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# Higher-mode response of tall buildings to near-fault ground-motion pulses

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## Introduction:

Strong ground motions in the vicinity of an earthquake fault often contain strong velocity pulses. Such pulses , dominant in the forward direction, are capable of causing extensive damage to engineering structures due to concentration of seismic energy in one or a few cycles of intense ground motion. To capture the impulsive nature of such ground motions, researchers have used simple mathematical pulses (see, for example, [1] for a review of different pulse models). Several studies have shown that such equivalent pulses can adequately represent the peak response of single degree of freedom (SDOF) oscillators having undamped natural period greater than about 0.7 times the pulse period. Based on this, it is implied in the literature that simple pulse models can characterize the peak response of multi degree of freedom (MDOF) oscillators if their fundamental period is relatively larger than the pulse period. Whereas this might be a reasonable assumption for short structures responding primarily in the first mode of vibration, its validity for tall buildings with significant higher modes of vibration is questionable due to the fact that simple pulses are unable to model the characteristics of ground motion at high frequencies. Therefore it is important to study whether or not higher modes of vibration are important in the response of tall buildings to near-fault ground motions, and how they affect the ability of simple pulses to capture the peak response of such buildings. This paper makes an attempt to shed some light into these issues by using generic frame models and a large dataset of recorded near-fault ground motions (see [1,2] for a more detailed description).

## Methodology:

Maximum interstory drift demands ($IDR_{max}$) are computed for 9-, 12-, 15-, and 18-story steel moment resisting frames (SMRFs) subjected to recorded ground motions and the equivalent pulse model of Mavroeidis and Papageorgiou [3]. The contribution of mode *i* to *IDR* is denoted by $\delta_{i,j}$. The results obtained for a 12-story SMRF subjected to the strike-normal component of the PTS record of the 1987 Superstition Hills, USA, earthquake is shown in Figure 1.

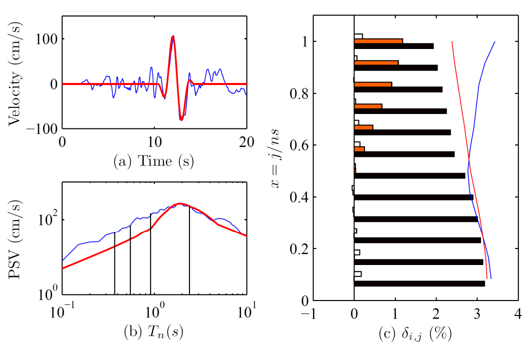


***Figure 1- (a) Ground velocity (blue) and equivalent pulse (red)***

***(b) Elastic pseudo-spectral velocity of a 5% damped SDOF, the vertical lines from right to left indicate the periods of the first four modes of vibration of the 12-story SMRF (c) Interstory drift ratios (expressed as a percentage of height) along the normalized height of the 12-story SMRF, the blue and the red lines correspond to the results obtained by using the actual ground motion and the equivalent pulse, respectively. The black, red, and white bars indicate the contribution of the first three modes of vibration when the actual record is used in the analysis. The pulse accurately represents the first mode of vibration, but underestimates the higher modes (see b) which results in under-estimation of drift demands at the upper stories. This example illustrates that matching the elastic response spectrum at periods close to and greater than the fundamental period of the frame is not sufficient to model the overall behaviour of the frame.***

## *IDR* at the roof:

If $IDR^{r,k}$ and $IDR^{p,k}$ are the maximum interstory drifts at the roof corresponding to a ground motion record *k* and its equivalent pulse respectively, the ability of the equivalent pulse to represent the ground motion *k* is evaluated by computing an error term $E_k$, defined as the ratio of the two. An average measure of this error is computed by using all the ground motion records that satisfy the condition that the fundamental period of the frame being analyzed is greater than or equal to 0.7 times the period of the predominant pulse contained in the ground velocity. This resulted in use of 35, 43, 50, and 56 records for the 9-, 12-, 15-, and 18-story SMRFs, respectively. The results are shown in Figure 2.

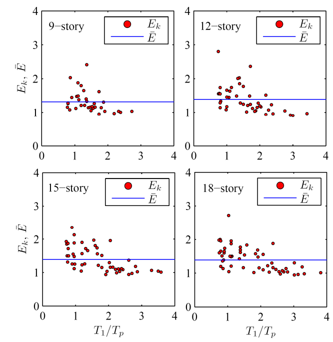


***Figure 2- Errors in predicting the peak interstory drift at the roof of 9-, 12-, 15-, and 18-story frames when using an equivalent pulse as a substitute for an actual ground motion. The errors are plotted as a function of the fundamental period of the frames normalized by the pulse period. The red circles denote the errors for individual ground motion records and the blue lines indicate the mean error of all records. The average error is about 1.4, which means that the pulses underestimate the IDR at the roof by a fraction of 1.4 compared to actual ground motions.***

## Heightwise distribution of *IDR*:

Maximum interstory drifts computed at each story of the SMRFs is divided into three groups A ($T_1$ is within 0.7$T_p$ to 1.3$T_p$), B($T_1$ is within 1.3$T_p$ to 2$T_p$), and C($T_1$ is greater than 2$T_p$) depending on the relative value of the fundamental period of the frame and the pulse period. For each group, the mean values of maximum interstory drifts are computed using actual ground motion and equivalent pulses. The results are shown in Figure 3.

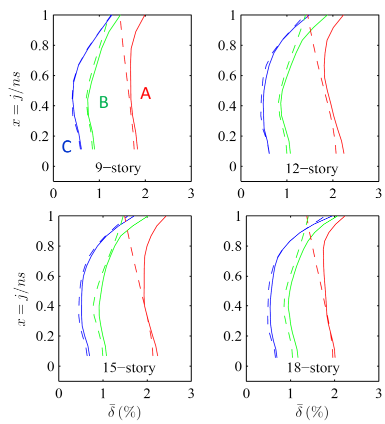


***Figure 3- Mean interstory drifts of the SMRFs along their height. The solid and dashed lines of different colours correspond to the results obtained by using actual ground motions and the corresponding pulses, respectively. The interstory drift is the largest for group A, where T1 is within 0.7Tp to 1.3Tp. In this group, the pulse performance is the worst. As the fundamental period of SMRFs is increased relative to pulse period, maximum drifts decrease, and the results obtained by using actual ground motions and their equivalents pulse get smaller too. These differences are the smallest for group C where the fundamental period of the frame is greater than two times the pulse period.***

## Conclusions:

- Higher mode response are important at upper stories and they become more important for taller structures.
- Maximum interstory drifts are the largest when then fundamental period of the structure is close to the pulse period. In such cases simple pulse models might significantly underestimate peak structural response.
- On average, simple pulse models are found to underestimate peak interstory drifts at the roof by a factor of 1.4 compared to actual near-fault ground motions.

## Selected References:

[1] Rupakhety R (2010) Contemporary issues in earthquake engineering. PhD thesis, faculty of Civil and Environmental Engineering, University of Iceland, Reykjavik.

[2] Rupakhety R and Sigbjörnsson R (2010) Can simple pulses adequately represent near-fault ground motions? Journal of Earthquake Engineering (under review)

[3] Mavroeidis G P and Papageorgiou A S (2003) A mathematical representation of near-fault ground motions. Bulletin of the Seismological Society of America, 93(3):1099-1131