QUANTITATIVE APPRAISAL OF DESTRUCTIVE EARTHQUAKES

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SUMMARY

Strong motion instruments have not captured so far variations of strong ground motion in the epicentral region of destructive earthquakes. Patterns of this variation may be recognised on field measurements of permanent sets.

Localised deformation is responsible to a great extent for the damage in the epicentral region. This mode of failure correlates well with a sliding block type of field measurements.

INTRODUCTION

There are few records of ground motion in the epicentral areas of destructive earthquakes. In the few cases where the epicentral area was equipped with strong motion instruments, the obtained records were too few to pick up the variation of ground motion. On the other hand, the strong motion in the epicentral region produces permanent sets of deformation; this deformation leads to geometric instabilities along collapse mechanisms or produces a vector field of permanent displacements. Both types of deformation may be quantified on simple structures. Bearing this use in mind the simple structures may be termed field indicators.

Each of the field measurements is associated with large uncertainty and is not amenable, on its own, to detailed analysis. A set, however, of identical field indicators scattered in a large area will show distinct patterns. The measurements may be correlated with ground motion characteristics and then with damage or directly with damage inflicted on more complicated structures.

This presentation is concerned with direct correlations of the field measurements with damage on engineering structures. The first part is a discussion of the set of simple structures that have the characteristics of field indicators. In the second part correlations are indicated between the field measurements and the inflicted damage. All the illustrations were obtained in the epicentral region of the May 6, 1976 Friuli earthquake.

FIELD INDICATORS

Among the instruments designed to record ground motion, the seismoscope may be classified as a field indicator. In general, a seismoscope is looked upon as a simple structure of a single natural period. $T_o \triangleq .75$ sec. and structural damping $\lambda = 10\%$; the response of the structure to the ground motion is recorded in two dimensions and the maximum response gives a point on the elastic response spectrum. Many simple structures of essentially one degree of freedom may be found in the field. Their behaviour is usually considered in terms of a linear pendulum (in either shear or rocking mode) but their response to ground motion is measured from their permanent deformation. Therefore, field measurements on this type of indicators give lower bounds of ground motion. There are other structures however which can absorb large deformation without getting unstable. These structures respond, beyond a stress threshold, to different levels of strong ground motion. Their mechanical analogue is a sliding block with some interface strength characteristics. The strength characteristic imposes a triggering threshold much higher than the one used by strong motion instruments (.01g) and limits their use as field indicators to the epicentral region only. Their measured response is not affected by built-in elastic constants and therefore they offer a measure of damage associated with concentrated excessive dislocations.

In the epicentral region of the May 6, 1976 Fruili earthquake an extensive network of field indicators was identified with the small distribution transformers of the electricity supply network. These transformers possess instrument characteristics: they are of uniform size, sitting on concrete pads inside uniform cabins (Fig. 1, 2, 3). A log is kept for each cabin at the regional ENEL centre in Udine. The log registers the exact dimensions of the transformers and the exact location of the cabins (an accurate location map is also available.) During the earthquake the transformers moved and left clear traces on the concrete platforms. The distribution network does not necessarily follow the population density, since transformers were allocated to isolated consumers i.e. farms. It is thought that a uniform density network of field indicators could have been selected from the network of distribution trans-

Fig 2. Distribution cabin at Bilerio.

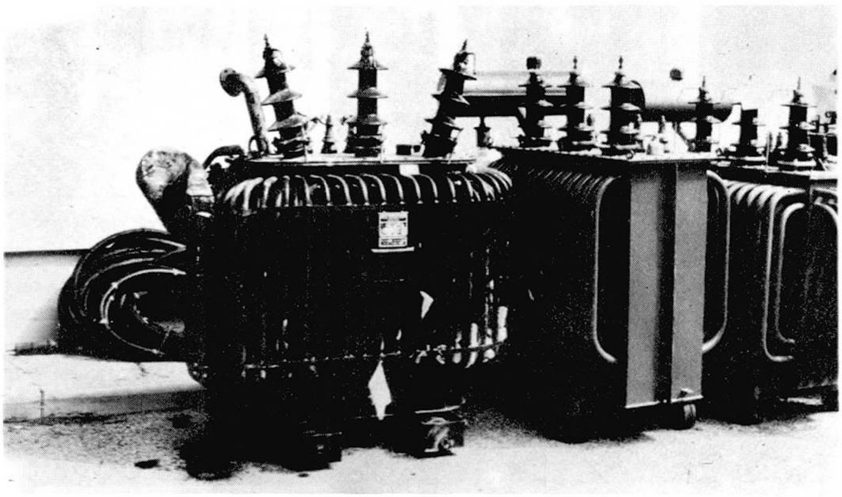


Fig 1. Damaged and new distribution transformers.

