FAULT CROSSING

DESIGN APPROACH

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NORTHWEST ALASKAN PIPELINE COMPANY

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SUMMARY

The DOI Stipulations for the Alaskan Leg of the Alaska Natural Gas Tranportation System (ANGTS) require that the gas pipeline resist failure resulting in line rupture during the life of the pipeline from maximum anticipated horizontal and/or vertical displacement in areas where the line crosses potentially active fault zones.

From Delta Junction to the Yukon Territory border (Delta South), four potentially active fault zones have been identified which cross the pipeline alignment. The aggregate width of these zones has been estimated at about 18 miles. To meet the DOI Stipulations, special fault crossing designs costing over $2.5 million/mile more than a normally buried pipeline will have to be constructed. This additional cost is a considerable price to pay when it is realized that:

1) The probability of experiencing fault movement in the Delta South region during the 25-year design life is extremely small.
2) The pipeline alignment is located throughout in a Class I location. The consequences of a pipeline rupture to life and property would therefore be minimal.
3) Special fault crossing designs cannot completely eliminate the possibility of rupture caused by ground motion.
4) The special fault crossing designs may have a negative impact on the environment and expose the pipeline to human hazards with even greater probabilities of occurrence (e.g., vandalism and sabotage), and
5) A gas pipeline rupture will have a negligible impact on the environment when compared with an oil pipeline.

Because of these factors, the decision to apply special fault crossing designs should be based on an economic comparison and evaluations of the design reliability and of the consequences of a pipeline rupture.

The Delta South fault study (Reference 1) showed that the probability of movement along any one of the four fault zones is small, on the order of 3 percent during the 25-year design life. Using this information as a starting point, the cost, reliability and rupture consequences of four fault crossing designs were investigated.

The probability of a pipeline rupture for each fault crossing design was then determined by combining the probability of expected levels of fault offsets with the probability of a rupture for that offset. The results of this analysis showed that the probability of a pipeline rupture in 25 years, considering all four fault zones in Delta South varies from approximately 6 percent to less than 1 percent depending on the fault crossing design. A comparative economic analysis was also performed to assess the total cost of each type of design. The total cost was taken as the initial construction cost plus the probable repair cost due to a fault-induced rupture which might occur during the 25-year design life of the pipeline.

Further, the consequences of each fault crossing design were qualitatively assessed with respect to impact on the environment, safety and susceptibility to human and other hazards.

Results of these analyses favor crossing the potentially active fault zones with a normally buried pipeline. This is because of the low probability of a pipeline rupture due to fault offsets, the economic comparison and the environmental consequences of the fault crossing modes and the inherent protection of the pipeline from human and other hazards in a belowground mode.

It is therefore requested that the OFI concur that the installation of a normally buried pipeline across the potentially active fault zones will substantially satisfy the design requirements provided the design includes specific measures that will detect pipe movement and limit the effects of a rupture.

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1.0 INTRODUCTION

The DOI Stipulations, with regard to fault crossing design, reads as follows:

3.2.2.2 "Minimum design criteria for a segment of the PIPELINE SYSTEM traversing a fault zone that is interpreted by the FEDERAL INSPECTOR as active shall be: (1) that the PIPELINE resist failure resulting in line rupture from maximum anticipated horizontal and/or vertical displacement in the foundation material anywhere within the fault zone during the life of the PIPELINE..."

To meet this Stipulation, special fault crossing designs in addition to the use of high toughness pipe, would have to be constructed across approximately 18 miles of four potentially active fault zones that have been determined to cross the pipeline alignment in Delta South. These special designs may require placing the pipeline in either aboveground embankments, oversized ditches, or protecting the buried pipe by enclosing it in waterproof culverts or concrete box-like structures. These designs cannot, however, completely eliminate the possibility of pipe rupture resulting from fault movements due to the uncertainties associated with the characterization of the fault zones (i.e., their location, width, geometry and complexity of motion).

In Section 2.0 of this report, differing philosophies of fault crossing design are discussed with regard to the ANGTS alignment in the Delta South region. Section 3.0 presents the probability of experiencing fault offsets at the four potentially active faults as well as the probability of pipe rupture during the 25-year design life of the gas pipeline. Section 4.0 provides a comparative economic analysis of the total cost of using a normally buried gas pipeline across the fault zones versus the construction of special fault crossing designs. Finally, Section 5.0

compares the consequences of using a normally buried pipeline versus special crossing designs to traverse the fault zones.

2.0 PHILOSOPHY OF FAULT CROSSING DESIGN

Because of the uncertainty associated with fault zone definition and the low probability of large fault offsets during the life of the pipeline, two philosophies of fault crossing should be assessed. The first philosophy (deterministic), which is outlined in the DOI Stipulations, is to design the pipeline to resist failure resulting in line rupture, caused by fault movements which might reasonably be expected to occur during the design life. The second philosophy (probabilistic) is to accept a low risk of pipeline rupture recognizing the small probability of fault movement and the uncertainties encountered with fault zone definition, and to minimize and accept the consequences of a rupture.

The first approach (design to resist failure) is reasonable if movement along a particular fault is considered to be likely (greater than 10 percent probability of occurrence during the design life), if the fault zone is well-defined and the consequences of a rupture are substantial. The second approach (minimizing the consequences of a rupture) is preferable when the probability of fault movement is small, less than 0.5 percent and the fault zones are not well-defined or the consequences of a rupture are not severe. For probabilities of fault movement between 0.5 percent and 10 percent, the decision between the two options should be based on the consequences of pipe rupture, reliability and consequences of constructing a particular fault crossing design, as well as the cost of the fault crossing design. The four potentially active fault zones within Delta South fall into this last category of probabilities as will be shown in Section 3.0.

The following fault crossing design concepts are considered in this report:

1) Normal burial utilizing Type I through Type V ditch.
2) Placement of the pipeline in an aboveground embankment constructed of select mineral material (EMBANKMENT MODE).

3) Placement of the pipe in oversized ditches and surrounding it with a) select mineral material backfill or b) select mineral material backfill with enhanced slip planes (OVERSIZED DITCH MODES).
4) Placement of the pipe within a buried a) waterproof, concrete box-like structure or b) protective culvert (PROTECTIVE CASING MODES).

