AN INTENSITY DEFINITION OF THE STRONG MOTION

EARTHQUAKES

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SYNOPSIS

The intensity of the strong motion earthquakes is defined as a combination of the average pseudo relative response velocity and the root mean square of the ground velocity. It is normalized so that to an earthquake of intensity about V on the MM scale a unit intensity is assignet. For intensity VI the proposed intensity definition gives 2-3, and for VII - about 6-12. The strongest intensity of 43 is obtained for the Pacoima Dam records, San Fernando 1971 earthquake. The proposed intensity definition, comparing to the Housner's spectral intensity, gives an increase of the intensity of long duration earthquakes, an decreas of the intensity of short duration earthquakes.

INTRODUCTION

There are many scales which qualitatively or quantitatively define the intensity of the earthquakes. Most of them are empirical. Regardless of the precise definition of the intensity in some of them, they can not serve for engineering purposes.

The need for an engineering measure of the intensity of the strong motion earthquakes has been acknowlidged since long ago and repeatedly emphasized. One measure which has an engineering meaning is the Housner's spectral intensity. However, the response spectrum, which is base for that intensity definition, is for elastic systems, but the behaviour of the structures during strong motion earthquakes is non-linear. Due to the elasto-plastic behaviour of the structures the Housner's intensity is an over estimation of the intensity of the short duration earthquakes, and under estimation of the intensity of the long duration earthquakes.

The intensity of the strong motion earthquakes in a way should be connected with the design parametars, such as the seismic coefficient and the ductility coefficient. One of the most important factors affecting the intensity of destruction is the duration of the strong motion. Therefore in defining the intensity of the strong motion earthquakes, in a way the influence of the duration of the ground motion should be included.

This paper presents an attempt to give an engineering measure for the intensity of the strong motion earthquakes, in which those factors have to be taken in account.

In defining the intensity of strong motion earthquakes, the pseudo relative response velocity, which can be connected with the design parametars, is taken as a base. The influence of the duration of the ground motion is taken by a term with an integral of the ground velocity square, which is included in the proposed intensity definition.

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DEFINITION OF THE INTENSITY OF THE STRONG MOTION EARTHQUAKES

The intensity of an earthquake is proportional to the damage or plastic deformations of structures caused by the earthquake. The plastic deformations of a structure depend on the intensity of the strong motion and the yield force level of the structure. These two parametars are conected between themself by their product, that is the energy absorbed by the structure in plastic deformations, Fig.1

The energy absorption of simple one degree of freedom system, with elasto-plastic characteristics like in Fig.1, is equal to,

$$E = P_y(S_d - S_{do}) \qquad (1)$$

Substituting $P_y = k S_{do}$, where k is the stifness of the system, the energy absorption per unit mass of the structure shell be,

$$E_1 = \frac{k}{m} S_{do}(S_d - S_{do}) \qquad (2)$$

The computation of the elasto-plastic deformations S_d of a wide range of structures, in order to compute the energy absorption, is impractical. Some simplifications should be made. As for now, it could be assumed that maximum response displacements of elastic and elasto-plastic systems are equal, Fig.1. In that case the following relations hold,

$$\frac{k}{m} = \omega^2 \ ; \quad S_d \omega = S_v \ ; \quad S_{do} \omega = S_{vo}$$

where S_{vo} is pseudo relative velocity of another, small intensity earthquake (Reference earthquake), taken as constant.

Now the intensity of an earthquake could be defined as an integral of the energy absorption by elasto-plastic systems, integrated from 0 to T of the response spectrum. That is,

$$I' = S_{vo}^2 \int_0^T \left(\frac{S_v}{S_{vo}} - 1 \right) dT \qquad (3)$$

In the case of an earthquake which has $S_v = S_{vo}$, this intensity becomes zero, because there will be no plastic deformations. Insted of that, for convinience, to that earthquake a unit intensity shell be assigned, and intensity redifined by normalizing it to the reference earthquake,

$$I_{sv} = 1 + \frac{I'}{S_{vo}^2 T} = \frac{1}{T} \int_0^T \frac{S_v}{S_{vo}} dT \qquad (4)$$

This expresion actually represents an average pseudo relative response velocity divided by a constant. If the assumption of equal elastic and elasto-plastic deflections (Fig.1) holds, this expresion could be a definition of the intensity of the strong motion earthquakes.

