ENGINEERING INTENSITY SCALE DATA FOR THE 1971 SAN FERNANDO EARTHQUAKE

by

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SYNOPSIS

The Engineering Intensity Scale (EIS), based on 5%-damped spectral response velocities (1), is used to provide mapped iso-intensity lines of the 1971 San Fernando earthquake in three period bands. Variations of EIS intensity with distance from the energy source are shown, as are comparisons with Modified Mercalli (MM) intensity. EIS intensity ratings for a high-frequency band are related statistically to damage of low-rise buildings, and ratings of an intermediate-period band are related to damage of high-rise buildings.

INTRODUCTION

The EIS, which is based on 5%-damped response spectra in various period bands, was introduced as a supplement to more subjective intensity scales such as the MM scale (1). EIS has been used for several years in studies of response to ground motion induced by underground nuclear detonations and as an effective aid in the estimation of damage, or lack of damage, from ground motion. The advantage of EIS is that it provides specific data derived from actual measurements of motion processed in a standard manner. Thus it is not only objective but simple, numerical, and convenient. Its obvious disadvantages are that it requires many actual records of ground motion and it takes time to process. However, in combination with other scales such as the MM, it provides valuable data for statistical and engineering uses.

The San Fernando earthquake in Southern California on February 9, 1971, provided a great many instrument records of ground motion over a large area as well as data on damage in this area. Because damage is frequency-dependent, EIS is a needed tool for evaluating the damage statistics (2). This paper is limited to providing EIS data for the San Fernando earthquake, some comparisons to another scale and to another case of ground shaking, and some damage relationships.

ENGINEERING INTENSITY SCALE

Details of the EIS are presented elsewhere (1, 5). Briefly, the scale is based on a matrix superimposed on a log-log plot of spectral response velocity, S_v, 5%-damped, versus period. There are ten rows of S_v intensity and nine columns or period bands. The intensity rows, numbered 0, 1, 2 ... 9, have the following bounds (cm/sec), and in sequence: 0.001-0.01, 0.01-0.1, 0.1-1.0, 1.0-4.0, 4.0-10, 10-30, 30-60, 60-100, 100-300, and 300-1000. The period bands, numbered I through IX, have the following bounds (sec): 0.01-0.1, 0.1-0.2, 0.2-0.4, 0.4-0.6, 0.6-1.0, 1-2, 2-4, 4-7, and 7-10, respectively. There are thus 90 "compartments" in the matrix, and a spectral curve would fall in nine of them if the instrument were able to cover the whole period range. Usually the plot is made on four-way (tripartite)

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paper so that acceleration and displacement may be read together with velocity for each period value.

EIS is reported simply as nine numbers in the same order as the period bands, and with each digit representing the appropriate intensity level. For example, the El Centro 1940 record, N-S component, would be reported by EIS as X56,777,76X, with each X indicating no data for that period band. Where broader period bands are acceptable, each of the three sets of three digits are averaged. If an X is present, as above, it is necessary to extrapolate to provide the missing number for averaging. This can usually be done on the spectrum with confidence. The nine-digit EIS value for El Centro N-S would be taken as 456,777,765, and the three-digit report would then be 5,7,6, which applies to period bands I, II, and III from 0.01 to 0.4 sec; bands IV, V, and VI from 0.4 to 2.0 sec; and bands VII, VIII, and IX from 2 to 10 sec, respectively. The three-digit system will be used here for the San Fernando earthquake.

THE DATA AND ITS TREATMENT

Data were obtained from 62 stations that recorded strong ground motion in the Los Angeles area from the February 9, 1971, San Fernando earthquake. The magnitude was 6.5 and the epicenter at 34° 24.0' N, 118° 23.7' W, about 3 mi north of Pacoima Dam. The basic movement was a thrust toward the south. The earthquake caused 64 deaths and about $.5 billion damage. The area included in this study is about 1,000 mi^2. The accelerometers were of several types (3) and were operated by what was then the Seismological Field Survey unit of the National Oceanic and Atmospheric Administration. The time histories of motion were digitized and corrected at the Calfiornia Institute of Technology, and response spectra were calculated (4). Only records taken at ground level or basement level were included in this study.

