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ENGINEERING DURATION OF STRONG MOTION AND ITS EFFECTS ON SEISMIC DAMAGE

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SUMMARY

In this paper, the existing definitions of strong ground motion duration are reviewed and re-classified into two different categories: record-based duration which was directly defined upon ground motion accelerograms and response-based duration which was defined upon response of structure subjected to ground acceleration. A new definition, i.e. engineering duration of earthquake ground motion is presented and its predicting equations are deduced. It shows that the new definition can much better reflect both the characteristics of ground motion and its effects on response of structure than can any definition presented ever before.

INTRODUCTION

It has been widely accepted that the duration of ground motion plays a significant role in causing seismic damage of structures during earthquakes. Since the earlier studies [1] on the dependence of duration on magnitude were carried out in 1960's, a number of studies on this problem have been conducted by seismologists and earthquake engineers from various angles [2-7,10]. The past studies on duration are essentially focusing on the three aspects: 1. definition and implication, 2. its correlation with other parameters, such as earthquake magnitude, distance, soil properties etc. and 3. the effects of duration on seismic damage to structures. As to the definition of duration, it is still a problem unsolved so far, though a variety of definitions have been suggested. In summary, they could be divided into two main categories: the record-based duration and response-based duration. The former was directly defined upon ground motion accelerograms and the "bracket duration" by Bolt, "fraction duration", [5, 8] Trifunac and Brady's duration, the "Second Moment Duration" by Xie and Zhou [5], Vanmarcke and Lai's duration etc. are examples of such kind. The latter was set upon the response of the single degree of freedom (SDOF) system subjected to ground acceleration [6, 7].

It is clear that a record-based duration could well correlated with seismic parameters but has nothing to do with the characteristics of structures and it is hardly to expect that a good correlation could be found between this kind of duration and severeness of structural damages. On the other hand, the existing response-based durations are very complicated in computation and rarely have seismic information involved in so that it is also very difficult to expect that an intuitive and strong correlation could be established between the response-based durations and seismic and structural parameters.

This paper is trying to define an "Engineering Duration" of ground motion which is directly related with the main structural characteristics and has a very similar expressions with record-based duration. It's correlations with seismic parameters and effects on structural damage are also examined.

ENGINEERING DURATION

1. The engineering duration T_e is defined here as the elapsed time from the first to the last acceleration equal to a_y on the accelerogram as shown in fig. 1. And a_Y, called Yielding Acceleration, could be expressed as

$$a_Y = Q_Y/(M \times BETA(T)) \qquad (1)$$

where Q_Y-the yeild strength of a given structure (as a SDOF system), M-the total mass of the same structure, and BETA(T)-the ordinate of the response spectrum of the accelerogram corresponding to the period and damping ratio equal to the fundamental period T and the damping ratio of the given structure respectively.

2. It can be easily worked out that the engineering duration is only an extension of bracket duration given by Bolt. But a constant acceleration threshold (for examples, 0.05 g or 0.10 g adopted by Bolt) has been replaced by an important structural index a_y which represents an acceleration limit to cause the structure entering the plastic deformation stage.

This substitution brings a merit to avoid subjective arbitrariness in defining the duration of ground motion and reflect somewhat objectively the characteristics of structure.

3. The Engineering Duration gives a very clear physical meaning. If the acceleration **a** of ground motion exceeds the yielding acceleration a_y of the given structure, the seismic force on this structure equals $M \times \mathbf{a} \times BETA(T) \quad Q_y$ and the plastic deformation will thus appear on the structure. Obviously, for different structures, each time history of acceleration will have different engineering duration T_e i.e. will give different effects on different structures. Particularly, the engineering duration T_e will be zero in case the maximum acceleration of ground motion less than the given yielding acceleration a_y. It means that the mentioned ground motion is of no significance to damage to the given structure. Additionally, one may find that for a given structure, different ground motions will also have different engineering durations which do represent the proper characteristics of respective ground motion.

