22. Slope Stability.

a. General.

1) This section provides information on how to recognize slope instability, the importance of avoiding unstable slopes when selecting pipeline alignments and general methods of slope stabilization. Both natural and man-made slopes are susceptible to slope failure, which is associated with downward movement and spreading of the soil mass.

2) If an unstable slope is suspected and may be encountered during construction, prepare a Soil Report in accordance with the requirements in Part Three, Section 20 (Geotechnical and Corrosion Submittals).

b. Slope Failures.

1) Causes. Installation of a pipeline in an area where slow but sustained ground movement is occurring due to creep phenomenon will eventually lead to pipe failure. Trench excavation for pipeline installation at the toe of a slope may lead to its failure. An ancient landslide may become reactivated by the vibration resulting from construction machinery used for trench excavation and pipeline installation. Slope failures are normally caused by excavation or undercutting the foot of an existing slope, by an increase in the pore water pressure, by seismic activity such as earthquakes, blasting or pile driving and by the long-term degradation and/or creep of the soil material.

2) Signs of instability. Recognition of areas susceptible to slope failure is of paramount importance in the selection of an alignment for a pipeline. An early sign of a slope failure is the formation of surface tension cracks in the upper part of the slope. Other signs include ridging of the soil surface and bulging at the toe of the slope. Apart from these surface features, surface or underground monitoring may accurately measure soil movement. Inclinometers are frequently used for underground movement monitoring.

c. Type of Soils.

1) The type of soil plays a significant role in the behavior of the slope.

a) Clays.

(1) Most failures in clay soils are of a rotational type where the failure surface is part of a curved surface. Clay soils behave differently in the short and long term. An excavation in clay may be stable in the short term but can become unstable in the long term. Effective stress parameters should be used for long term stability analysis, while total stress parameters should be used for short-term analysis.

(2) Stiff fissured clays pose a serious problem as they contain slickensides and shrinkage cracks. Water infiltrating these cracks reduces the shear strength substantially. If such soils are encountered, a geotechnical engineer should be consulted to evaluate the safety factor of the slope and the effect of the pipeline construction on its stability.

b) Granular soils. In granular soils, the failure is mostly translational. Ground water is a critical factor for the stability of granular soils as it reduces the effective stress resulting in a reduction of the soil shear strength. The safety factor decreases by almost fifty (50%) percent in the presence of ground water. Many slope failures occurring after heavy rainfall are due to a rise in the groundwater table.

c) Residual soils. Residual soils that are formed by the in-situ weathering of rock usually have a complex structure as they preserve many of the physical features of the parent rock such as joints, faults and folds. Most failures in residual soils are of the translational type. Because of the variable nature of the residual soils, it is very difficult to perform a reliable slope stability analysis. Instead, the local experience should be used to assess the risk of failure.

d. Selection of Pipeline Alignment.

1) Any area with a potential for slope failure should be avoided as much as possible by selecting alternative pipeline alignments. If alternative alignments are not available or are prohibitively expensive, consideration should be given to stabilizing the slopes. A thorough site investigation and slope stability analysis should be performed and the slope factor of safety determined before, during, and after the installation of the pipeline.

e. Method of Stabilization.

1) Numerous methods of slope stabilization may be utilized and basically fall into three groups.

a) Reduce the amount of mass which may drive the slope to failure. Reducing the slope angle is a case in point.

b) Increase the soil strength. This may be achieved by different ground modification techniques such as grouting or soil nailing.

c) Control the ground water by providing positive drainage and/or diverting the water flow from the slope area.

f. References.

1) Hsai-Yang Fang, Foundation Engineering, 2nd edition, 1991, Van Nostrand Reinhold.

2) Hunt R.E., Geotechnical Engineering Investigation, 1st edition, 1984, McGraw Hill.