A REVIEW OF THE PERFORMANCE OF MINE TAILINGS IMPOUNDMENTS UNDER EARTHQUAKE LOADING CONDITIONS

by

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ABSTRACT

A preliminary assessment of the stability of loosely placed mine tailings impoundments under earthquake loading conditions is often difficult to conduct because of the lack of in situ test data and the limitations of established procedures which use the results of the SPT or cone. As an alternative, this paper summarizes the results of reported performance of tailings impoundments under various earthquake loading conditions and presents the data in a format consistent with other empirical approaches.

Key Words: mine tailings, case record, earthquake loading, liquefaction

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INTRODUCTION

The performance of loose and saturated and hydraulically placed mine tailings under earthquake loadings conditions is not well documented in the current literature. The two case records which are often referenced describe failures of impoundments constructed by the so-called upstream method; these failures occurred in 1965 in a copper mining district of central Chile (Dobry and Alvarez, 1967) and in 1978 in a gold mining area of the Izu Peninsula of Japan (Okusa and Anma, 1980 and Marcuson et al, 1979). The considerable damage associated with these failures, and particularly the large loss of life in Chile, were likely the impetus for the development of the so-called and downstream centreline construction methods. These events have also led to the development of regulations and guidelines in many parts of the world which favour the downstream and centreline construction methods. Although current practice is to avoid large structures constructed by the upstream method, there still exists situations where loose and saturated tailings form the foundation for small structures, stacked tailings cones, final covers at close-out. The performance under a particular seismic event must be addressed.

HYDRAULIC FILL EMBANKMENT DAMS VERSUS MINE TAILINGS

It is interesting to note that the hydraulic fill method of embankment dam constructed was developed from many years of previous experience with mine tailings disposal. In 1938, the Fort Peck Dam Failure was considered clear evidence of the inadequacies of hydraulic fill embankment dams, even though the later investigations associated the failure with foundation materials. This event, and later the damage to the Dry Canyon and Haiwee hydraulic fill dams in the 1952 Arvin-Tehachati earthquake in California were factors which contributed to the development of uncertainty with the hydraulic fill construction method. For example, since the 1940's the hydraulic fill construction method has not seriously been considered for new construction in California (Jansen et al, 1976).

The conviction that the hydraulic fill method of embankment construction was unsafe under earthquake loading conditions seemed to be supported by the dramatic failure of the upper and lower San Fernando hydraulic fill dams in California during the 1971 San Fernando earthquake. This highly publicized event led to several detailed inquiries into the performance of hydraulic fill embankment dams in California; the majority of these water retaining structures were constructed before 1940. As part of this overall study Seed et al, (1978) reviewed the performance of many embankment dams which experience strong ground shaking during earthquakes. Their conclusions indicated that well built hydraulic fill embankment dams with reasonable slopes on good foundations could survive moderate ground shaking; for example, a maximum acceleration in rock of about 0.2 g from a magnitude 6.5-7.0 earthquake.

Considering the many similarities in the depositional process, and in some cases gradational characteristics, between hydraulic fill embankment dams and mine tailings, one is led to ask the question if a similar detailed review of mine tailings was conducted would the findings similarly support a less pessimistic view of the stability of loosely placed mine tailings under certain theshold levels of earthquake loading?

PERFORMANCE ASSESSMENT

The performance of mine tailings under earthquake loading conditions is evaluated by assessing the seismic exposure of each site. The seismic exposure is simplified to the magnitude and epicentral distance; other, more accurate and site specific information was not available. The performance of each tailings impoundment was evaluated from published reports (or the lack of reported failures). The following assumptions were made for this assessment:

1. The absence of reported large deformations and/or failures at tailing impoundment sites infers that no large deformations or failures occurred.

2. The tailings basin storage characteristics are such that the perimeter embankment rises rapidly during the first few years of operation. Large deformations or a failure shortly after commencement of operation would represent a significant event that would have been reported.

3. The magnitude-epicentral distance relationship for various earthquakes in Chile and Japan are comparible.

The same method of performance evaluation has been presented for natural deposits by Youd and Perkins (1978) and Kuribayashi et al (1977), for example. Youd and Perkins provide a theoretical justification for a linear relationship between epicentral distance to the farthest occurrence of liquefaction in natural sediments and earthquake magnitude when plotted on a magnitude versus logarithm of epicentral distance plot. A similar relationship is hypothesized for mine tailings impoundments. This method of evaluation is very approximate considering the many factors which influence performance. However the sophistication of the method of analysis matches the quality of data available, an important consideration in geotechnical engineering as discussed by Lambe (1973).

