Vulnerability Assessment of RC Frames Based on Alternative Intensity Measures Considering the Characteristic of Pulse-like Ground Motions

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Abstract

Pulse-like ground motions are a special class of ground motions that are particularly challenging to characterize for earthquake hazard assessment. These motions are characterized by a "pulse" in the velocity time history of the motion, and they are typically very intense and have been observed to cause severe damage to structures in past earthquakes. So it is particularly important to characterize these ground motions. Previous studies show that the severe response of structure is not entirely accounted for by measuring the intensity of the ground motion using spectral acceleration of the elastic first-mode period of a structure ($Sa(T_1)$). This paper will use several alternative intensity measures to characterize the effect of pulse-like ground motions in vulnerability assessment. The ability of these intensity measures to characterize pulse-like ground motions will be evaluated.

Pulse-like ground motions and ordinary ground motions are selected as input to carry out incremental dynamic analysis. Structural response and vulnerability are estimated by using $Sa(T_1)$ as the intensity measure. The impact of pulse period on structural response is studied through residual analysis. By comparing the difference between the structural response and vulnerability curves using pulse-like ground motions and ordinary ground motions as the input, the impact of velocity pulse on vulnerability is investigated and the shortcoming of using $Sa(T_1)$ to characterize pulse-like ground motion is analyzed. Then, vector-valued ground motion intensity measures($Sa(T_1)\&R_{T1,T2}$, $Sa(T_1)\&R_{PGV,Sa}$) and inelastic displacement spectra($Sdi(T_1)$) are used to characterize the damage potential of pulse-like ground motions, the efficiency and sufficiency of these intensity measures are evaluated. The study shows that: the damage potential of near fault ground motions with velocity pulse is closely related to the pulse period of strong motion as well as first mode period of vibration and nonlinear features of the structure. The above factors should be taken into account when choosing a reasonable ground motion parameter to characterize the damage potential of pulse-like ground motions. Vulnerability curves based on $Sa(T_1)$ show obvious differences between using near fault ground motions and ordinary ground motions, as well as pulse-like ground motions with different pulse periods as the input. When using vector-valued intensity measures such as $Sa(T_1)\&R_{T1,T2}$, $Sa(T_1)\&R_{PGV,Sa}$ and inelastic displacement spectra, the results of vulnerability analysis are roughly the same. These ground motion intensity measures are more efficient and sufficient to characterize the damage potential of near fault ground motions with velocity pulse.

Keywords: vulnerability, pulse-like ground motions, intensity measures, inelastic displacement spectra

1. Introduction

The serious damage of engineering structures in the near fault zone of 1994 Northridge earthquake, 1995 Kobe earthquake and 1999 Chi-Chi earthquake has aroused strong concern of scientists and engineers in earthquake engineering. Strong ground motion data and earthquake damage experience shows that near fault pulse-like ground motion is one of the main reasons causing the failure of engineering structures [1-5]. These motions, which are characterized by a pulse in the velocity time history, are a special class of ground motions that are particularly challenging to characterize for seismic vulnerability assessment.

It is important to understand the effects of near fault pulse-like ground motions on structures, because they have been observed with great damage potential. These ground motions usually have larger PGV values and have on average larger elastic spectral acceleration values at moderate to long periods than ordinary ground motions[6]. Additionally, the great damage potential of these motions to nonlinear multi-degree-of-freedom structures can't be entirely accounted for by using spectral acceleration of the elastic first-mode period of a structure, Sa(T1) as the intensity measure of the ground motion[7,8].Several alternative intensity measures that are better able to characterize the effect of pulse-like ground motions were sued in this paper for response prediction and vulnerability assessment.

2. Structure model and ground motions

A regular eleven-story RC frame structure designed according to the Chinese Seismic Design Code (GB50011-2001) was used for the case study. Geometrical characteristics of the structure are shown in Fig.1. Section dimensions of structural members and materials are list in Table 1. A modified version of the DRAIN-2DX [9] program was used to establish the finite element model and perform the nonlinear dynamic response history analysis. The structural components were modeled by elastic-plastic beam-column element. A 2% strain-hardening ratio was considered to model the cyclic behavior of the structural components. P-Δ effect was considered by adding a geometric stiffness matrix to the stiffness matrix of each element. Different yield surfaces were specified to beam members and column members to distinguish the different mechanic behaviors. The fundamental period of vibration of the structure is 1.6s.

