Robert Pyke, Consulting Engineer

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Tim McCrink
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Re: Selection of Peak Acceleration Values and Seismic Coefficients

Dear Tim,

As discussed by telephone, I am pleased to provide this summary of my understanding of better practice regarding the selection of peak acceleration values for use in either the design of buildings and other engineered facilities or the assessment of geotechnical problems such as slope stability and liquefaction and the separate, but related, question of the selection of seismic coefficients for use in pseudo-static analyses of walls or slopes.

Ideally, the same value or values of peak acceleration should be used for both the design of buildings and geotechnical assessments, and the peak acceleration should be just one component of a more complete description of the design earthquake motion which should also contain information regarding the frequency content and duration of the motions. In the general case, more than one motion and hence more than one peak acceleration might be specified, both because damaging motions from more than one source might affect a given site and because the owner and his engineers might be willing to accept or may wish to design for different levels of risk.

Either deterministic or probabilistic methods, or some combination of these, can be used to evaluate the design motions for a particular site. In the deterministic approach design magnitudes are assigned to significant seismic sources and the expected peak accelerations at the site are determined for these magnitudes. In the probabilistic approach, a mathematical model of the various seismic sources is constructed and the probabilities that given levels of motions at the site will be exceeded are computed.

The probabilistic approach has been used principally for building design in those cases where the owner desires or is required to use design loadings which are more site-specific than the basic provisions of the building code. A common design practice has been to size structures so that they do not exceed code allowable stresses and deflections for motions that have a 50 percent probability of exceedance in 50 years and to check that they will not collapse for motions that have a 10 percent probability of exceedance in 50 years. More stringent requirements now apply to state and public school buildings which the State of California requires be designed to prevent structural damage for motions that have a 40 percent chance of exceedance in 100 years and to hospitals and essential services buildings which have to be designed to prevent damage for motions that have only a 20 percent chance of exceedance in 100 years. Such probabilistic analyses may be conducted directly in terms of response spectrum amplitudes or they may be conducted in terms of the peak acceleration which is then used to scale an appropriately shaped elastic response spectrum.

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Regardless of whether it is arrived at deterministically or probabilistically, the peak acceleration that is used to scale an elastic response spectrum (sometimes called the zero period acceleration) should be the peak acceleration of the expected motion within the range of frequencies of engineering interest. This acceleration is sometimes referred to as an effective peak acceleration and is generally similar to the peak accelerations of recorded motions with the exclusion of high frequency spikes that are outside the range of frequencies that will affect the structure of interest. No hard and fast rule can be given regarding the possible decrease from recorded peak accelerations to effective peak accelerations since this is very much a function of individual recorded motions. When expected peak accelerations are obtained from formulae or charts that average the recorded values of peak accelerations for an appropriate suite of records, no adjustment is necessary.

While the probabilistic approach could also be used to select ground motions for use in the evaluation of geotechnical problems such as slope stability and liquefaction, this has not been common practice and there are no readily-available guidelines for their use. This results in part from the fact that the results of both slope stability and liquefaction evaluations have usually been expressed as a factor of safety and many authorities require that the factor of safety be not less than unity even for the ground motions corresponding to the "maximum credible" earthquake. More widespread use of the probabilistic approach awaits further development and implementation of procedures for computing deformations rather than factors of safety so that meaningful acceptance criteria can be established for different probabilities of occurrence.

It is clear, however, that if reference is made to peak accelerations in general descriptions of the seismic environment, then those accelerations should be not less than the effective peak accelerations with a probability of occurrence of 10 percent in 50 years. It is inappropriate to cite some lower value such as the "repeatable high ground acceleration" of Ploessel and Slosson (California Geology, September 1974) without reference to specific problems and methods of analysis. The reduction of the peak acceleration to the "repeatable high ground acceleration" of Ploessel and Slosson is in fact similar to the reduction of the peak shear stress to an average shear stress in the procedures for evaluating the potential for liquefaction developed by the late Professor H. Bolton Seed and his colleagues at the University of California, Berkeley, and such a reduction is appropriate in that context.

Selection of Seismic Coefficients

Perhaps the best example of a situation where the peak acceleration should <u>not</u> be used directly is provided by pseudo-static analyses of slope stability. These are very much simplified analyses in which a constant lateral force is expected to somehow equivalence the cyclic loading and possible variation in material properties that actually take place during earthquake shaking. Historically, the choice of an appropriate seismic coefficient (and a corresponding acceptable factor of safety) has been a matter of acceptable local practice without any particular rational including linkage to expected peak accelerations or the duration of strong shaking.

