ESTIMATION OF STRONG GROUND MOTION STATIONARY DURATION FROM STOCHASTIC STRUCTURAL RESPONSE ANALYSIS

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ABSTRACT :

Strong motion duration is important parameter for nonlinear behaviour of structures and foundation soils. The estimates of duration of future earthquake shaking together with the knowledge of intensity of such shaking are essential tools in the hands of a design engineer. The definition of duration, as used by different investigators, has evolved with time from simple "bracketed" definitions to frequency dependent functional. In this paper, the frequency-dependent duration is defined via stochastic response analysis of SDOF structures. The present definition of duration combined with information about Fourier spectral amplitudes at all frequencies will provide most of the parameters of the strong ground motion, necessary for analysis of response of structures and soils to earthquake excitation. The stationary duration proposed here has been defined in such a way that it represents the duration of an equivalent stationary response of SDOF systems with specified natural periods and damping ratios. Acceleration time histories of major earthquakes in India are used to illustrate the estimation of the proposed duration.

KEYWORDS: Strong motion duration, Arias intensity, Effective duration, Stationary duration of response.

1. INTRODUCTION

The duration of strong ground motion is widely recognized as an important characteristic affecting the response of man-made structures. It is related to the total energy exciting a structure and may be used to evaluate the rate of this energy input. The significance of this excitation duration is particularly important for nonlinear structures as the number of response cycles is directly related to duration. Knowledge of duration of strong motion is also necessary for prediction of seismic performance of soils at sites where liquefaction is possible.
Page et al [1] define the duration to be the time interval between the first and last time when the acceleration exceeds the limit of 0.05g . Husid et al [2] define duration as the time interval during which 95% of the total energy is coming to recording station. Trifunac and Brady[3] define the duration of an excitation function f(t), which can be acceleration, velocity, displacement as the time during which 90% of the value of integral $\int_0^t f(\tau)d\tau$ is achieved. Bolt[4] suggested that the duration of an excitation function should be considered in narrow frequency bands as it is physically a frequency dependent function.
The energy dissipated by structure during the excitation depends on its natural frequency and damping. Hence, a new definition of duration could be formulated and called the 'duration of strong motion response'.

2. THEORETICAL FORMULATION

The PSDF of a stationary stochastic process of duration T_s can be defined from its Fourier amplitude spectrum $FS(\omega)$ as follows (Bendat and Piersol[5])

$$G(\omega)= |FS(\omega)|^2 / \pi\, T_s \tag{1}$$

The strong motion part of an accelerogram can be considered as weakly stationary process and this definition can be applied to obtain its PSDF(Elghadamsi et al[6]). The duration of strong motion felt by a structure may be different from the apparent strong-motion duration of input excitation. It will thus be useful to determine the stationary duration for each natural period and damping ratio which will correctly represent the severity of structural response to a given input acceleration. Such a frequency and damping dependent duration can be termed as 'stationary duration of response'.

Let $T_s(\omega_0, \zeta)$ be the stationary duration which would provide exact matching between the time history response of a SDOF structure with natural frequency ω_0 and damping ratio ζ with the corresponding expected value of the peak amplitude obtained from PSDF defined in terms of the Fourier spectrum FS(ω) of ground acceleration as

$$G(\omega)= |FS(\omega)|^2 / \pi\, T_s(\omega_0, \zeta) \tag{2}$$

To obtain $T_s(\omega_0, \zeta)$ for a given accelerogram , we first consider the PSDF $G'(\omega)$ without $T_s(\omega_0, \zeta)$ as

$$G'(\omega)= |FS(\omega)|^2 / \pi \tag{3}$$

The PSDF of the displacement response of an oscillator with the natural frequency ω_0 and damping ratio ζ to this input PSDF can be written as

$$ED(\omega) = G'(\omega)\, |H(\omega)|^2 ; \quad \boxed{H(\omega) = 1 \big/ \left[(\omega_0^2 - \omega^2)^2 + 4\zeta^2 \omega_0^2 \omega^2\right]^{1/2}} \tag{4}$$

