A SHORT DURATION EQUIVALENT EARTHQUAKE

J. P. Wong (I)
M. M. Paz (II)
Presenting Author: J. P. Wong

This paper presents a proposed artificial short duration (three seconds) equivalent earthquake that may be used as input for time history study of severe earthquakes. The equivalent earthquake is a simple, smooth function with three constants that can be varied to represent different magnitude and dominant frequency range. The El Centro earthquake is used as an example to illustrate the proposed artificial short duration equivalent earthquake.

INTRODUCTION

At the present time the design of earthquake resistant structures for moderate earthquake is no longer a problem. However, the design for severe earthquake still remains a topic for further studies. Any acceptable practical design procedure not requiring a time history study must lead to a design which will perform reasonably well when scrutinized by a time history study. It is a well known fact that a severe earthquake has a longer time duration, therefore it is of interest to investigate a short duration, artifically generated, equivalent earthquake ("equivalent earthquake" hereafter). The proposed equivalent earthquake has a duration of three seconds.

EQUIVALENT EARTHQUAKE

The problems associated with severe earthquakes are essentially due to the uncertainty of the future earthquake motion. Each earthquake motion has its own characteristics, namely, dominant frequency range, intensity and duration. In general, the dominant frequency range is location dependent, and a stronger earthquake has a longer time duration.

The duration of the proposed equivalent earthquake is limited to three seconds. We would like the equivalent earthquake to be a simple, smooth function, and to behave similar to the compound envelope function suggested by Jennings, et al. (Ref. 1), which consists of a rise portion, a level portion, and a decaying portion. These are three constants which can be adjusted to represent different intensity and dominant frequency range.

For a one degree of freedom system the equation of motion is

$$\ddot{x} + 2\xi\omega\dot{x} + \omega^2 x = a(t) \tag{1}$$

(I) Professor of Mechanical Engineering, University of Louisville, Louisville, Kentucky 40292, USA

(II) Professor of Civil Engineering, University of Louisville, Louisville, Kentucky 40292, USA

where a(t), the equivalent acceleration of the earthquake is expressed as

$$a(t) = u(f)\ \sin[\theta(t)] \tag{2}$$

We define

$$\theta(t) = At + Bt^C \tag{3}$$

in which A, B, and C are constants to be determined. The functions u(f) can be determined from a typical past earthquake in a specified region. For the well known El Centro earthquake the function u(f) in terms of g's is given by

$$u(f) = \begin{cases} 0.22f & f \leq 1.5 \text{ hz} \\ 0.33 & 1.5 \leq f \leq 3.5 \text{ hz} \\ \dfrac{2.16}{f^{1.5}} & f \geq 3.5 \text{ hz} \end{cases} \tag{4}$$

A typical plot of the equivalent earthquake is shown in Fig. 1.

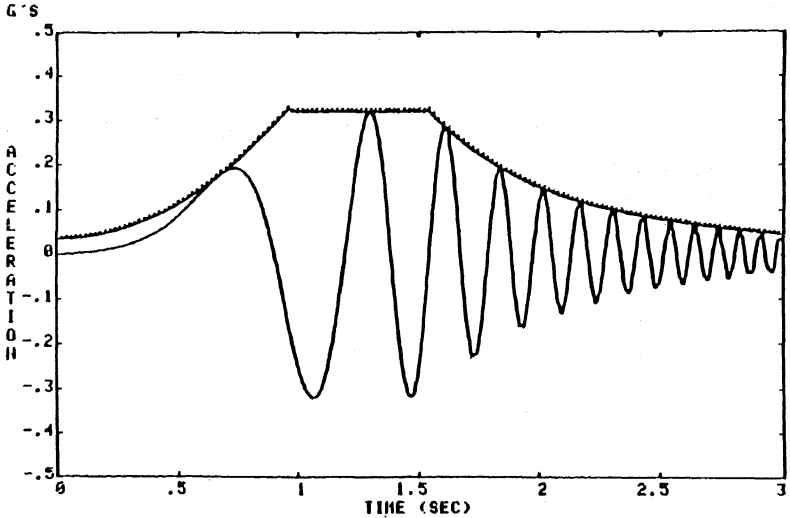

Fig. 1 A Typical Equivalent Earthquake

CONSTANTS A, B AND C

The constants A, B, and C are determined via an topimization technique. We define an objective function ϕ

$$\phi = \sum_{f} \sum_{\xi} [R - R_e]^2 \tag{5}$$

where R is the response due to the target earthquake, R_e is the response due to equivalent earthquke, and the summations are applied at various natural frequencies in the range of interest, and also at a sequence of damping ratios of interest, say at ξ = 1%, 5%, and 10%. We seek the minimum of the objective function ϕ by a standard search technique (Ref. 2), which determines the constants A, B, and C.

Since the response of an actual earthquake such the El Centro earthquake is highly irregular, the term R used in equation (5) are the values after a standard five-point smoothing technique.

A comparison of the smoothed El Cenro earthquake and the equivalent earthquake with ξ = 2%, 5%, and 10% are presented in Figs. 2, 3, and 4, respectively. In these figures, the line without dots is the smoothed El Centro response, and the line with dots is the response due to equivalent earthquake.