CORRELATION WITH MAGNITUDE, DISTANCE AND SOIL CONDITIONS

A number of prediction equations of duration has been developed in terms of Magnitude M, Distance R and soil conditions (s=0, 1 and 2, represents rock, moderate and soft soil respectively). For example, McGuire [8] presented the prediction equations for bracket duration T_b (0.05g) and Trifunac-Brady's 90% relative energy duration T_{fb} as

$$T_b = 9.974\ e^{2.000M} \times R^{-1.270} \times e^{0.200s} \qquad (2)$$

$$T_{fb} = 1.209\ e^{0.150M} \times R^{0.350} \times e^{0.730s} \qquad (3)$$

Also Zhou and Katayama [9] have presented the prediction equation for the Second Moment Duration T_{xz} as

$$T_{xz} = 0.253 \times 10^{0.173M} \times 10^{0.149s} \times R^{0.155} \qquad (4)$$

The prediction equation of engineering duration T_e could be easily established from these existing results as shown in equations (2), (3) and (4), only if the shape of seismic energy distribution along the time axis $a^2(t)$ could be approximately assumed as the Normal Gaussian Distribution. According to this assumption, the engineering duration T_e could be expressed in term of T_b, or T_{fb}, or T_{xz}[10], such as

$$T_e = T_b \cdot [\ln(a_m/a_y)/ \ln (a_m/a_b)]^{1/2} \qquad (5)$$

$$T_e = 1.26\ T_{fb}\ [\ln(a_m/a_y)]^{1/2} \qquad (6)$$

$$T_e = 2\ T_{xz}\ [\ln (a_m/a_y)]^{1/2} \qquad (7)$$

where

a_b -- 0.05g, the designated acceleration level taken as the threshold for bracket duration.

a_m -- the maximum acceleration of ground motion

From equations (2) and (5), (3) and (6), and (4) and (7), several prediction equations of engineering duration could be obtained from different sources [10]. They are respectively expressed as follows and illustrated in fig. 2.

$$T_e = 9.974\ e^{2.000M} \times R^{-1.270} \times e^{0.200s}[\ln(a_m/a_y)/\ln(a_m/a_b)]^{1/2} \qquad (8)$$

$$T_e = 1.470\ e^{0.150M} \times R^{0.350} \times e^{0.730s}[\ln(a_m/a_y)]^{1/2} \qquad (9)$$

$$T_e = 0.506 \times 10^{0.173M} \times R^{0.155} \times 10^{0.149s} \times [\ln (a_m/a_y)]^{1/2} \qquad (10)$$

By now, three different prediction equations have been deduced by directly using the existing results developed by different authors. It is not the purpose of this paper to compare those results and indicate their implication. What should be stated is that the prediction equation of engineering duration could be directly deduced from any existing or new prediction equations developed for other record-based durations. Thus, the correlation between engineering durations and seismic parameters and soil properties could be easily estalished.

EFFECTS ON SEISMIC DAMAGE AND COLLAPSE OF STRUCTURES

In order to estimate the effects of engineering duration on destructiveness and collapse of structures, a comprehensive study has been carried out for two mechanical models of SDOF nonlinear system [11]. These two models both have hysteretic force-deformation relation but model I with linearly degrading stiffness and model II with rigidity and strength cyclically deteriorated shown in fig. 3. Additionally, three different natural periods of 0.2, 0.5 and 1.0 second were taken on each model for examining the different effects on models with different rigidities. In computation, forty artificially generated acceleration time-histories with 10 maximum acceleration of different levels were used as inputs. As examples, two of them are illustrated in figure 4. The engineering durations of those ground motions are ranging within 6-30 second for all SDOF system considered. As a criterion of collapse , $u=u_c$ or Q_i $0.2Q_y$ (only for model II) was taken into account where u is the relative displacement of SDOF system and Q_i, the ultimate strength of SDOF system after several cyclical degradation.

