-M1979 Table 6.6 Clause 6.4.8.1.5; NEB Gas Pipeline Regulations Subsection 51(4)).	I II III IV	0.72 SMYS 0.60 SMYS 0.40 SMYS 0.32 SMYS
Maximum allowable hoop stress at uncased road crossings. (CSA Standard Z184-M1979 Clause 6.4.1.2.2, 6.4.1.2.3)	I II III IV	0.60 SMYS 0.50 SMYS 0.50 SMYS 0.40 SMYS
Maximum allowable hoop stress at uncased rail crossings. (CSA Standard Z184 - M1979 Clause 6.4.4.4.2)	Primary Secondary (or industrial)	0.2 SMYS 0.5 SMYS
Maximum allowable hoop stress at cased rail and road crossings. (CSA Standard Z184-M1979 Clause 6.4.4.3(a)).	I II III IV	0.72 SMYS 0.60 SMYS 0.50 SMYS 0.40 SMYS
Maximum allowable hoop stress at river crossings. (constraints adopted by Foothills Pipe Lines (South Yukon) Limited).	I II III IV	0.60 SMYS 0.60 SMYS 0.50 SMYS 0.40 SMYS

Maximum allowable hoop stress in fabricated pipe line assemblies (pipeline side of station isolating valve). (CSA Standard Z184-M1979 Clause 6.4.1.2.4(a))...........0.6 SMYS

6.1.1.2 Combined Membrane Stresses in Straight Pipe Due to Pressure, Temperature Differential and Earthquake

Stress intensity due to pressure and positive temperature differential............0.90 SMYS

Stress intensity due to pressure, positive temperature differential, and compressive stress due to design operating earthquake.........................1.00 SMYS

Maximum longitudinal compressive strain computed using an inelastic analysis due to pressure, positive temperature differential, and compressive strain due to design contingency earthquake...............ε_c'

Where ε_c' is chosen to prevent formation of a wrinkle due to membrane strains. (ε_c' = 0.4 percent for detailed design. Actual critical compressive strains will depend on local operating conditions and will be used where necessary in the final design stages).

6.1.1.3 Longitudinal Tensile Stress

	Class Location	Maximum Stress
Maximum longitudinal tensile stress due to pressure, negative temperature differential, and tensile stress due to design operating earthquake.	I	0.72 SMYS
	II	0.60 SMYS
	III	0.50 SMYS
	IV	0.40 SMYS

6.1.2 Combined Bending and Membrane Stresses and Strains

6 1.2.1 Design Maximum Condition

Combined bending strains due to differential pipe movements; and membrane stresses and strains due to pressure and temperature differential computed in an inelastic analysis.

Maximum longitudinal tensile strain ....ε_t''
Maximum longitudinal compressive strain......ε_c''

6.1.2.2 Allowable Design Condition

Combined bending strains due to differential pipe movements; and membrane stresses and strains due to pressure, temperature differential, and "Design Operating Earthquake" computed in an inelastic analysis.

Maximum longitudinal tensile strain ....0.8 ε_t''
Maximum longitudinal compressive strain......0.8 ε_c''

Combined bending strains due to differential pipe movements; and membrane stresses and strains due to pressure, temperature differential, and "Design Contingency Earthquake" computed in an inelastic analysis.

Maximum longitudinal tensile strain............. 1.00 ε_t''
Maximum longitudinal compressive strain.......... 1.00 ε_c''

Where $\varepsilon_t'' = 0.5$ and ε_c'' is equal to the compressive strain when a wrinkle may form ($\varepsilon_c'' = 0.5$ percent for detailed design. Actual critical compressive strains will depend on local operating conditions and will be used where necessary in the final design stages).

6.1.3 Pipeline Stability

Safe span length between anchors or pipe supports or areas where pipe is subjected to loss of support and is designed for elastic stability will be the smaller span determined from the following conditions:

Axial compressive load due to pressure
and positive temperature differential........$0.8F_{cr}$

where, F_{cr} = critical load for elastic instability.

Stress intensity due to gas pressure,
temperature differential, and maximum
compressive bending stress...................1.00 SMYS

In other areas sufficient uplift resistance and bearing restraint will be provided to prevent excessive compression or tension and overall instability of the pipeline, particularly at field bends.

6.1.4 Free Bending During Construction

Maximum compressive bending strain
for wrinkling....................................ε_c'''

Allowable compressive bending strain
during construction.............................$0.80\varepsilon_c'''$

Where ε_c''' is equal to the compressive strain when a wrinkle may form ($\varepsilon_c''' = 0.35$ percent for detailed design).

6.1.5 Ovalling

Maximum circumferential stress due to weight of overburden, or soil reactions, under zero internal pressure to protect against collapse or denting of the pipe.............................0.80 SMYS

This limit may be exceeded provided detailed calculations show that out-of-roundness due to overburden at deep burial depths or due to soil reactions will not interfere with the passage of pigging devices and that collapse or denting will not occur.

where SMYS is the specified minimum yield strength of the steel

7.0 DESIGN GUIDELINES

The function of the design criteria in the design of the system is to determine safe limits for temperature differential, earth movements and to determine minimum soil support or special support requirements to stabilize the pipeline in unstable areas. The stress analysis for these and other conditions and the design guidelines derived from the reconciliation of the stress analysis with the design criteria will be provided in the detailed stress analysis documentation.

7.1 Gas Pressure

Wall thickness and hoop stress level are chosen in accordance with applicable codes and regulations. Material properties of the pipeline are chosen in the metallurgical design to prevent brittle fracture propagation or ductile fracture initiation as a result of Design Maximum Loadings.

7.2 Temperature Differential

Maximum allowable positive and negative temperature differentials in each earthquake zone can be determined from the design criteria. These will be controlled by limiting maximum operating gas temperatures at compressor stations.

7.3 Differential Ground Movements

Differential ground movements could be caused by soil settlements, static or seismic slope movements, fault movements, liquefaction or by frost heave (in the chilled system). These loadings will impose bending strains in the pipeline and these strains, combined with membrane strains are restricted in the design criteria to prevent fracture initiation in tension or wrinkling in compression and to prevent denting or excessive ovalling.

Soil-pipe interaction analyses are used to determine the differential movements corresponding to the "Design Condition" and the "Design Maximum Condition". Differential settlements or differential frost heave will be controlled within the allowable design levels by design, surveillance and maintenance.

7.4 Pipeline Stability

Instability of the buried pipeline could be caused by positive temperature differential and insufficient soil restraint and would be characterized by the pipeline pushing downward, sideways or out of the ground. This condition will be avoided by locating the pipeline in stable soils which will provide sufficient bearing support, by using select backfill materials in unstable soil areas and by providing sufficient uplift resistance to restrain the pipe in the ground.

Uplift resistance, and soil bearing support requirements to stabilize straight pipe and to stabilize field bends are determined from structural analyses using soil properties derived for the various soils that will be encountered along the route.

7.5 Special Designs

Special designs include road crossings, river crossings, slope stability and movements, muskeg crossings, anchoring restraints and foundations and seismic liquefaction.These designs will be consistent with the requirements for integrity of the pipeline.

7.6 Construction Stresses

Maximum burial depths and compaction requirements where necessary can be determined from the criteria corresponding to the out-of-roundness and stress limits for ovalling.

Curvature of river crossing profiles and temporary support requirements to avoid wrinkling or excessive tension will be determined for design and construction purposes so that the criteria for construction stresses will not be violated.

7.7 Monitoring

The safe range of pipe movements for settlements and frost heave will be determined in the stress analysis and reconciliation with the design criteria. The monitoring system, to be applied in unstable soil areas, will be designed to have sufficient measurements intervals and frequency of measurements to identify trends toward critical stress in accordance with the NEB Regulations at which time remedial maintenance procedures would be implemented.

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APPENDIX B

DRAINAGE AND EROSION CONTROL DESIGN CRITERIA

APPENDIX B

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2-00-02-00-TP-0051	TYPICAL TRENCH PLUG
2-00-02-00-TP-0052	TYPICAL EMBANKMENT OPENING
2-00-02-00-TP-0053	TYPICAL DRAINAGE DITCH CHECKS
2-00-02-00-TP-0054	TYPICAL CULVERT INSTALLATION

Figure No.	Title
1.4.5	TYPICAL CUT IN ICE-RICH SOILS

DRAINAGE AND EROSION CONTROL DESIGN CRITERIA

1.0 INTRODUCTION

This section presents design criteria for the drainage and erosion control measures introduced in the previous section. The measures are grouped as primary, secondary and tertiary.

Primary measures and specifications provide the minimum standard required along the right-of-way. With the possible exception of culverts, all primary measures will be constructed with available mainline equipment, and will use readily available material. Readily available material is defined as either native material or select borrow material.

Primary measures include:

a) Trench plugs;
b) diversion dikes;
c) channel or waterway restoration;
d) mound breaks;
e) culverts;
f) embankment openings;
g) ditches or imposed waterways.

Secondary measures and specifications may be required to enhance the performance of primary measures, to protect the primary measures against erosion or to satisfy site specific pipeline integrity.

Secondary measures include:

a) Coarse material fill;
b) culvert inlet structures;
c) culvert outlet structures;
d) guide banks;
e) channelization;
f) drainage ditches;
g) subdrains.

Tertiary measures generally consist of armoring secondary measures to ensure that those measures employed to provide pipeline stability would survive design flow conditions. (They should be required only under severe hydraulic conditions.)

1.1 DESIGN FLOWS AND FAILURE CONSIDERATIONS

Design flows and related D & E controls considered for the design reflect the mechanism and magnitude of potential failure. D & E control measures are designed to protect pipeline integrity which might be threatened during the course of a single flood event.

Design flows considered are:

a) An instantaneous peak flow having a return period in the order of 100 years, (flow regime 1);

b) a lower magnitude peak flow having a return period in the order of 10 years, (flow regime 2);

1.1.1 Flow Regime 1

Flow regime 1 is used for D & E control measures design where a single flood event will threaten the integrity of the pipeline.

Flow regime 1 applies to the:

a) Design of permanent culvert facilities where natural concentrations of flow exist;

b) design of erosion control measures at embankment openings.

Estimates of this design flow are provided by the Hydraulic Consultants.

1.1.2 Flow Regime 2

Flow regime 2 is used for D & E control measures design where multiple flood events could be experienced before threatening the integrity of the pipeline.

Flow regime 2 applies to:

a) Specification of material for culvert approaches and outlet sections (Section 4.3);

b) consideration of material requirements and reconstructed geometry of small streams where channel restoration or channelization may apply;

c) mound breaks and diversion dikes;

d) longitudinal drainage ditches.

This flow corresponds to about 0.66 times the design flow regime 1 (Hydraulic Consultants).

1.2 DESIGNATED MATERIALS

Materials are categorized into native, borrow, special and manufactured.

1.2.1 Native Materials

Native soils are categorized on the basis of a soil erodibility index (SEI) for bare soils provided by the Geotechnical Consultants. The categories and relevant parameters are as follows:

a) SEI 1: low erodibility, maximum allowable velocity range from 1.0 m/s to 1.5 m/s; typically gravel, peat or compacted clay soils;

b) SEI 2: moderate erodibility, maximum allowable velocity range from 0.5 m/s to 1.0 m/s; typically medium to coarse sand or clay till;

c) SEI 3: high erodibility, maximum allowable velocity less than 0.5 m/s; typically silt, silty sand or fine sand.

1.2.2 Borrow Materials

Six categories of material may be used for D & E Control facilities:

a) Class A, 9.5 mm minus screened pipeline bedding and padding material;
b) Class B, 19 mm minus crushed sand and gravel;
c) Class C, 90 mm minus sand and gravel;
d) Class D, 100 mm minus general fill material;
e) Class E, 250 mm minus erosion protection material;
f) Rock riprap Class I, D_{100} of 225 - 300 mm, D_{50} of 160 - 230 mm and D_{15} of 125 - 175 mm.

1.2.3 Special Materials

Dry powdered natural bentonite or equivalent expandable, highly plastic clay may be required for trench plugs.

Rock riprap heavier than Class I may be required for special designs at river and stream crossings.

1.2.4 Manufactured Materials

Galvanized culverts and galvanized premanufactured end sections will be required as follows:

Type	Size (mm)	Steel Thickness (mm)	Corruguations (mm)	Pre-manufactured End Sections
Circular CSP	600	1.6	68 x 13	no
Circular CSP	800	1.6	68 x 13	no
Circular CSP	900	2.0	68 x 13	no
Circular CSP	1200	1.6	125 x 25	yes
Pipe-arch CSPPA	1870 x 1230	3.5	68 x 13	yes
Pipe-arch CSPPA	2130 x 1400	3.5	68 x 13	yes

CSP: Corrugated Steel Pipe
CSPPA: Corrugated Steel Pipe Pipe-Arch

For all culverts, total length should be a multiple or a combination of standard section lengths e.g., 4 m, 5 m or 7 m. Culvert sections should be joined together with 600 mm wide galvanized dimpled band connections.

Filter cloth will be required for trench plugs.

1.3 LEVELS OF EROSION PROTECTION

Erosion protection requirements are determined by the velocity of the water flowing over the material. Using this principle the design of erosion control measures incorporates five levels related to velocities expected. The extent of the protection implemented is determined by the SEI and the water velocities expected.

Application of erosion protection is limited to localized areas experiencing sufficient flows to require protection, for example culvert outlets and drainage ditches. For a higher level of erosion protection, the thickness of a same class of material is increased as specified to compensate for fines washed out during floods and the natural stabilization process.

1.3.1 Level 0:

For velocities of 0 to 1.0 m/s place a 200 mm layer of Class D material (or alternatively 200 mm of soil having a SEI of 1).

1.3.2 Level 1:

For velocities of 1.0 to 1.5 m/s place a 400 mm layer of Class D material.

1.3.3 Level 2:

For velocities of 1.5 to 2.5 m/s place a 300 mm layer Class E material.

1.3.4 Level 3:

For velocities of 2.5 to 3.5 m/s place a 500 mm layer of Class E material.

1.3.5 Level 4:

For velocities of 3.5 to 5 m/s place a 600 mm layer of material meeting the specifications for rock riprap class I.

1.4 BURIED MODE OF CONSTRUCTION

Drainage and erosion control requirements for the buried mode of construction will generally be determined during construction. Designs should be in accordance with the guidelines presented herein.

1.4.1 Channel Restoration

Channel restoration guidelines apply for cross drainage wherever identifiable channel and intermittent drainage courses (swale or gully) are encountered which are capable of supplying some concentration of flow.

Channel restoration includes:

a) Restoration of intermittent drainage courses (swale, gully) to their approximate natural geometry and slope;

b) restoration of waterway channels to their approximate natural geometry and slope;

c) erosion control by provision of bed and bank material which is of equal or greater coarseness than the native channel material, and protection of exposed floodplain materials if native material is easily eroded.

1.4.1.1 Restoration of Waterway Channel

Restoration of the channel to its approximate natural geometry and slope applies whenever a waterway channel can be identified. The restored channel should have dimensions as follows:

a) Width not less than the width of the active channel;

b) height equal 1.5 m above the channel bottom or height equal to high water marks, whichever is greater.

The restored channel should be formed with a constant bed slope joining the natural channel bed at both upstream and downstream of the disturbed area.

1.4.1.2 Channel Erosion Control

Bed and bank material of equal or greater coarseness than native channel material should be used where the native channel is composed of erodible materials. If unavoidable channels are formed in easily erodible materials, such materials should be adequately protected. Class E material should normally provide the maximum size of material required.

If construction through an identifiable floodplain or muskeg region results in surface exposure of silty materials (high Soil Erodibility Index, SEI 3) such materials should be adequately protected.

Sections of winter construction may require some channel restoration work to be carried out during the following seasons, due to the fact it may not be possible to identify small channels during the initial winter construction period.