The performance of mine tailings impoundments was assessed under the following earthquakes:

- Chilean Earthquake October 1st, 1928 (Dobry and Alvarez, 1967; Seed, 1975; Smith, 1969)
- Chilean Earthquakes 1930-1964 (Dobry and Alvarez, 1967 and Dobry and Alvarez, 1969)
- La Ligua Earthquake, Central Chile March 28th, 1965 (Lastrico and Monge, 1974)
- Northern Chile Earthquake, December 28th, 1966 (Dobry and Alvarez, 1969)
- Central Chile Earthquake, July 8th, 1971 (Lastrico and Monge, 1974; Wahler, 1976)
- Izu-Ohshima-Kinkai Earthquake, Izu Peninsula, Japan January 14 and 15, 1978 (Okusa and Anma, 1980; Marcuson et al, 1979).

The two geographic areas studied are shown on Figures 1 and 2 in Central Chile and Japan. The data are divided into two classes -

operational and non-operational impoundments. The magnitude-epicentral distance relationship for these structures is summarized on Figures 3 and 4. The boundary between "no reported damage" and "reported failures" (or reported minor damage in the case of non-operating impoundments) is suggested on Figures 3 and 4 and compared with similar studies by Youd and Perkins (1978), Dixon and Burke (1973), Kuribayashi et al (1977) and Kuribayashi and Tatsuoka (1978) on Figure 5. In the case of the Youd and Perkins relationship on Figure 5, liquefaction induced ground failure is considered a ground displacement exceeding 100 mm in recent fluvial and aluvial granular sediments. The work of Kuribayashi et al are for sites in Japan; the correlation by Dixon and Burke is for a site in California; and the relationship suggested by Youd and Perkins is based on world-wide data.

A comparison of the boundary between damage and no reported damage for operational impoundments versus non-operating sites on Figure 5 may be a reflection of the increased zone of saturation in operating impoundments. The similarity of these relationships to published data is illustrated on Figure 5.

CONCLUSION

On the basis of this very approximate assessment of the performance of mine tailings under earthquake loading conditions it appears that a linear relationship between magnitude and epicentral distance can be developed and might be reasonably applied for preliminary studies. These findings are somewhat similar to the assessment of hydraulic fill embankments in California by Seed et al in that there is a threshold level of ground shaking below which satisfactory performance is predicted.