A set of 70 near-fault pulse-like ground motions collected by Tothong and Cornell [10] was utilized in this study. This set is an aggregation of records identified in three previous papers [11-13]. All ground motions were recorded on firm soil or rock sites and at least one of the referenced authors has identified a pulse in the velocity time history. The processed ground motions came from the Next Generation Attenuation project database, and were oriented in the fault-normal direction. A set of 70 'ordinary' ground motions with no velocity pulses was also used for comparison with the pulse-like record set.

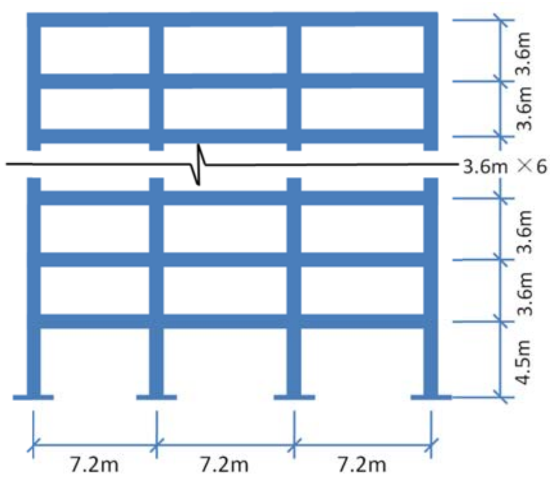


Fig.1 - The 11-story case-study RC frame

Table 1 - Section dimension and material of beams and columns

Srory number	Side column (mm×mm)	Center column (mm×mm)	Beam (mm×mm)	Concrete	Steel bar
1-6	600×600	650×700	300×700	C30	HRB335
7-11	550×550	600×650	300×700	C30	HRB335

3. Shortage of Sa(T1) to characterize pulse-like ground motions

IDA was performed subjecting to pulse-like ground motion as well as ordinary ground motion set. The response parameter considered here is the maximum inter story drift ratio, denoted by θ_{max}, observed in any story. Fig.2 shows the 16th, 50th and 84th IDA curves based on Sa(T_1) as the intensity measure. As seen in the figure, in the sense of statistics, the structural response observed from pulse-like ground motions is larger than that of ordinary ground motions for the same ground motion intensity level characterized by Sa(T_1). Fig.3 shows the vulnerability curves based on Sa(T_1) as the intensity measure by using pulse-like and ordinary ground motions as the input. As shown in the figure, pulse-like ground motions cause larger exceeding probability of every limit state than ordinary ground motions. It follows that Sa(T_1) does not completely account for the larger structural responses observed from pulse-like ground motions.

An important property of pulse-like ground motions is the period of the velocity pulse, denoted by Tp, following Alavi and Krawinkler [8], Tp is measured as the period associated with the maximum of the velocity response spectrum. An important parameter of pulse-like ground motions that affects structural response is the period of the velocity pulse with respect to the modal period of the structure, denoted by Tp/T1[14-19]. Fig.4 and fig.5 respectively shows the 50th IDA curves and vulnerability curves based on Sa(T1) as the intensity measure by using pulse-like ground motions of different Tp/T1 values as the input. As shown in the figures, significant difference can be observed between median IDA curves and vulnerability curves, which means that the effects of the period of the velocity pulse are not well predicted by traditional intensity measure of ground motion intensity such as Sa(T1). If an improved intensity measure can better distinguish between the pulse-like records with different Tp/T1 values, then the problems of Sa(T1) might be addressed and IM-based structural vulnerability assessments would be feasible even when pulse-like ground motions are considered.