However, the long duration earthquakes can give maximum elasto-plastic displacements longer than the maximum elastic displacements.

With short duration earthquakes it is opposite. Therefore the intensity defined by expresion (4) would be an underestimation of the intensity of long duration earthquakes, and an over estimation of the intensity of short duration earthquakes.

The maximum intensity of an earthquake generally is not along one of the axis of recording of the motion. If the intensities along the horizontal axis x and y, - I_x and I_y, are taken as vectors, the maximum intensity would be the rezultant vector, which intensity is

$$I = \sqrt{I_x^2 + I_y^2} \qquad (5)$$

Further in the text all definitions of the intensity reffer to the rezultant intensity computed in that way.

Another definition of the intensity of the earthquakes, which takes in account the duration of the motion, could be given by the following expression,

$$I'' = \int_0^t v^2 dt \qquad (6)$$

where v is the ground velocity, and t is the duration of the ground motion. With this definition it is an opposite case: the intensity of long duration earthquakes is over estimated and the intensity of short duration earthquakes is under estimated. Thus, a combination of the intensities defined by expressions (4) and (6) should give the best definition of the intensity.

In expression (4) the intensity became a linear function of the pseudo relative velocity S_v. In order to combine (4) and (6) the intensity defined by (6) also should become linear function of the ground velocity v. It should be normalized also, by dividing with $T\, S_{vo}^2$, as was done with expression (4). Thus, expression (6) becomes,

$$I_v = \sqrt{\frac{\int_0^t v^2 \cdot dt}{T\, S_{vo}^2}} \qquad (7)$$

This term also should be computed as rezultant of the intensities obtained for the two horizontal components (Eq.5).

Both, (4) and (7) now are dimensionless and could be combined. Their combination gives the following proposed intensity definition,

$$I_p = \frac{a\, I_{sv} + b\, I_v}{2}$$

As a base should serve the term due to the pseudo relative velocity (I_{sv}). The second term (I_v) should serve as a correction. In that point of view, for the coefficients a and b in the previous equation was found a = 1 and b = 3. Thus, the final expression for the proposed intensity definion becomes,

$$I_p = \frac{1}{2S_{vo}}\left[\frac{1}{T}\int_o^T S_v dT + \sqrt{\frac{3}{T}\int_o^t v^2 dt}\right] \qquad (8)$$

where the first and second terms are rezultants for the two horizontal compônents.

That is a dimensionless quantity. For the strong motion earthquakes it gives intensity more than one. An intensity less than one would mean a small intensity earthquake, and no plastic deformations in the commonly designed structures.

The advantage of the presented intensity definition is in that it could be used fordesign purposes. For example, if the ratio of the intensities of two earthquakes is 2, the ratio of the design seismic coefficients should be the same also, or the expected avarage ratio of the ductility coefficients shell be 2, if same design seismic coefficients are used in the both cases.

PRACTICAL RESULTS

For analysis of the proposed intensity definition 40 pairs of records have bee analized, all of the Western United States, for which there are available data.

The first term in expression (8) was computed by integrating the response spectra given in Ref.2. The damping of structures was assumed 5% of the critical. The period of integration of the pseudo relative velocity spectra was taken T = 3 seconds. The reasons for such an assumpion were given in Ref.1. The second term in expression (8) was computed by using the computed integral by Trifunac(5). For S_{vo} of the reference earthquake was taken a value which corresponds to seismic coefficints S_{ao} = 0,02g/T, which gives S_{vo} = 3.12 cm/second.

On Fig.2 the ratio I_p/I_{sv} is presented, that is the ratio of the proposed intensity definition and the component of the intensity due the pseudo relative response velocity, versus the duration of the strong ground motion. As can be seen, the long duration earthquakes have an encreased relative intensity, and short duration earthquakes decreased. The ratio between the highest and the lowest value of I_p/I_{sv} is about 2. Such one ratio betweene proposed intensity and the Housner's intensity can be more than 3. Those results are in good agreement with the experience gained with short duration earthquakes, for instance like the Parkfield 1966 and Port Huenemme 1957 earthquakes, which had high acceleration and low MM intensity. The numbers besides the results on the Figs.2 and 3 are the same numbers for the earthquakes used in Ref.2.