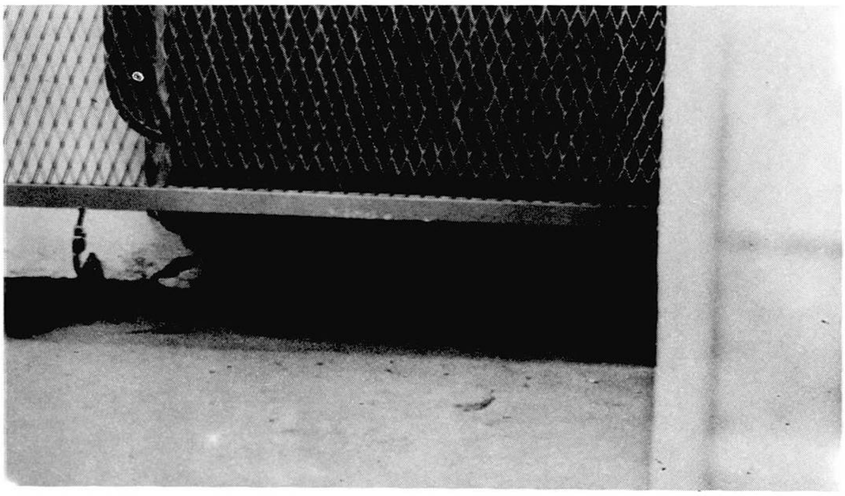


Fig 3. The transformer inside the cabin has moved during the earthquake; one of the back wheels fell into the oil drainage well.

formers in the earthquake area. A systematic recording of the slip vectors of the transformers in the network would have accounted for the scatter of the parameters for each individual station and would have revealed patterns with respect to the variation of geology and topography.

Field measurements in the epicentral area of the May 6, 1976 earthquake were restricted in a zone running NW-SE The slip vectors of the transformers that were studied in this zone are shown on Fig. 4. The transformers at the NW end of the zone surround the nearest strong motion instrument that recorded the main shock at Diga de l' Ambiesta. The measurements have been described elsewhere (1,2). The transformers, in general, moved in a N-S direction. Exceptions were found on recent alluvium where motion was in both directions. Displacements were also larger on recent alluvium.