1.4.2 Mound Breaks and Diversion Dikes

1.4.2.1 Mound Breaks

Mound break guidelines and associated measures will apply to regions where no identifiable channels exist. The mound break will consist of about a 4 m break in the backfill mound which can be formed in a single pass of a dozer or grader.

Mound breaks should be provided at the bottom of all natural depressions capable of providing cross drainage. Between channel restorations, maximum average mound break spacing will vary with longitudinal slope and exposed soil type as follows:

		MAXIMUM AVERAGE BREAK AND DIVERSION DIKE SPACING		
	Longitudinal Slope	SEI 3(*) (silts or fine sands)	SEI 2 (coarse sand or clay till)	SEI 1 (gravel, peat or compacted clay)
	less than 2%	65 m	150 m	not required
	2% - 5%	50 m	65 m	150 m
(**)	5% - 10%	30 m	50 m	65 m
(***)	10% - 20%	15 m	30 m	50 m
(****)	20% - 40%	10 m	15 m	30 m
	greater than 40 %	6m	10 m	15 m

(*) SEI: Soil Erodibility Index: 3(high), 2(medium), 1(low).

(**) Longitudinal slopes greater than 5% require a diversion dike with each mound break.

(***) Longitudinal slopes greater than 10% require a trench plug with mound break and diversion dike.

(****) Longitudinal slopes greater than 25% should be carefully assessed to determine possible subdrain requirements.

Mound breaks should be spaced at not more than 50 m in muskeg areas.

Mound break spacings proposed are consistent with spacings adopted for previous pipeline work. The principle of the variable spacing approach is to limit acccumulated water flows to values which the terrain will withstand. Some limited longitudinal erosion may occur due to the washing of fines from the exposed material, however the overall right-of-way should remain stable.

1.4.2.2 Diversion Dikes

Diversion dikes are required with mound breaks on longitudinal slopes greater than 5% to direct flow off the right-of-way. Diversion dike configurations are illustrated on drawing 2-00-02-00TP-0050.

If the dike is made of non-select material (trench spoil or native fill), the top width and the height of the dike should be about 1.0 m.

If silty soils are used in construction of diversion dikes, the upslope face of the diversion dikes should be protected to Level 0 erosion protection.

If the entire dike is made of Class D material, the top width and the height of the dike should be about 0.6 m and no protection against erosion is needed for the dike.

In every case, the height of the diversion dike should be greater than the anticipated settlement.

Diversion dikes should be skewed downhill such that the downslope gradient is about 5%, to limit erosive forces by surface flows. The dikes should span the full width of the disturbed area and should be extended 1 to 3 m into undisturbed vegetated terrain on the downslope side to ensure that water escapes the right-of-way. They should end randomly to discourage concentration of flow along the edge.

1.4.3 Trench Plugs and Subdrains

Groundwater flow within the pipeline trench will be controlled by trench plugs as a standard measure. Subdrains will only be used as a special measure under severe conditions.

1.4.3.1 Trench Plugs

Where erosion of the backfill from water flowing through the pipeline trench is a potential problem, impervious pipeline trench plugs should be placed across the trench. This will force the groundwater up to the surface and off the right-of-way.

The extent of trench plug erosion protection is limited to the pipeline trench itself. A trench plug should not be considered as a stabilization measure for the entire right-of-way. Slope stability concerns, particularly in the case of thawing of frozen soils and generation of excess pore pressure, will be considered as part of the geotechnical design.

The trench plugs should be generally located as follows:

a) With mound break and diversion dike where the longitudinal pipeline slope is greater than 10%;

b) at the top of slopes having a gradient greater than 10% and where required to assist in removing water from the trench before it flows on a steeper grade;

c) At the edges of any perched muskegs or other elevated regions of high moisture content, to prevent drainage of such regions through the pipeline trench.

Each trench plug must be installed with a mound break and a diversion dike.

Trench plugs should not be installed where an unweighted pipe has a trench depth to bottom of pipe less than 2 m and longitudinal slope less than about 10%. Trench plugs under these conditions could promote pipeline instability due to buoyancy.

The 1.0 m thick impervious trench plug formed of natural bentonite or other acceptable material should be installed in the pipeline trench as illustrated on the typical drawing 2-00-02-00-TP-0051. Upslope of the plug a 1.0 m thick free draining gravel filter should be installed with filter cloth which prevent infiltration of fines into the gravel filter. The associated diversion dike should be located such that the uphill toe of the dike coincides with the downhill edge of the gravel filter at the centreline of the pipeline.

1.4.3.2 Subdrains

Subdrains are used to lower a high groundwater table within the pipeline right-of-way. Subdrains will be considered as a special measure under conditions of possible shear failure of material within the pipeline trench. For purposes of design assessment, assumed shear failure of saturated sand bedding material gives a critical slope of 16 degrees or 29%. This indicates that longitudinal slopes greater than 25% should be considered for subdrain application where high ground- water conditions exist.

Given a longitudinal slope greater than 25%, subdrains should only be required if:

a) Native soils are frozen or are composed of poor draining unfrozen soils;

b) a present or potential flow source exists. This could be identified by surface drainage patterns, springs, a muskeg or other indication of high water content, or by borehole evidence of very ice-rich material within the ultimate thaw-bulb upslope of the critical area.

If conditions requiring a subdrain are encountered in unfrozen soils, details for construction may be directly adopted from those existing for pipelines in southern regions.

If soil is frozen, conventional subdrains cannot be used because they will likely be frozen and hence ineffective. A conceptual solution to the problem of providing a subdrain in frozen soils is to provide a non-conventional subdrain which runs parallel to and directly beneath the pipeline. The subdrain would extend the full length of the critical slope and would drain into coarse gravels provided at the toe of the slope. During the period prior to pipeline operation, potential groundwater problems would be handled by trench plugs. During initial operation of the pipeline, the subdrain would be quickly warmed and should be fully functional before the time the thaw-bulb around the pipe allowed the groundwater flow to bypass the trench plugs.

1.4.4 Drainage Ditches and Drainage Ditch Checks

1.4.4.1 Drainage Ditches

For the below grade mode in through-cut conditions which do not allow diversion of right-of-way surface flows onto undisturbed terrain, a surface drainage ditch should be provided to convey flows downslope until the first available point of cross drainage. The ditch should parallel the pipeline centreline, starting at the uppermost mound break to be affected by this drainage condition. Ditch layout and configuration shall be as shown on the drawing 2-00-02-00-TP-0050 (sheet 2). Ditch bottom should be protected to Level 1 for longitudinal slopes less than 15%, and Level 2 for longitudinal slopes greater that 15%. Surface drainage may be provided by ditches with diversion dikes as illustrated on the drawing 2-00-02-00-TP-0050 (Sheet 1).

For the abovegrade restrained mode in cut conditions, a surface drainage ditch should also be provided to convey flow downslope until the first available point of cross drainage as illustrated on the drawing 2-00-02-00-TP-0054 (sheet 1).

The drainage ditch geometry is not critical. The drainage ditch should have a depth of about 0.3 m and a width of about 1.5 m.

1.4.4.2 Drainage Ditch Checks

Ditch checks should be used in drainage ditches for velocity or sediment control. Ditch checks should be installed where required by Manager on longitudinal slopes greater than 10%. They may be used for temporary or permanent control. Temporary ditch checks could be made of hay bales or equivalent degradable material and permanent ditch checks should be made of free-draining granular material as shown on the typical drawing 2-00-02-00-TP-0053.

Ditch checks spacing (L) is determined by the following formulae:

$$L = \frac{H - 0.2}{S_D - S_S}$$

If ditch checks are used for velocity and sediment control.

$$L = \frac{H}{S_D - S_S}$$

If ditch checks are used for velocity control.

Where:

L = Spacing of ditch checks (m);
H = Ditch check height (m);
S_D = Design slope (m/m);
S_S = Stable slope for the ditch material (m/m).

1.4.5 Cut Slope Treatments

In ice-rich terrains, cut slopes will generally be vertical as shown in Figure 1.4.5. To allow for natural slumping of this cut, the parallel interceptor ditch should not be installed any closer (from the initial toe of the cut) than a distance equal to the height of the cut. Vertical cuts in excess of 5 m high may require special design based on site specific geotechnical criteria and are beyond the scope of this report.

1.5 ABOVEGRADE RESTRAINED "CUT-FILL" MODE OF CONSTRUCTION

In the abovegrade "cut-fill" restrained mode of construction, there should be no interception of significant concentrated flows. The surface of the workpad downslope of the pipeline should be graded to a minimum cross slope to encourage water not to concentrate and flow longitudinally along the pipeline. This grading should be done as a standard measure with this construction mode.

1.6 ABOVEGRADE RESTRAINED MODE OF CONSTRUCTION

In the abovegrade restrained mode of construction, cross drainage of flow will be provided either by culverts or embankment openings. In cut sections, to prevent any erosion from undermining the concrete pipeline restraints, a shallow ditch as described in Section 4.4.4 should be provided to confine parallel flows and any erosion which might occur.

Single culvert cross drainage facilities will be used for conditions where estimated design flows do not exceed about 4.0 m^3/s. Where estimated flow is greater than 4.0 m^3/s or severe aufeis conditions exist, an embankment opening is generally considered necessary.

1.6.1 Culvert Facilities

Culvert wall thickness and corrugations are based on dynamic design load for off-highway trucks (type 773B-50 ton) and on a 300 mm minimum cover over the 600, 800 and 900 mm circular culverts, and a 600 mm minimum cover over the 1200 mm and the pipe-arch culverts.

Channelization, guide banks and erosion protection materials are the erosion control measures which may be required for culverts.

1.6.1.1 Culvert Location and Installation

The locations of culverts shown on the alignment sheets are approximate and subject to field adjustment. Culverts should be located at all identified channels, and at the bottom of all gullies and swales. Culvert locations at the Alaska Highway have been used for guidance.

Drainage ditch installation as part of maintenance activity should be provided between culverts in areas where ponding of water on the right-of-way occurs.

Specified culvert positioning with respect to the existing ground surface is made with consideration of critical flow velocity through the culvert, ponding at the culvert inlet and ease of maintenance. Culverts should be installed on natural grade except for the 600 mm, 800 mm and 900 mm diameter culverts installed on natural slopes greater than 2%. For these culverts, the invert at the culvert inlet should be 0.1 m below the natural ground surface and the invert at the culvert outlet should be 0.1 m above natural ground surface.

To minimize sedimentation within the culvert, all culverts slope should be greater than 1%.

Culverts without end sections (600 mm, 800 mm, and 900 mm diameter) should be installed with projected ends which extend one half the culvert diameter at the inlet and one culvert diameter at the outlet both beyond the toe of the embankment.

Coupling of culvert sections should be avoided under pipeline concrete restraints. A culvert section of 7 m should be used under pipeline concrete restraints in order to facilitate maintenance work should any culvert couplings fail.

Where insulation is provided in the workpad, insulation should be placed below each culvert as shown on the drawing 2-00-02-00-TP-0054 (sheet 2).

Class B material should be used for culvert bedding and padding, as shown on the drawing 2-00-02-00-TP-0054 (sheet 2). The bedding is that portion of the foundation which is shaped to contact the bottom of the culvert. The bedding material should be at least 150 mm thick. A uniform blanket of loose material should cover the shaped bedding to a depth sufficient to allow the corrugations to become filled with the material (American Iron and Steel Institute, 1971 and 1980). The bedding should be wide enough to permit efficient compaction of the backfill under the haunches of the culverts, but not so wide as to interfere with bolting procedures.

The backfill and padding material should be placed alternatively in 150 m layers on both sides of the culvert and compacted to a minimum of 95% standard Proctor density during summer construction and 90% standard Proctor density during winter construction. This compaction could be manual or mechanical depending upon field conditions.

Pipe-arch culverts exert greater pressures against the soil at the bottom corner plates than elsewhere around the culvert. It is very important in pipe-arch installations to ensure that relative movement of the corners to the bottom is favorable. A softer or yielding foundation under the bottom as compared to the corners is essential.

1.6.1.2 Culvert Sizing

The culvert sizing procedures used for design is provided in Appendix A of this report.

Estimated variables which are used in the design are:

a) Design peak flow having a return period in the order of 100 years;

b) cross slope;

c) culvert skew;

d) culvert length;

e) tailwater conditions;

f) terrain storage capacity upstream of culvert.

Culverts are designed on the basis that design flow will pass through with a headwater height less than or equal to the culvert diameter. ($HW \leqslant 1D$).

Culvert capacity reduction due to excessive settlement or due to obstruction by ice, sediment or debris is in most cases not considered in the design. The integrity of the culvert installations will be assured by regular maintenance to rectify these problems.

1.6.1.3 Channelization and Culvert Skew

The requirement for skew of the culvert across the right-of-way must be addressed on a site specific basis, considering the state of channel development and terrain slopes. The proposed maximum skew angle of 45 degrees is adopted from highway and railway practices.

It is recommended to align the culvert slope with the terrain slope whenever channels or steep sloped gullies are encountered.

Culverts need not be skewed when in muskeg regions, at the bottom of gentle swales or in other regions having no identifiable channel.

Under conditions where it is preferred to skew the culvert, but where the indicated skew angle approaches or exceeds 45 degrees, channelization work may be required. Channelization work may be undertaken, as required, either upstream or downstream but preferably downstream of the culvert. The constructed channel should have a flow capacity (dimensions) and erosion resistance comparable to the natural channel.

1.6.1.4 Inlet and Outlet Erosion Protection

The requirement for smooth flow transitions and erosion protection at culvert inlet and outlet sections is dictated by the anticipated culvert outlet velocity calculated for a 10 year return flow at the projected or premanufactured end section as applicable. The following erosion protections are thus defined for outlet sections by outlet velocities:

a) For outlet velocities of 0 to 1.0 m/s use Level 0 protection extending a minimum distance of 2 culvert diameters (D) from the culvert or end section invert.

b) for outlet velocities of 1.0 to 1.5 m/s use Level 1 protection extending a minimum distance of 2D from the culvert or end section invert;

c) for outlet velocities of 1.5 to 2.5 m/s use Level 2 protection extending a minimum distance of 3D from the culvert of end section invert;

d) for outlet velocities of 2.5 to 3.5 m/s use Level 3 protection extending a minimum distance of 3D from the culvert or end section invert;

e) for outlet velocities of 3.5 to 5 m/s use Level 4 protection extending a minimum distance of 4D from the culvert or end section invert.

Outlet protection in all applications should extend 500 mm to each side and above the culvert.

Inlet protection for all applications should consist of restoration of the disturbed area with material conforming to the outlet protection specification. This material should extend 500 mm to each side and above the culvert.

1.6.1.5 Guide Banks

Pervious dikes formed of coarse gravel and cobbles may be required to extend upstream from some culverts to:

a) Serve as guide banks under conditions where the flood plain flow of a small stream would impinge on the workpad;

b) provide limited detention under conditions where a longitudinal right-of-way slope would cause some flow to bypass the culvert;

c) provide smooth flow transition from the natural channel to the culvert.

The guide banks should be constructed to have a top elevation approximately level with the top of culvert at the inlet. The guide banks may be of nominal geometry as defined by natural angle of repose for the material. Guide bank location, length and alignment should be determined in the field.

1.6.1.6 Culvert Anti-Seepage Measures

Culvert anti-seepage measures will be considered as a special measure under conditions of possible piping failure of material along the culvert and they will be designed on a site specific basis.

1.6.1.7 Culvert in Fish Streams

Drainages providing fish habitat require site specific culvert designs in order to accommodate fish passage across the right-of-way. As part of the design process, specification for culverts, installation procedures and measures in order to prevent accelerated erosion have been developed.

The design of culverts in fish streams has been based on the Fisheries and Marine Service (Dryden and Stein, 1975) report.