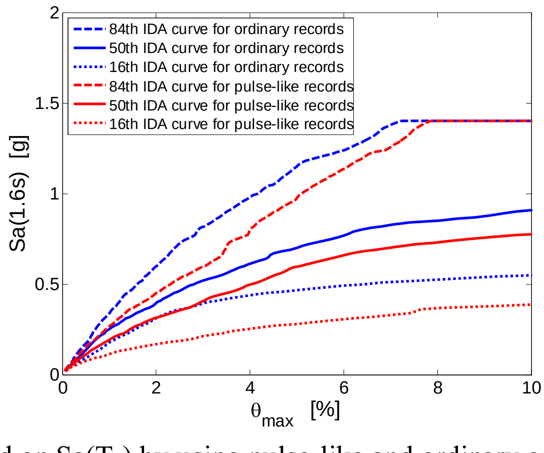


Fig.2 - IDA curves based on Sa(T_1) by using pulse-like and ordinary ground motions as the input

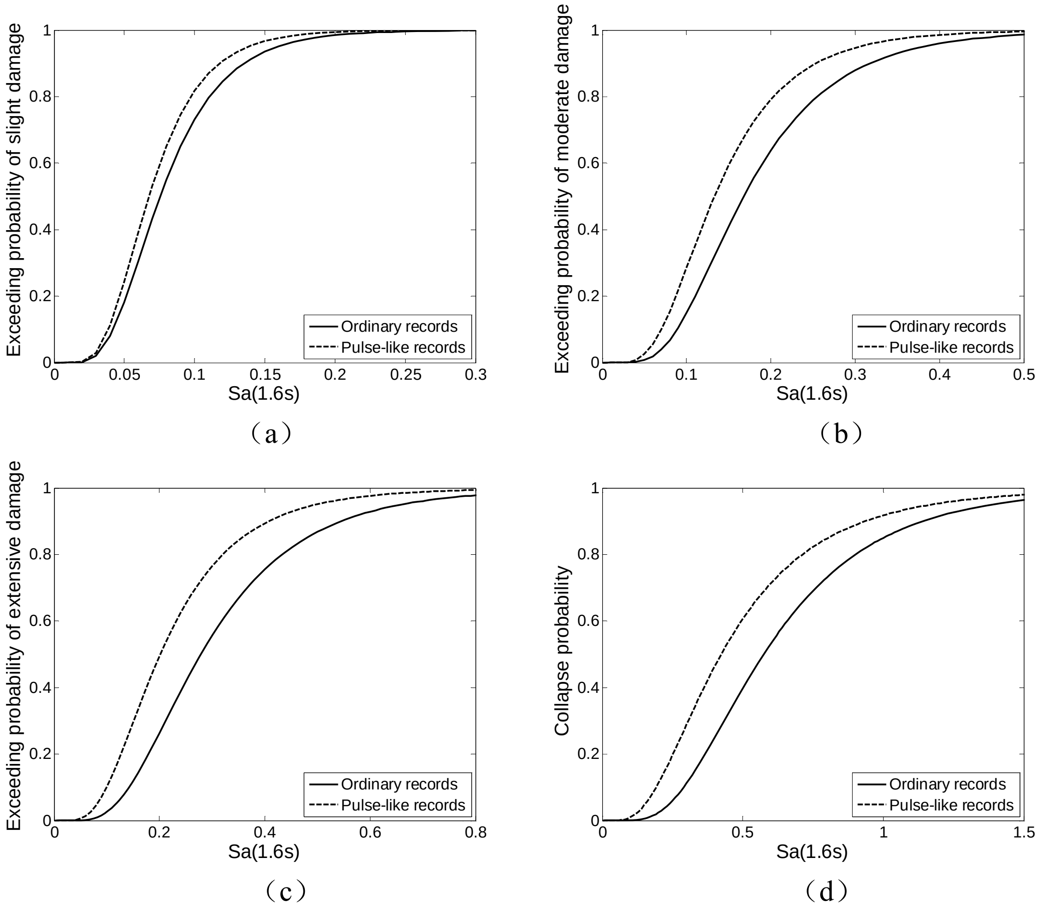


Fig.3 - Vulnerability curves based on $Sa(T_1)$ by using pulse-like and ordinary ground motions as the input