In recent years a basic point of reference has been that the U.S. Army Corps of Engineers manual for seismic design of new dams (which are generally considered to be among the more critical civil engineering facilities) requires use of a seismic coefficient of 0.1 in Seismic Zone 3 and 0.15 in Seismic Zone 4, in conjunction with a minimum factor of safety of 1.0. In California, many state and local agencies also require the use of a seismic coefficient of 0.15 but impose the slightly more conservative requirement that the minimum computed factor of safety be not less than 1.1. Clearly, however, engineering judgement must be still be applied as to the applicability of pseudo-static analyses and the acceptable factor of safety might be varied with the uncertainties involved in a particular analysis.

Further, it is now possible to make an approximate but rational connection between the seismic coefficient that is used in a pseudo-static stability analysis and the expected amplitudes and duration of ground motion by working backwards through the method for computing displacements of slopes that was originally suggested by Newmark (1965). This approach was first explored by Seed (1979) who drew the general conclusion that for embankments composed of materials which show no significant loss of strength as a result of cyclic loading, "it is only necessary to perform a pseudo-static analysis for a seismic coefficient of 0.1 for magnitude 6.5 earthquakes or 0.15 for magnitude 8.25 earthquakes and obtain a factor of safety of the order of 1.15 to ensure that displacements will be acceptably small".

While Seed simplified his conclusion to make it independent of the peak acceleration, the procedure that he suggested can be used to make more site specific evaluations of appropriate seismic coefficients by referring to the attached figure which is based on the same study by Makdisi and Seed (1978) that Seed used in his 1979 lecture and paper. The figure shows displacements computed by the Newmark method (specifically for embankments ranging in height from 50 to 250 feet, but generally applicable to earth slope with depths to bedrock in that order, and generally conservative for shallower depth to bedrock) as a function of the acceleration ratio, k_y/a_{max}, where k_y is the critical seismic coefficient (that is, the seismic coefficient that reduces the factor of safety to unity) and a_{max} is the expected peak acceleration. Ranges of the most likely displacements are indicated for magnitudes 6.5, 7.5 and 8.25 (magnitude being an indicator of duration of strong shaking) and likely displacements for intermediate magnitudes can be interpolated. The predicted displacements should necessarily be small for magnitudes less than about 6.5 since field experience indicates that smaller magnitude, shorter duration earthquakes do not usually cause significant slope failures. While there are number of approximations made in the Newmark method and in the construction of the attached figure, if the acceleration ratio and magnitude are such that they fall below the line marked "acceptably small displacements", the slope involved might generally be considered to be safe from failure. Thus, for a magnitude 8.25 earthquake, non-failure conditions are indicated if the critical seismic coefficient is at least equal to half the expected peak acceleration. Conversely, if a pseudo-static analysis using a seismic coefficient equal to one-half the peak acceleration yields a factor of safety greater than 1.0, the displacements are likely to be acceptably small. Similarly, for magnitudes 7.5, 7.0 and 6.5, if the seismic coefficient is taken as one-third, one-fourth and one-fifth of the expected peak acceleration, and the computed factor of safety is greater than 1.0, the displacements are likely to be acceptably small. The seismic coefficients obtained in this way are shown as a function of peak acceleration and magnitude in the attached Figure 2.

Sincerely,

Robert Pyke

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Bibliography:

Hynes,M.E., and Franklin,A.G., "Rationalizing the Seismic Coefficient Method", U.S. Army Waterways Experiment Station Miscellaneous Paper GL-84-13, July 1984.