The following design criteria have been developed for these culvert installations and specifically for the two types of fish streams; those streams supporting fish movements not associated with reproductive activities and those streams supporting fish during the spawning migrations:

a) The scheduling of installation should be consistent with the requirements of the Northern Pipeline Agency's environmental terms and conditions (Northern Pipeline Agency, 1980);

b) the culvert inverts should be laid a minimum of 150 mm below the normal streambed elevation;

c) the culverts inverts should be backfilled such that no exit or entrance draw-downs can develop;

d) prefabricated end sections or end flanges or riprap should be placed at the culvert inlet and outlet. Erosion protection at the ends of the culvert should extend approximately two culvert diameters (2D) past the culvert inlet and outlet;

e) multiple culvert installations should be separated by at least 1.8 m;

f) during low-water periods, culverts should be designed to maintain a minimum water level of 200 mm, or a level comparable to that of the watercourse if the watercourse exhibits a minimum water level less than 200 mm;

g) culvert slopes should be kept as close to normal stream slope as conditions permit;

For those streams supporting fish during spawning migration:

h) average cross-sectional velocity through a culvert should not exceed 0.9 m/s or the natural average stream velocity during fish migration periods, unless the culvert design includes a selected region wherein velocities are low enough to permit fish passage;

i) the delay during which the critical velocity (0.9 m/s) required for fish migration may be exceeded should be a maximum of 7 days once in 50 years and 3 days once in the average annual flood (recurrence interval of 2.33 years).

1.6.2 Embankment Openings

Embankment openings should generally be considered for streams which have a design peak flow in excess of 4.0 m^3/s or where a severe aufeis potential exists.

Embankment openings consist, as shown on the drawing 2-00-02-00-TP-0052, basically of a free span pipeline over an opening adequately protected against erosion.

Since the embankment opening may provide a free span which approaches pipeline limitations, it is essential to prevent erosion of the workpad abutments.

The workpad abutments should be protected to the specified level of erosion protection extending 1.0 m beyond the toe of the underlying fill.

If there is any possibility of concentrated flow against the workpad away from the opening, either guide banks should be provided or the affected length of workpad should be armoured with a 500 mm cover of Class E material.

1.7 SPECIAL DESIGN

Any condition or combination of conditions which cannot be handled by the facilities or methodology presented herein should be assessed as a special design.

1.8 CULVERT DESIGN PROCEDURES SUMMARY

1. Locate culvert (KP).

2. Determine the presence or absence of fish and fish movement at the culvert site. If fish are present, the culvert is designed on a site specific basis considering the design criteria presented in section 1.6.1.7. If fish are not present proceed through steps 3 to 15.

3. Assign a design flow Q_{100} (m^3/s), (return period of about 100 years), as obtained from the Hydraulic Consultants.

4. Determine a trial size culvert D (m) using the following table (assuming a head of water HW (m) at the inlet less than or equal to the culvert diameter or rise D):

Design Flow Q (m^3/s)	Culvert Size (mm)
< 0.3	600 CSP
0.3 - 0.5	800 CSP
0.5 - 1.0	900 CSP
1.0 - 2.0	1200 CSP
2.0 - 3.0	1870 x 1230 CSP Pipe-arch
3.0 - 4.0	2130 x 1400 CSP Pipe-arch
> 4.0	Special Design

5. Determine the natural channel slope (m/m) and assign a culvert slope S (m/m).

6. Approximate the length of the culvert L (m) taking into account culvert slope and offset, culvert skew angle, height of cover above culvert, type of availabe manufactured lengths. The above assumptions must be confirmed in the field prior to construction.

7. Assign a Manning's "n" for the culvert.

8. Assign an entrance loss coefficient Ke (0.9 for a projected end and 0.5 for a premanufactured end section).

9. Calculate the critical depth of flow dc (m) using Manning's equation.

10. Compare the existing tailwater TW (m) to the value of $\frac{dc + D}{2}$ (Alaska Department of Highways, 1977.)

    The larger of these two values becomes the height of water at the culvert outlet ho (m).

11. Calculate the total head loss H (m), where H = Friction loss + Entrance loss + Velocity head.

12. Calculate the head water HW (m) at the inlet using the following equation:

$$HW = H + ho - SL$$

Where HW = Inlet head water (m);
H = Total head loss (m);
ho = Height of water at outlet (m);
S = Culvert slope (m/m);
L = Culvert length (m).

If the head water (HW) calculated here exceeds the culvert diameter or rise (D), repeat the procedure using the next larger culvert. If HW is less than D, proceed to the next step.

13. Calculate the culvert outlet velocity V (m/s) using normal depth of flow as computed by Manning's equation for the size, the roughness and the slope of the culvert selected. For this calculation use the 10 year return period flow rate Q_{10} (m^3/s). The Q_{10} is assumed equal to the design flow rate Q_{100} (m^3/s) divided by 1.5.

If a premanufactured end section is used, the culvert outlet velocity should be adjusted considering the end section as a sudden expansion.

14. Determine the level of erosion protection required using the above outlet velocity calculation and the following table:

Outlet Velocity (m/s)	Level of Erosion Protection	Material	Thickness (mm)	Protected Inlet	Length Outlet
< 1.0	Level 0	SEI or Class D Material	200	Disturbed Area	2 culvert dia. or rise
1.0 - 1.5	Level 1	Class D Material	400	Disturbed Area	2 culvert dia. or rise
1.5 - 2.5	Level 2	Class E Material	300	Disturbed Area	3 culvert dia. or rise
2.5 - 3.5	Level 3	Class E Material	500	Disturbed Area	3 culvert dia. or rise
3.5 - 5.0	Level 4	Rock Riprap Class I	600	Disturbed Area	4 culvert dia. or rise
> 5.0	Special Design				

15. As a final check, calculate the height of water HTC (m) that would back up at the culvert inlet at the time of concentration (tc(min) = 40 $\sqrt{\text{Drainage Area (km}^2)}$) if the culvert was plugged.

This is the storage experienced at the culvert inlet and can be related to the possibility and the severity of culvert failure and the consequence to pipeline integrity. This may initiate special design consideration (larger culvert or embankment opening).

1.9 REFERENCES

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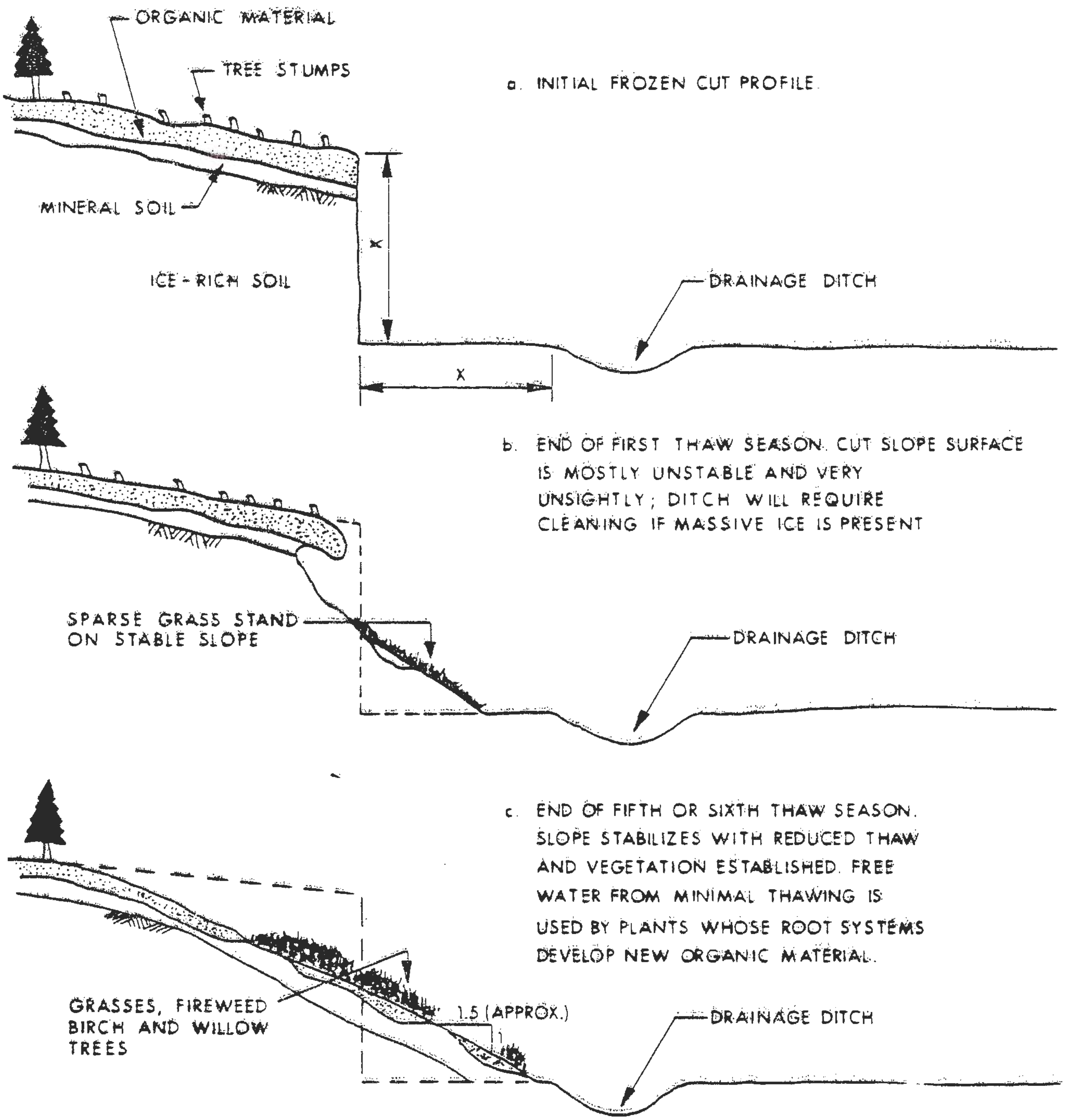

(ADAPTED FROM BERG AND SMITH, 1976)

Foothills Pipe Lines (South Yukon) Ltd.

TITLE
THE ALASKA HIGHWAY GAS PIPELINE PROJECT

TYPICAL
CUT IN ICE-RICH SOILS

	DRAWN	CHECKED	APPROVED	APPROVED
BY	G. Y.			
DATE	81 09 17	81-9-17		

SCALE N.T.S. PREPARED BY YUKON PIPELINE DESIGN

FIGURE 1.4.5.