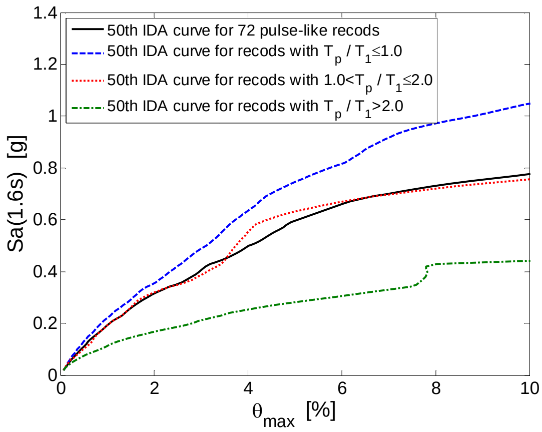


Fig.4 - Median IDA curves based on $Sa(T_1)$ by using pulse-like ground motions of different T_p/T_1 values as the input

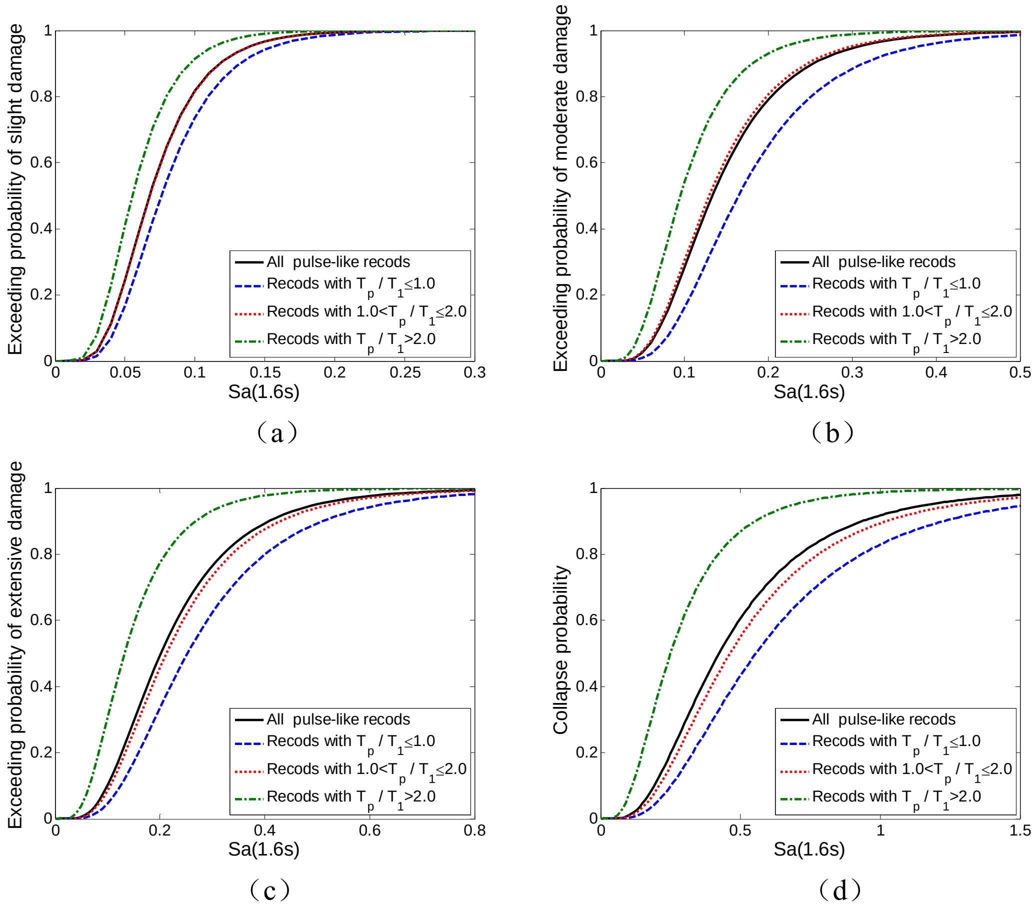


Fig.5 - Vulnerability curves based on $Sa(T_1)$ by using pulse-like ground motions of different T_p/T_1 values as the input