EIS ratings were determined from the response spectra for the three-digit scale described above as well as for other period bands. In making the ratings, the envelope S_V value of the two horizontal components of each station was used. Generally, one component controlled most of the period range. The highest rating was 6,8,7 at Pacoima Dam and the lowest 3,4,4. Contours of iso-EIS lines were drawn on maps between points of equal EIS intensity for each period band considered, with the assumption that EIS values varied linearly between data points. Figure 1 is a map showing iso-EIS lines for the average intensity of bands I, II, and III (from 0.01 to 0.4 sec). Figure 2 shows the same for bands IV, V, and VI (from 0.4 to 2.0 sec), and Figure 3 for bands VII, VIII, and IX (from 2 to 10 sec). Station locations are shown by dots.

The relative scale between the bands varies with distance from the epicenter, showing the frequency-dependence of spectral period bands with distance and geology. Figure 4 shows the approximate EIS rating (and S_V) versus distance along line A, as indicated on the EIS maps for each period band. The high-frequency band attenuates more rapidly than the others, and the long-period band has almost a level intensity for some distance, crossing over the medium-period band IV, V, VI. This condition is no doubt due in some degree to the deep alluvium in the Los Angeles basin. The maps and Figure 4 show that period bands must be considered in design and in damage estimation as well as in statistical work and in research. Because the EIS scale is based on spectral velocity, the effective relative energy intensity can readily be derived. For example, the area between EIS contours can be related to the exposure to energy demands in certain period bands or average periods.

Figure 5 is a MM intensity map for the same earthquake (3). Comparisons with EIS are difficult because of the scale. The maximum MM rating is VIII-XI versus the maximum EIS rating of 6,8,7. Figure 6 is an EIS map for the three-digit short-period band (I, II, and III) for an underground nuclear explosion in Nevada (1). The closest station, at a 7-km distance, had an EIS rating of 5,6,5, and ratings in San Francisco (550 km away) were 0,1,1, and Los Angeles (539 km away) ratings were 0,1,2, the latter indicating the long-period dominance at long distances. EIS can be applied to large areas, as in this figure, as well as to the zone of greatest shaking, as in Figures 1, 2, and 3.

Damage has been correlated with EIS levels in extensive studies. Low-rise buildings are best evaluated by the high-frequency portion of the three-digit EIS rating, namely the average of bands I, II, and III (Figure 1). The mean damage factor, M_{DF}, or mean ratio of repair cost to replacement cost, for such buildings was found to be (2);

$$\log (M_{DF}) = 8.44 \log (EIS) - 7.72 \tag{1}$$

For high-rise buildings (6), the EIS levels of Figure 2 (for period bands IV, V, and VI) were found to provide the best correlation with damage. The equation is:

$$\log (M_{DF}) = 10.9 \log (EIS) - 10.3 \tag{2}$$

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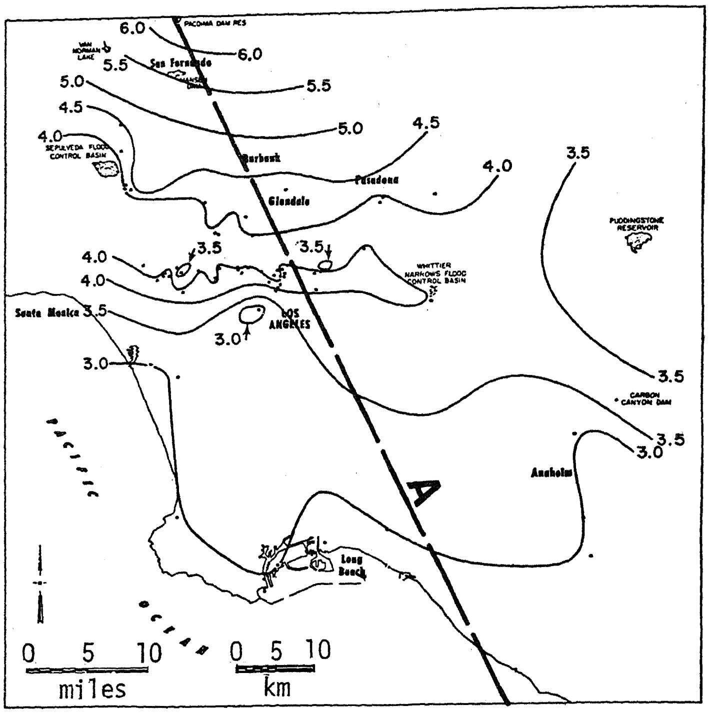