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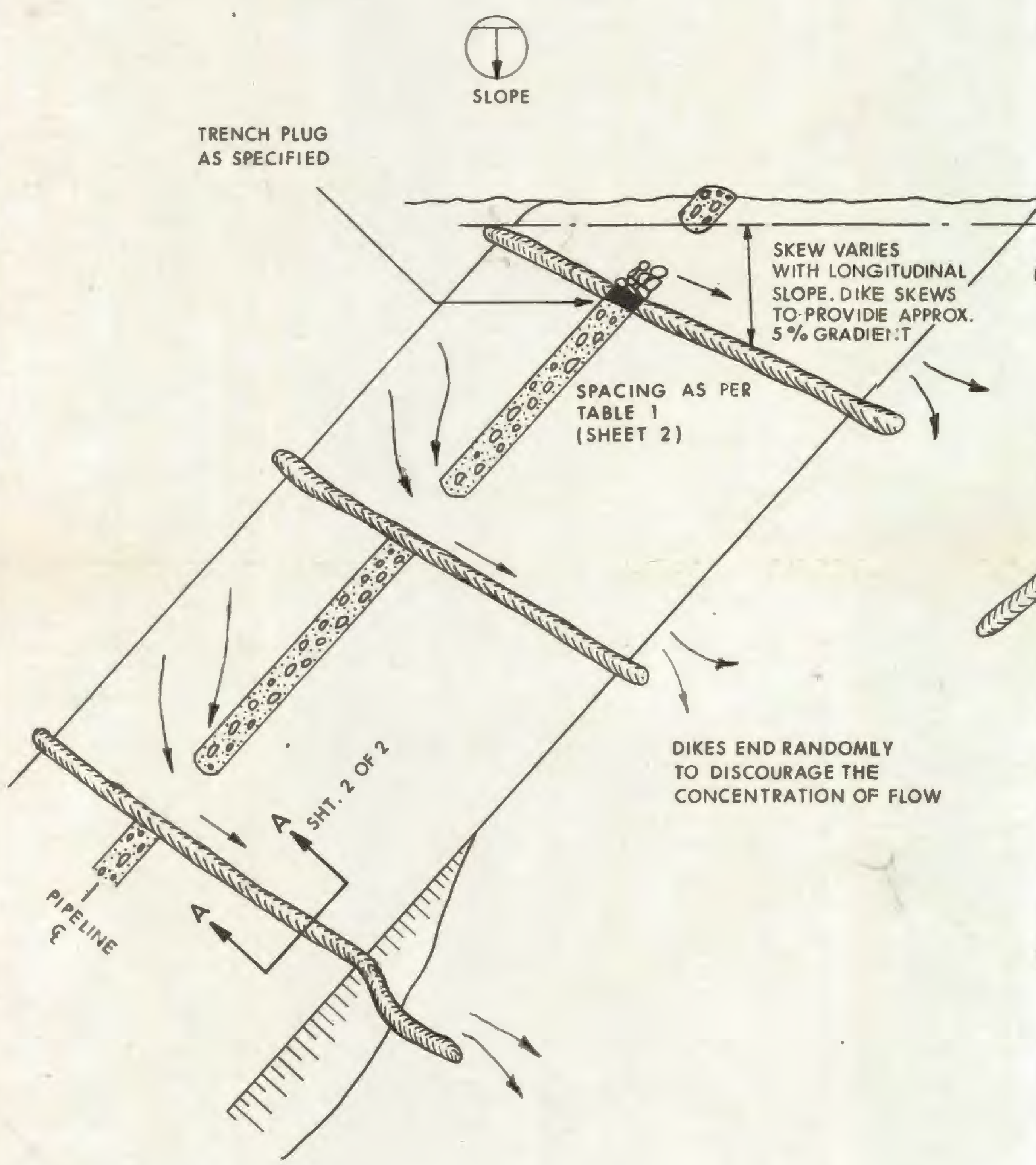
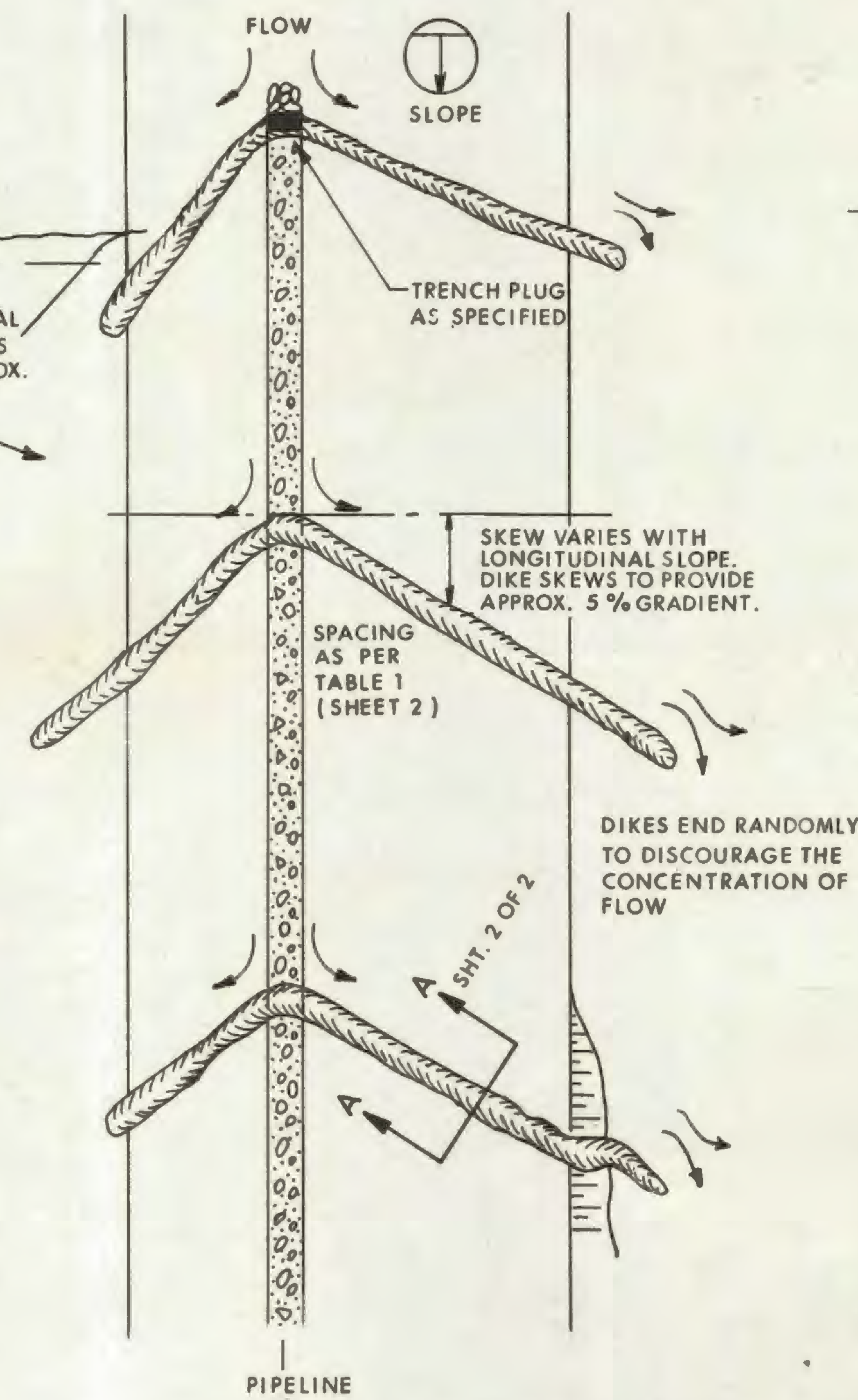
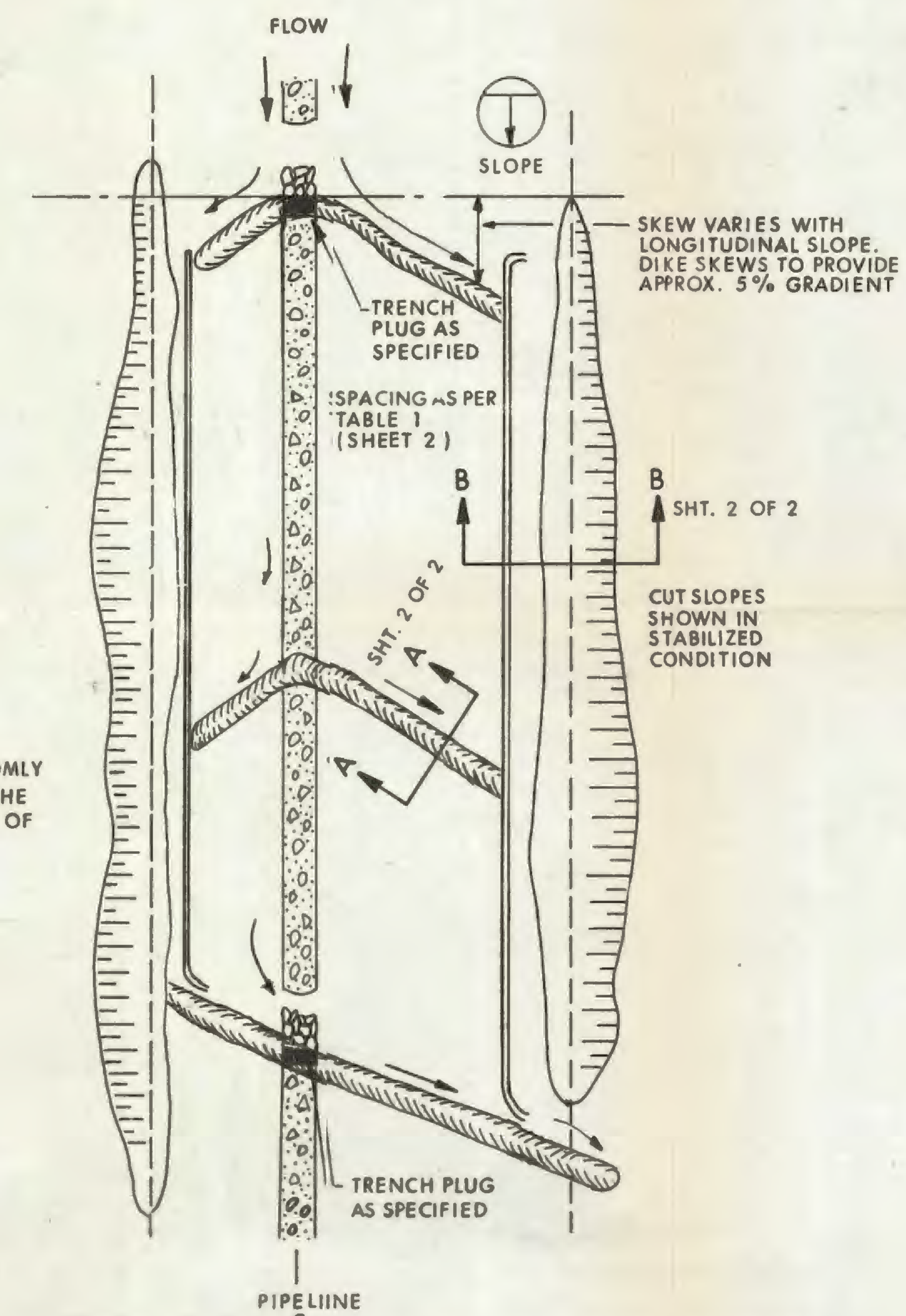


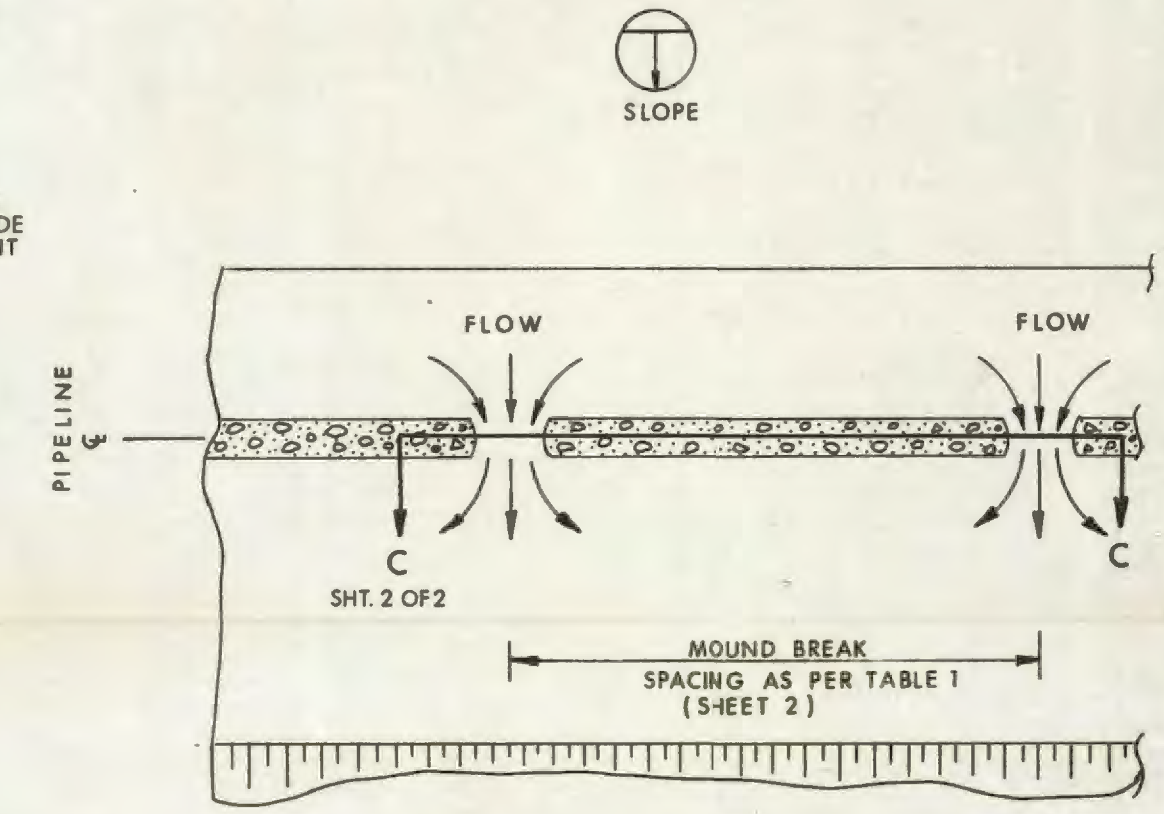
PLAN VIEW – DIAGONAL DIVERSION DIKES



PLAN VIEW – HERRING BONE DIVERSION DIKES



PLAN VIEW – DIVERSION DIKES WITH DITCHES



PLAN VIEW
MOUND BREAK

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sheet 1

PROFESSIONAL ENGINEER
P. St. J. PRICE
ALBERTA

GENERAL NOTES

REFERENCE DRAWING

DRAWING NO.	TITLE
2 00 02 00 TP 005	TYPICAL TRENCH PLUGS

MICROFILM RECORD

FILE NO.	DATE

REVISIONS

NO.	DESCRIPTION	DATE	BY	CHKD.	APPR. YPD	APPR. PR.
0	SUBMIT TO FEARO OFFICE AND NPA.	820210				

NORTHERN PIPELINE AGENCY

ENGINEERING RECORDS

DRAWN BY A. ZSUFFA	CHECKED BY	DATE: 810918
ENGINEER		81 10 29
SUPERVISOR		81 12 22
MANAGER		

FOOTHILLS APPROVALS

ENGINEER	DATE:
SUPERVISOR	
MANAGER	

SCALE N. T. S.

Foothills Pipe Lines (South Yukon) Ltd.

THE ALASKA HIGHWAY GAS PIPELINE PROJECT

TYPICAL
MOUND BREAK AND
DIVERSION DIKES
(SHEET 1 OF 2)

PREPARED BY
YUKON PIPELINE DESIGN JOINT VENTURE
APK CANUCK MONENCO PETROTECH

RGN	ZONE	FACILITY	NO.	DWG. TYPE	DRAWING NO.	REV.
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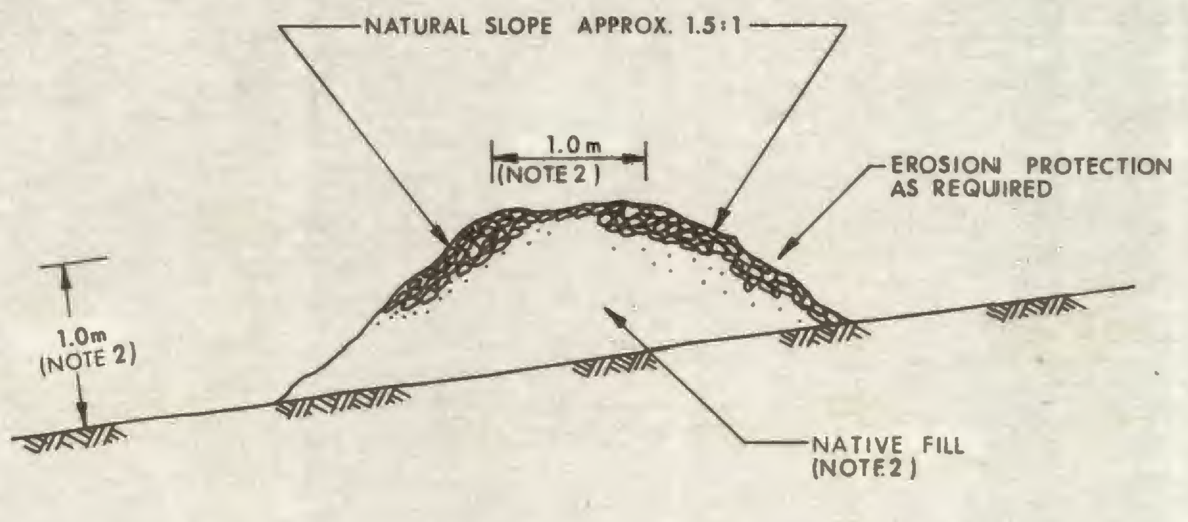
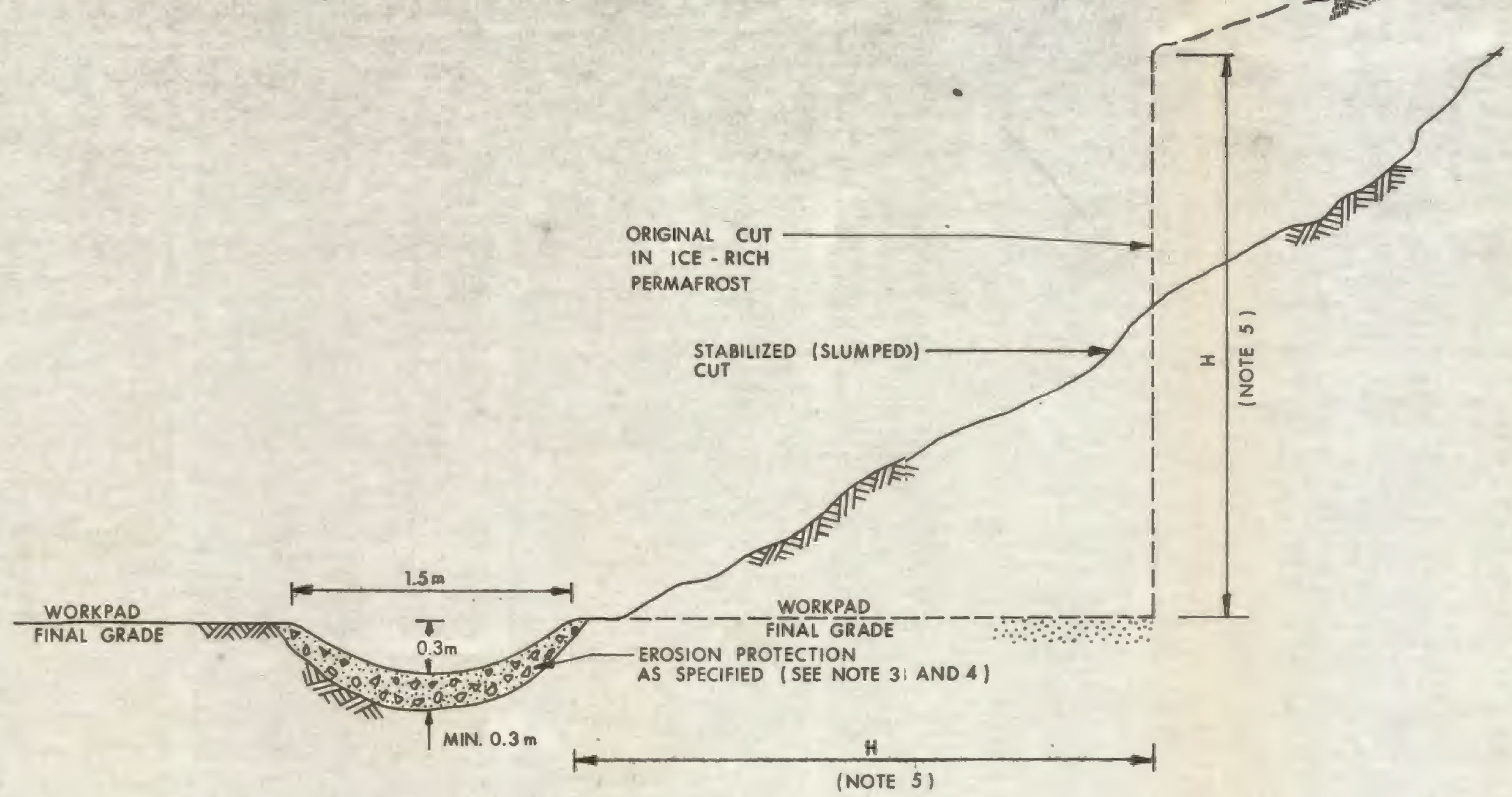