Examples of these special fault crossing designs are shown in Figures 2-1 through 2-3. For comparison, Type I conventional ditch and Type V insulated pipe/overexcavation ditch are also shown. The oversized ditch modes and the protective casing modes are design concepts only. The ditch types shown in Figures 2-2 and 2-3 would be used in areas of stable soil conditions. Other oversized ditch and protective casing types for unstable or frost susceptible soil conditions will have to be developed. The protective casing modes shown in Figure 2-3 will only accommodate small offsets (less than 3 feet). A much larger structure would have to be used to allow for the 3 feet or larger fault offset which might occur in Delta South.

An aerial fault crossing mode was additionally considered. This mode would span the fault zones on aboveground supports, similar to Alyeska's VSM design. For long sections, approximately one-half mile and more, this mode was dropped from further consideration as a fault crossing design since it does not conform to pipeline fracture control. This is because backfill does effectively provide additional fracture propagation resistance and thereby reduces the required pipe fracture arrest toughness. Pipeline on aboveground supports will however, be used in other special cases such as major river crossings where the aboveground span is less than one-half mile. In this report, it is assumed that adequate restraint is obtained from the aboveground embankment mode to provide the necessary overburden load for fracture control.

The special fault crossing design concepts will reduce the probability of pipe rupture given a fault offset. However, the costs are high and the environmental consequences resulting from these designs are likely to be more severe than the results of a rupture of a normally buried pipeline.

3.0 PROBABILITY OF FAULT MOVEMENT AND PIPELINE RUPTURE

South of Delta Junction, four potentially active fault zones crossing the pipeline alignment have been identified (Reference 1): The Tok River Zone, the Dry Creek Zone, the Mansfield Creek Fault and the Canteen Fault. Table 3-1 presents the probability of one occurrence of fault movement of various levels of net displacement at the pipeline over 25 years for each of these four fault zones. The probability of more than one occurrence of fault movement over 25 years at each of these zones is approximately one-hundredth of the probability of one occurrence and can be neglected.

For a given fault offset, the probability of pipeline rupture depends upon the depth of pipe burial, the type and strength of the soil surrounding the pipe and the pipeline material properties. Of major importance to the gas pipeline is whether the pipe is surrounded by ice-bonded frozen soil or by unfrozen soil (i.e., whether the pipe and frost bulb during fault offset can move independently of the surrounding soil). Table 3-1 presents estimates of the probability of pipeline rupture for various levels of fault movement for a normally buried pipeline surrounded by frozen and unfrozen soils, respectively (Reference 2). These estimates are based upon the current pipe specification, less than 4-feet depth of cover, and sandy or silty soil surrounding the pipeline. They represent an extrapolation of results obtained from the analyses of pipelines at fault crossings for a number of other projects and some preliminary analyses of the gas pipeline.

Probabilities of pipeline rupture for various levels of fault offsets are also presented in Table 3-1 for the oversized ditch modes, the protective casing modes, and for the embankment mode of fault crossing. The performance of the select backfill and enhanced slip plane oversized ditch modes were assumed to be similar. Therefore, Table 3-1 presents only a single rupture probability for the general class of oversized ditch modes. Since analytical or test data does not presently exist to quantitatively define the probability estimates shown in Table 3-1 for the special designs, the values were derived by qualitatively assessing how well each crossing mode would perform relative to a pipeline which is normally buried (see Table 3-1 for rationale).

The estimates of conditional rupture probabilities (i.e., the probability of rupture given a fault offset) and fault offset probabilities in Table 3-1 were multiplied together to obtain the probability of failure for each fault crossing design (see Table 3-2). The resultant probability of pipe rupture in 25 years for normally buried pipe is 2.5 percent if it is placed in frozen soil and 0.7 percent if it is placed in thawed soils. Pipe placed in oversized ditches or in a culvert casing is estimated to have a 1.8 percent or 1.5 percent probability of rupture in frozen ground and 0.35 percent and 0.3 percent in unfrozen ground, respectively. Pipe placed in a concrete box is estimated to perform similarly in either frozen or unfrozen soil with a rupture probability of 1.7 percent. The probability of pipe rupture for the embankment mode is 0.2 percent. Table 3-2 also indicates about a 3 percent probability for all levels of fault movement within 25 years for each of the four fault zones.

The probability figures shown in Table 3-2 are based on the pipeline crossing only one fault zone. If we assume that fault movement along each of the four Delta South fault zones is independent, then the total probability P, for K occurrences of pipe rupture due to overall fault movement during a 25-year period is given by the binomial distribution as:

$$P_{[K]} = \binom{n}{K} p^K \quad (1-p)^{n-K} \qquad (3\text{-}1)$$

where n is the number of fault zones and p is the probability of pipe rupture in a 25-year period for each zone. Assuming that approximately 50 percent of the pipeline in the fault zone will be in frozen soil and

50 percent in unfrozen soil, the value for P will work out to 1.6 percent for conventional ditching, 1.05 percent for the oversized ditch mode and 0.90 and 1.70 percent for the protective casing modes, respectively. Table 3-3 shows the probability for K occurrences of fault-induced rupture of the pipeline for the normal burial mode and the special fault crossing modes. It is seen that more than one occurrence of rupture is unlikely and can be neglected.

In summary, the data in Table 3-2 show that the probability of a fault offset along each fault in Delta South during a 25 year design life is very small, on the order of 3 percent. In addition, the results of Table 3-3 show that the probability of fault-induced pipeline rupture along the Delta South portion of ANGTS is also low; on the order of 6 percent for normally buried pipe, 3.5 percent to 6.5 percent for pipe placed in protective casings or in oversized ditches, and less than one percent for pipe placed in an aboveground embankment. With these low probabilities, NWA recommends that the prudent design approach is to use normal burial with implementation of a pipeline and seismic monitoring program, and an Operating and Maintenance Plan.

4.0 COMPARATIVE COST ANALYSIS OF DESIGN ALTERNATIVES

4.1 General

This section presents a comparative cost analysis for fault crossing in Delta South between normal ditch burial of the pipeline and the special fault crossing design alternatives. The damage scenario investigated in this section considers the total costs associated with the occurrence of a fault-induced pipeline rupture sometime during the 25-year design life.

Construction costs (for activities beginning in 1985 and continuing through 1987) were made assuming a total width of 17.72 miles across all four Delta South fault zones. For normal burial of the pipeline, construction costs are a function of the ditching mode utilized. It was estimated that:

- Type I conventional ditch would be used over 3.82 miles,
- Type II-C* permafrost ditch over 8.57 miles,
- Type IV* deep burial ditch over 0.25 mile, and
- Type V* insulated overexcavation ditch for 4.87 miles.

