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Land related problems associated with construction and operation of the proposed pipeline from Prudhoe Bay to Valdez, Alaska, can appropriately be summed up by one word, "erosion." If erosion under all conditions is controlled, siltation of stream beds will be prevented and the integrity of the pipe will be maintained. The pipeline technologists have acquired a great fund of experience in dealing with erosion and associated problems in recent years. What is envisioned to pose serious problems associated with TAPS, is the presence of permafrost along most of the route. It is in this area of environmental conditions that experience is almost totally lacking and, appeal must be made to theoretical evaluations to predict how the environment will respond to a buried 4-foot pipe full of warm oil.

TAPS engineers, as well as their materials consultants, are as aware of these problems as are environmental scientists and are exerting every effort to choose a route with maximum stability. One possible difference is the approach of the two groups is that TAPS may accept a certain risk in choosing alternate routes, whereas, environmental scientists desire a positively fail-safe line. It is here that some conflict may arise. Since it is recognized that it is permafrost that makes this project unique, and experience in dealing with it is sparse, most of this report will be concerned with interactions of permafrost and engineering activities.

Heat transfer calculations have led to the conclusion that no amount of thermal insulation will prevent permafrost melting by a buried hot pipeline. Therefore, if the line is to be buried, which TAPS prefers because of security, the material supporting the line must maintain its foundation strength after melting occurs. Coarse grained materials, sands and larger, whatever their geologic origin, retain their bearing strength with minimum distortion as frost and ice melts and the water drains away. Silt, on the other hand, may lose its supporting strength when permafrost melts. With these facts in mind, TAPS location and material engineers are endeavoring to locate the line on coarse materials. Where frozen silts cannot be avoided, the pipe will be supported on piles above ground and insulated with polyurethane. Frozen bedrock does not pose a problem because it retains its foundation qualities whether frozen or not.

North of Brooks Range, the true Arctic, permafrost is continuous (with certain exceptions), deep, and requires considerable heat to melt. South of the Brooks, the taiga of Interior Alaska, permafrost may be intermittent, discontinuous, sporadic, or absent. Under either of these conditions, intensive route exploration is necessary to utilize coarse materials as foundation for the line. Even with intensive efforts, TAPS engineers expect that some frozen silts will be missed and decisions will have to be made in the field on construction techniques as construction progresses. Thickness of frozen soils decreases and temperature of permafrost is warmer southward and, in general, ice content of frozen materials decrease with depth. Even in the Arctic, water content near the surface is markedly higher than at about 15 feet in depth.

To properly assess bearing strength of unconsolidated materials, several fundamental considerations must be kept in mind. Two of the most important factors are texture, and its related pore space, and water content, whether as ice or liquid. Any frozen material tends to remain stable when thawed if the total volume of water is less than the total pore space. The lower the degree of saturation, the better the bearing properties of a material as it is warmed, and the coarser the texture the better its stability with melting. However, even gravels with super saturation, such as can occur when ice fills all pores and forces the particles apart, will not be completely stable when the ice melts. Melted silts and clays can be stable if their total water content is less than the total pore space. TAPS engineers are thoroughly aware of these relationships and are considering them in their search for an optimum route.

Major river channels are free of permafrost even in the Arctic and some portions of the pipe may be placed in this location; Sagavanirktok River is an example. Even where the gravels are frozen, if the degree of saturation is less than 100 percent, they will remain stable when thawed. Moreover, if foundation materials are above the influence of ground water, soil moisture decreases with depth, digging a deeper ditch may provide better stability because percent saturation decreases. During winter months, upper horizons are colder than underlying ones and moisture, as vapor, tends to move toward the lower temperature and be frozen in place. In summer, moisture migration may be reversed if the surface horizons gain enough heat. However, this transfer of moisture is slow, and because winters are longer than summers, the net transfer of moisture is upward. This explains why near surface layers contain more ice than deeper layers. By this reasoning, the lacustrine sediments of Copper Basin may provide stable bearing materials- the degree of stability depending on the present saturation.

Erosion of freshly backfilled material has been controlled where perma-frost is not a problem. However, if backfilling is with frozen material, it will thaw and cause an erosion problem. Continued surveillance of the entire route will have to be maintained to eliminate movement of thawed soil. If efforts to control erosion are diligent and based on sound logic, the total effect can be minimized. If all efforts to build and maintain a stable pipeline are successful, it is to the advantage of all concerned. This ultimate result can best be attained by preserving the natural environment to the highest degree.

Another problem that should be anticipated as warm oil melts permafrost is the water of condensation at the interface of thawed and frozen material. On slopes, this could prove to be a real erosional hazard unless provisions are designed into the line to remove accumulated water that may travel along the frozen surface to form seepage areas at lower levels. Even though liquid water is not present a short distance from the frozen surface, water moving in the vapor phase toward the cold surface will condense, collect as liquid water, and flow downhill.

Another very important aspect of pipeline operations, independent of permafrost, is that of corrosion. In the past this has been by far the most important source of numerous small leaks, and these are the hardest to detect. Corrosion is really an electrolytic transfer of metallic cations from the pipe to the soil by the flow of electricity. The tendency for this to occur is measured by the Redox or Eh potential and is most pronounced where dissimilar materials are crossed, where chemical reduction conditions are present, as in swampy areas, and any stray currents caused by man's activity. Such corrosion can be prevented by two separate or combination of two methods.

Good pipeline technology now prescribes that the pipe be electrically insulated from its surrounding soil environment. Early pipelines were laid bare and many corroded in a short time to form pin holes which leaked oil to the environment. Electrical insulation effectively prevents such corrosion. A further step in corrosion control is cathodic protection. This consists in keeping a low charge of direct current flowing from the environment to the pipe to counteract stray currents in the environment flowing in the opposite direction. Either of these protective measures is effective and both should be employed in critical sections such as river crossings and valuable recreational areas.

In summary, anticipated land related problems of TAPS construction and operation involve erosion and permafrost degradation. With this foremost in our minds, steps to avoid environmental damage should include, but are not limited to, the following:

1. In routing the line, seek coarse, well-drained materials and avoid wet, frozen silts. Even fairly fine materials provide good foundations if the percent saturation is low and kept that way.

2. Be prepared to take prompt, intensive measures to control erosion wherever it threatens.

3. Anticipate drainage problems on slopes as permafrost melts when warm oil enters the line. Those problems will probably last for years as water vapor from within the melted permafrost condenses on the cold interface between melted and frozen substrate. This condensate will run down hill and issue as seeps which could cause unstable conditions.

4. Provide corrosion protection for the entire length of the line. In critical sections, combine electrical insulation with cathodic protection.

5. On major river crossings and critical resource areas, X-ray every weld to prevent small leaks as well as a major break. In some cases extra heavy pipe might be called for.

6. If a choice of routes must be made where supporting materials are equal but where a valuable resource is threatened, the route favoring the resource shall be chosen. If the alternate route to protect a resource is excessively longer than the other, extra protective measures might be adequate and cheaper as well as providing a total shorter length of pipeline. Every extra mile is an added potential risk.

7. Provide valves at major river crossings and critical resource areas to contain the contents of the line should a break occur.

8. Install a leak detection system that will detect small leaks as well as large ones. If such a system is not now available, support research to develop one.