SECTION A-A

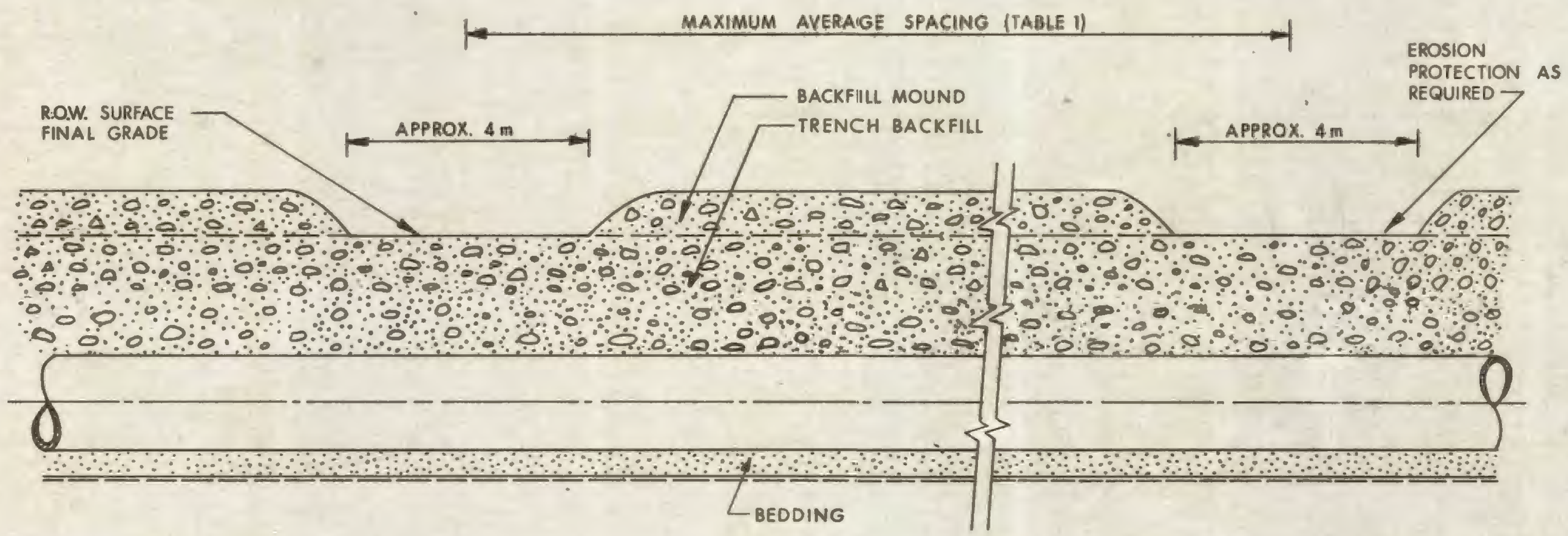
DIKE (HERRING BONE AND DIAGONAL)



SECTION B-B

NOTES

1. MOUND BREAKS SHALL BE LOCATED AT ALL NATURAL DEPRESSIONS CAPABLE OF PROVIDING CROSS DRAINAGE. MOUND BREAKS SHALL BE SPACED AS PRESCRIBED BY TABLE 1.
2. IF A DIVERSION DIKE IS MADE OF CLASS D MATERIAL, THE TOP WIDTH AND THE HEIGHT OF THE DIKE SHALL BE ABOUT 600 mm AND NO ADDITIONAL EROSION PROTECTION IS REQUIRED.
3. DRAINAGE DITCHES SHALL BE PROTECTED TO LEVEL 1 EROSION PROTECTION FOR LONGITUDINAL SLOPES LESS THAN 15% AND TO LEVEL 2 EROSION PROTECTION FOR SLOPES GREATER THAN 15%.
4. LEVELS OF EROSION PROTECTION:
   a) LEVEL 0 - 200 mm LAYER OF CLASS D MATERIAL (OR ALTERNATIVELY 200 mm OF SOIL HAVING A SEI OF 1).
   b) LEVEL 1 - 400 mm LAYER OF CLASS D MATERIAL.
   c) LEVEL 2 - 300 mm LAYER OF CLASS E MATERIAL.
5. VERTICAL CUTS IN ICE-RICH PERMAFROST IN EXCESS OF 5 m HIGH SHALL BE APPROVED BY MANAGER.



SECTION C-C

MOUND BREAKS

TABLE 1: MAXIMUM AVERAGE MOUND BREAK AND DIVERSION DIKE SPACING.

LONGITUDINAL SLOPE GRADIENT	SOIL CHARACTERISTICS SEI 3 (*) (SILTS OR FINE SANDS)	SEI 2 (COARSE SAND OR CLAY TILL)	SEI 1 (GRAVEL, PEAT OR COMPACTED CLAY)
LESS THAN 2%	65 m	150 m	NOT REQUIRED
2% - 5%	50 m	65 m	150 m
5% - 10% (**)	30 m	50 m	65 m
10% - 20% (***)	15 m	30 m	50 m
20% - 40% (****)	10 m	15 m	30 m
GREATER THAN 40%	6 m	10 m	15 m

(*) SEI: SOIL ERODIBILITY INDEX: 3 (HIGH), 2 (MEDIUM), 1 (LOW)

(**) LONGITUDINAL SLOPES GREATER THAN 5 % REQUIRE A DIVERSION DIKE WITH EACH MOUND BREAK.

(***) LONGITUDINAL SLOPES GREATER THAN 10% REQUIRE A TRENCH PLUG WITH MOUND BREAK AND DIVERSION DIKE.

(****) LONGITUDINAL SLOPES GREATER THAN 25% SHOULD BE CAREFULLY ASSESSED TO DETERMINE POSSIBLE SUBDRAIN REQUIREMENTS.

MOUND BREAKS SHOULD BE SPACED AT NO MORE THAN 50m IN MUSKEG AREAS.

PROFESSIONAL ENGINEER P. St. J. PRICE ALBERTA

GENERAL NOTES	REFERENCE DRAWING		MICROFILM RECORD		REVISIONS						NORTHERN PIPELINE AGENCY
	DRAWING NO.	TITLE	FILE NO.	DATE	NO.	DESCRIPTION	DATE	BY	CHKD.	APPR. YPD FPL	
					0	SUBMIT TO FEARO OFFICE AND NPA.	82 02 10				

ENGINEERING RECORDS

DRAWN BY A. Z.	CHECKED BY	DATE: 81 09 16
ENGINEER		81 12 23
SUPERVISOR		81 12 22
MANAGER		

FOOTHILLS APPROVALS

ENGINEER	DATE:
SUPERVISOR	
MANAGER	

SCALE N. T. S.

Foothills Pipe Lines (South Yukon) Ltd.

THE ALASKA HIGHWAY GAS PIPELINE PROJECT

TYPICAL MOUND BREAK AND DIVERSION DIKES (SHEET 2 OF 2)

PREPARED BY YUKON PIPELINE DESIGN JOINT VENTURE

APK CANUCK MONENCO PETROTECH

RGN	ZONE	FACILITY	NO.	DWG. TYPE	DRAWING NO.	REV.
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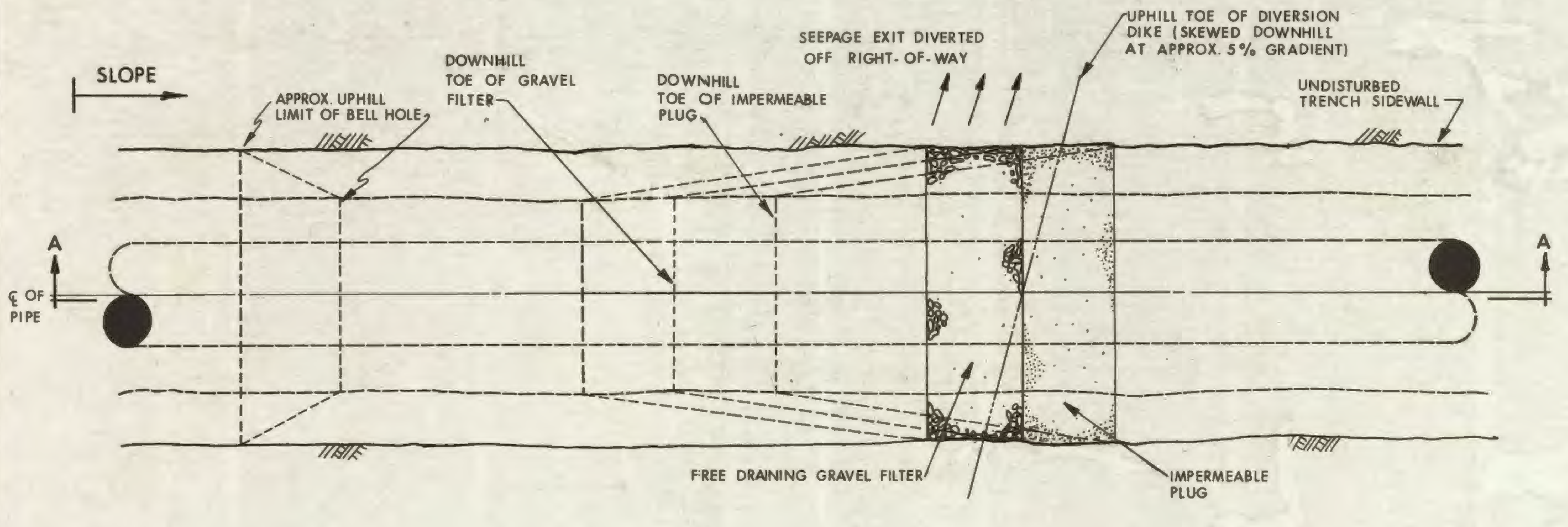
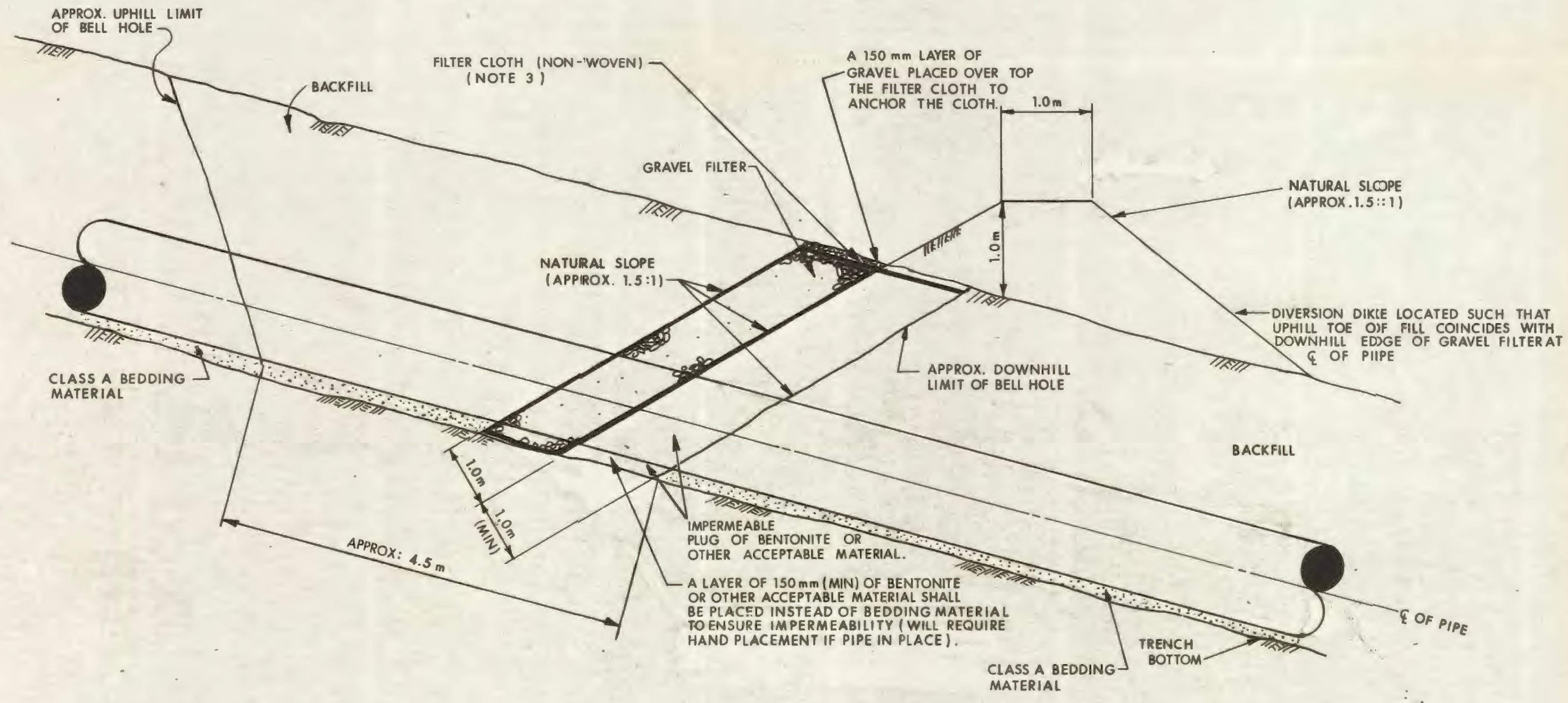


PLAN VIEW
BACKFILL MOUND & DIVERSION DIKE NOT SHOWN



SECTION A - A
BACKFILL MOUND NOT SHOWN

MATERIALS REQUIRED:

DIVERSION DIKE:
NATIVE FILL (NO EXCESS ORGANICS OR THAW UNSTABLE MATERIAL

IMPERMEABLE PLUG:
DRY POWDERED NATURAL BENTONITE OR EQUIVALENT HIGHLY PLASTIC CLAY

GRAVEL FILTER:
CLASS 'C' GRANULAR MATERIAL OR EQUIVALENT FREE DRAINING GRANULAR MATERIAL

FILTER CLOTH:
NON-WOVEN; PENROAD 350 OR EQUIVALENT

NOTES

1. TRENCH PLUGS, WHERE REQUIRED ON LONGITUDINAL SLOPES GREATER THAN 10%, WILL BE SPECIFIED ON THE DRAWING, HOWEVER, THE FREQUENCY AND PRECISE LOCATION OF THE TRENCH PLUGS ARE TO BE ESTABLISHED IN THE FIELD ON THE BASIS OF FIELD OBSERVATIONS, TRENCH LOCAL TOPOGRAPHY AND DRAINAGE PATTERNS.
2. TRENCH PLUGS MUST BE LOCATED PRIOR TO TRENCH BACKFILLING. SUFFICIENT OPEN TRENCH MUST BE MAINTAINED TO INSTALL THE TRENCH PLUG (APPROXIMATELY 4.5 m AT TRENCH BOTTOM ELEVATION) TRENCH PLUGS SHALL BE CONSTRUCTED AS SOON AS PRACTICAL AFTER PIPE INSTALLATION AND GENERAL BACKFILLING TO MINIMIZE TRENCH WALL SLUMPING, AND WATER INFILTRATION.
3. FILTER CLOTH SHALL BE INSTALLED TO TOTALLY WRAP THE GRAVEL FILTER MATERIAL. MINIMUM OVERLAP OF 0.6 m IS REQUIRED.