The remaining 0.21 mile represents a river aerial crossing. In addition to construction costs, estimates of minimum repair costs and repair time were made for the rupture scenario assuming 250 lineal feet of 48 inch diameter mainline pipe must be replaced. The total cost of each fault crossing mode was then determined and compared.

*Typicals of these ditch types appear in the Design Criteria Manuals, Volumes 1 and 2.

4.2 Rupture Scenario

Table 4-1 shows the construction and repair cost breakdown in 1987 dollars for the Delta South rupture scenario. This table depicts a somewhat unrealistic scenario where the pipeline rupture occurs in the first year (1987). It is provided only as a reference point.

Table 4-2 and Table 4-3 show the cost breakdown and the total costs, respectively, in 1987 dollars for a rupture scenario. The extent of damage is assumed to be the same irrespective of which year the rupture occurs during the 25-year design life. A repair cost inflation rate of 9 percent and a 6 percent discount rate have been included.

Tables 4-2 and 4-3 show that, from a total cost standpoint, the normal burial mode for fault crossing is preferable. The two main contributing factors to this conclusion are:

1) The small probabilities of pipeline rupture which dramatically reduce the values of the probable repair cost; and
2) The large differential between construction costs for normally buried pipe and those for the special fault crossing designs.

This differential is so large that holding all other values constant, the probability of pipeline rupture for the normal burial mode could be made 100 percent (i.e., a rupture will occur) and the special crossing designs would still not be economically attractive.

5.0 CONSEQUENCES OF FAULT CROSSING DESIGNS

In this study, the consequences of constructing alternative fault crossing designs have been broken into three general categories:

1) Impact on the immediately surrounding environment;
2) Effect on the health and safety of the public, and
3) Susceptibility to other hazards.

The last category includes hazards such as vandalism, sabotage and vehicular impacts.

This section presents a qualitative comparison between the fault crossing modes in each of these areas. First, the consequences associated with each crossing mode are discussed and then ranked relative to each other with respect to each consequence.

5.1 Environmental Consequences

The alternate modes of fault crossings may affect the surrounding environment by:

1) Altering sheet flow and surface drainage patterns;
2) Requiring the use of larger quantities of imported mineral materials;
3) Imposing a visual impact;
4) Affecting the movement of large mammals; and
5) Requiring additional restoration.

The following discussion assesses each fault crossing mode with respect to these issues:

- Normal Burial Mode - Some imported material may be necessary to cross the fault zones but the impacts on the environment and drainage patterns would be no greater than for any other portion of the pipeline.

- <u>Oversized Ditch and Protective Casing Modes</u> - Both oversized ditch modes and the buried culvert mode will require significantly greater quantities of select mineral material than the normal burial mode (see Figures 2-2 and 2-3a). This may require additional processing and/or additional material sites. Each additional material site will increase the visual impact and will require restoration. The processing of material may impact local air quality and water resources. The extra width of the backfilled area may have an effect on drainage patterns, possibly causing some ponding and channelization. The installation of low-water crossings will be comparable to that for normal burial and impacts on the animal population as a result of these modes in the fault crossing areas will be minimal.

  The concrete box alternative (see Figure 2-3b) would require the processing of and importation of select materials for concrete aggregate. Processing could impact local air quality and water resources, and additional material sites may be required.

- <u>Embankment Mode</u> - A typical embankment design would rise a minimum of 7 feet above the original grade and will be a minimum of 43 feet wide (See Figure 2-1c). The embankment will have to be constructed of well-draining material to prevent the formation of a solid mass surrounding the pipe in the winter. A substantial amount of select mineral material will therefore be required resulting in far greater environmental impacts than would result from normal burial. The 2:1 slope of the embankments will allow for the passage of large mammals (mainly moose, bison and possibly caribou). Of primary concern is the effect the embankment design will have on drainage patterns. In areas of existing sheet flow, properly designed culverts will be necessary to maintain existing drainage patterns. The design of these culverts must account for the chilled pipe effect and the weight of the embankment. Since the Federal Stipulations require that the pipeline design not "change the nature" of the wetlands, special care will have to be taken so that drainage channels are not created where sheet flow previously existed resulting in erosion, sedimentation, downslope dewatering or upslope ponding.

Based on the above environmental discussion, each fault crossing mode was subjectively rated in Table 5-1. This comparison shows that the normally buried mode is preferable. The embankment mode is the least environmentally attractive fault crossing mode.

5.2 Health and Safety Consequences

The main impact on the health of the public or wildlife due to pipeline rupture involves the leakage of natural gas in large heavy concentrations within a localized area. If rupture occurs, it is assumed that the same amount of gas will be vented into the atmosphere regardless of the fault crossing mode. Therefore, from a health standpoint, they are judged to be equal.

The impact on safety due to pipeline rupture is primarily the explosive nature of such an event. The forces induced on the pipe due to a sudden pressure release may force it into a whipping action. In addition, there is always a probability of fire when the escaping gas mixes with the atmosphere. The Delta South fault zone areas are all Class I Locations. The impact of a pipeline rupture on the health or safety of any population in the area will therefore be negligible. The following discussion briefly describes the safety hazards associated with each fault crossing design assuming a pipeline rupture has occurred.

- Normal Burial and Oversized Ditch Modes - The pipe whip will be restrained by the overburden pressure of the backfill and the inertia of the frost bulb. This will reduce pipe motions. However, the rupture of the pipeline will cause some flying debris when the pipe breaks through the backfill.

- Protective Casing Modes - The pipe whip will not only be restrained by the overburden pressure of the backfill, but also by the protective structure. However, the whip action of the pipe may cause it to break through the culvert or concrete box sending objects through the air in the vicinity of the rupture. From a safety standpoint, this method of fault crossing would probably be less desirable than normal burial.

- Embankment Mode - The pipe placed in an embankment will be less restrained than the normally buried pipeline. More flying debris will result from a rupture using this mode of fault crossing than from a normal burial.

Based on the above conclusions, the normal and oversized ditch burial modes are preferable to the embankment mode or protective casing modes.

5.3 Susceptibility to Other Hazards

The gas pipeline will also be subjected to other hazards. These include:

- Vehicle Impact - This includes accidental collisions by construction equipment, automobiles, aircraft, etc.
- Vandalism/Sabotage - This includes malicious or intentional damage to the pipeline, such as simple tampering, deliberate fire, misuse of construction equipment and the criminal use of explosives and firearms by individuals or groups.