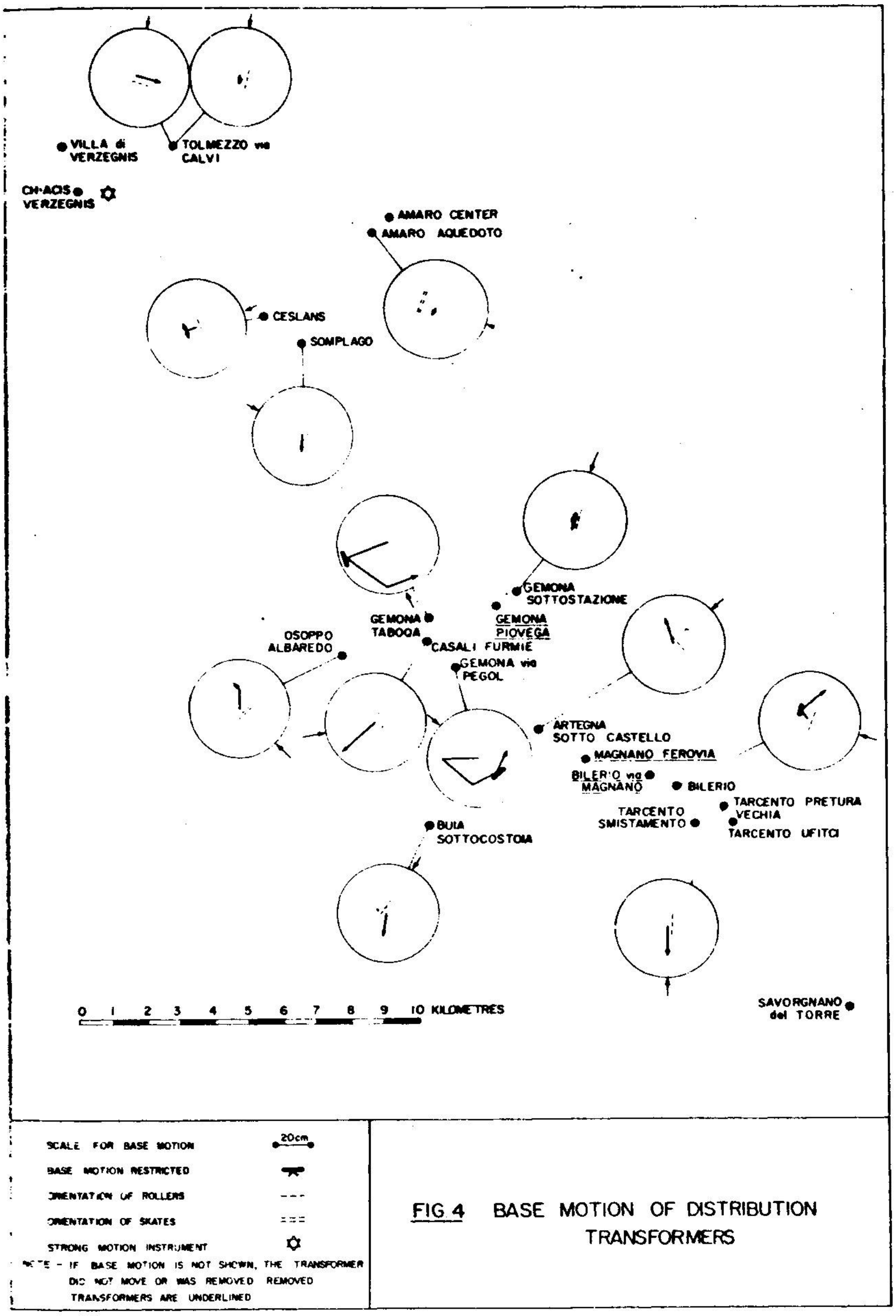


FIG 4 BASE MOTION OF DISTRIBUTION TRANSFORMERS

CORRELATION WITH DAMAGE

By and large, damage in the epicentral area may be attributed to excessive dislocations. The dislocation, necessary to produce collapse varies from structure to structure. This type of damage may be correlated to the slip vectors of sliding blocks in the area. The illustrations below are taken from the epicentral region of the May 6, 1976 Friuli earthquake and parallels are drawn to the few field measurements obtained from the distribution transformers in the same area.

Natural slopes were unstable enough to be triggered by relatively small horizontal dislocations. Of special interest were small landslides, like the one by the road at Cornino (Figure 5); similar landslides might have been responsible for foundation failures in the badly hit villages on alluvial slopes.

The transformers slip varied on alluvial slopes (e.g. Gemona) but was not as

Fig 5. Small landslide by the road at Cornino.

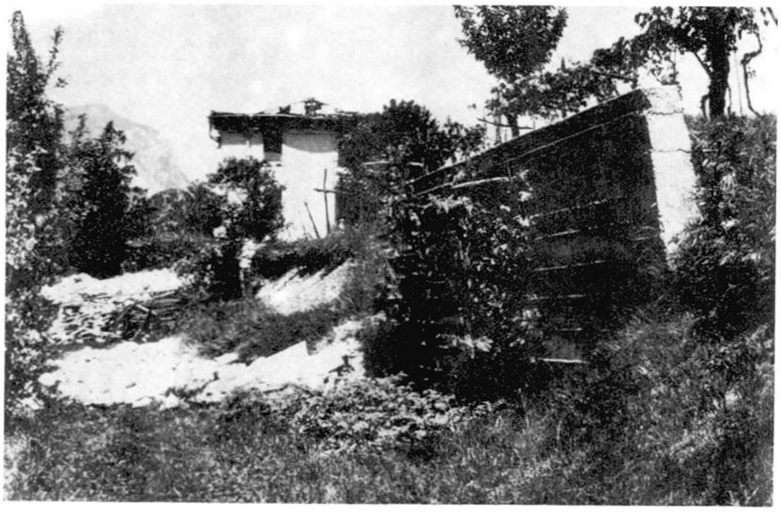


Fig 6. Failure of masonry retaining wall at Gemona.