By computing the moments m_0, m_2 and m_4 of $ED(\omega)$ and using the total duration, T, of the input excitation, the various statistical parameters of the response are given as (Cartwright and Longuet-Higgins[7])

$$x_{rms}= (m_0)^{1/2} \tag{5}$$

$$N = T(m_4/m_2)^{1/2} /\pi \tag{6}$$

$$\epsilon= [(m_0 m_4 - m_2^2) / m_0 m_4]^{1/2} \tag{7}$$

Using the statistical parameters N and ϵ ,we have computed the peak factor η_{max} to get the expected value of response peak as (Gupta and Trifunac[8])

$$SD'(\omega_0,\zeta) = [\eta_{max}].x_{rms} \tag{8}$$

From this the stationary duration $T_s(\omega_0, \zeta)$,which will ensure exact matching of the expected maximum response given by eqn. (8) of the SDOF oscillator computed by using the PSDF in

eqn.(2) with that of the time history solution SD(ω_0, ζ) ,can be defined as

$$T_s(\omega_0,\zeta) = [SD'(\omega_0,\zeta) / SD(\omega_0,\zeta)]^2 \quad (9)$$

3. RESULTS AND DISCUSSION

To illustrate the application of the foregoing theory for computing the strong-motion stationary duration as a function of oscillator frequency and damping values, seven different acceleration times histories recorded from Indian earthquakes are considered with widely varying non-stationary characteristics. Details of these accelerograms are listed in Table-1. Typical example results on the computed durations along with the input acceleration time histories are shown in Fig. 1.

TABLE 1: Details of the acceleration records used to compute the example results.

Sr. No.	Name of Earthquake	Date D M Y	Recording Site	Epicentral Dist. (km.)	Magni-tude	Comp.	Total Duration (Sec)
1.	Koyna Dam	10 12 1967	Koyana 1A Gallery	12.6	6.5	Long.	13.38
2.	Kangra	26 04 1986	Shahpur	10.46	5.5	N75E	26.76
3.	Meghalaya	10 09 1986	Saitsama	24.75	5.2	S05E	21.96
4.	North-East India	18 05 1987	Umrongso	99.38	6.2	N63W	14.04
5.	Shillong Plateau	06 02 1988	Nongkhlaw	26.46	5.8	S10E	47.28
6	Uttarkashi	20 10 1991	Bhatwari	19.62	6.8	N05W	46.16
7.	Chamoli	29 03 1999	Gopeshwar	8.72	6.5	N20E	34.34

From the results in Fig. 1, it is seen that the strong-motion duration as experienced by a structure vary significantly with the natural period and damping of the structure. The dependence of strong-motion duration on the structural damping is not accounted in any of the existing methods. In the existing methods, the dependence on the frequency also is not accounted precisely, because they consider the durations for band-pass filtered accelerograms for the purpose. From the results in Fig. 1, it is seen that the strong-motion duration may change significantly even for two nearby frequencies. Further, the effective strong-motion duration experienced by structures with low dampings and/or high natural periods are seen to be even larger than the physical duration of the input excitation.

Thus the proposed method is able to provide a complete response spectrum, of the strong motion duration, similar to the response spectra of the peak response amplitudes. It is possible to develop scaling relations for the duration similar to those for the spectral amplitudes and utilize those in the probabilistic seismic hazard analysis applications. This duration for a particular structure can be used as a critical value of the duration for simulation of spectrum compatible accelerograms from the corresponding uniform hazard response spectrum.