The probability of pipeline damage and rupture due to these other hazards is approximately equal to or greater than the probability for a fault offset. For example, the annual probabilities of fault movement versus the probability of some of the other pipeline hazards for an area such as Delta South are estimated from Reference 3 to be:

<u>Annual Probabilities of Occurrence</u>

Fault Movement	1/800
Aircraft Collision	1/10,000
Vehicle Collision	1/1000
Vandalism (aboveground pipe)	1/50
Sabotage (aboveground pipe)	1/1000

It is evident from this table that an aboveground pipeline is more susceptible to vandalism, and just as susceptible to sabotage and vehicle collision as it is to fault offset.

The susceptibility to other hazards for the fault crossing design modes can be summarized as follows:

- Normal Burial Mode - The location of the pipeline has low visibility and it is protected from vehicle impacts, sabotage and vandalism.

- Oversized Ditch and Protective Casing Modes - Comparable to normally buried pipeline in terms of vehicle impacts, sabotage and vandalism.

- Embankment Mode - The pipeline is highly visible and susceptible to vandalism and sabotage.

In Table 5-2 the fault crossing modes have been ranked based on their susceptibility to other hazards and it shows that the burial modes for crossing the fault zones are preferred.

6.0 CONCLUSIONS

The results of this fault crossing design study lead to the following conclusions:

- Special fault crossing designs can reduce, but cannot completely eliminate the possibility of fault-induced pipeline rupture or damage during the life of the gas pipeline.
- The decision to design special fault crossings should be based on a cost, reliability and consequence analysis when the probability of offset on a particular fault is small (less than 10 percent) over the life of the pipeline.
- Each of the four Delta South fault zones is estimated to have only a 3 percent probability of offset in 25 years. This leads to a 10 percent chance of movement in 25 years in Delta South and only a 6 percent probability that a normally buried pipeline would experience a rupture.
- Total cost comparisons of various fault crossing modes strongly favor the normally buried pipeline, principally because of its lower construction cost and to a lesser extent because of the small probabilistic repair costs due to expected fault movements over a 25-year period.
- The normally buried pipeline is preferred when its overall impact on the environment and on health and safety and its susceptibility to vandalism and sabotage is assessed.

In view of the above, it is requested that the OFI concur that the installation of a normally buried pipeline across potentially active fault zones will substantially satisfy the design requirement to resist failure resulting in line rupture caused by fault movement, provided the design includes the following:

1) NWA will specify high toughness pipe in the mainline pipe specification. Due to the inherent pipe toughness, this pipe will resist fracture initiation and thereby minimize the probability of line rupture.
2) NWA will use in-line crack arrestors made of extra heavy wall pipe with high toughness. These crack arrestors will arrest a propagating ductile fracture and minimize the extent of line rupture. The distance between these inserts will be modified in the potentially active fault zones to provide for a more frequent installation as compared to non-active zones.
3) NWA will select the mainline block valve spacing in accordance with the requirements of 49 CFR 192, and to the extent possible, place mainline valves to provide for a straddling of the potentially active fault zones. If required, this will include the addition of valves to provide for the fault zone isolation potential.
4) NWA will install a seismic monitoring system in accordance with stipulation requirements. This system will include annunciators along the pipeline right-of-way, located at Compressor Station sites.
5) NWA will undertake a pipeline monitoring program which will determine pipe movements and/or changes in pipeline curvatures.
6) NWA will prepare an Operation and Maintenance Plan which will address recognition of seismic events and the associated fault locations, potential damage repair procedures/logistics and the flow resumption procedures.

REFERENCES

(1) "Final Report ANGTS - Delta South Fault Study," Woodward-Clyde Consultants, Orange, California, May 1981.

(2) Kennedy, R. P., "Preliminary Discussion on the Risk of Fault Movement Induced Pipeline Rupture for the Alaska Segment of the ANGTS," SMA Draft 14702.01, Structural Mechanics Associates, dated June 1981.

(3) Acres American Final Report, "Yukon River Bridge Use Risk Analysis," prepared for Fluor Engineers and Constructors, Inc., Northwest Alaskan Pipeline Company, December 1981.

(4) Pipeline Design Criteria Manual, Volumes 1 and 2.

(5) "Mainline Pipe Fracture Control Methodology," June 1, 1982.

TABLE 3-1

Probabilities of Fault Offset and Pipeline Rupture Given Fault Offsets on Each of Four Fault Crossing Zones South of Delta Junction

Fault Offset (Meters)	Probability of Movement in 25 Years (P_M)	CONDITIONAL PROBABILITY OF RUPTURE ($P_{R/M}$)								
		UNFROZEN SOIL				FROZEN SOIL				ALL SOILS
				Protective Casing				Protective Casing		
		Normal Burial	Oversized Ditch	Culvert	Concrete Box	Normal Burial	Oversized Ditch	Culvert	Concrete Box	Embankment
0-0.5	0.0030	0.01	0.005	0.001	0.001	0.30	0.10	0.001	0.001	0.003
0.5-1.0	0.0079	0.05	0.03	0.005	0.005	0.60	0.30	0.005	0.005	0.01
1.0-1.5	0.0064	0.10	0.05	0.05	0.50	0.90	0.50	0.50	0.50	0.03
1.5-2.0	0.0045	0.20	0.10	0.10	1.0	1.0	0.75	0.75	1.0	0.05
2.0-2.5	0.0030	0.35	0.20	0.20	1.0	1.0	0.90	0.90	1.0	0.15
2.5-3.0	0.0020	0.50	0.25	0.25	1.0	1.0	1.0	1.0	1.0	0.20
>3.0	0.0038	0.70	0.30	0.30	1.0	1.0	1.0	1.0	1.0	0.25

Notes:

1) Probabilities for pipe normally buried in frozen and unfrozen soil were taken from Reference 2.

2) Probabilities for pipe in oversized ditches surrounded by unfrozen soil were determined by assuming behavior slightly better than normal burial in unfrozen soil for small offsets and much better for large offsets. In frozen soil, it was assumed that the select backfill would become ice-bonded and, therefore, would perform only slightly better than normal burial in frozen soil.

3) Probabilities for the embankment mode were determined assuming minimal ice-bonding of the select material such that the embankment would perform better than the oversized ditch mode in unfrozen soil.