Fig. 7. Duomo Gemona; Failure of the retaining wall.

large as in the valley. The slip vectors, however, were large enough to cause the failure of retaining walls. Figure 6 was taken from Gemona. The low strength masonry wall could not resist the slip vector as did the concrete wall sitting next to it.

Figure 7 shows the failure of the retaining wall at Duomo, Gemona. Was this failure responsible for the collapse of the southern wall of the Duomo?

Figure 8 freezes an early stage of collapse of a masonry building at Gemona. This mode of failure looks similar to the failure of the mass behind a retaining wall and indicates that failure was initiated by the large rotations of the window-frame. The same mode of failure could be interepreted as the result of large vertical component of motion. This component of motion, although sensed by the transformers, could not be decoupled from the rocking mode.

An unfinished brick building in Gemona moved on its concrete foundation like the transformers in the region (Fig. 9).

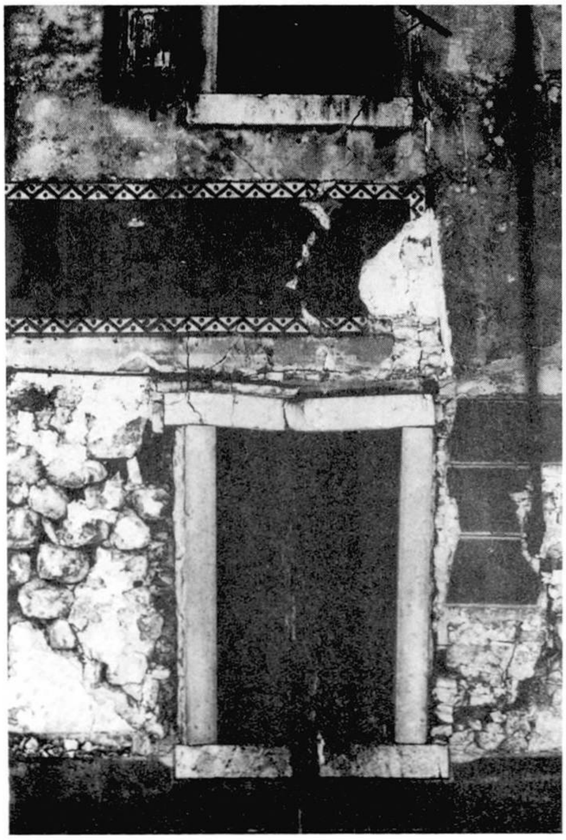


Fig. 8 Collapse mechanism of masonry wall at Gemona.

