SEISMIC DESIGN SPECTRA FOR TRANS-ALASKA PIPELINE

by

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SYNOPSIS

The proposed 48-inch Trans-Alaska Pipeline is intended to transport approximately 2,000,000 barrels of crude oil per day from the Alaskan north slope at Prudhoe Bay along a 790-mile overland route to Valdez on Prince William Sound. The seismic design criteria, as embodied in the design spectra used for the pipeline and facilities, are described herein. Lack of space precludes discussion of the associated criteria applicable to slope stability and dynamic movement of slopes, evaluation of liquefaction potential, selection of materials, etc. This paper is limited to a discussion of the ground motions used as a basis for preparing design spectra for structures and the aboveground pipeline, and a brief discussion of the general nature of the design to provide for large fault motions that might be expected in certain sections of the pipeline.

OPERATING AND CONTINGENCY PLAN EARTHQUAKES

Continued efficient operation of the pipeline is not possible if large relative deformations take place. A level of strain in the pipe of the order of 0.004 has been considered to be the "operating" deformation limit. Since this limit is considerably below the level at which dangerous deformations might result in possible leakage from the pipeline, a smaller intensity of earthquake motion is considered in the design for the "operating" earthquake than for the more extreme condition, designated herein as the "contingency plan" earthquake. This extreme condition is intended to be the level for which large values of ground motion might be developed, involving the pipeline or structures, leading to possible deformations that might approach the point of oil leakage but generally will not reach it. The intensity of the operating earthquake is generally taken as one-half the intensity of the Contingency Plan earthquake.

For the larger earthquake, larger values of damping are considered applicable. Deformations approaching limiting values, involving admissible amounts of yielding, are considered to occur in the Contingency Plan earthquake.

EARTHQUAKE MOTIONS CONSIDERED FOR DESIGN

The magnitudes and intensities of ground motion in the various sections of the pipeline were selected with regard to the previous occurrence of earthquakes in these sections, the existence of well-defined faults, or other geologic evidences of potential or previous actual seismic motion. Magnitudes ranging from 5.5 to 8.5 were considered. In the region where earthquakes of Magnitude 8.5 might be considered reasonable, it was felt that these would occur at some distance from the pipeline, and therefore the design seismic motions in this section of the pipeline are taken the same as the values used for the region with

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Magnitude 8.0.

The seismic motions used in the design are given in Table 1. These take into account implicitly the maximum ground motions that are likely to occur, but are based explicitly on the "effective" values of such motions and not on the maximum spikes or possible maximum instrument readings that might be recorded. The table shows two sets of values. The "ground motion" values for either acceleration or velocity are those which are considered to affect the stability of slopes, the liquefaction of cohesionless materials, and the strains in underground pipe.

The ground motion acceleration levels in the table are for rock or highly competent soils. In general, less competent soils cannot transfer to the pipeline or to near-surface structures the high intensities of acceleration that can be transmitted by rock or competent sediments. However, even though reduction in ground motion acceleration values are considered under certain circumstances, where deep soil layers are found, a reduction of the acceleration values to less than the values listed under the heading "structures" is not permitted.

The "structures" values of acceleration and velocity listed in the table are those that are considered applicable to the design of above-ground pipeline and structures in which some ductility can be mobilized. Ductility factors of the order of 2 to 5, depending on the type of structure and its importance in maintaining the integrity of the pipeline, were considered. An average value of the order of about 3 was used as a basis since it is felt that this is a conservative lower bound that can assuredly be reached in the design of the important structures that might have an influence on the integrity of the oil-containing capacity of the pipeline.

The values of design ground displacement d_s used in determining design spectra were determined from the structures design values of acceleration a_s and velocity v_s by the relation:

$$d_s = 6\, v_s^2 / a_s \qquad (1)$$

This relation gives values of d_s, for the 4 magnitudes listed in the table, of approximately 12, 8, 5.4, and 3.6 in. However, these values are generally not of importance in any of the design conditions.

It should be realized that extreme peak values or spikes of acceleration might range up to several times as high as the values in Table 1, and extreme peak values of velocity might be somewhat larger than the values in the table.

DESIGN SPECTRA

The design spectra used are based in general on the recommendations given by Newmark and Hall(1), with only slight changes. For the 2 percent damping value, applicable to the operating earthquake, the amplification factors for structures design values of acceleration, velocity and displacement, were taken as 4.3, 2.8, and 1.8, respectively. These were applied generally to values not greater than one-half those given in

Table 1 for structures accelerations and velocities, and to one half of the values of d_s stated below Eq. (1).

For the Contingency Plan earthquake the corresponding amplification factors were taken respectively as 1.9, 1.5, and 1.2. In either case, the largest of the two spectra was considered as controlling the design.

Properties of the soil and rock in various regions are taken into account in the detailed design spectra used. Increases in the spectra are made under conditions where amplified responses might be expected because of poor foundation conditions.

In general, vertical and horizontal excitations are combined in considering their effect on design.

COMMENTS ON SEISMIC DESIGN COEFFICIENTS

It is interesting to compare the effective seismic coefficients or net acceleration values (which can be used as a measure of the total base shear, among other things), that are computed from spectra amplified in accordance with the amplification factors stated above, with the structures design accelerations from Table 1. In the range from 2 to 6 hertz, these seismic coefficients are given directly by the amplification values multiplied by the design seismic accelerations for structures. In this range, the operating earthquake values with 2 percent damping govern, and the net coefficients are, for Magnitudes of 8.0, 7.5, 7.0, and 5.5, respectively, 0.70, 0.47, 0.32, and 0.22. A comparison of even the smallest of these with the usual values considered applicable in Zone 3, in accordance with the Uniform Building Code provisions, indicates the conservatism in the design of the pipeline in terms of its provision for seismic hazards. The largest value approaches the seismic design coefficients that might be appropriate for nuclear power plants.

In all cases, the coefficients are greater by a considerable margin than those used for buildings designed for human occupancy, including school buildings, in the regions of greatest seismic activity in the United States.

FAULT MOTIONS

Because the pipeline must traverse regions that may be expected to have surface fault displacements, provision is made for this in the construction. These special provisions are of some interest in two regions where large fault motions might be expected. In the Chugach Range, fault motions of the order of 5 ft are considered possible. In this region, the pipe is generally placed underground in a shallow trench in rock, but the placement is made in such a way that the rock trench has relatively shallow sloping sides so that, when fault motions occur, the pipe is lifted bodily out of the trench and deformed slightly but not to the extent that it will rupture. The trench is filled with gravel that can easily be displaced.

The other region where large fault motions might be expected is in the zone where the Denali Fault crosses the pipeline. Here motions of the order of as much as 20 ft are considered possible, and the pipeline is placed aboveground on 40-foot wide bents, arranged in such a way that the pipe can slide on the bents to take up the deformation of the fault without failure, although some distortion will take place.

In these regions longitudinal components of strain in the pipe are considered as well as transverse motions both horizontally and vertically.

REFERENCES

1. Newmark, N. M. and W. J. Hall, "Seismic Design Criteria for Nuclear Reactor Facilities", Proceedings 4th World Conference on Earthquake Engineering, Santiago, Chile, 1969, Vol. II, B-4, pp. 37-50.

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TABLE 1. DESIGN SEISMIC MOTIONS

Magnitude	Design Accel., Gravities		Design Veloc., in/sec	
	Ground Motion	Structures	Ground Motion	Structures
8.0	0.60	0.33	29	16
7.5	0.45	0.22	22	11
7.0	0.30	0.15	14	7
5.5	0.12	0.10	6	5