Comparison of a liquefaction theory with field observations

R. O. DAVIS and J. B. BERRILL (1983). *Géotechnique* **33**, No. 4, 455–460

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We have read with interest the Technical note prepared by Davis and Berrill which claims 'to compare some well-known liquefaction results obtained by Seed and his co-workers at the University of California with extant field liquefaction data obtained mainly from Japanese earthquakes'.

The study presented by Davis and Berrill is an interesting approach for checking the applicability of liquefaction evaluation procedures but it seems pertinent to point out the following.

The 'field' data used by the Authors in their Fig. 1 is somewhat deficient and does not include a number of the far field liquefaction data points obtained in Japanese earthquakes since 1975 and several other US earthquakes. A more complete field liquefaction data set is shown in the accompanying Fig. 1, and this would presumably provide a better basis for evaluating the applicability of the 'theory' discussed by Davis and Berrill.

The theory used by the Authors is based on some field data and some experimental data first presented by Seed in 1976 and subsequently updated continuously, coupled with an acceleration attenuation law proposed by Cornell *et al.* There are many such attenuation laws—but when the data presented by Seed *et al.* are coupled in this way with attenuation laws developed by others the result ceases to be the work of Seed and his co-workers but rather a hybrid new theory developed by the Authors for this specific study.

If the theory were being used it would seem appropriate to base it on the following results.

- (a) The most recent version of the curves shown in the Authors' Fig. 2 which were published by Seed & Idriss (1981) and Seed, Idriss & Arango (1983). These new curves are based on an extensive set of field liquefaction data obtained in earthquakes in Japan, China, USA, Argentina and Guatemala and provide a good basis for evaluating field performance. In fact, however, the updated curves are quite similar to those shown in the Authors' Fig. 2.

- (b) An attenuation law for accelerations developed in Japan, since the field data in Fig. 1 come mostly from Japanese earthquakes. On the basis of a study of 300 accelerograph records obtained in Japanese earthquakes, Iwasaki, Katayama, Kawashima & Saeki (1978) presented the relationship

$$a_{\max} (\text{gal}) = 18.4 \times 10^{0.302M} \times X^{-0.8}$$

where M is the earthquake magnitude and X is the epicentral distance in kilometers.

Using these two results in the analytical approach adopted by Davis and Berrill leads to the prediction of a maximum distance from an earthquake epicenter to sites where liquefaction could be expected to occur as shown by the line labelled $N_1 = 5$ in the accompanying Fig. 1. The line is drawn for $N_1 = 5$ since Davis and Berrill indicate that the $N_1 = 5$ case is 'perhaps more representative overall', and soils with significantly lower N_1 values are not likely to exist in seismically active areas.

It may be seen that the use of the more comprehensive field data set shown in Fig. 1 together with the relevant theory of Seed and his co-workers, and Iwasaki *et al.*, leads to the conclusion that the agreement between the 'theoretical' line in Fig. 1 and the field data is in fact quite good and does not 'overestimate the field data at small magnitudes by as much as an order of magnitude'. This should not be surprising since most of the components of the theory are based on field observations and the results are compared with field observations. However, it does require that all available field data are included in compiling the data set used in making such comparisons.

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Fig. 1. Maximum epicentral distance to a site of liquefaction for earthquakes of different magnitudes

Fig. 2.

Seed, H. B., Idriss, I. M. & Arango, I. (1983). Evaluation of liquefaction potential using field performance data. *J. Geotech. Engng Div. Am. Soc. Civ. Engrs* **109**, No. 3, 458–482.

Authors' reply

Our article presented a comparison of analytical results obtained from the Berkeley liquefaction analysis with actual field liquefaction data. It is possible that the degree of agreement may be altered as more field data become available. We noted this in our article, pointing out that '...increasing interest in liquefaction phenomena will undoubtedly result in a growing number of well-documented case histories.

In their discussion, Tokimatsu and Seed present six new data points. A glance at Fig. 1 shows that these new data greatly improve the agreement with the Berkeley theory. Unfortunately, these data cannot be considered as well-documented case histories. No citation or reference is given for any of the points. Indeed, even the earthquakes to which they refer remain unnamed. If the six new points do correspond to reliably reported case histories of liquefaction on level ground, then they are of considerable interest. In the absence of any documentation, however, they hold little value for the discriminating observer.

There is some merit in the suggestion by

Tokimatsu and Seed that a Japanese attenuation expression be used in the comparison, and we agree that the expression of Iwasaki, Katayama, Kawashima & Saeki (1978) is appropriate. However, it is essential that the expression is first corrected for characteristics of the SMAC-B2 instruments on which the bulk of the Japanese data were recorded. This requirement was noted by Iwasaki, Kawashima & Takagi (1981), and by Crouse & Turner (1980). Indeed, Crouse & Turner pointed out that '... failure to correct these accelerograms could have a major bearing on considerations of liquefaction potential at a site ...'. The SMAC-B2 recorded peak accelerations are approximately 70% of true ground acceleration. Modifying the Iwasaki attenuation expression accordingly results in the line shown in Fig. 2. We have plotted only the line for $N = 5$. The line for $N = 1$ would be parallel but higher on the graph.

One additional case history has come to our attention since publication of our article. This is the Nihonkai-Chubu (Japan sea) earthquake of 26 May 1983. This magnitude 7.7 earthquake caused liquefaction at epicentral distances up to 140 km (Japanese Society for Soil Mechanics and Foundation Engineering, 1983). Figure 2 replots the data from our original article together with this new datum point. We have also corrected the Borrego Mountain earthquake case from magnitude 6.5 to magnitude 6.8. Our article discussed this point.

We can now compare the upper bound predicted by the Berkeley theory using the Japanese attenuation relationship with the documented field data shown in Fig. 2. Evidently, the Berkeley theory now yields results which are conservative for both large and small earthquakes, especially so for small earthquakes. For $M=6$, we find that Seed's analysis suggests that liquefaction may occur at distances as great as 80 km, while experience suggests an upper limit of approximately 10 km. We do not feel the theoretical line and field data shown on Fig. 2 represent any appreciable improvement over the comparisons shown in our article, and we stand firm in our original conclusions.

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