4. Alternative intensity measures for pulse-like ground motions

Several alternative intensity measures were considered to characterize the effect of pulse-like ground motions in vulnerability assessment. The first one is a vector intensity measure based on spectra acceleration values at two periods, denoted by $Sa(T_1)\&R_{T1,T2}$, $R_{T1,T2}= Sa(T_2) /Sa(T_1)$, where T_1 is constrained to equal the first-mode period of the structure and T_2 is chosen to capture important characteristics of the spectrum's shape, here $T_2=2T_1$. The second one is also a vector intensity measure based on spectra acceleration values and peak ground velocity PGV, denoted by $Sa(T_1)\& R_{PGV,Sa}$, $R_{PGV,Sa}=PGV/Sa(T_1)$. The third one is inelastic spectra displacement, denoted by $Sdi(T_1)$. Incremental dynamic analysis and vulnerability assessment were performed by using these three alternative intensity measures. Fig.6 shows vulnerability curves based on $Sa(T_1)$ and $R_{T1,T2}$ by using pulse-like ground motions of different T_p/T_1 values as the input , where $R_{T1,T2}=0.45$ for example. Fig.7 shows vulnerability curves based on $Sa(T_1)$ and $R_{PGV,Sa}$ by using pulse-like ground motions of different T_p/T_1 values as the input , where $R_{PGV,Sa}$ =0.2 for example. Fig.8 shows vulnerability curves based on $Sdi(T_1)$ by using pulse-like ground motions of different T_p/T_1 values as the input. As shown in these figures, the differences between vulnerability curves by using pulse-like ground motions of different T_p/T_1 values as the input are significantly decreased, comparing with intensity measure $Sa(T_1)$. These ground motion intensity measures are more effective to characterize the damage potential of near fault ground motions with velocity pulse.