The computation results are shown in figure 5-6 [11] and the histograms indicate that with increasing of engineering duration the number of collapsed structures are propotionally increased. It could be believed that a very good correlation is existing between the engineering duration and collapse of structures. Engineeing duration does play a significant role in causing the damage and collapse of buildings.

CONCLUSIONS

The engineering duration of ground motion is defined directly on the ground motion accelerogram by using the important structural parameters as a threshold. It could be determined without mixing any subjective arbitrariness and has a very clear physical meaning that the only ground motion during the engineering duration will play an important role in causing damage to structures. The correlation between engineering duration and other factors could be established directly as indirectly from existing or future developed ones for other durations. From a number of nonlinear analysis, it has shown that the engineering duration is a good measures describing the severence of ground motion and its effects on the seismic destructiveness of structures.

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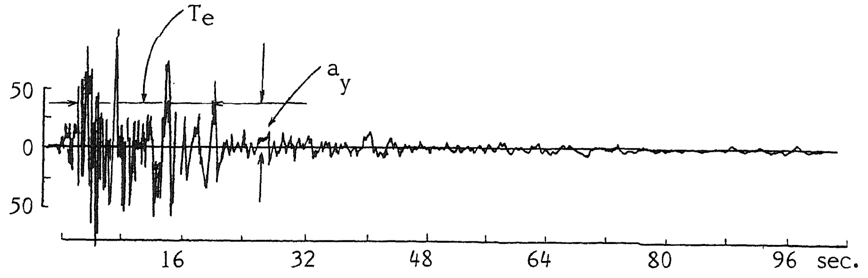


Fig.1 Definition of Engineering Duration on Accelerogram

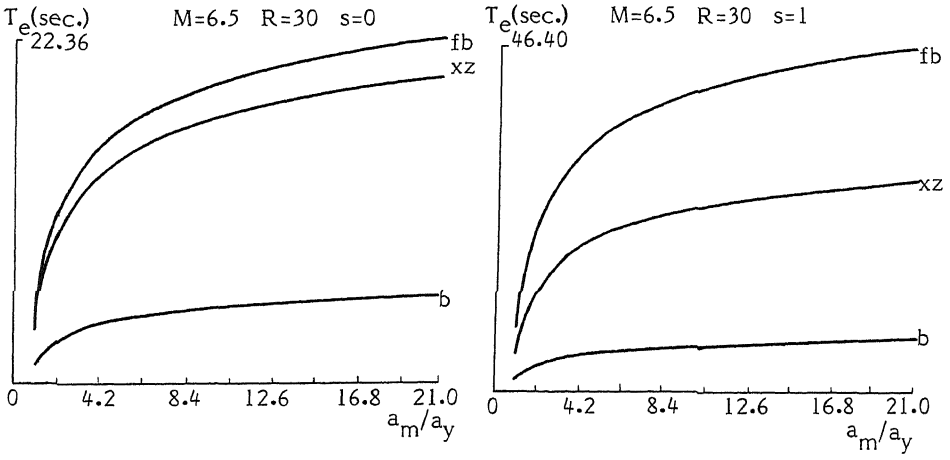
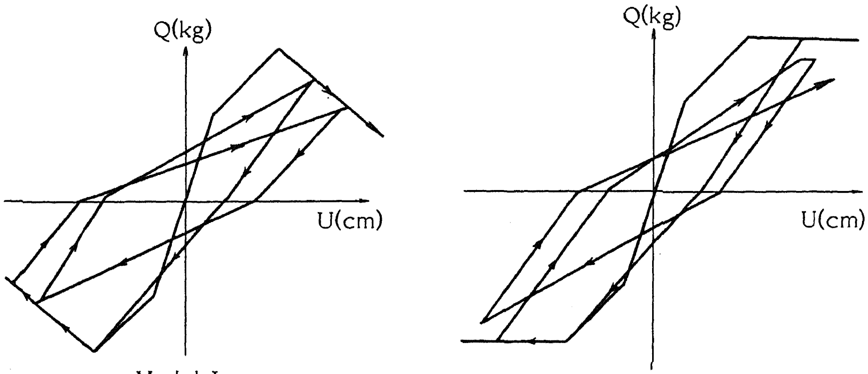