4) Probabilities for pipe placed in a culvert in unfrozen and frozen soil were determined to be an order of magnitude less than for the normal burial mode assuming offsets less than the spacing between the pipe and the culvert. For larger offsets, its behavior was assumed to be similar to the oversized ditch mode in unfrozen soil. In frozen soils, it was assumed that the select backfill would become ice-bonded and for large offsets in frozen soil, the culvert mode was assumed to behave similar to normal burial in frozen soil.

5) Probabilities for pipe placed in a concrete box in unfrozen <u>and</u> frozen soil were determined by assuming behavior similar to the culvert mode for small offsets (smaller than the spacing between the pipe and box). For larger offsets, it was assumed that contact between the pipe and box would in all likelihood rupture the pipeline.

TABLE 3-2

Probabilities of Pipeline Rupture Within 25 Years for Each of Four Fault Crossing Zones South of Delta Junction

Fault Offset (Meters)	Probability of Movement in 25 Years (P_M, Percent)	PROBABILITY OF RUPTURE ($P_R = P_{R/M} \cdot P_M$), PERCENT								
		UNFROZEN SOIL				FROZEN SOIL				ALL SOILS
		Normal Burial	Oversized Ditch	Protective Casing: Culvert	Protective Casing: Concrete Box	Normal Burial	Oversized Ditch	Protective Casing: Culvert	Protective Casing: Concrete Box	Embankment
0-0.5	0.30	0.003	0.0015	0.0003	0.0003	0.09	0.03	0.0003	0.0003	0.0009
0.5-1.0	0.79	0.04	0.024	0.004	0.004	0.47	0.24	0.004	0.004	0.008
1.0-1.5	0.64	0.06	0.032	0.032	0.32	0.58	0.32	0.32	0.32	0.019
1.5-2.0	0.45	0.09	0.045	0.045	0.45	0.45	0.34	0.34	0.45	0.023
2.0-2.5	0.30	0.10	0.06	0.06	0.30	0.30	0.27	0.27	0.30	0.045
2.5-3.0	0.20	0.10	0.05	0.05	0.20	0.20	0.20	0.20	0.20	0.040
>3.0	0.38	0.27	0.11	0.11	0.38	0.38	0.38	0.38	0.38	0.095
Σ	3.00	0.70	0.35	0.30	1.7	2.5	1.8	1.5	1.7	0.20

Notes:

1) Probabilities of fault offset were taken from Reference 1.

2) Probabilities of pipeline rupture given the fault offset ($P_{R/M}$) were taken from Table 3-1.

TABLE 3-3

Probability of K Occurrences of Pipeline Rupture Due to Faulting in the Delta South Region Over a 25 Year Period

Number of Ruptures (K)	PROBABILITY OF PIPELINE RUPTURE (%)				
	NORMAL BURIAL	OVERSIZED DITCH	PROTECTIVE CASING CULVERT	PROTECTIVE CASING CONCRETE BOX	EMBANKMENT
1	6.1	4.2	3.5	6.5	0.80
2	0.15	0.07	0.05	0.17	∼0
3	∼0	∼0	∼0	∼0	∼0

TABLE 4-1

Construction Costs and Added Costs
Due to Pipeline Rupture in 1987
(1987 Dollars)

FAULT CROSSING MODE		CONSTRUCTION 1) COSTS ($1000)	REPAIR 2) COSTS ($1000)
NORMAL BURIAL		183,467	1,512
OVER-SIZED DITCH	SELECT BACKFILL	226,310	1,512
	ENHANCED SLIP PLANE	232,447	1,512
PRO-TECTIVE CASING	CULVERT	228,611	1,639
	CONCRETE BOX	428,988	2,091
EMBANKMENT		242,692	1,512

1) Costs for 17.72 miles of fault crossing (based on 1986/1987 heating season).

2) Repair costs are for replacement of 250 lineal feet of 48 inch diameter pipe.

TABLE 4-2

Construction Costs and Fault-Induced Probabilistic Losses Due to Rupture Assumed Equally Likely To Occur in Each Year of the 25-Year Pipeline Life (1987 Dollars)

FAULT CROSSING MODE		CONSTRUCTION COSTS ($1000)	REPAIR COSTS ($1000) [1]
NORMAL BURIAL		183,467	135
OVER-SIZED DITCH	SELECT BACKFILL	226,310	93
	ENHANCED SLIP PLANE	232,447	93
PRO-TECTIVE CASING	CULVERT	228,611	84
	CONCRETE BOX	428,988	199
EMBANKMENT		242,692	18

1) Repair cost inflation rate = 9%
Discount rate = 6%

TABLE 4-3

Cost Comparision of Fault Crossing Modes for Rupture Scenario
(1987 Dollars)

FAULT CROSSING MODE		TOTAL COSTS [1] ($1000)	Δ COSTS [2] ($1000)
NORMAL BURIAL		183,602	0
OVER-SIZED DITCH	SELECT BACKFILL	226,403	42,801
	ENHANCED SLIP PLANE	232,540	48,938
PRO-TECTIVE CASING	CULVERT	228,695	45,093
	CONCRETE BOX	429,187	245,585
EMBANKMENT		242,710	59,108

Notes:

1) Total Cost = Construction Cost + (Repair Cost) X (Probability of Rupture)

2) Δ Cost = (Normal Burial Total Cost - Special Fault Crossing Total Cost)

TABLE 5-1

Relative Ranking of Fault Crossing Modes
(Environmental Impacts)

FAULT CROSSING MODE		RATING BY CONSEQUENCE 1) Drainage	Use of Mineral Materials	Visual Impact	Animal Passage	Restoration	AVERAGE RATING 2)
	NORMAL BURIAL	1	1	1	1	1	1.0
OVER-SIZED DITCH	SELECT BACKFILL	2	3	1.5	1	3	2.1
OVER-SIZED DITCH	ENHANCED SLIP PLANE	2	3	1.5	1	3	2.1
PRO-TECTIVE CASING	CULVERT	1.5	3	1	1	2	1.7
PRO-TECTIVE CASING	CONCRETE BOX	1	2	1	1	1	1.2
EMBANKMENT		3	3	3	2	3	2.8

Notes:

1) 1 = Small; 2 = Intermediate; 3 = Great

2) Based on equal weighting of five consequences.