PROFESSIONAL ENGINEER P. St. J. PRICE ALBERTA

GENERAL NOTES

REFERENCE DRAWING

DRAWING NO.	TITLE
2 00 02 00 TP 0050	TYPICAL MOUND BREAK & DIVERSION DIKES (2 SHEETS)

MICROFILM RECORD

FILE NO.	DATE

REVISIONS

NO.	DESCRIPTION	DATE	BY	CHKD.	APPR. TPD	APPR. FPL
0	SUBMIT TO FEARO OFFICE AND NPA.	82 02 10				

NORTHERN PIPELINE AGENCY

ENGINEERING RECORDS

		DATE:
DRAWN BY T.A.O.	CHECKED BY	81 08 28
ENGINEER		81 10 23
SUPERVISOR		81 12 22
MANAGER		

FOOTHILLS APPROVALS

	DATE:
ENGINEER	
SUPERVISOR	
MANAGER	

SCALE N.T.S.

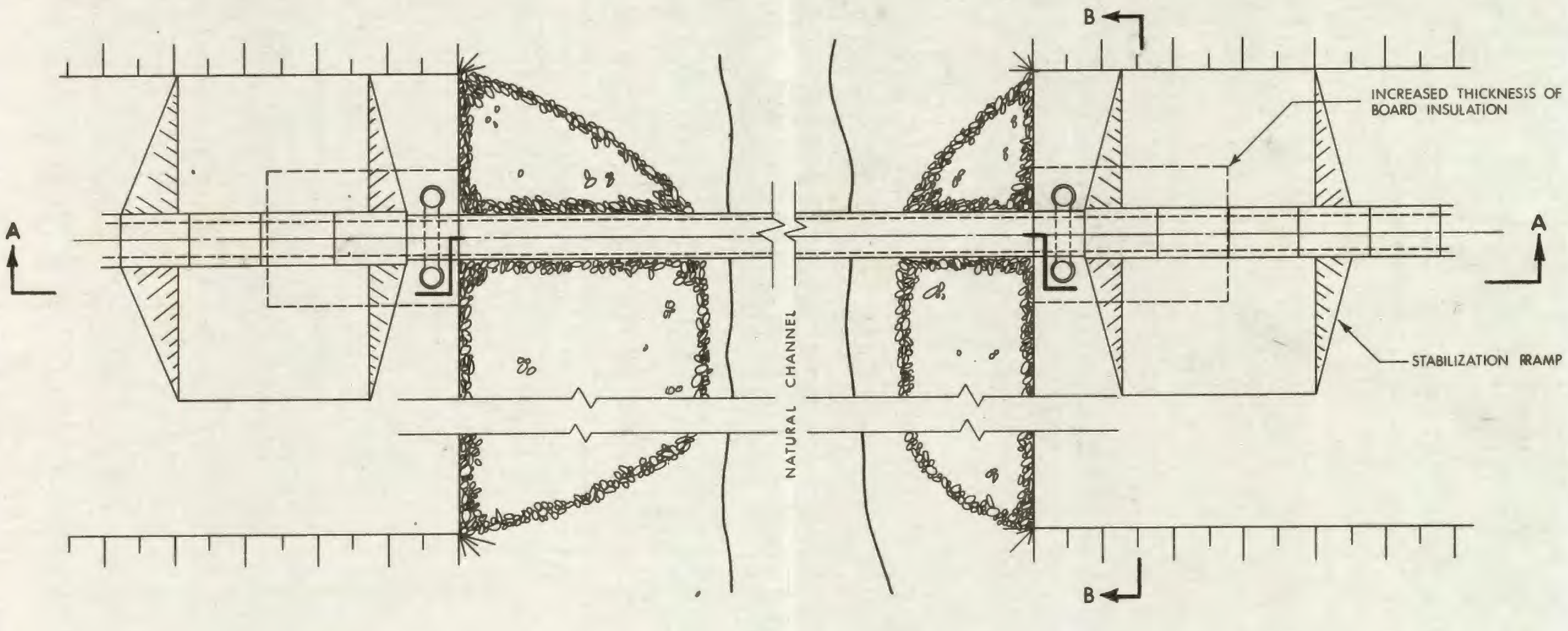
Foothills Pipe Lines (South Yukon) Ltd.
THE ALASKA HIGHWAY GAS PIPELINE PROJECT

TYPICAL
TRENCH PLUG

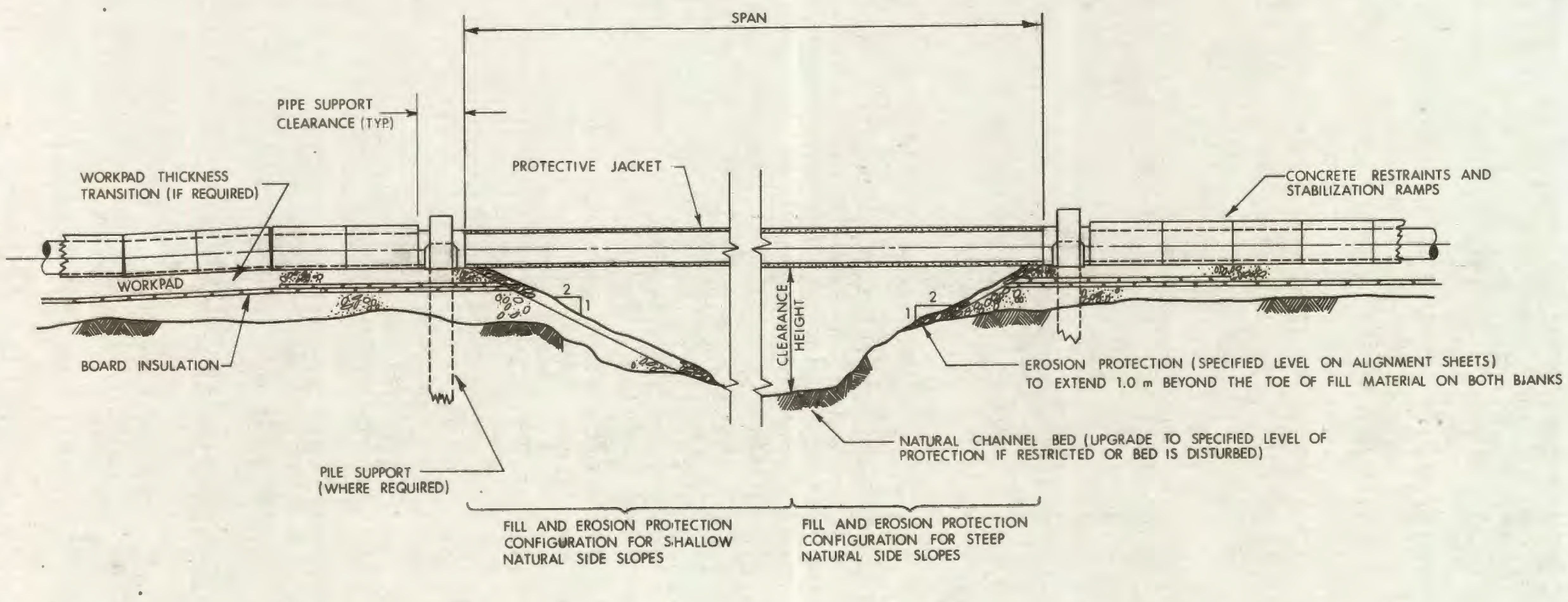
PREPARED BY
YUKON PIPELINE DESIGN JOINT VENTURE
APK CANUCK MONENCO PETROTECH

RGN	ZONE	FACILITY	NO.	DWG. TYPE	DRAWING NO.	REV.
2	0 0	0 2	0 0	T P	0 0 5 1	0

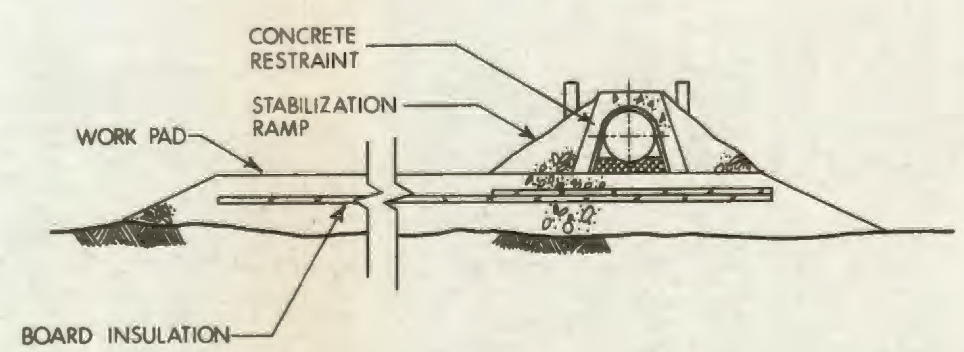
METRIC A2, FORM 260 AUG. 80



PLAN VIEW



SECTION A-A



SECTION B-B

NOTES

1. THIS DRAWING IS APPLICABLE ONLY IF THE ABOVE GROUND CONCRETE RESTRAINED MODE IS PRESENT ON EACH SIDE OF THE CHANNEL.
2. FREE SPAN LENGTH, CLEARANCE HEIGHT AND LEVEL OF EROSION PROTECTION ARE SPECIFIED ON A SITE SPECIFIC BASIS.
3. TEMPORARY CONSTRUCTION ACCESS ACROSS CHANNEL SHALL BE REMOVED UPON COMPLETION OF CONSTRUCTION.
4. FOR STRUCTURAL DETAILS, MATERIALS AND DIMENSIONS OF EMBANKMENT OPENING SEE DRAWINGS 2 00 02 00 EN 0046 AND 2 00 02 00 EN 0049

PROFESSIONAL ENGINEER ALBERTA

GENERAL NOTES

REFERENCE DRAWING

DRAWING NO.	TITLE
2 00 02 00 EN 0029	PIPE WALL FIELD TRANSITION
2 00 02 00 EN 0046	CONCRETE COATED FREE SPAN
2 00 02 00 EN 0049	INSULATED CO-AXIAL STEEL FREE SPAN

MICROFILM RECORD

FILE NO.	DATE

REVISIONS

NO.	DESCRIPTION	DATE	BY	CHKD.	APPR. YPD	APPR. FPL
0	SUBMIT TO FEARO OFFICE AND NPA.	82 02 10				

NORTHERN PIPELINE AGENCY

ENGINEERING RECORDS

		DATE:
DRAWN BY S. GOURLIE	CHECKED BY	82 01 13
ENGINEER		82 01 20
SUPERVISOR		82 01 20
MANAGER		

FOOTHILLS APPROVALS

	DATE:
ENGINEER	
SUPERVISOR	
MANAGER	

SCALE N.T.S.

Foothills Pipe Lines (South Yukon) Ltd.

THE ALASKA HIGHWAY GAS PIPELINE PROJECT

TYPICAL EMBANKMENT OPENING

PREPARED BY

YUKON PIPELINE DESIGN JOINT VENTURE

APK CANUCK MONENCO PETROTECH

RGN	ZONE	FACILITY	NO.	DWG. TYPE	DRAWING NO.	REV.
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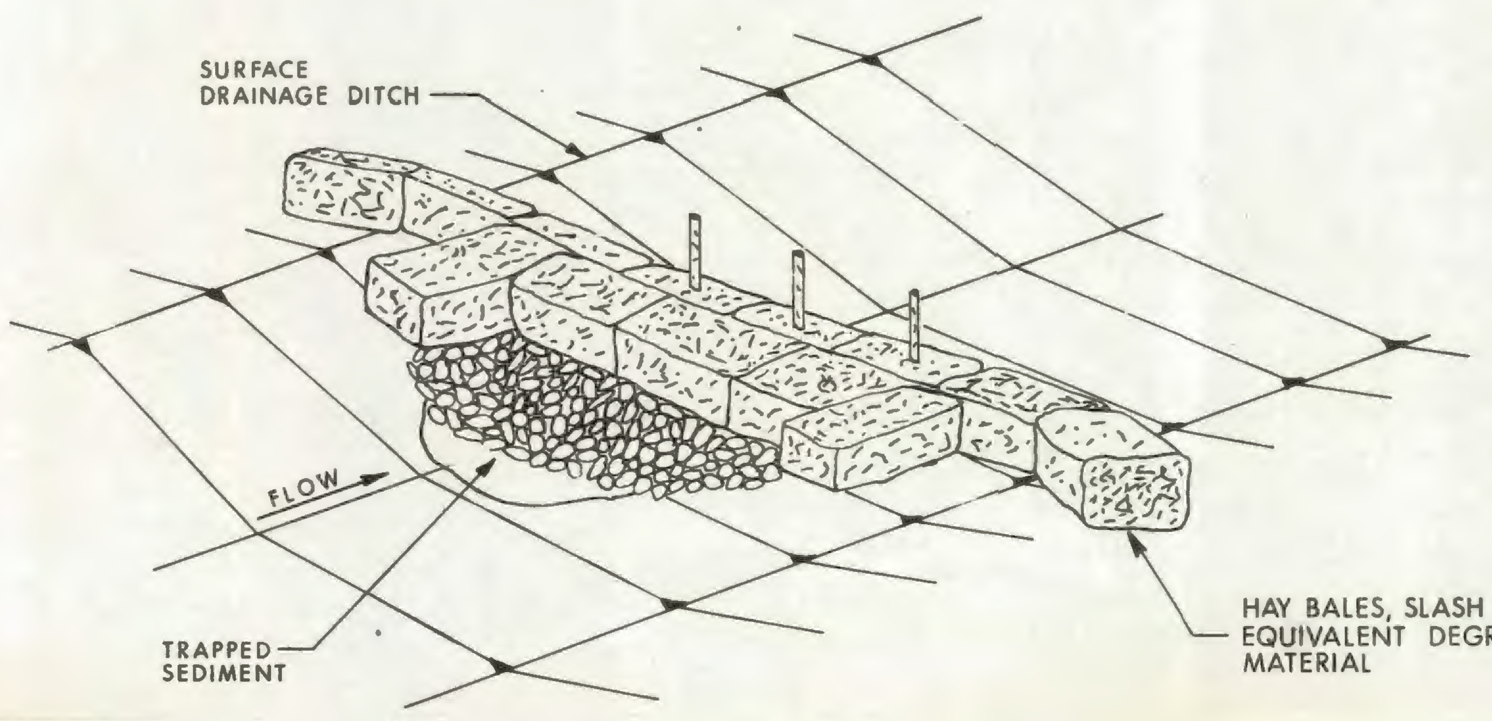
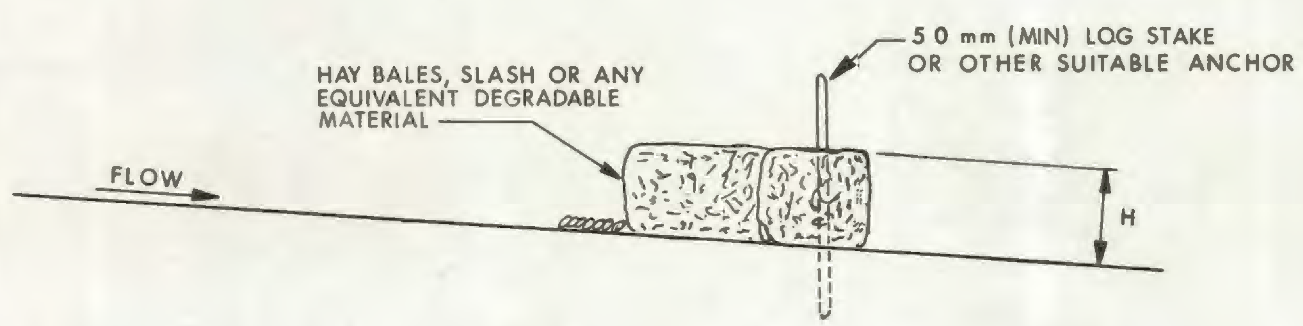
METRIC A2, FORM 260 AUG. 80

