Development of vulnerability surface of high-rise RC frame by means of IDA

Chao Xu[1] (xuchao@cea-igp.ac.cn), Zengping Wen[1], Junju Xie[1]
1. Institute of Geophysics, China Earthquake Administration(CEA), Beijing 10081, China

Introduction

The damage potential of strong motion is commonly presented by an intensity measure (IM). For high-rise buildings, scalar-valued IMs are usually hard to characterize the damage effect of strong motion to the structures. In this study, different alternative vector-valued IMs comprised of two ground motion parameters were used to present the ground motion potential to an elven story RC frame. The efficiency of these vector-valued IMs was studied and vector-valued IM based vulnerability surfaces were developed.

Vector-valued intensity measures

Four vector-valued IMs were considered to evaluate the seismic vulnerability of the structure. For all the vector-valued IMs, spectral acceleration at fundamental period of the structure was selected as the first parameter (denoted as IM_1). The second parameters (denoted as IM_2) were defined as:

$$R_{PGV,S_a}=PGV/S_a(T_1) \quad , \quad R_{T_1,T_2}=S_a(T_2)/S_a(T_1) \quad , \quad \varepsilon(T_1)=[\ln S_a(T_1)_{record}-\mu_{\ln S_a(T_1)}]/\sigma_{\ln S_a(T_1)}$$

$$Np=S_{a,avg}(T_M,\ldots T_N)/S_a(T_1) \quad \text{where} \quad S_{a,avg}(T_M,\ldots T_N)=\left(\prod_{i=M}^{N}S_a(T_i)\right)^{1/(N-M+1)}$$

It is recalled that the normalization of IM_2 with respect to IM_1, lets IM_2 be independent with respect to the scaling level of IM_1. $\varepsilon(T_1)$ is defined as a measure of the difference between the spectral acceleration of a record and the mean of a ground motion prediction equation at the given period T_1. R_{T_1,T_2} , Np and $\varepsilon(T_1)$ carry information about the spectral shape, which may be expected to account for the effect of higher mode response and structural softening.

Structural model and ground motion records

A regular eleven-story RC frame structure designed according to the Chinese Seismic Design Code (GB50011-2001) was selected for the case study. A modified version of the DRAIN-2DX program was used to perform the nonlinear dynamic time history analysis. The fundamental period of vibration of the structural model is T_1=1.6s. The capacity of the structure in terms of inter-story drift ratio is list in Tab.2. Forty ground motion records taken from the PEER Strong Motion Database are selected to perform the vulnerability assessment.

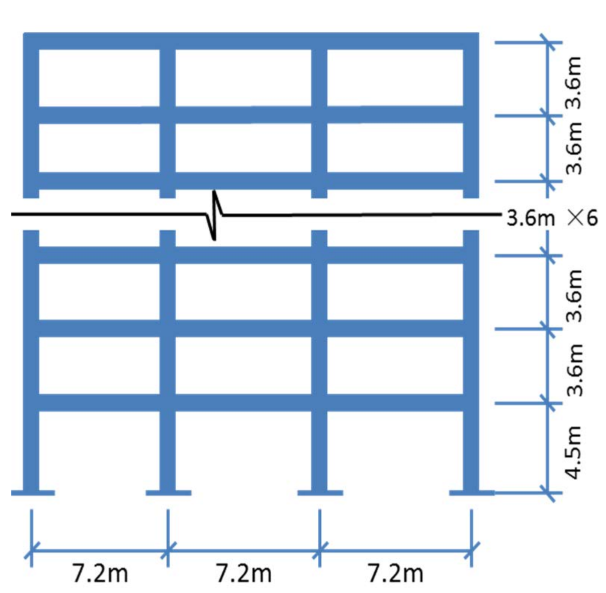


Fig.1 Dimension of the RC frame

Tab.1 Section dimensions and materials of structural members

Story Number	Side Column (mm×mm)	Middle Column (mm×mm)	Beam (mm×mm)	Concrete	Steel Bar
1-6 story	600×600	650×700	300×700	C30	HB335
7-11story	550×550	600×650	300×700	C30	HB335

Tab.2 Capacity in terms of inter-story drift ratio

Damage States	Slight Damage	Moderate Damage	Extensive Damage	Collapse
Mean Value	0.286%	0.654%	1.25%	3.6%
Coefficient of Variation	0.38	0.38	0.38	0.38