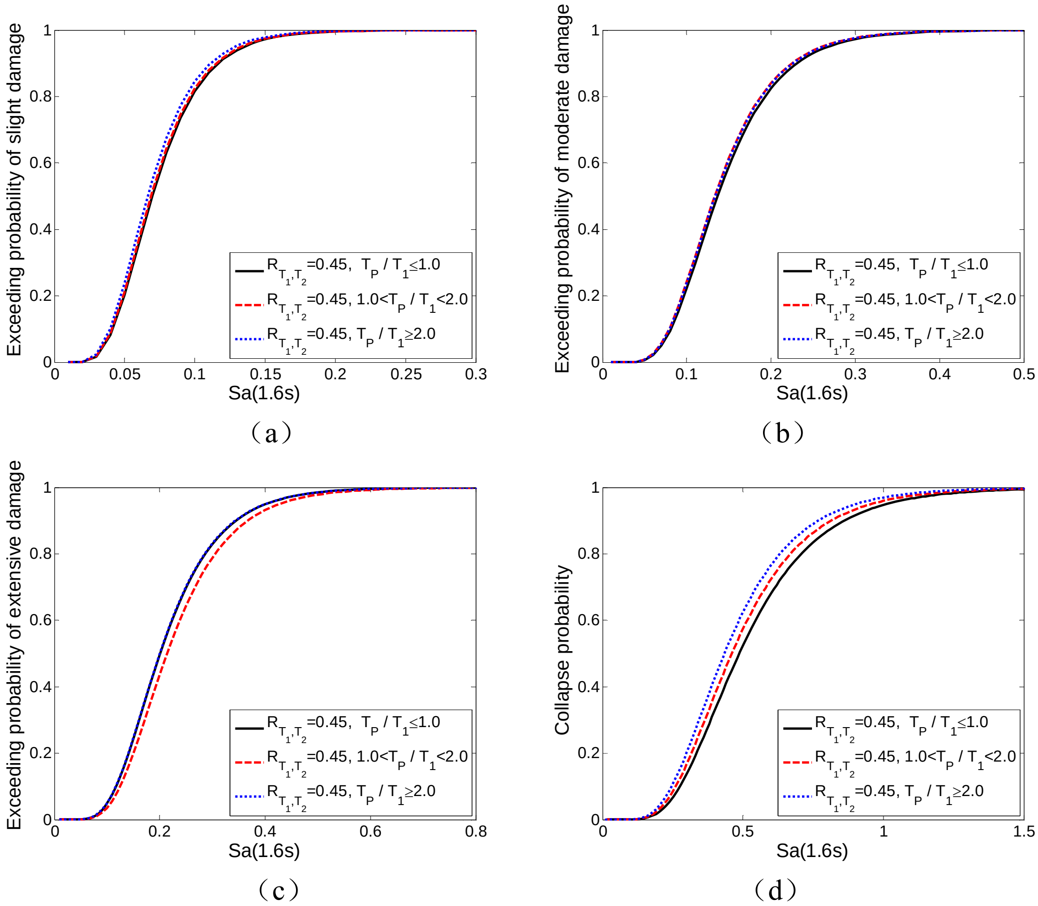
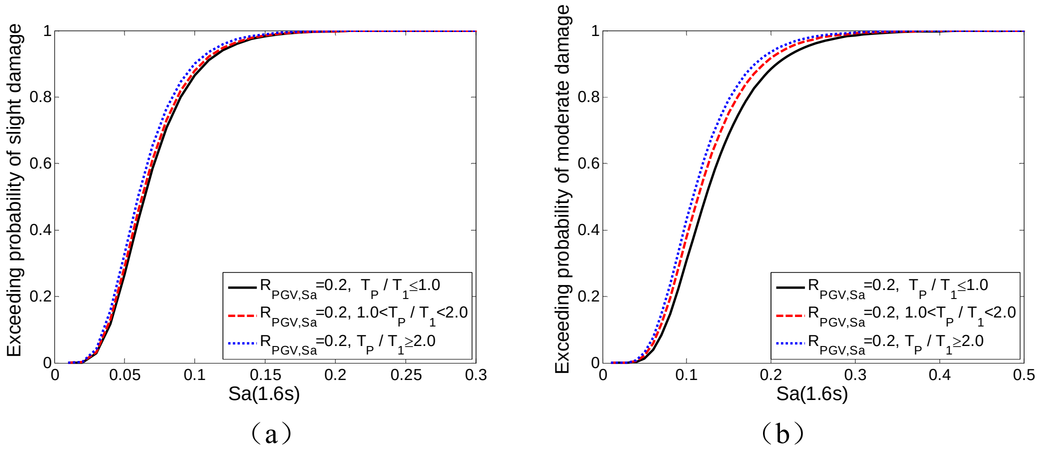
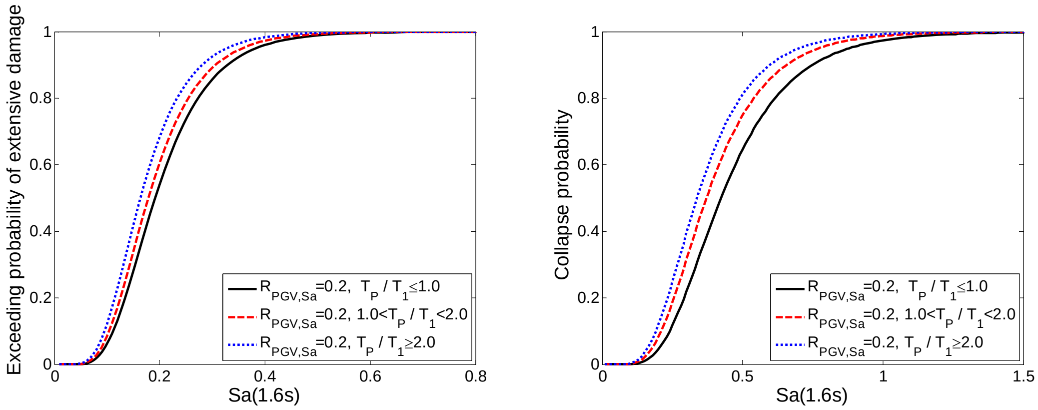