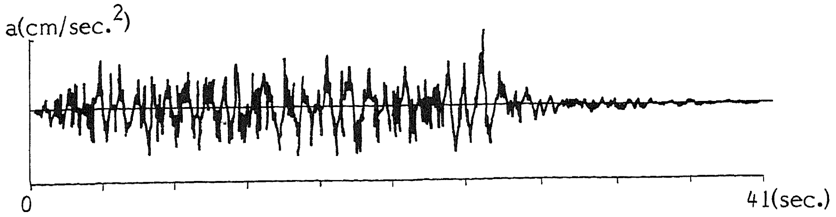
Fig.2 Regressive Curves of Engineering Duration vs. Magnitude, Distance and Soil Conditions



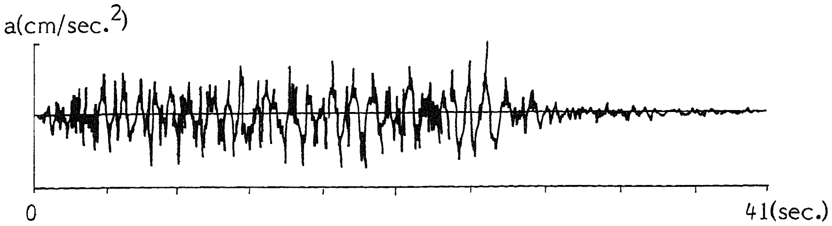
Model I

Model II

Fig.3 Curve of Restoring Force-Deformation of Model I and II



Sample 1



Sample 2

Fig.4 Examples of Artificially Generated Accelerograms used for Collapse Analysis

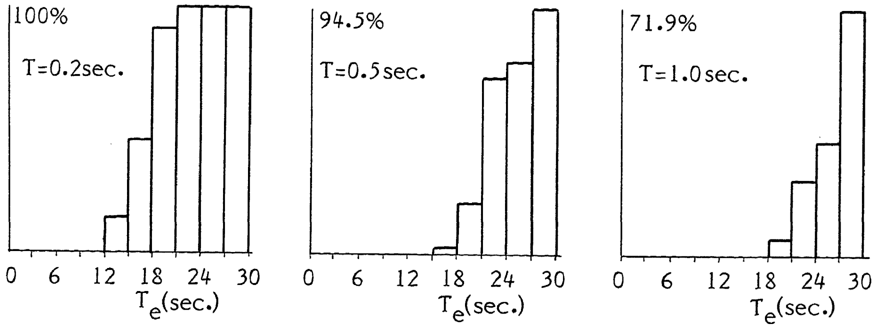


Fig.5 Histograms of Number of Collapsed Structures for Model II

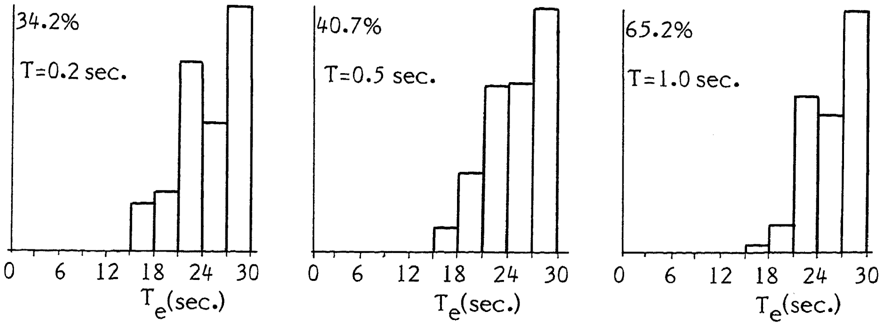


Fig.6 Histograms of Number of Collapsed Structures for Model I