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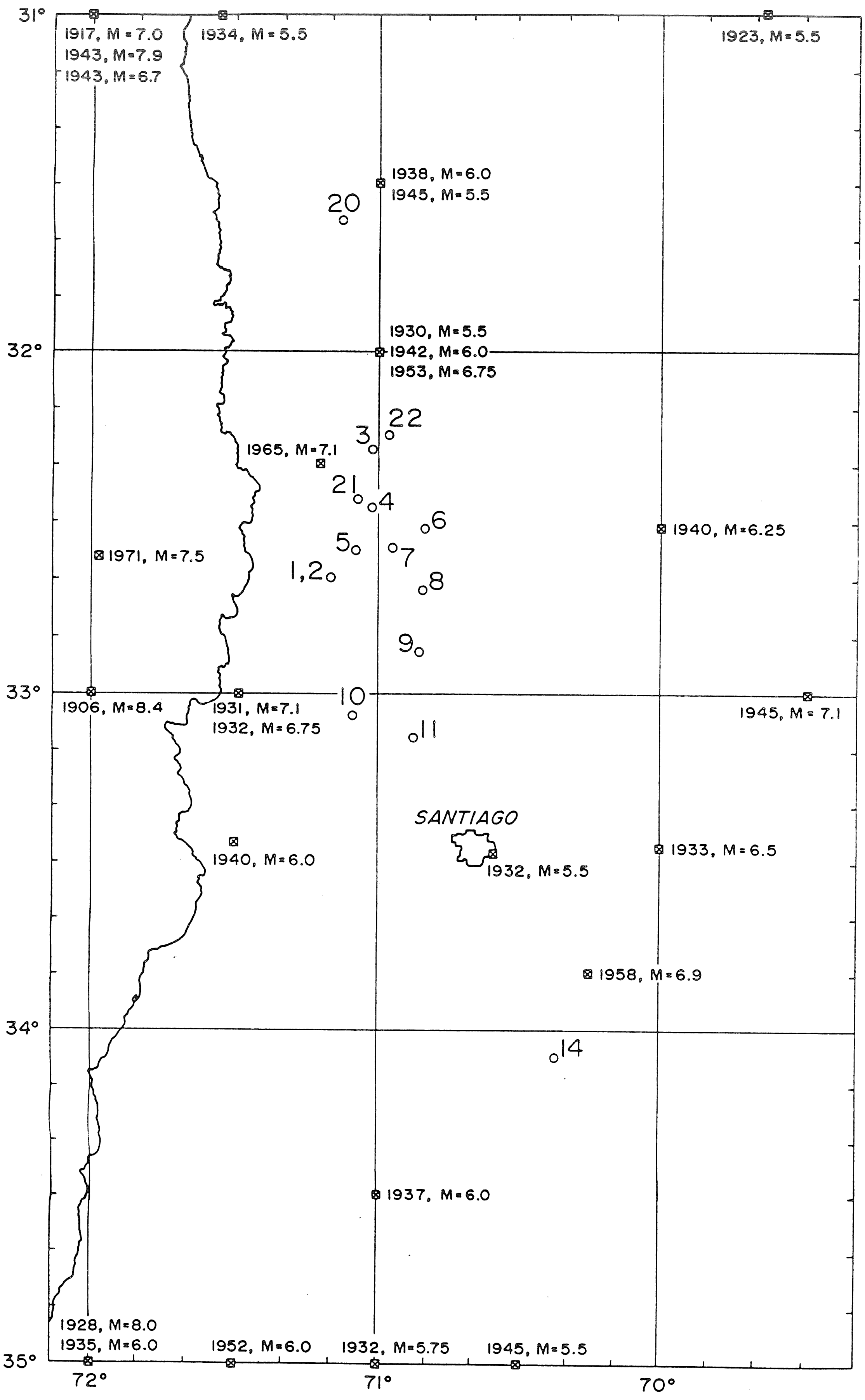