Method for developing vulnerability surface

The structural probabilistic seismic demand was estimated by means of IDA, as shown in Fig.2. Then the vector-valued vulnerability can be computed as:

$$F_{DS/IM_1,IM_2}(IM_1=x_1,IM_2=x_2)=\Phi\left(\frac{\ln x_1-\mu_{\ln IM_{1,cap}/EDP=\exp(\mu_{\ln EDP_C/DS}),IM_2=x_2}}{\sqrt{\beta^2_{IM_{1,cap}/EDP=\exp(\mu_{\ln EDP_C/DS}),IM_2=x_2}+\beta^2_{EDP_C/DS}}}\right)$$

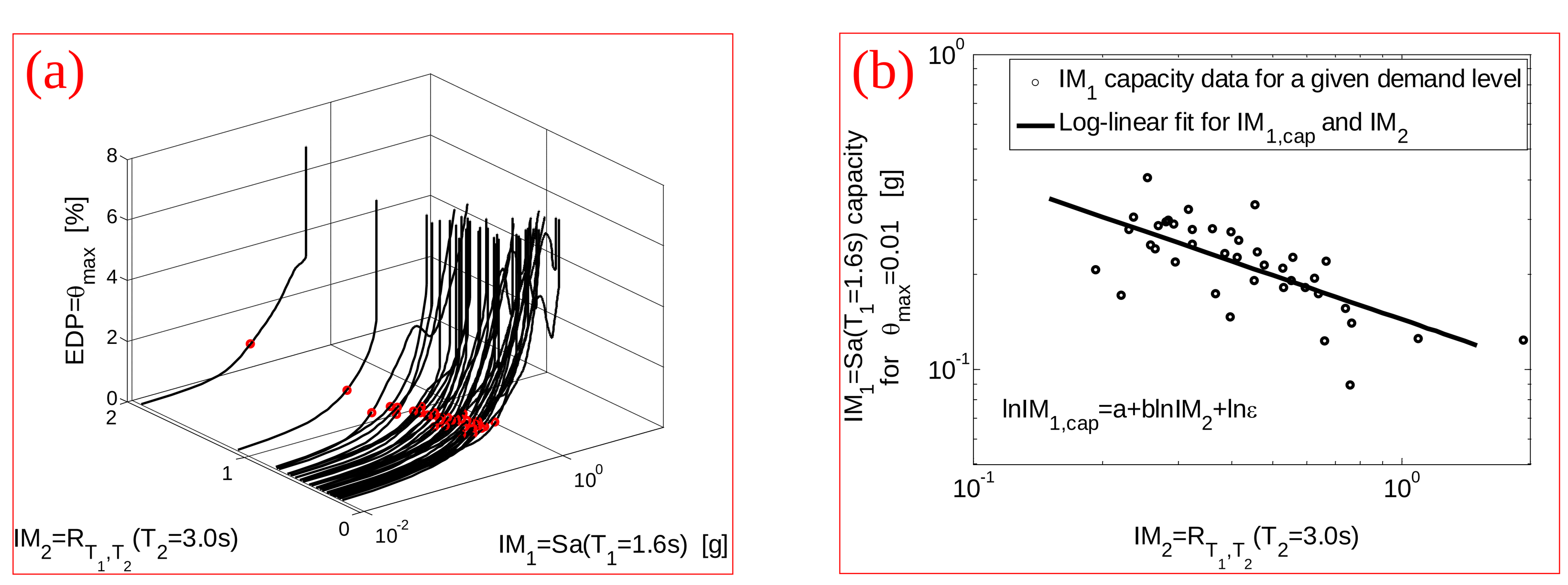


Fig.2 Estimation of structural response by means of vector-valued IM via IDA: (a) IDA curves plotted with a vector-valued IM and IM capacity points for a given demand level; (b) IM_1, IM_2 pairs corresponding to occurrence of the given demand and the log-linear regression model

Efficiency of the vector-valued IMs

Fig.3 shows that $S_a(T_1)$ capacity (denoted by $S_a(T_1)_{cap}$) tends to be larger for smaller $R_{T_1,T_2}(T_2$=3.0s), which means that the structural response tends to be larger for larger $R_{T_1,T_2}(T_2$=3.0s) when records are scaled to a specific $S_a(T_1)$ level. That is, $R_{T_1,T_2}(T_2$=3.0s) explains part of the variation of structural response.