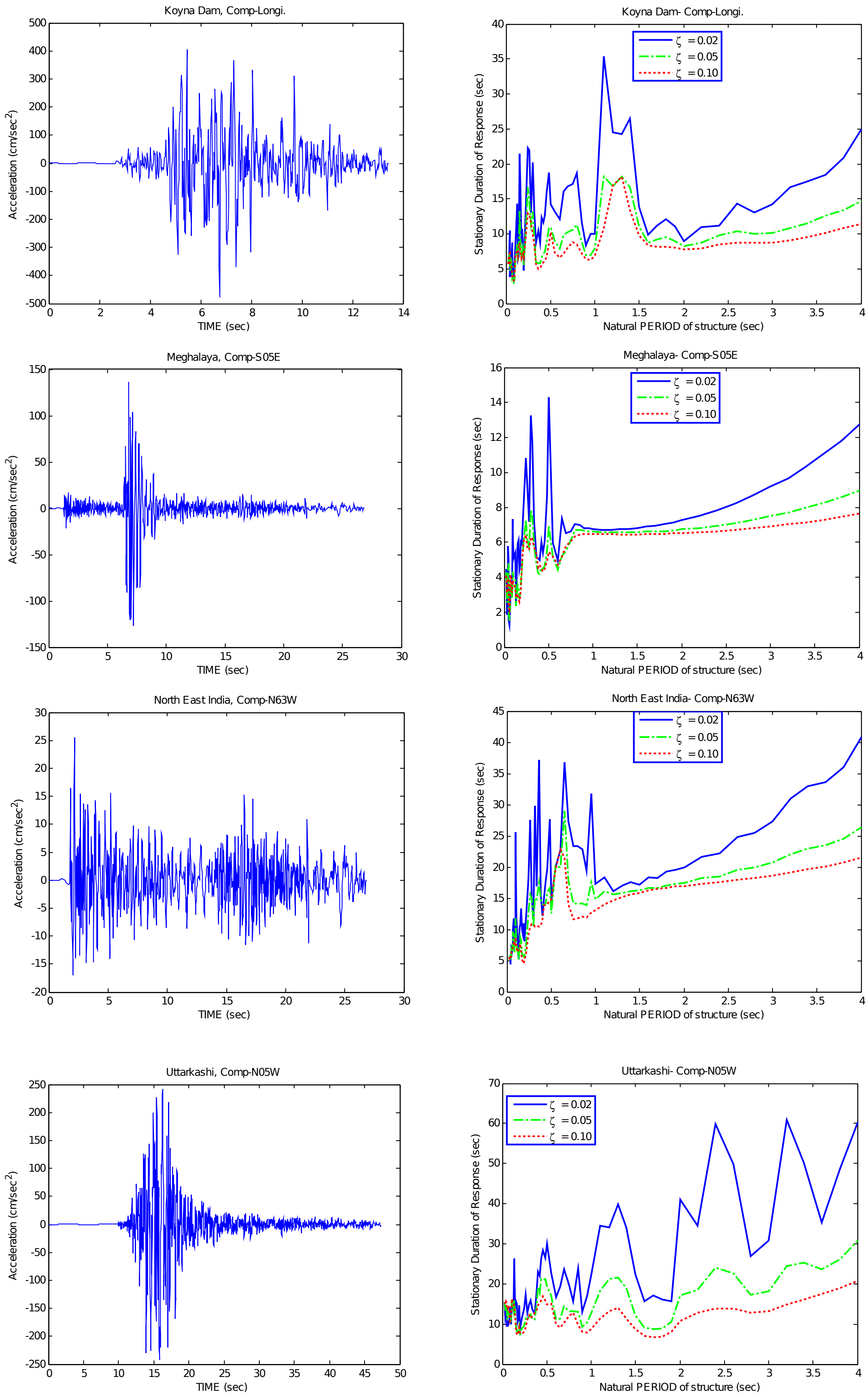

Fig.1: Illustrative example results on strong motion stationary duration of stationary response.

4. CONCLUSIONS

The strong motion duration is most commonly defined for the ground acceleration records. Due to predominance of high frequency content in the ground acceleration, such duration is not appropriate for low and intermediate frequency structures. To consider the frequency dependent nature of duration, some studies define the durations for the accelerogram filtered through several narrow frequency bands. However, this method is also unable to account for the effect of structural damping on the duration. The proposed definition of duration is able to consider the effects of both the structural frequency and damping ratio. It is found that the effective strong motion duration felt by a structure may be quite different from the apparent strong motion duration of ground motion. Hence the stationary duration of response can be considered more appropriate for structural response analysis applications. This duration, along with the ground motion intensity, can provide a useful measure of the damaging potential of an earthquake.

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