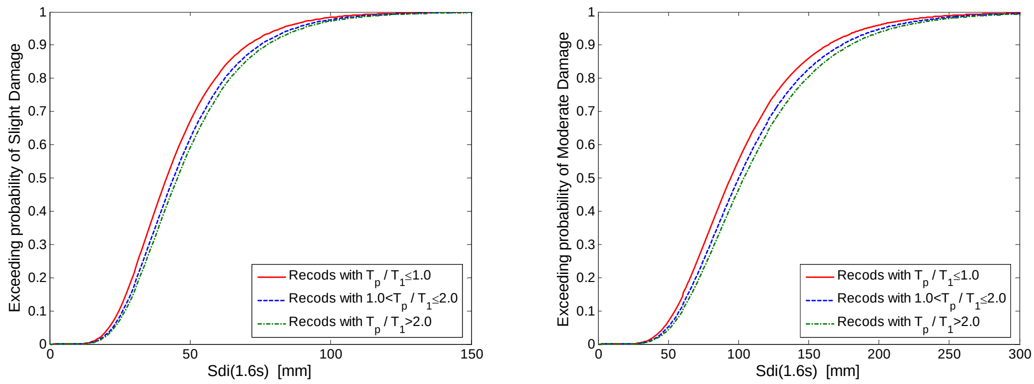
Fig.6 - Vulnerability curves based on Sa(T_1) and R_{T_1,T_2} by using pulse-like ground motions of different T_p/T_1 values as the input (here $R_{T_1,T_2}=0.45$)



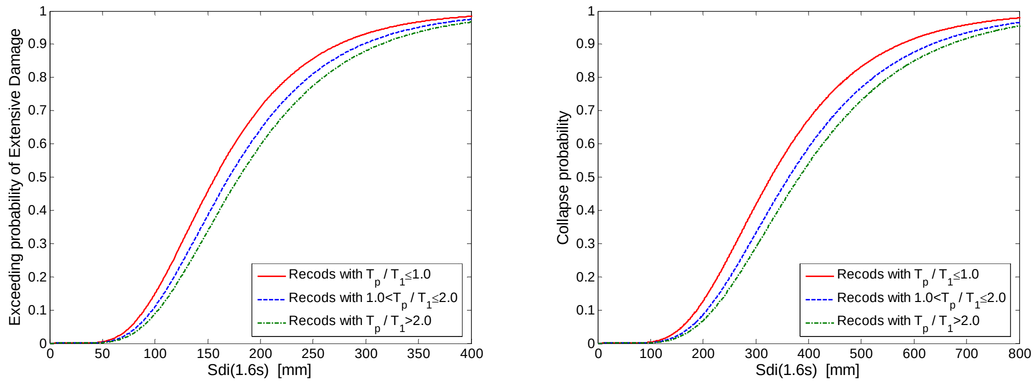


（c） （d）

Fig.7 - Vulnerability curves based on $Sa(T_1)$ and R_{PGV,S_a} by using pulse-like ground motions of different T_p/T_1 values as the input (here $R_{PGV,S_a}=0.2$)



(a) (b)



(c) (d)

Fig.8 - Vulnerability curves based on $S_{di}(T_1)$ by using pulse-like ground motions of different T_p/T_1 values as the input

5. Conclusions

Near-fault pulse-like ground motions are of particular concern to engineers because of their potential to cause large structural response. But, their effects are not well characterized by traditional ground motion intensity measure such as elastic spectral acceleration $Sa(T_1)$. Several alternative intensity measures has been considered to characterize the effect of pulse-like ground motions. The results show that IDA curves and vulnerability curves based on $Sa(T_1)$ show obvious differences between using near fault ground motions and ordinary ground motions, as well as pulse-like ground motions with different pulse periods as the input. When using vector-valued intensity measures such as $Sa(T_1)\&R_{T1,T2}$ and $Sa(T_1)\&R_{PGV,Sa}$, and inelastic displacement spectra $S_{di}(T_1)$, the results of vulnerability analysis are roughly the same. These alternative ground motion intensity measures are more effective to characterize the effects of near-fault pulse-like ground motions. These suggest that when using the alternative ground motion intensity measures, it is less important to carefully identify representative pulse-like records as, and it is less important that the ground motions used in dynamic analysis be exactly representative of some expected earthquake event.

6. Acknowledgements

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