TABLE 5-2

Relative Ranking of Fault Crossing Modes
(Susceptibility to Other Hazards)

FAULT CROSSING MODE		RATING BY CONSEQUENCE[1]		AVERAGE[2] RATING
		Vehicle Impact	Vandalism/Sabotage	
	NORMAL BURIAL	1	1	1
OVER-SIZED DITCH	SELECT BACKFILL	1	1	1
OVER-SIZED DITCH	ENHANCED SLIP PLANE	1	1	1
PRO-TECTIVE CASING	CULVERT	1	1	1
PRO-TECTIVE CASING	CONCRETE BOX	1	1	1
EMBANKMENT		2	2	2

Notes:

1) 1 = Small; 2 = Intermediate; 3 = Great

2) Based on equal weighting of two consequences.

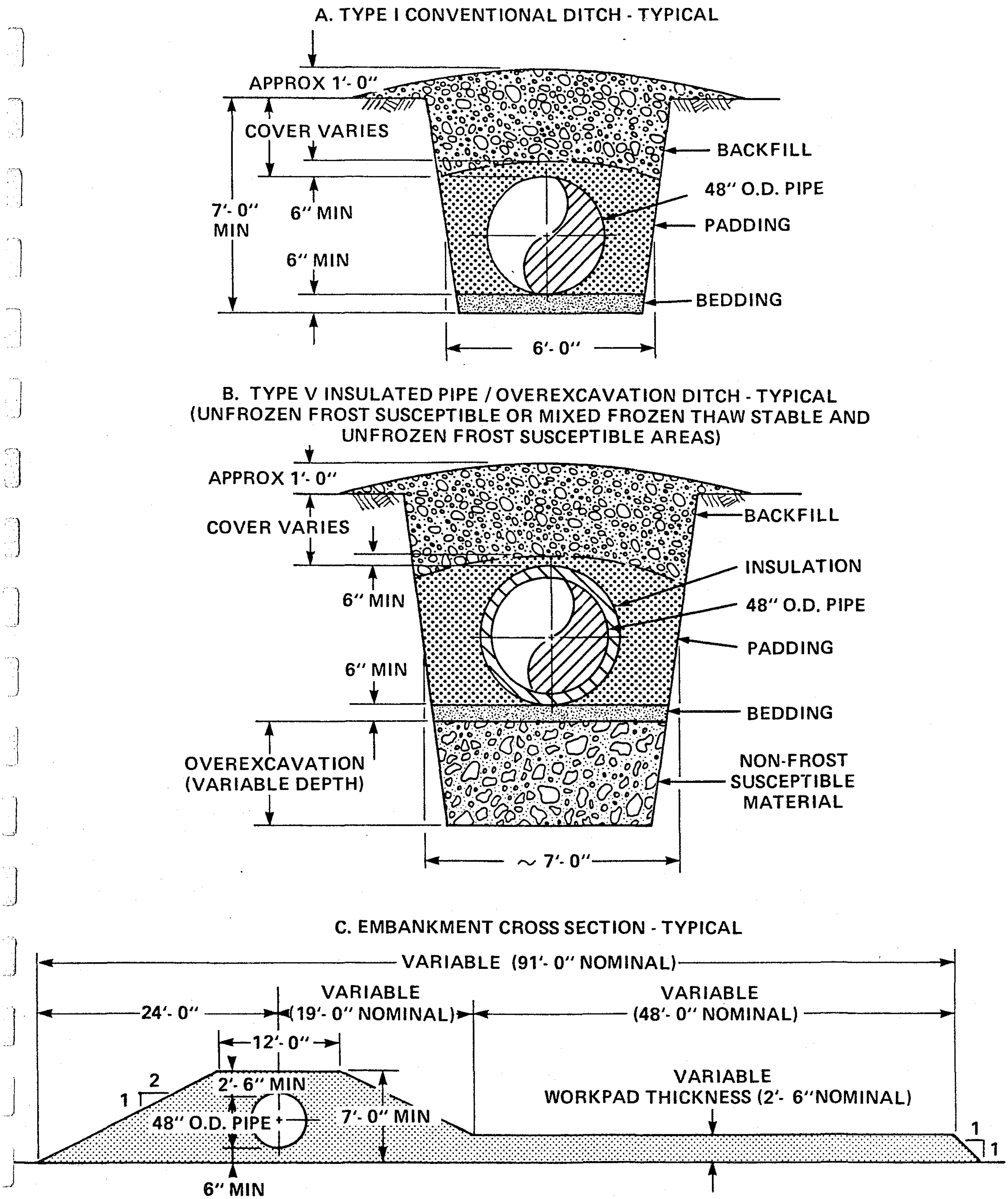
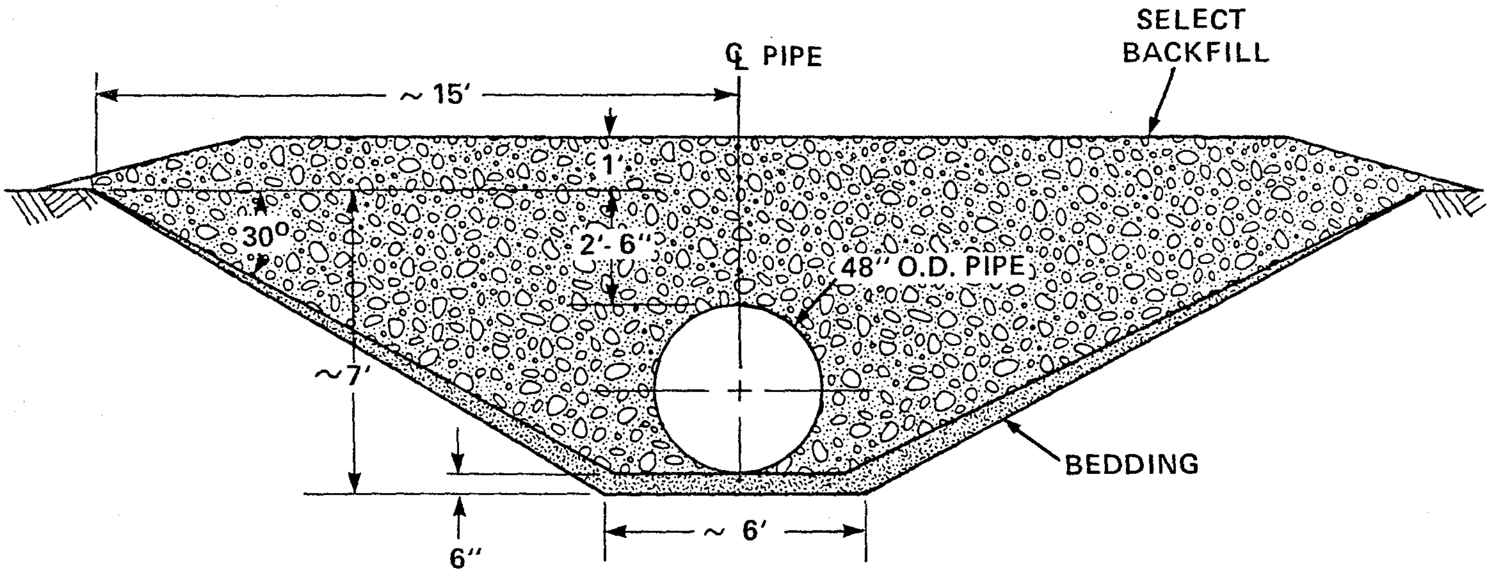