FIGURE 1--ISO-ENGINEERING INTENSITY SCALE PLOT. AVERAGE OF PERIOD BANDS I, II, AND III

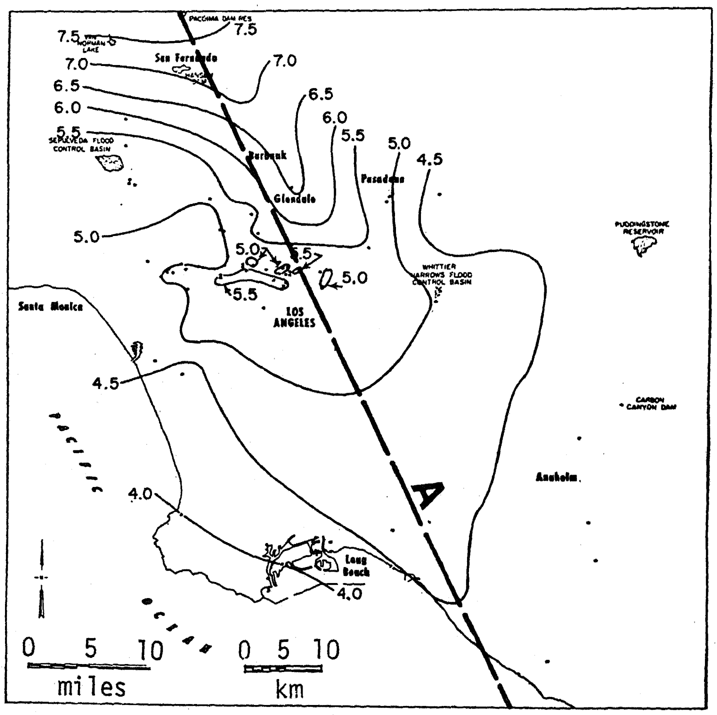

FIGURE 2--ISO-ENGINEERING INTENSITY SCALE PLOT. AVERAGE OF PERIOD BANDS IV, V, AND VI