FIGURE 1. Tailings Sites in Chile

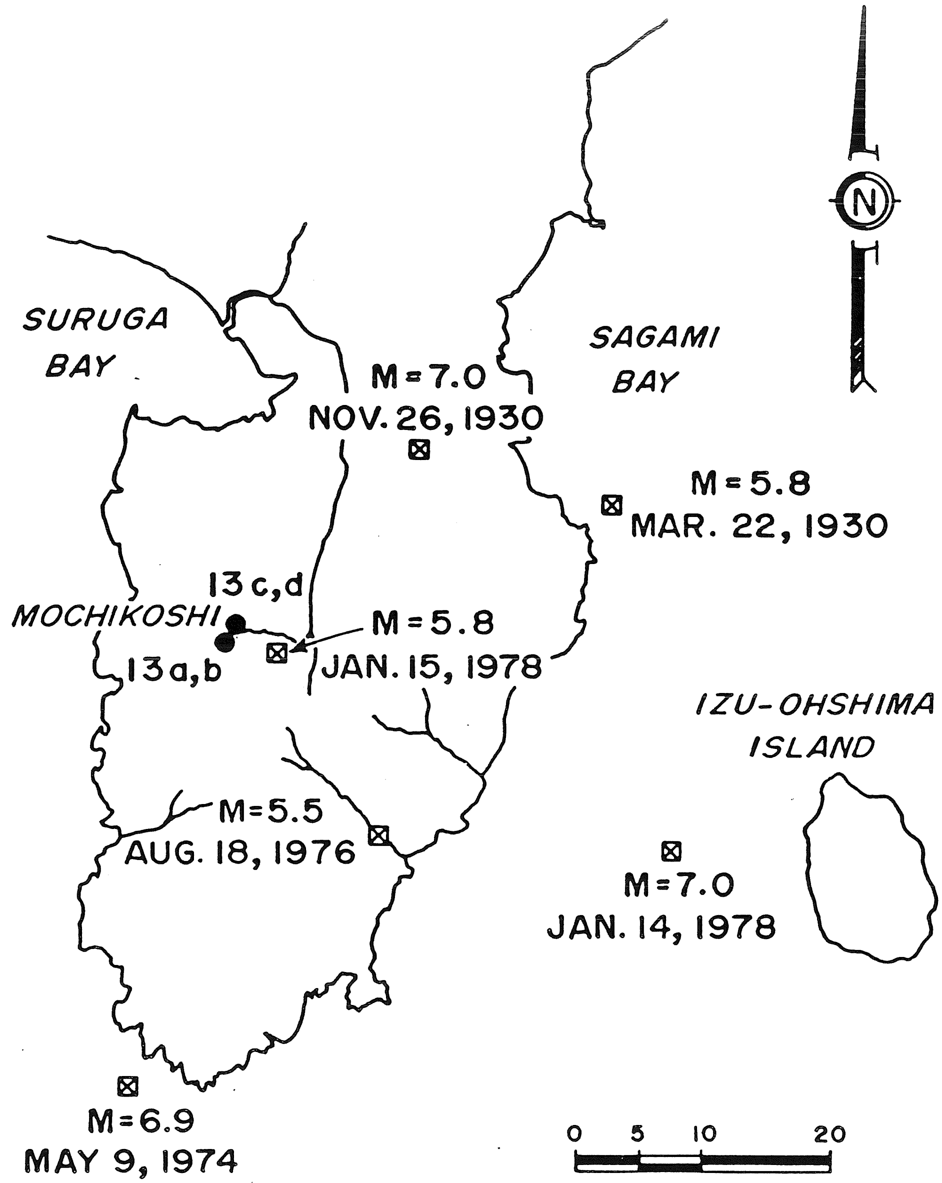

FIGURE 2. Tailings Sites in Japan