Figure 2-1. Typical Normal Ditch Burial and Embankment Cross Sections

A. SELECT BACKFILL - TYPICAL



B. ENHANCED SLIP PLANE - TYPICAL

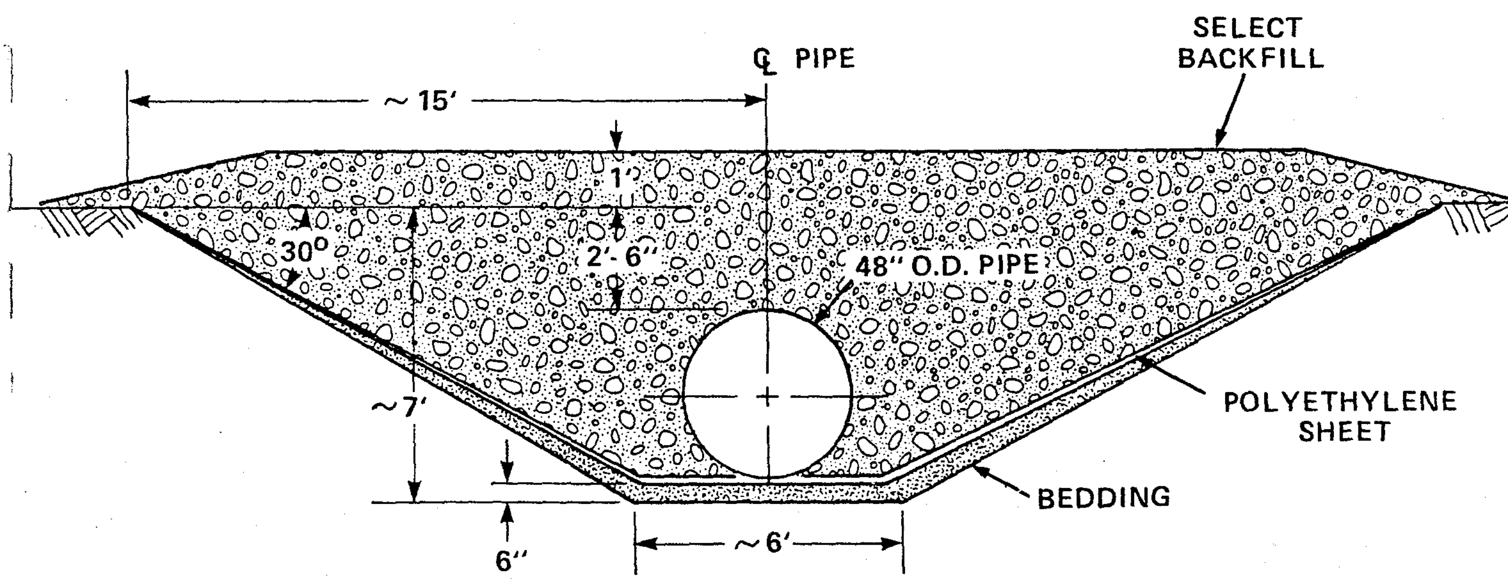


Figure 2-2. Typical Oversized Ditch Modes'