Most interesting is the relation between the proposed intensity and the MM(Modified Mercali) intensity, although the last one is not a reliable measure, Fig.3. As one could expect, there is wide scatter of the results. That is one proof more that MM intensity is not reliable. Such scatter of the results partially is due to not reliable informations for the MM intensity of some earthquakes. As most reliable results for the MM intensity are the data for the Parkfield 1966 and San Fernando 1971 earthquakes, which on Fig.3 are given as black points.

However, still the MM scale is commonly used one. Thus, there should be given an average relation between the proposed intensity and the MM intensity.

According to the results presented on Fig.3, a unit intensity correspods to earthquakes of about V intensity on MM scale(Reference earthquake). For intensity VI the proposed intensity definition gives 2-3, and for VII - about 6-12. For the stronger intensity earthquakes there is not enough data to get that relation. As an indication of the intensity of very strong motion earthquakes could serve the intensity of 43 for the records of the Pacoima Dam, San Fernando Earthquake. At that point the intensity of the earthquake was IX on the MM scale. There was found a local amplification of the ground motion at that point. Thus, one can conclude that for intensity IX on MMS, the proposed intensity definition gives an intensity $I_p < 43$.

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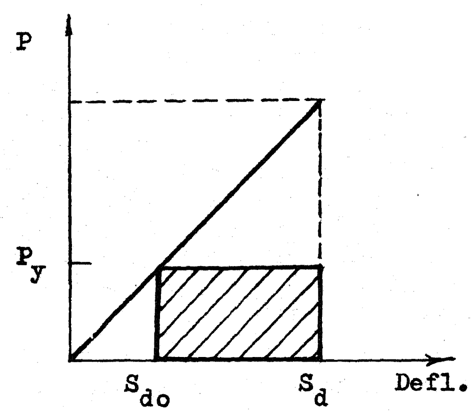