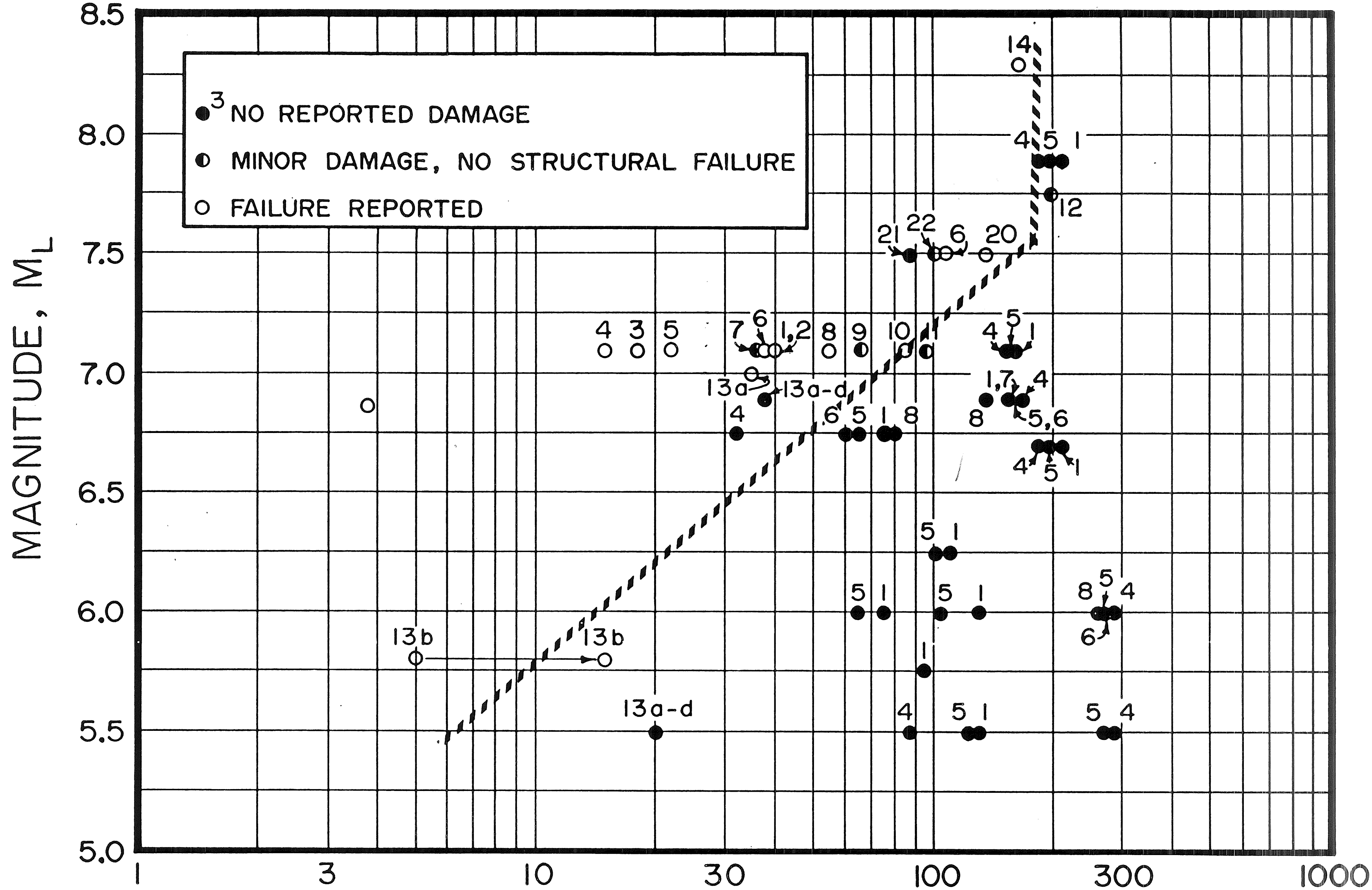

FIGURE 3. Operating Tailings Impoundments Performance

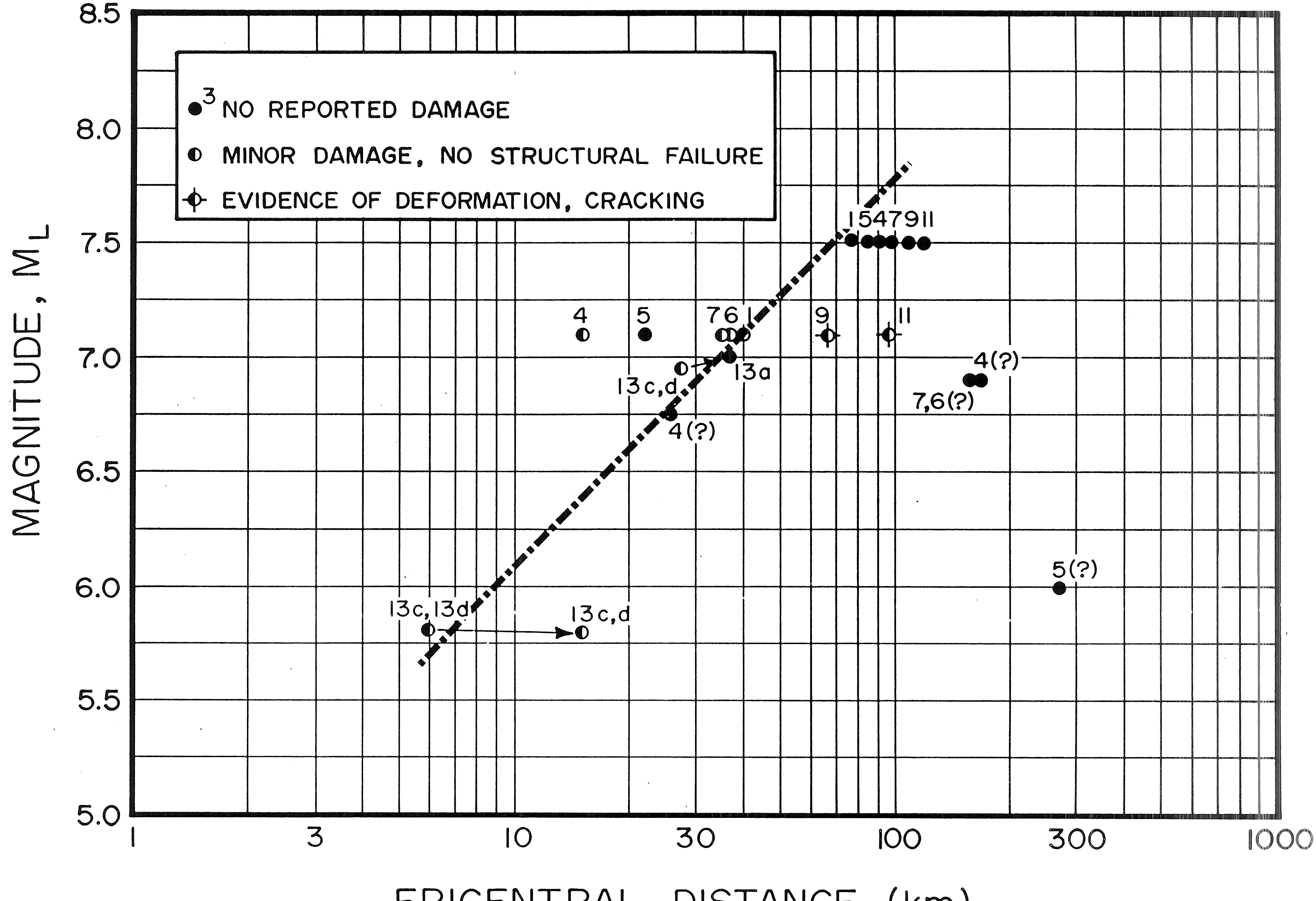