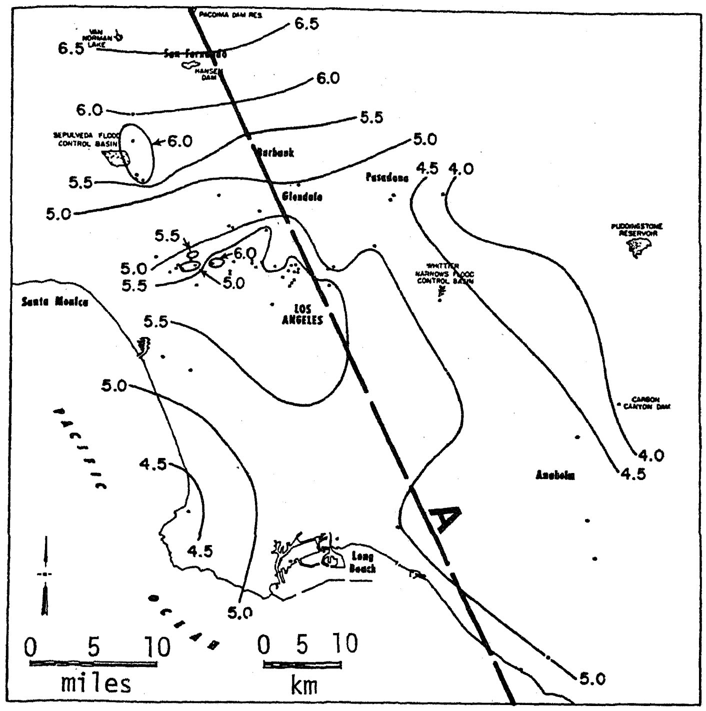

FIGURE 3--ISO-ENGINEERING INTENSITY SCALE PLOT. AVERAGE OF PERIOD BANDS VII, VIII, AND IX

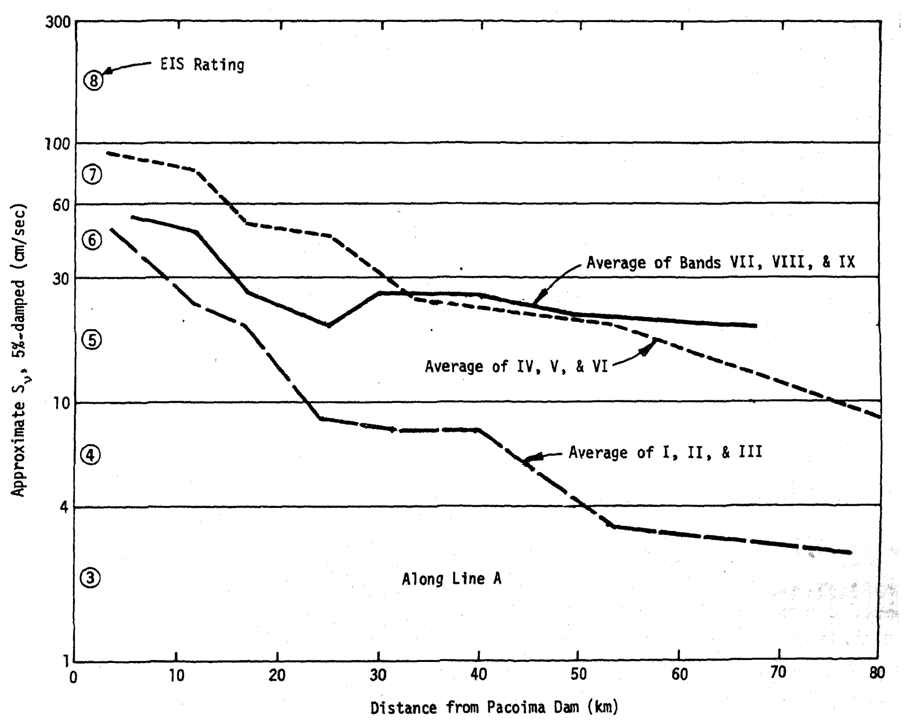

FIGURE 4--EIS RATING VERSUS DISTANCE