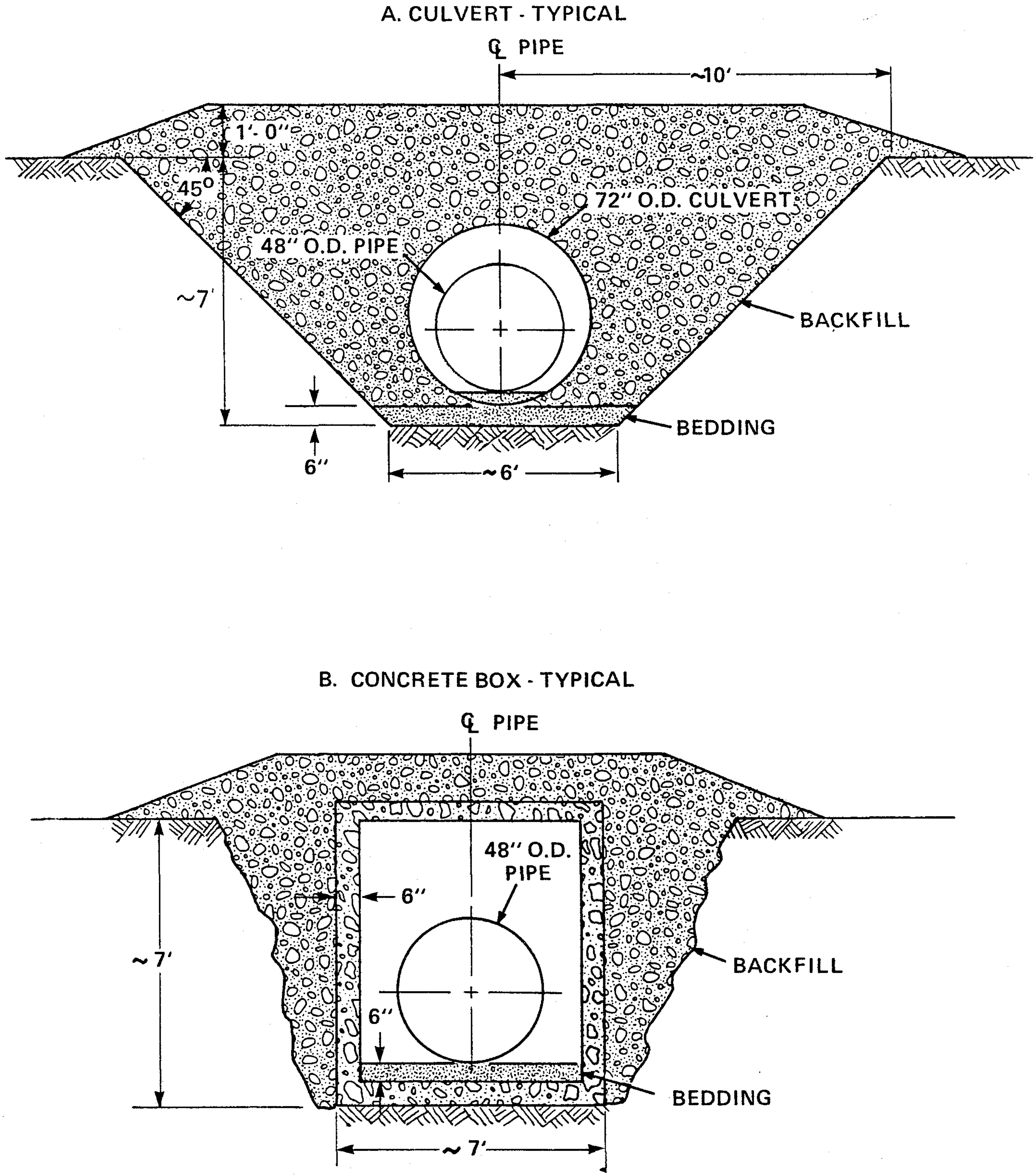


Figure 2-3. Typical Protective Casing Modes

NORTHWEST ALASKAN PIPELINE COMPANY
3333 Michelson Dr.
Irvine, California 92730
(714) 975-6007

901.0

GOA-82-2129

August 4, 1982

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AUG 09 1982
State of Alaska
Office of
Pipeline Coordinator

"BUSINESS" Information for Federal Government purposes in accordance with 10 CFR 1504 (F.R. Vol. 46, No. 240, December 15, 1981, pages 61222 thru 61234)

Mr. W. T. Black
Director, Office of Engineering
Office of the Federal Inspector
2302 Martin
Irvine, CA 92715

Subject: Fault Crossing Design Approach

Dear Mr. Black:

Northwest Alaskan Pipeline Company (NWA) is required by stipulations attached to the Federal Right-of-Way Grant for the Alaska Pipeline Segment to prepare a Seismic Plan (Stipulation 1.6.1) and to design the pipeline "by appropriate application of modern state of the art seismic design procedures..." (Stipulation 3.2). The key elements of these requirements provide for:

- Seismic monitoring
- Identification and delineation of faults
- A pipeline designed to resist failure
- Procedures for safe shutdown

In February 1981 NWA provided your office with a draft text of a "Seismic" plan in compliance with Stipulation 1.6.1. This plan included as an appendix a special report prepared by Newmark and Kennedy entitled "Seismic Design Criteria for the Alaska Segment of the ANGTS Pipeline Project". Subsequently, the Pipeline Design Criteria Manual was prepared with the intention of replacing the "Seismic" plan by addressing seismic requirements within the Criteria Manual (Section 20) and adding at a later date Section 17, "Fault Crossing", to specifically fulfill the requirements of Stipulation 1.6.1. Similar seismic criteria for other pipeline facilities have already been included in counterpart sections of the Design Criteria Manuals (i.e., compressor station structural criteria is found in Section 6 of the Compressor and Metering Station Design Criteria Manual, Vol. No. 3). The Newmark-Kennedy Report, updated by an addendum dated February 1982, continues to be the basis for design.

Enclosed is a special report, prepared in the context outlined above, that addresses the pipeline crossing of fault zones. It identifies the four potentially active fault zones that cross the pipeline from Delta South to the Canadian Border, analyzes alternative design approaches and proposes a design concept based on the probability of occurrence that fulfills the requirements of Stipulation 3.2.2. It is recommended that after reviewing the report, a meeting be held between our respective staff members to further discuss this design concept. After achieving agreement in principal on the design approach to be taken in fault crossing situations, Section 17 of the Pipeline Design Criteria Manual can be prepared and transmitted for your formal review and approval. In order to prepare Section 17 and forward it to you office by October 7th, the date indicated in our recent draft of key NWA-OFI activities, we should complete the discussions within the next few weeks.

The information contained in the enclosed volume is considered confidential/proprietary by NWA and remains the property of Alaska Northwest Natural Gas Transportation Company, a partnership. The petition accompanying this transmittal letter requests the OFI to consider this volume "BUSINESS" information pursuant to 10 CFR 1504.

Questions arising during the review of this material should be addressed to either myself of Nils Hetland at (714) 975-5573.

Very truly yours,

George P. Wuerch
Manager, Regulatory
and Governmental Affairs

GPW/dn
Enclosure (4 copies)

cc: N.W. Hengerer, OFI, WDC (w/1 copy of enclosure)
A.C. Mathews, OFI, WDC (w/4 copies of enclosures)
A.G. Ott, SPO, FBX (w/2 copies of enclosures)

Enclosure to Northwest Alaskan Pipeline Company
Letter GOA-82-2129 of August 4, 1982 to
Mr. W. T. Black

PETITION FOR "BUSINESS" DESIGNATION
SUBMITTED TO OFI PURSUANT TO 10 CFR PART 1504

I. The information enclosed with the above referenced Northwest Alaskan Pipeline Company (NWA) letter, qualifies for a "BUSINESS" designation on the basis that it is confidential/proprietary, commercial information, the release of which may substantially impair the competitive position of the sponsors of the Alaska gas pipeline segment of the Alaska Natural Gas Transportation System (ANGTS). NWA has incurred substantial costs to develop the information, involving over four years' work and millions of dollars, including both direct and indirect costs. Moreover, the sponsors do not have a final, unconditional Certificate of Public Convenience and Necessity from the Federal Energy Regulatory Commission (FERC), and the information clearly would be of substantial value to anyone contemplating the construction of a pipeline from the North Slope through the central region of Alaska or in similar climates and geologic regimes. Even after a final FERC certificate has been obtained, the information contained in the document submitted is of such a nature that it might be used in third-party litigation against the sponsors. NWA has given serious consideration to a request for a "SENSITIVE" designation and to the recent order from the International Trade Commission, Department of Commerce (e.g., 15 CFR Parts 379, 385 and 399, published F.R. Vol. 47, No. 2, January 15, 1982, p. 141) restricting export of technical data related to gas transmission. Although the less restrictive "BUSINESS" designation has been requested, the advanced technology represented by this information clearly should not be disclosed except as authorized by NWA.

II. The OFI may contact the following named persons concerning this petition:

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