FIGURE 4. Non-operating Tailings Impoundments Performance

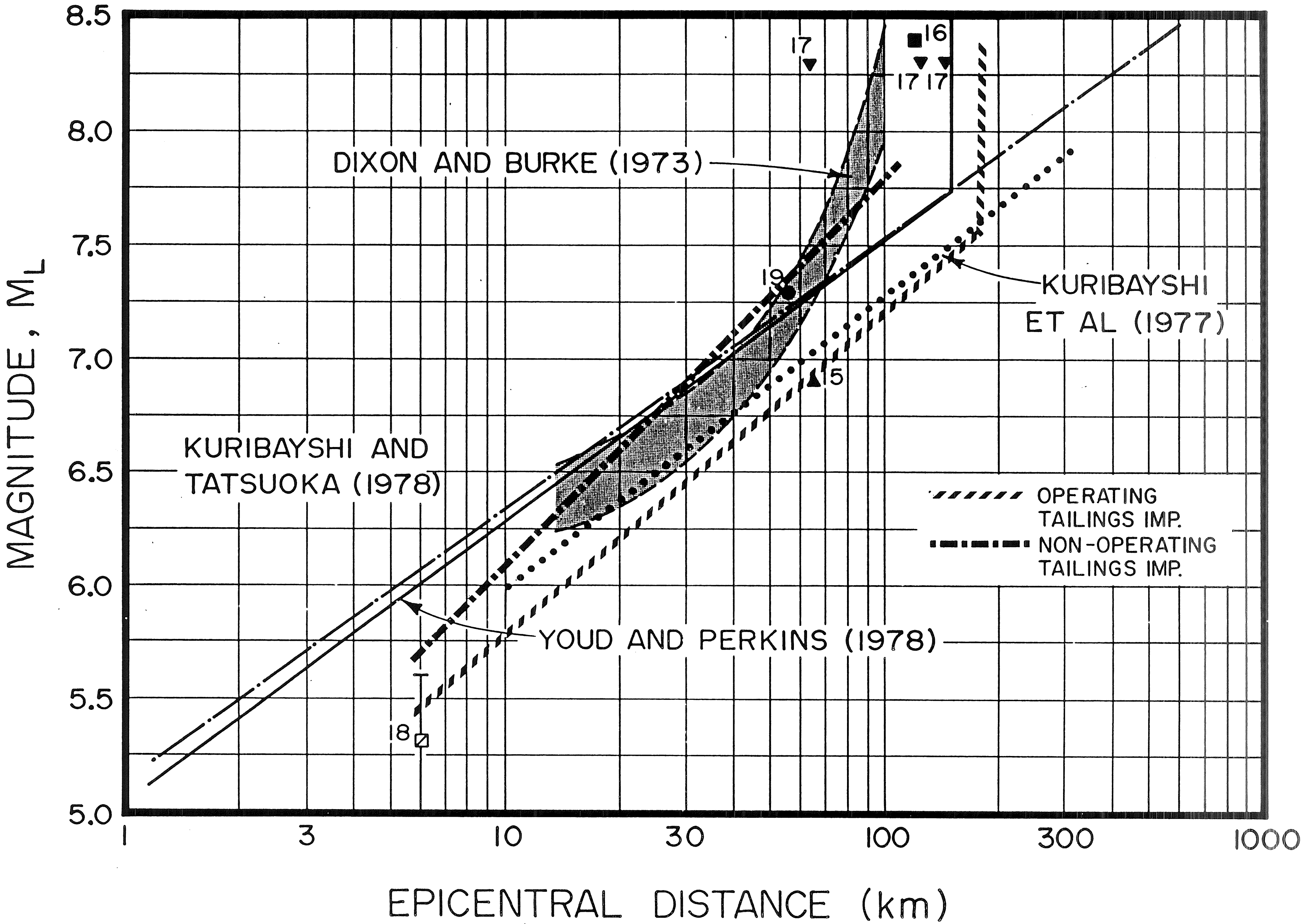

FIGURE 5. Comparison of Trends