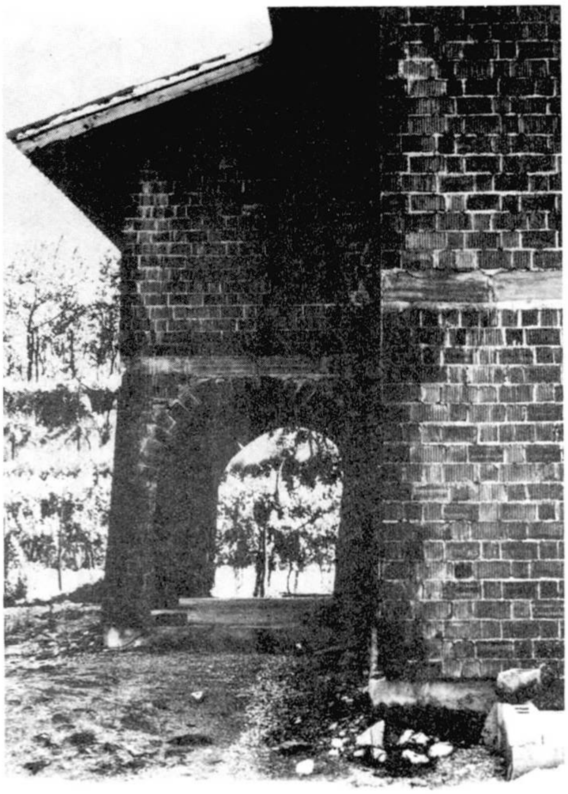
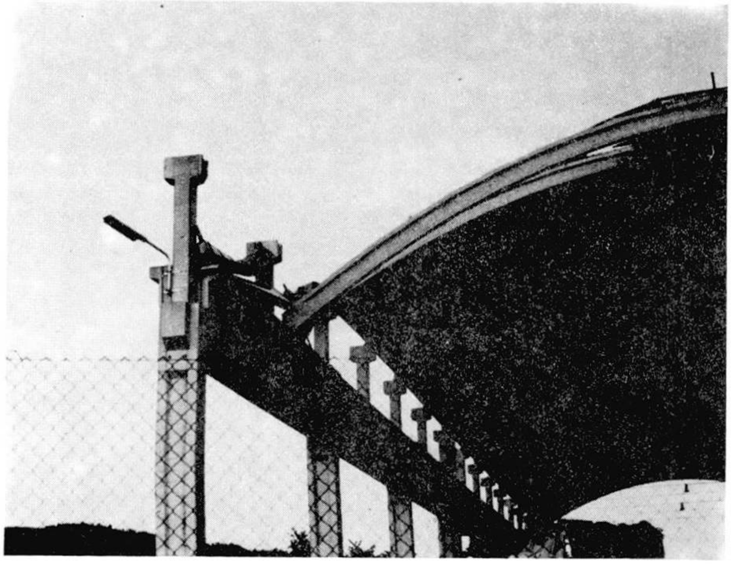


Fig. 9 Gemona; the building moved back and forth on the concrete base.

Figure 10 shows the mode of collapse of an industrial hangar. In this case the relatively small slip vector measured on the ground was amplified by the elastic deformation of the column.

Dislocations along joints in prefabricated buildings may be critical in their earthquake performance as shown on Figure 11. The building is in Majano across the road from another building that collapsed. A variation of the joint strength in one direction could have set up the collapse mechanism.



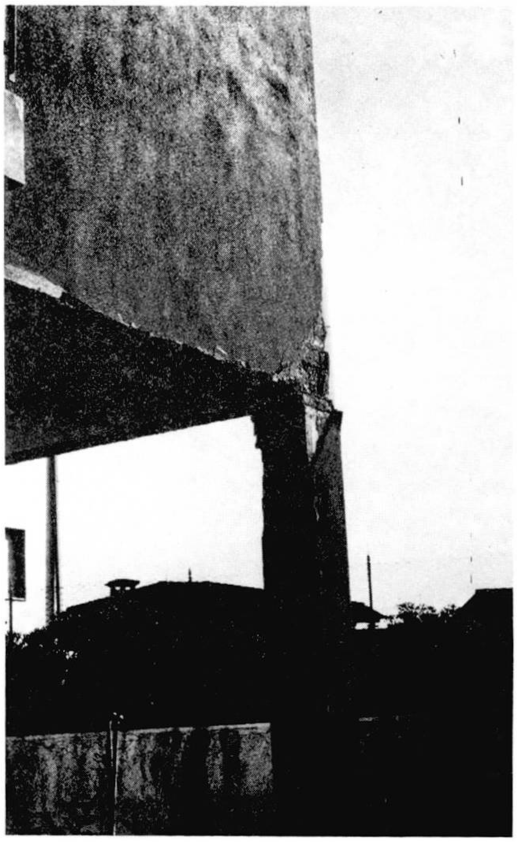


Fig. 10 (above) Industrial hangar at Magnano; collapse mechanism.

Fig. 11 (right) Slip at the joint of a prefabricated building at Majano.

On the recent alluvium the transformers showed large displacements. The same large dislocations could be seen along the supports of the prestressed bridge across the Tagliamento River (Figure 12).

Fig. 12 Prestressed bridge over the Tagliamento River; slip of the supports.

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1. PAPASTAMATIOU D.: The May 6, 1976 Fruili earthquake: field measurements I, Proc 15th ESC General Assembly, Krakow, September 1976.

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