Fig.1 Assumed Force - Deflection Relationship

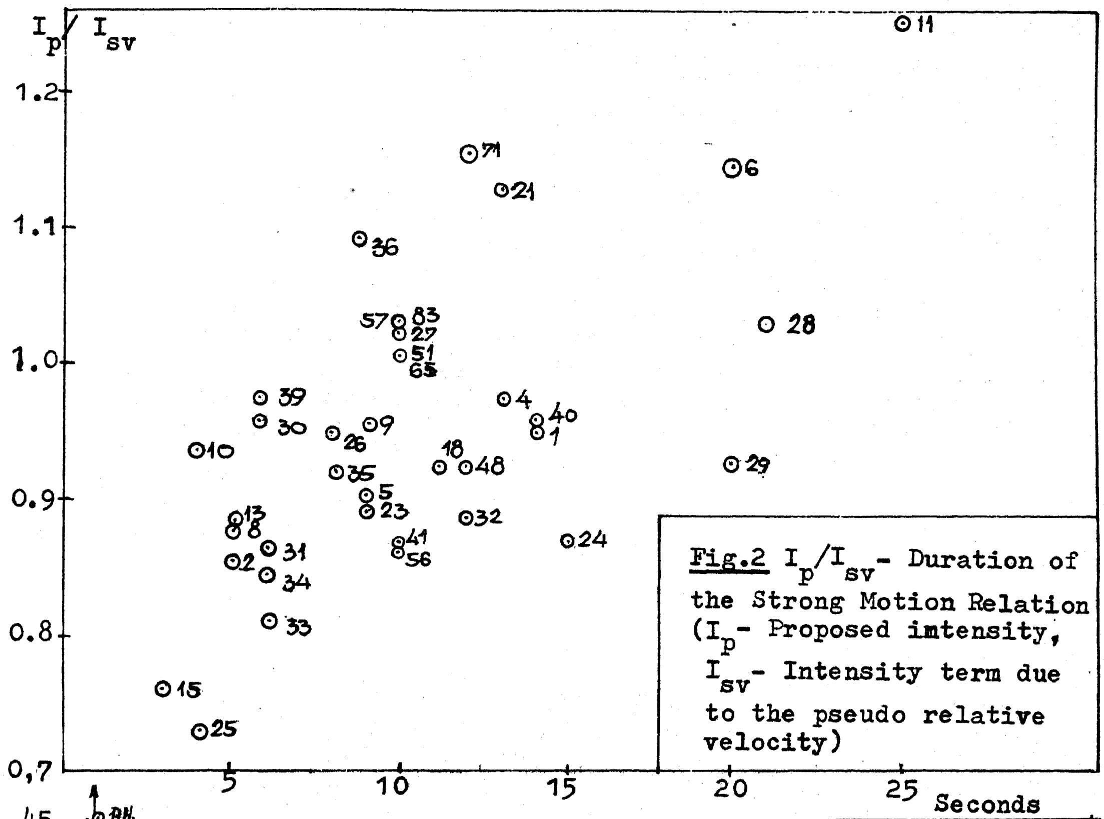

Fig.2 I_p/I_{sv}- Duration of the Strong Motion Relation (I_p- Proposed intensity, I_{sv}- Intensity term due to the pseudo relative velocity)

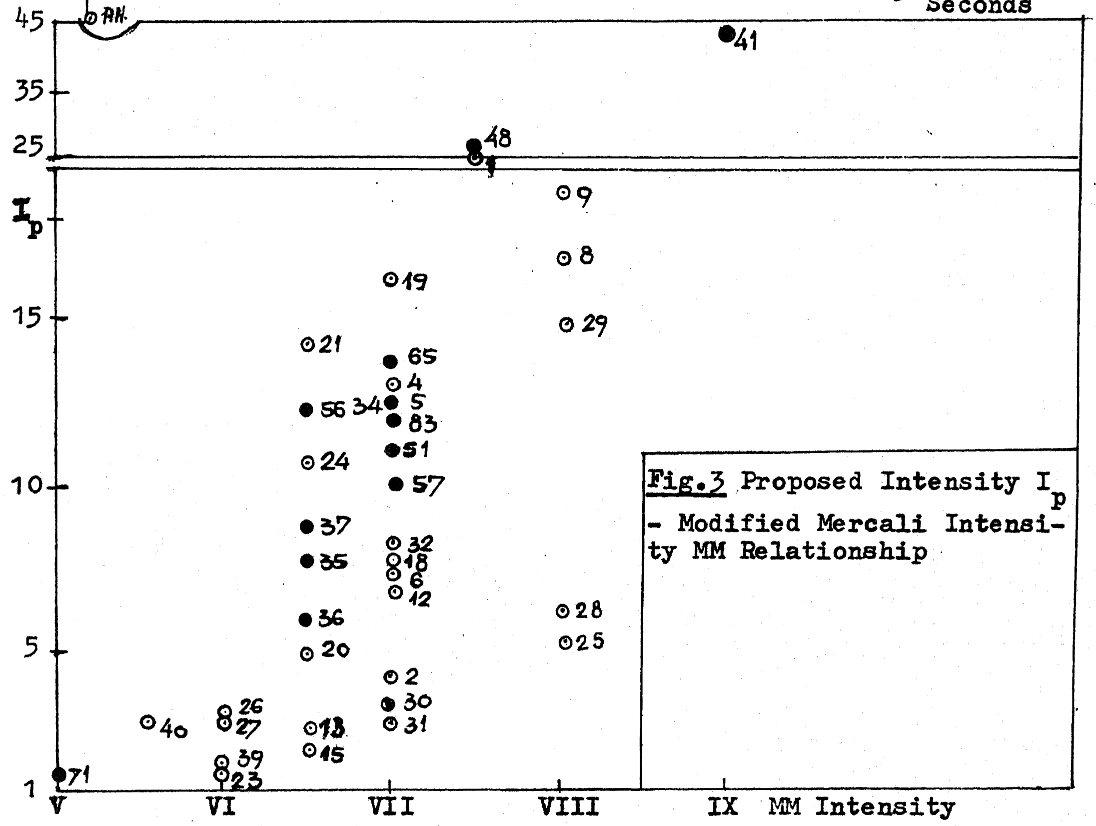

Fig.3 Proposed Intensity I_p - Modified Mercali Intensity MM Relationship