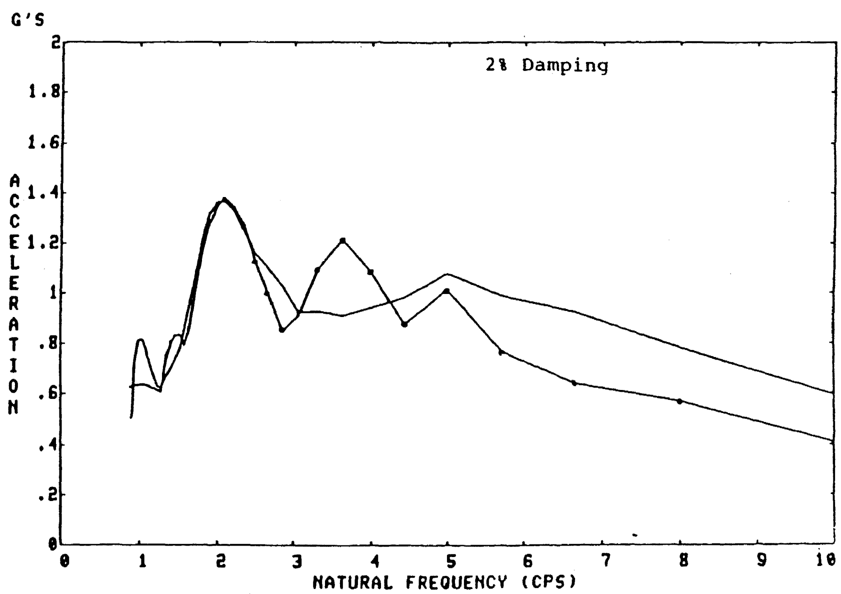

Fig. 2 A Comparison of Responses, ξ = 2%

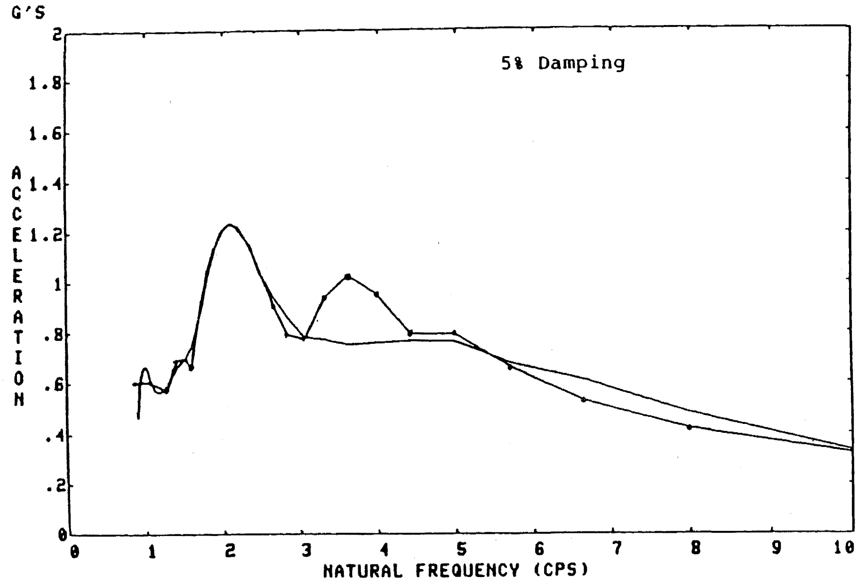

Fig. 3 A Comparison of Responses, ξ = 5%

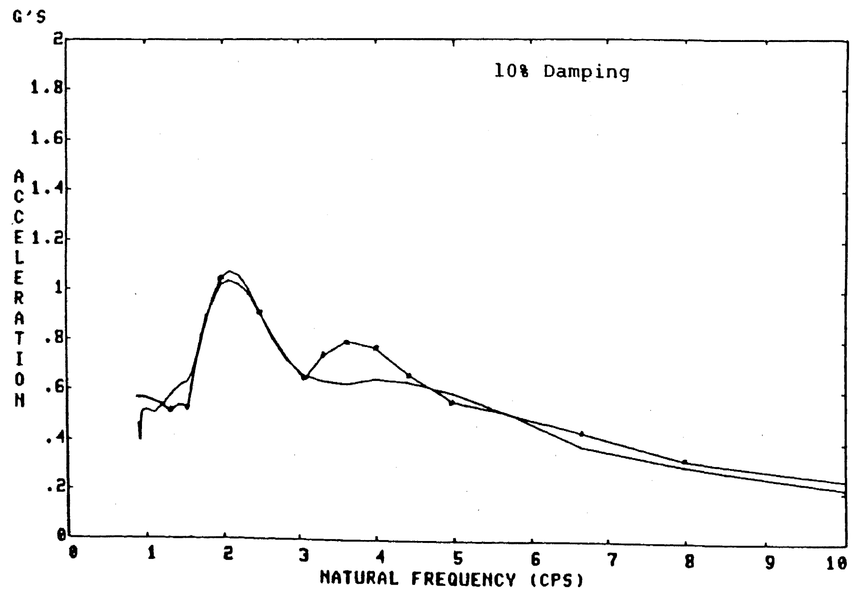

Fig. 4 A Comparison of Responses, ξ = 10%

The constants for ξ = 2%, 5%, and 10% are summarized:

ξ,%	A	B	C
2	6.93	9.05	3.33
5	7.83	9.65	3.95
10	7.60	8.63	3.93

CONCLUSION AND RECOMMENDATION

A simple, smooth function is proposed as a short duration equivalent earthquake. The proposed function has a compound envelope, and three constants, which are determined by correlation study. When the proposed equivalent earthquake was employed to represent the El Centro earthquake, reasonable agreements between the responses were observed. Of the three constants, for higher damping as one may expect in severe earthquakes, the constants A and C are relatively insensitive to the change of damping, the constant B is more sensitive to the change of damping. This equivalent earthquake technique may or may not be adequate for other severe earthquake motions. Further studies are necessary before we can make a more definite statement.

References:

1. Jennings, P. C., Housner, G. W., and Tsai, N. C., "Simulated Earthquake Motions," EERL Report, California Institute of Technology, April 1968.

2. Fox, R. L., "Optimization Methods for Engineering Design," Addison-Wesley, 1971.