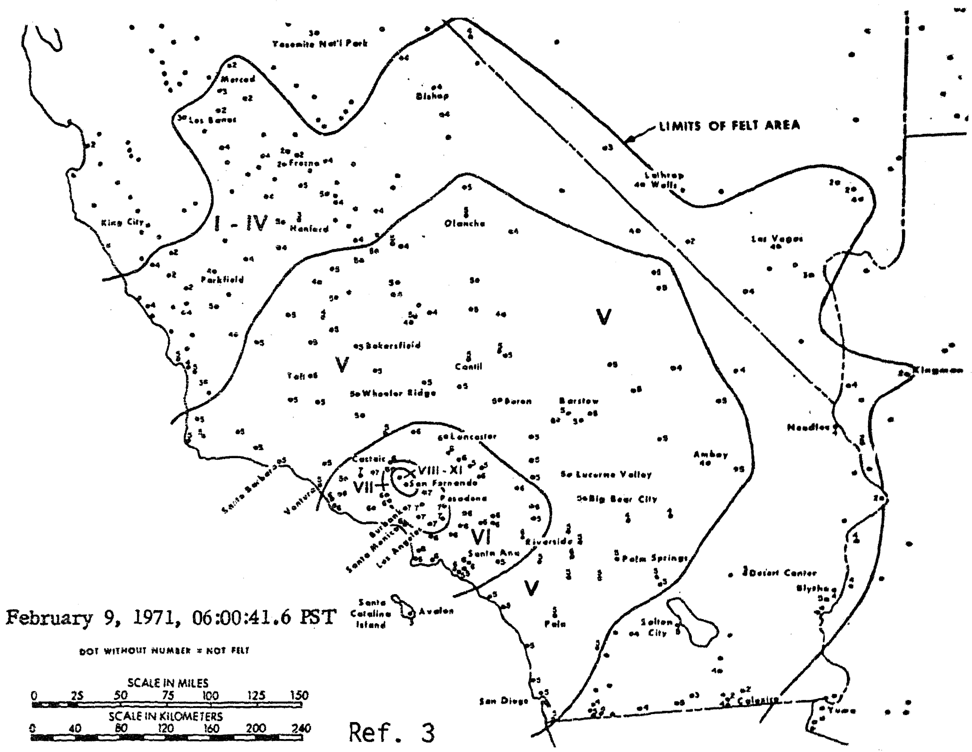

FIGURE 5--MODIFIED MERCALLI INTENSITY MAP FOR SAN FERNANDO EARTHQUAKE

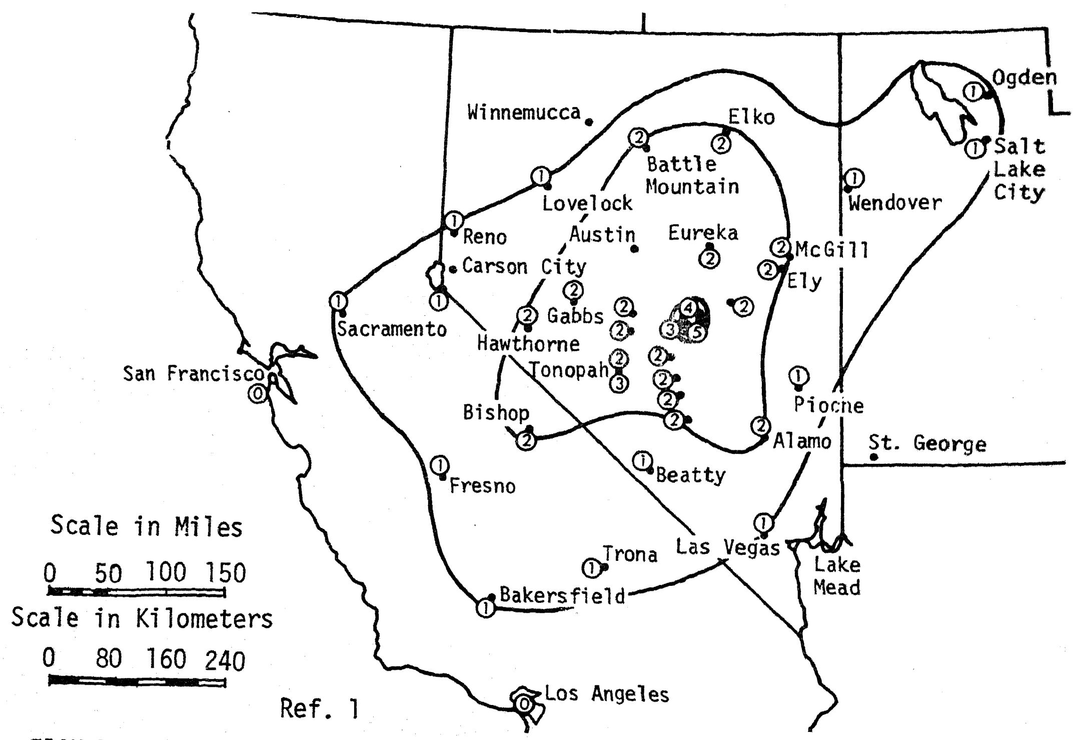

FIGURE 6--ISO-EI LINES FOR AVERAGE OF BANDS I, II, AND III, NUCLEAR EVENT