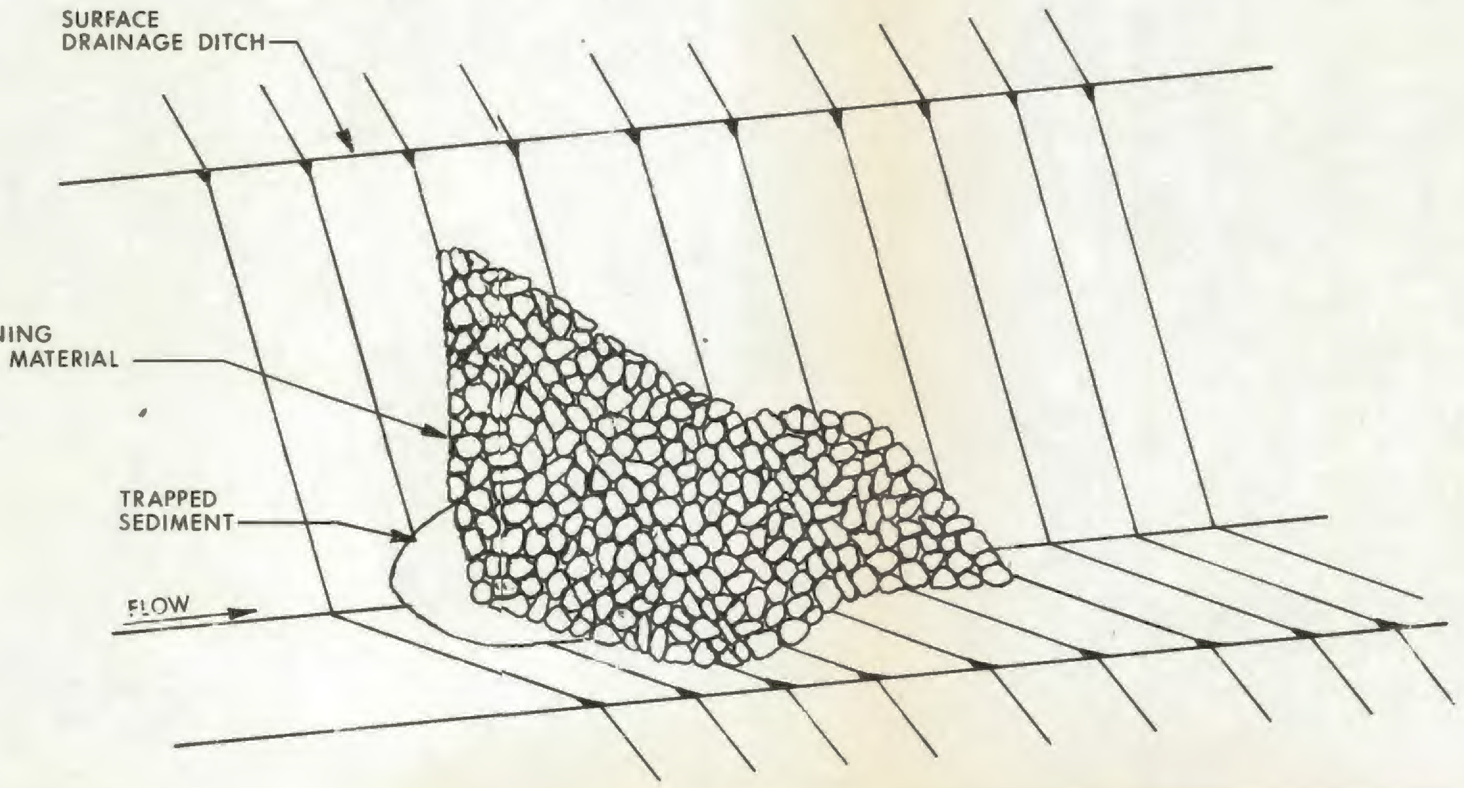


PICTORIAL

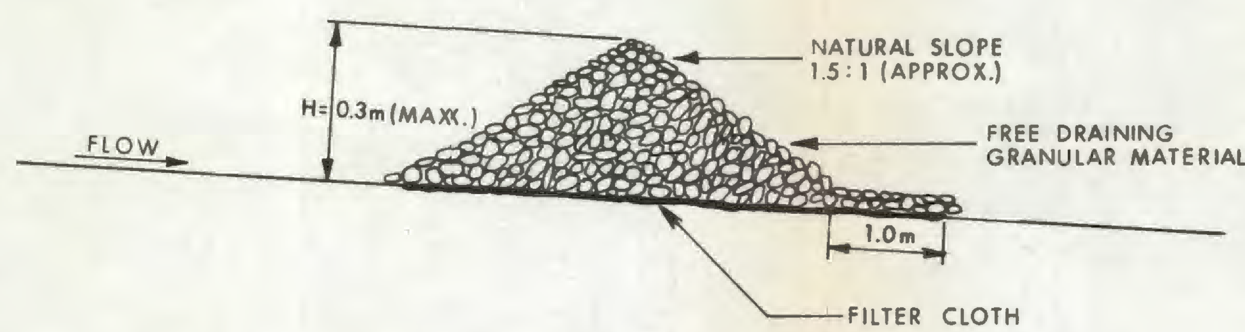


SECTIONAL VIEW

TEMPORARY DRAINAGE DITCH CHECK



PICTORIAL



SECTIONAL VIEW

PERMANENT DRAINAGE DITCH CHECK

DESCRIPTION OF MATERIALS

TEMPORARY DITCH CHECKS
HAY BALES, SLASH OR ANY EQUIVALENT DEGRADABLE MATERIAL AND 50 mm (MIN.) LOG OR OTHER SUITABLE ANCHOR.

PERMANENT DITCH CHECKS
CLASS C GRANULAR MATERIAL OR EQUIVALENT FREE DRAINING GRANULAR MATERIAL.

FILTER CLOTH
NON WOVEN PENROAD 150 OR EQUIVALENT.

NOTES

1. DITCH CHECKS SHALL BE USED IN DITCHES FOR VELOCITY OR SEDIMENT CONTROL. DITCH CHECKS SHALL BE INSTALLED WHERE REQUIRED BY MANAGER ON LONGITUDAL SLOPES GREATER THAN 10 %. THEY MAY BE USED FOR TEMPORARY OR PERMANENT CONTROL.

2. DITCH CHECKS SPACING (L) IS DETERMINED BY THE FOLLOWING FORMULAE:

$$L = \frac{H - 0.2}{S_d - S_s}$$ IF DITCH CHECKS ARE FOR VELOCITY AND SEDIMENT CONTROL

$$L = \frac{H}{S_d - S_s}$$ IF DITCH CHECKS ARE FOR VELOCITY CONTROL

WHERE :
L = SPACING OF DITCH CHECKS (m)
H = DITCH CHECK HEIGHT (m)
S_d = DESIGN SLOPE (m/m)
S_s = STABLE SLOPE FOR THE DITCH MATERIAL (m/m)

PROFESSIONAL ENGINEER ALBERTA P. St. J. PRICE

GENERAL NOTES	REFERENCE DRAWING		MICROFILM RECORD		REVISIONS							NORTHERN PIPELINE AGENCY
	DRAWING NO.	TITLE	FILE NO.	DATE	NO.	DESCRIPTION	DATE	BY	CHKD.	APPR. YPD	APPR. FPL	
					0	SUBMIT TO FEARO OFFICE AND NPA	820210					

ENGINEERING RECORDS		
DRAWN BY G.Y.	CHECKED BY	DATE: 81 09 11
ENGINEER		81 10 29
SUPERVISOR		81 12 22
MANAGER		

FOOTHILLS APPROVALS	
ENGINEER	DATE:
SUPERVISOR	
MANAGER	

SCALE N.T.S.

Foothills Pipe Lines (South Yukon) Ltd.

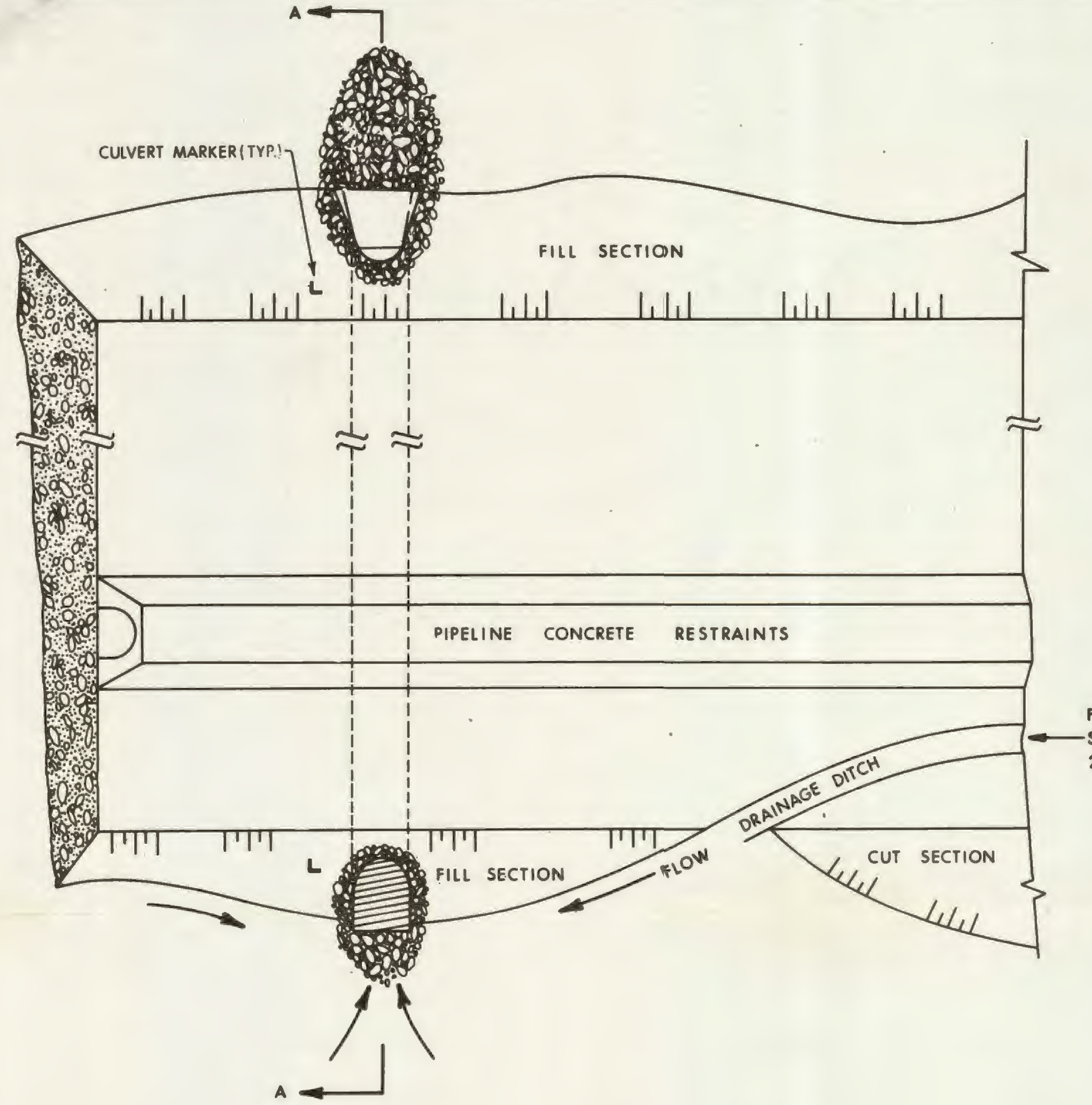
THE ALASKA HIGHWAY GAS PIPELINE PROJECT

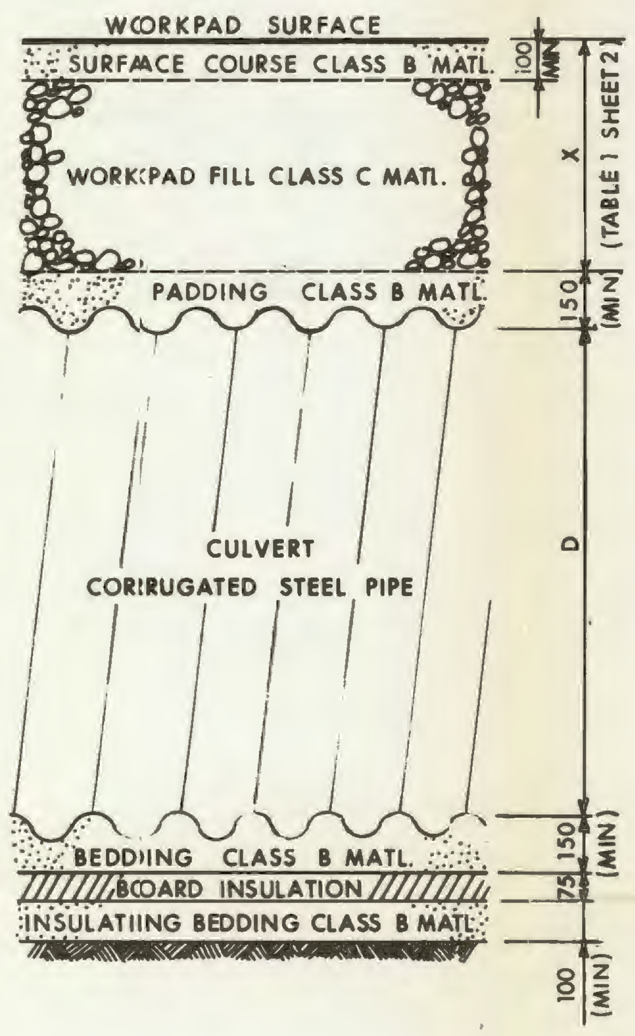
TYPICAL DRAINAGE DITCH CHECKS

PREPARED BY
YUKON PIPELINE DESIGN JOINT VENTURE
APK CANUCK MONENCO PETROTECH

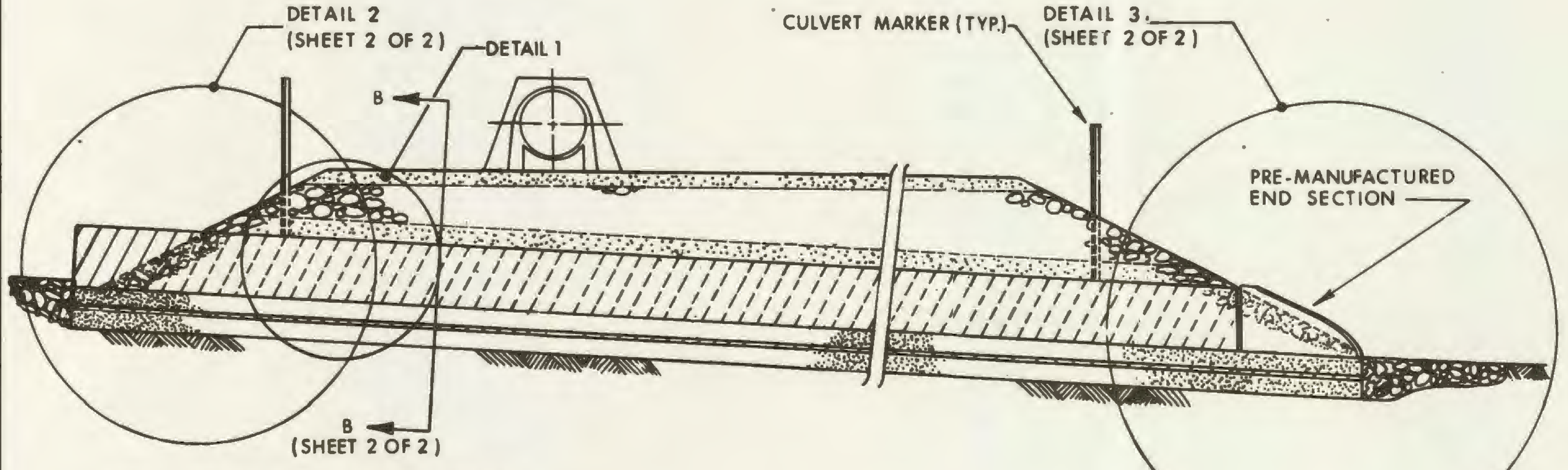
RGN	ZONE	FACILITY	NO	DWG. TYPE	DRAWING NO.	REV
2	0 0	0 2	0 0	T P	0 0 5 3	0

METRIC A2 FORM 260 AUG 80





DETAIL 1



TYPICAL INLET / OUTLET CONFIGURATION (INLET SHOWN) FOR 600, 800 AND 900 mm CULVERT INSTALLATION.