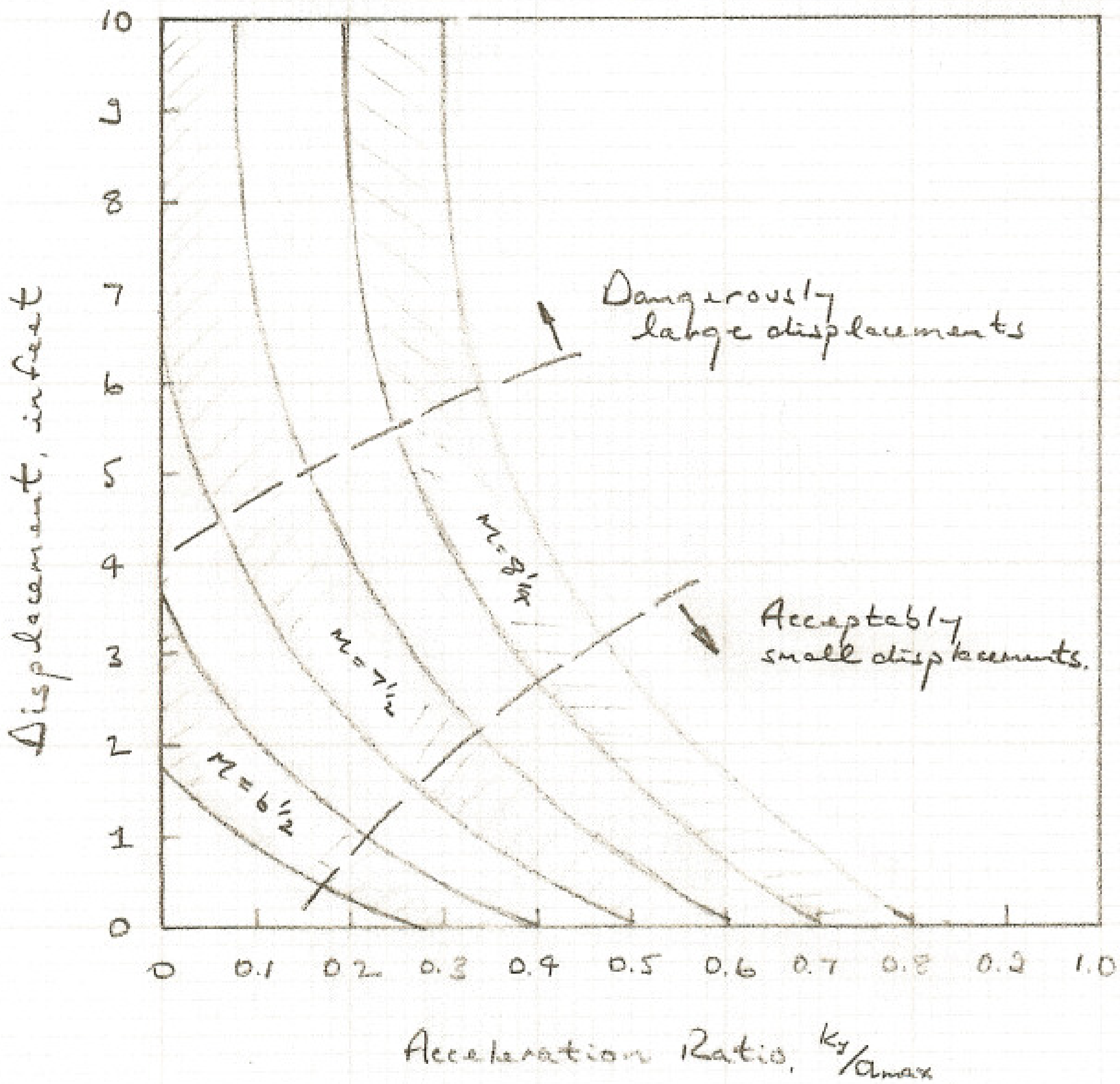
Makdisi,F.I., and Seed,H.B., "Simplified Procedure for Estimating Dam and Embankment Earthquake- Induced Deformations", Journal of Geotechnical Engineering, ASCE, Vol.104, No.GT7, July 1978.

Marcuson,W.F., and Franklin,A.G., "Seismic Design, Analysis, and Remedial Measures to Improve Stability of Existing Earth Dams", U.S. Army Waterways Experiment Station Miscellaneous Paper GL-83-23, September 1983.

Newmark,N.M., "Fifth Rankine Lecture: Effects of Earthquakes on Dams and Embankments", Geotechnique, Vol.5, No.2, June 1965.

Seed,H.B., "Nineteenth Rankine Lecture: Considerations in the Earthquake Resistant Design of Earth and Rockfill Dams", Geotechnique, Vol.24, No.3, September 1979.

Seed,H.B., "Earthquake-Resistant Design of Dams", Proceedings of a Symposium Sponsored by the Geotechnical Engineering Division of ASCE, Philadelphia, May 1983.