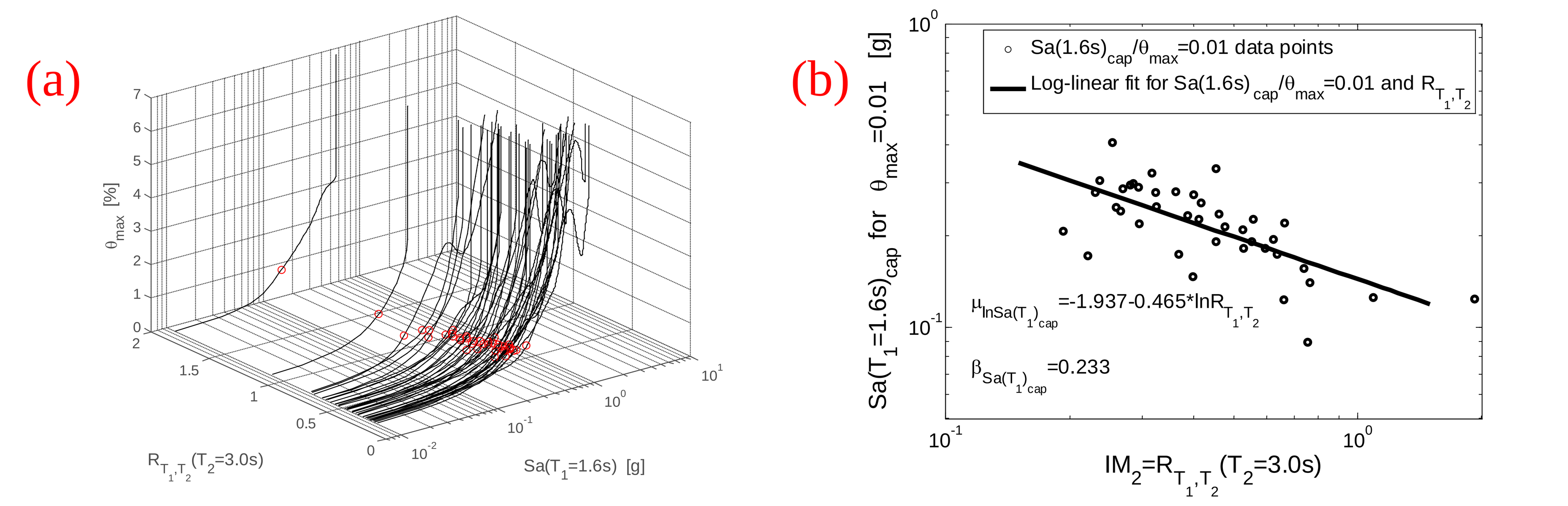


Fig.3 (a) IDA curves based on $S_a(T_1)$ and $R_{T_1,T_2}(T_2$=3.0s); (b) $S_a(T_1)$ and $R_{T_1,T_2}(T_2$=3.0s) pairs as well as the log-linear regression corresponding to a demand level of 1% maximum inter-story drift ratio

T_2 is selected over arrange of possible values for R_{T_1,T_2} to maximum efficiency, as shown in Fig.4. We see that the optimal T_2 value is 2.4s, which can result in a minimum dispersion.