SECTION A-A

TYPICAL INLET / OUTLET CONFIGURATION (OUTLET SHOWN) FOR 1200 mm AND PIPE-ARCH CULVERT INSTALLATION.

MANUFACTURED MATERIALS

GALVANIZED CULVERTS AND GALVANIZED PRE-MANUFACTURED END SECTIONS ARE REQUIRED AS FOLLOWS:

TYPE	CULVERT SIZE	CULVERT WALL THICKNESS	CORRUGATION	PRE-MANUFACTURED END SECTIONS AT INLET & OUTLET
CIRCULAR CSP	600	1.6	68 x 13	NO
CIRCULAR CSP	800	1.6	68 x 13	NO
CIRCULAR CSP	900	2.0	68 x 13	NO
CIRCULAR CSP	1200	1.6	125 x 25	YES
PIPE-ARCH CSPPA	1870 x 1230	3.5	68 x 13	YES
PIPE-ARCH CSPPA	2130 x 1400	3.5	68 x 13	YES

CSP CORRUGATED STEEL PIPE
CSPPA CORRUGATED STEEL PIPE PIPE-ARCH

CULVERT MARKERS: ANGLE 35 x 35 x 6 - 3000 LONG MILD STEEL, c/w 1 COAT PRIMER AND 2 COATS ORANGE ACRYLIC LACQUER.

NOTES

1. CULVERTS SHALL BE INSTALLED ON NATURAL GRADE EXCEPT FOR THE 600 mm, 800 mm, AND 900 mm DIAMETER CULVERTS INSTALLED ON NATURAL SLOPES GREATER THAN 2%. FOR THESE CULVERTS, THE INVERT AT THE CULVERT INLET SHALL BE 100 mm BELOW THE NATURAL GROUND SURFACE AND THE INVERT AT THE CULVERT OUTLET SHALL BE 100 mm ABOVE NATURAL GROUND SURFACE.
2. EROSION PROTECTION AS DESCRIBED IN TABLE 2 (SHEET 2 OF 2) SHALL BE PROVIDED. EROSION PROTECTION SHALL EXTEND 500 mm EACH SIDE AND ABOVE THE CULVERT INLET AND OUTLET.
3. THIS TYPICAL DRAWING DOES NOT APPLY FOR CULVERTS INSTALLED IN FISH STREAMS.
4. FOR ALL CULVERTS, TOTAL LENGTH SHOULD BE A MULTIPLE OR A COMBINATION OF STANDARD SECTION LENGTH e.g., 4 m, 5 m, OR 7 m. CULVERT SECTIONS SHALL BE JOINED TOGETHER WITH 600 mm WIDE GALVANIZED DIMPLED BAND CONNECTIONS. COUPLING OF CULVERT SECTIONS SHALL BE AVOIDED UNDER PIPELINE CONCRETE RESTRAINTS. A CULVERT SECTION OF 7 m SHALL BE USED UNDER PIPELINE CONCRETE RESTRAINTS.

GENERAL NOTES

A. ALL DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED.

REFERENCE DRAWING

DRAWING NO.	TITLE
2 00 02 00 TP 0050	TYPICAL MOUND BREAK AND DIVERSION DIKES (2 SHEETS)

MICROFILM RECORD

FILE NO.	DATE

REVISIONS

NO.	DESCRIPTION	DATE	BY	CHKD.	APPR. YPD	APPR. FPL
0	SUBMIT TO FEARO OFFICE AND NPA	820210				

NORTHERN PIPELINE AGENCY

ENGINEERING RECORDS

DRAWN BY	CHECKED BY	DATE:
V. J. R.		81 08 15

ENGINEER
SUPERVISOR
MANAGER

FOOTHILLS APPROVALS

ENGINEER — DATE:
SUPERVISOR
MANAGER

SCALE N.T.S.

Foothills Pipe Lines (South Yukon) Ltd.

THE ALASKA HIGHWAY GAS PIPELINE PROJECT

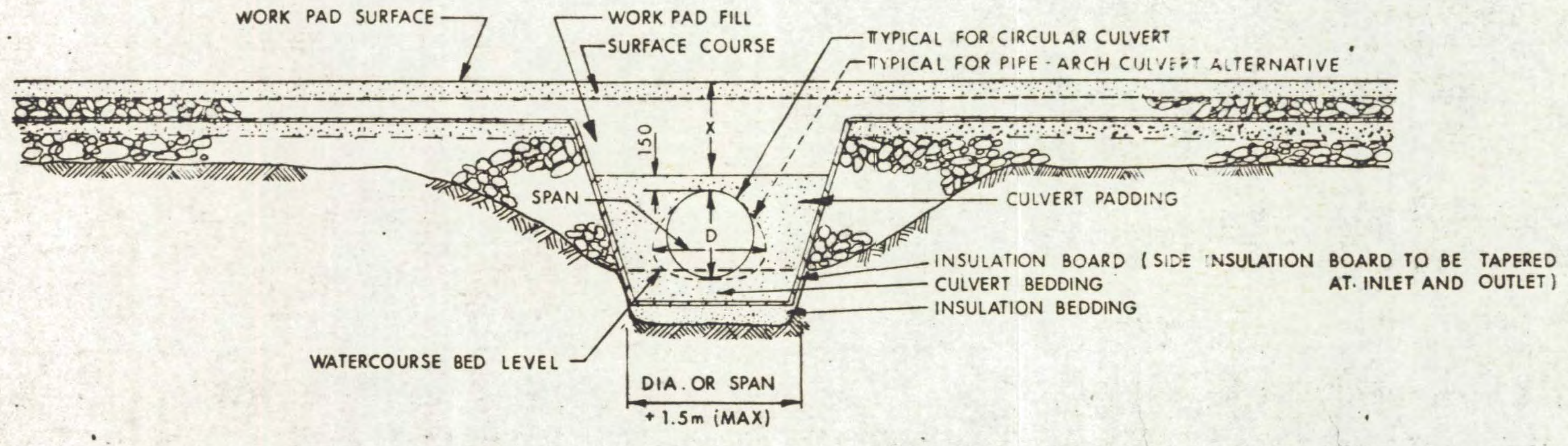
TYPICAL CULVERT INSTALLATION

(SHEET 1 OF 2)

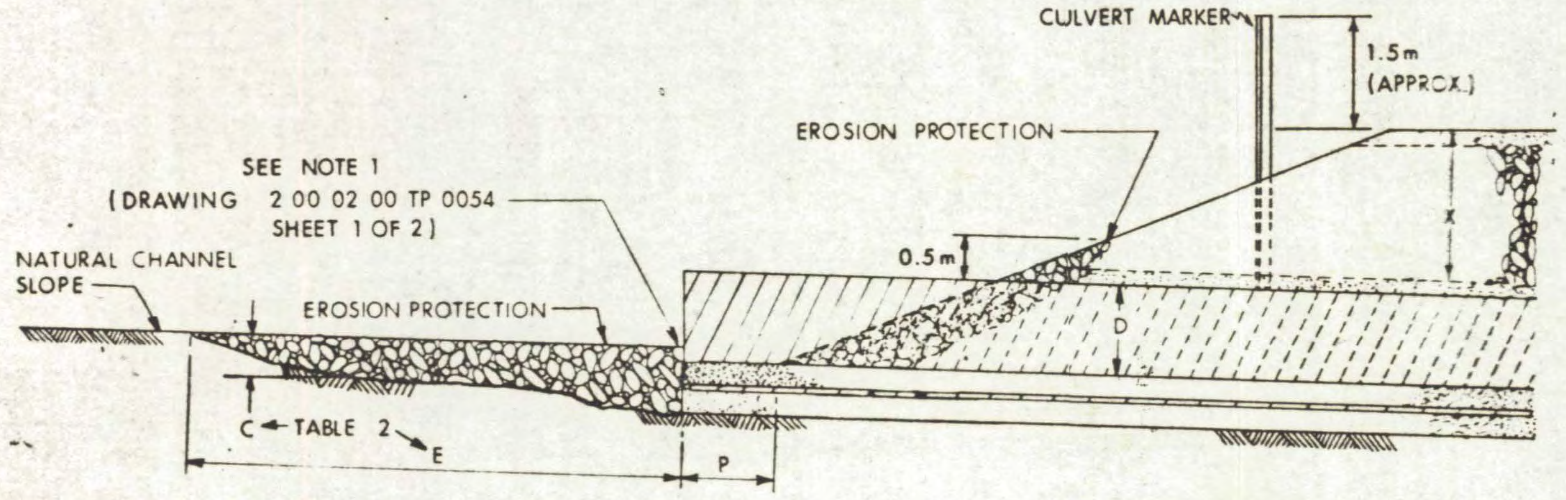
PREPARED BY
YUKON PIPELINE DESIGN JOINT VENTURE
KPK CANUCK MONENCO [illegible]

RGN	ZONE		FACILITY		NO.		DWG. TYPE		DRAWING NO.				REV
2	0	0	0	2	0	0	T	P	0	0	5	4	0

METRIC A2, FORM 260 AUG.80

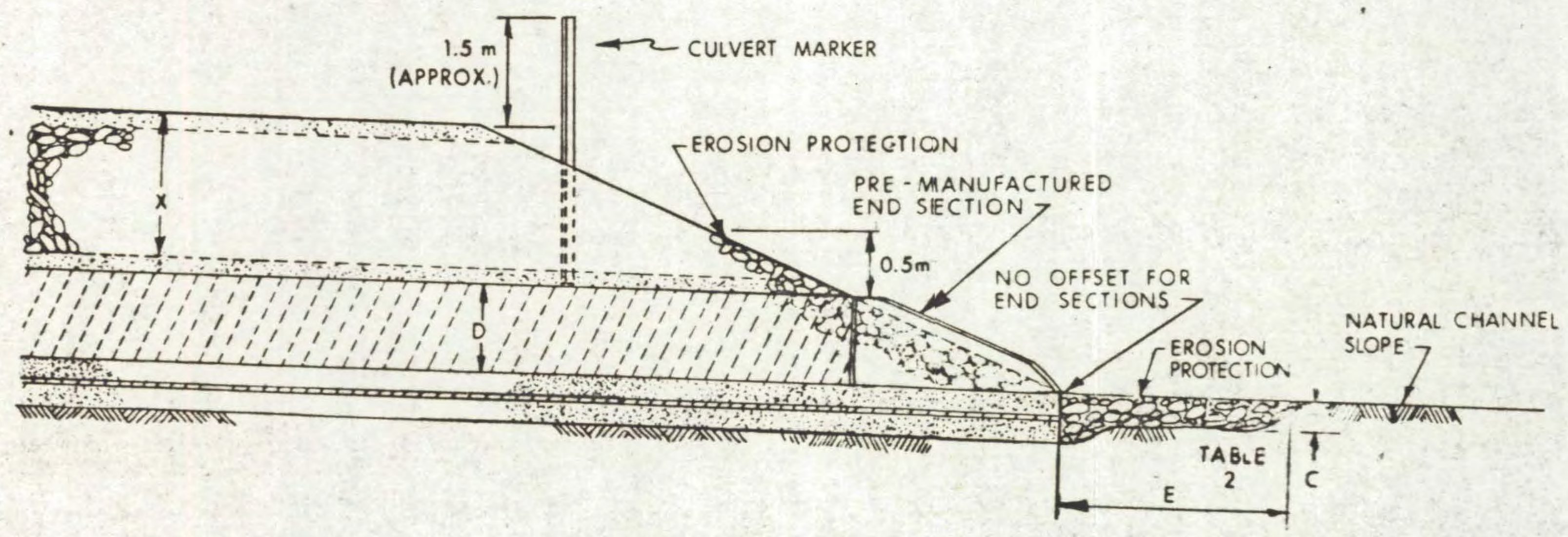


SECTION B-B



DETAIL 2

TYPICAL INLET / OUTLET CONFIGURATION (INLET SHOWN) FOR 600, 800 AND 900mm CULVERT INSTALLATION



DETAIL 3

TYPICAL INLET / OUTLET CONFIGURATION (OUTLET SHOWN) FOR 1200mm AND PIPE-ARCH CULVERT INSTALLATION.

TABLE 1 : CULVERT FEATURE DIMENSIONS

D	X	P			
CULVERT DIAMETER OR RISE	MINIMUM COVER	PROJECTED END LENGTH INLET	OUTLET		
600	300	300	600		
800	300	400	800		
900	300	450	900		
1200	600	END SECTION	END SECTION		
1230	600	END SECTION	END SECTION		
1400	600	END SECTION	END SECTION		

TABLE 2: LEVELS OF EROSION PROTECTION

LEVEL	MATERIAL	C	E INLET	E OUTLET
0	SEL 1 OR CLASS D MATERIAL	200	DISTURBED AREA	2×CULVERT DIA. OR RISE
1	CLASS D MATERIAL	400	DISTURBED AREA	2×CULVERT DIA. OR RISE
2	CLASS E MATERIAL	300	DISTURBED AREA	3×CULVERT DIA. OR RISE
3	CLASS E MATERIAL	500	DISTURBED AREA	3×CULVERT DIA. OR RISE
4	ROCK RIPRAP CLASS I	600	DISTURBED AREA	4×CULVERT DIA. OR RISE

PROFESSIONAL ENGINEER ALBERTA
P. St. J. PRICE

GENERAL NOTES

A. ALL DIMENSIONS ARE IN MILLIMETRES UNLESS OTHERWISE SPECIFIED.

REFERENCE DRAWING

DRAWING NO	TITLE

MICROFILM RECORD

FILE NO	DATE

REVISIONS

NO	DESCRIPTION	DATE	BY	CHKD	APPR YPD	APPR FPL
0	SUBMIT TO FEARO OFFICE AND NPA	820210				

NORTHERN PIPELINE AGENCY

ENGINEERING RECORDS

DRAWN BY	CHECKED BY	DATE
V. J. R.		81 09 17
ENGINEER		
SUPERVISOR		
MANAGER		

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ENGINEER	
SUPERVISOR	
MANAGER	

SCALE N.T.S

Foothills Pipe Lines (South Yukon) Ltd.
THE ALASKA HIGHWAY GAS PIPELINE PROJECT

TYPICAL
CULVERT INSTALLATION
(SHEET 2 OF 2)

PREPARED BY
YUKON PIPELINE DESIGN JOINT VENTURE
AKL CANUCK MONENCO PETROTECH

RUN	ZONE	FACILITY	NO	DWG TYPE	DRAWING NO.	REV
2	0 0	0 2	0 0	T P	0 0 5 4	0

METRIC A2 FORM 260 AUG 80