Typical Displacements Computed by Newmark Method

after Makdisi and Seed (1978)

Fig. 1

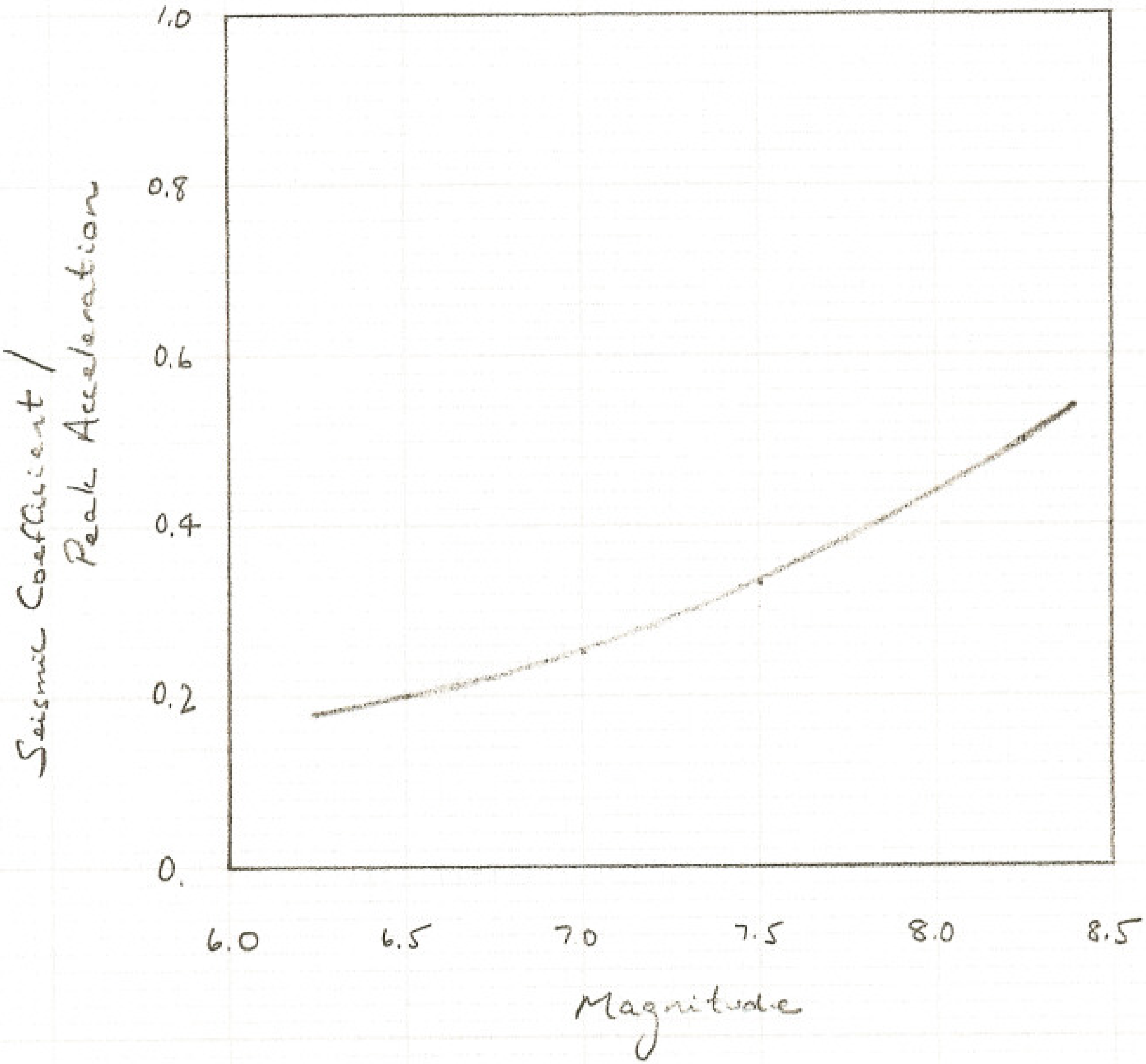

1.0
0.8
0.6
0.4
0.2
0.
6.0
6.5
7.0
7.5
8.0
8.5
Seismic Coefficient / Peak Acceleration
Magnitude

Fig. 2