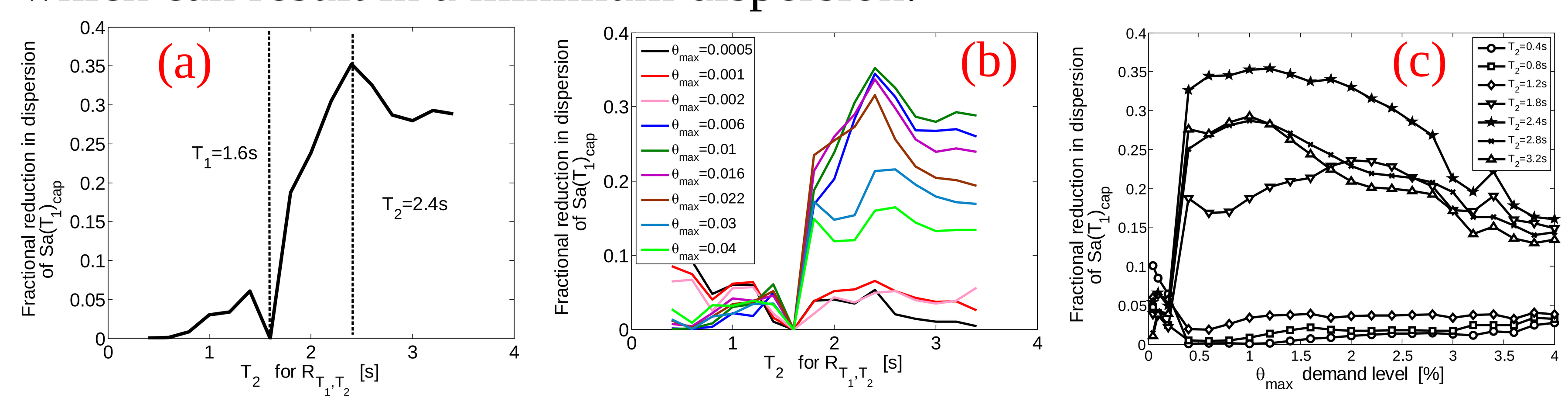
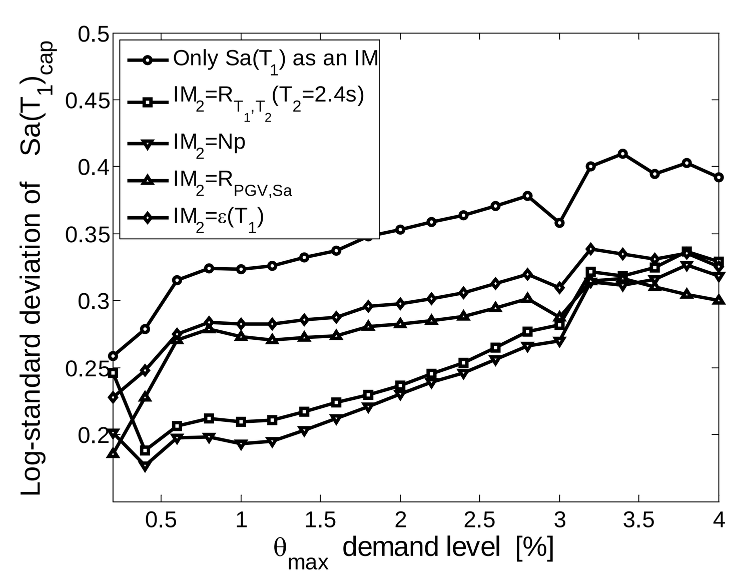


Fig.4 Fractional reduction in dispersion of $S_a(T_1)_{cap}$ by R_{T_1,T_2} for T_2 between 0.3s and 3.4s: (a)drift demand level of 1%; (b),(c) different drift demand levels between 0.05% and 4%



As shown in Fig.5, vector-valued IMs are more efficient than scalar IM such as $S_a(T_1)$. Np is the most appropriate alternative IM_2 for vulnerability analysis.

Fig.5 Dispersion of $S_a(T_1)_{cap}$ corresponding to different drift demand levels between 0.05% and 4% by using different IMs

Vulnerability surfaces based on vector-valued IM

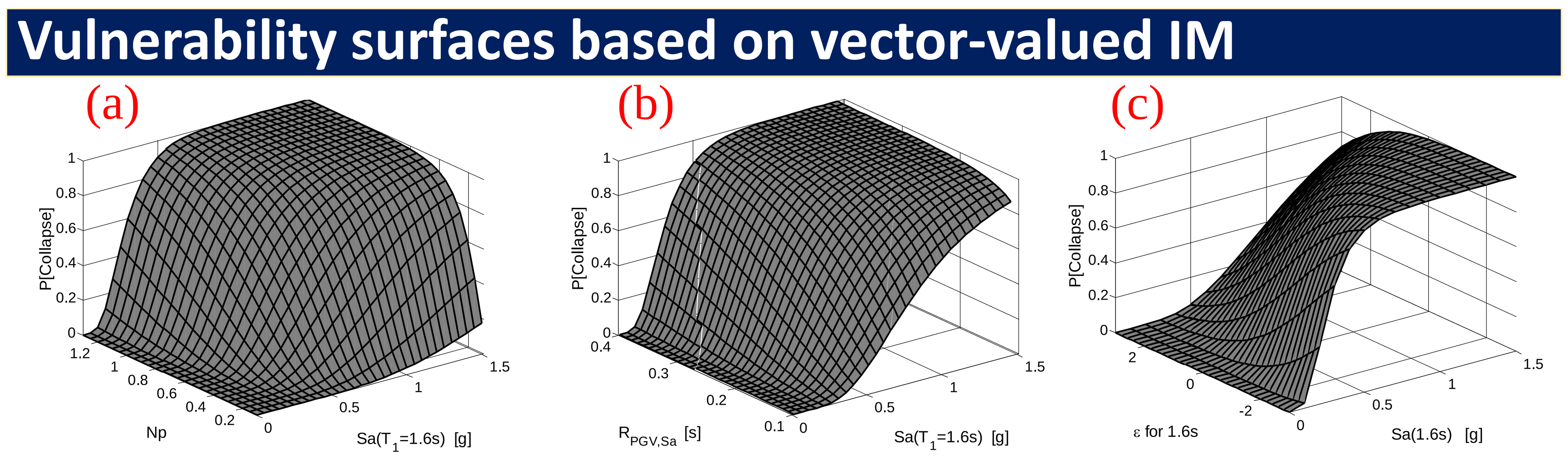


Fig.6 Vulnerability surfaces characterized by two ground motion parameters: (a) $S_a(T_1)$ and Np; (b) $S_a(T_1)$ and $R_{PGV/Sa}$; (c) $S_a(T_1)$ and $\varepsilon(T_1)$.

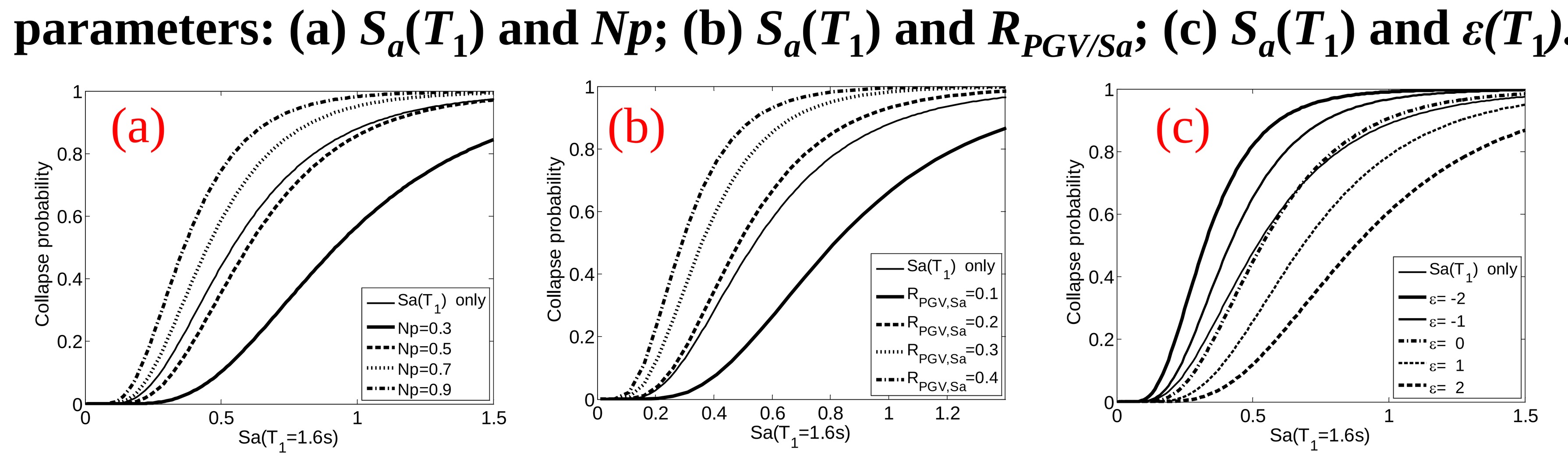


Fig.7 $S_a(T_1)$ based vulnerability curves with different IM2 values: (a) Np; (b) $R_{PGV/Sa}$; (c) $\varepsilon(T_1)$.

Summary

- The dispersion of structural demand can be significantly reduced by using vector-valued IMs, especially for high intensity levels.
- As a result of using more efficient vector-valued IMs in vulnerability analysis, the number of nonlinear dynamic analysis and the limitations of ground motion selection can be greatly reduced.
- Compared to scalar IM based vulnerability curves, vulnerability surfaces characterized by two ground motion parameters are more informative, which can reveal the impact of different ground motion parameters on structural response and damage probability.