INFLUENCE OF NEAR-FAULT VELOCITY PULSES ON SEISMIC RESPONSES OF REINFORCED CONCRETE FRAMES

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ABSTRACT :

Under the condition of the elastic response spectral characteristics being fixed, the engineering properties of near-fault velocity pulse are studied in this paper. Firstly, two sets of ground motion time histories (GMTHs) are constructed, the first set containing the observatory recordings that were recorded during large events and contain distinct velocity pulses, while the second set containing artificial GMTHs that are synthesized numerically to match the target response spectra that are just the spectral accelerations of the GMTHs in the first set. During synthesizing process, by using the narrow-band time history superposition method to control peak velocity, those artificial GMTHs can be constructed not to contain velocity pulses. Secondly, by analyzing the differences between the dynamic responses of reinforced concrete frame excited by these two sets of inputs, the influences of velocity pulse on the seismic responses, especially elastic-plastic seismic responses, of structure are studied with the elastic response spectral characteristics of inputs being consistent. The results show that as to the structural dynamic response parameters, such as the storey shear force, the inter-storey drift, and the maximum storey displacement etc., after the seismic response of structure enters into the elastic-plastic phase, the structural responses increase significantly under the input of ground motion containing velocity pulse, compared with those caused by the input without velocity pulse, despite the fact that the spectral accelerations of the inputs are the same. Therefore, under such circumstance, the response spectrum cannot demonstrate thoroughly the influences of velocity pulse on the structural seismic responses.

KEYWORDS: Ground motion, Near-fault velocity pulse, Reinforced concrete frame, Response spectrum, Artificial ground motion

1. INTRODUCTION

The influence of near-fault ground motion containing velocity pulse on engineering structures has drawn the attentions of more and more researchers. Bertero et al (Bertero, 1976; Bertero et al, 1978) studied this issue in the early time. Thereafter, there are two main methods in the study of the influence of near-fault velocity pulse on structures. The first one investigates the influence of velocity pulse on the simplified single-degree-of-freedom or multiple-degree-of-freedom system (Sasani and Bertero, 2000; Alavi and Krawinkler, 2000; Marvoeidis and Dong, 2004), whereas the second establishes the models of practical structures under the inputs of the natural seismic records or artificial ground motions, and thus studies the influence of velocity pulse on structures by test or numerical analysis method. In the second method, the structural models can be classified into reinforced concrete frame (Ghobarah, 2004; Seneviratna and Krawinkler, 1997; Ayan and Boduroglu, 2004; Alavi and Krawinkler, 2004) and steel frame (Anderson and Bertero, 1987; Hall et al, 1995). In addition, some researchers also studied the influence of velocity pulse on the base isolated structures (Makris and Chang, 2000; Hall and Ryan, 2000; Jangid and Kelly, 2001) and bridge (Li and Zhu, 2004).

In order to definitely disclose the contribution of velocity pulse alone to the engineering properties of near-fault ground motion, the spectral influence should be excluded. Aiming at this target, this paper takes the reinforced concrete frame as example to study the influence of velocity pulse on the structural seismic response under the condition that the response spectra of the inputs to structures are consistent, and its main idea can be summarized as follows. Firstly, collect the natural ground shaking records of strong events that contain distinct velocity pulses from the existing strong motion observatory data bank, and choose five representative velocity-pulse-containing (VPC) records from the above collected set according to the peaks and the durations of velocity pulses. Secondly, taking the response spectra of the representative records as the target spectra and using the method of superimposing narrow-band time history in the time domain to control the peak velocity, the artificial GMTHs that contain no velocity pulse are synthesized (Zhao and Zhang, 2006). Thus two sets of GMTHs that are used as inputs in structural dynamic analysis are formed, i.e. the natural VPC records and the numerically synthesized not-velocity-pulse-containing (NVPC) artificial GMTHs. Their response spectra are same and their main difference rests with containing velocity pulse or not. Thirdly, established are six reinforced concrete frame models with different natural periods which are all fallen into the range of the controlling period used to synthesize the above artificial GMTHs. And finally, scale the two sets of input GMTHs into different levels in order to keep the structures at elastic and elastic-plastic state respectively, and then calculate and compare the dynamic responses of structures under these two sets of inputs to disclose the influence of velocity pulse on structural seismic responses.

2. INPUT GROUND MOTIONS AND STRUCTURAL MODELS

2.1 Natural Seismic Records and Artificial GMTHs

From the existing strong motion observatory data bank, these records containing distinct velocity pulses can be collected, and from this subset five records whose peak ground acceleration (PGA), peak ground velocity (PGV) and pulse duration (T_p) are all representative can be selected according to the peaks and the durations of velocity pulses. Some parameters of these records are shown in Table 1, with their acceleration and velocity time histories shown in Fig.1. The above acceleration records are all downloaded from the website http://peer.berkeley.edu. From the velocity histories can be seen that these records all contain distinct velocity pulses. With the spectral controlling period being taken to 10.0s, the response spectra of the five records can be calculated. And then, as to each record, with its response spectrum as the target, three artificial GMTHs are synthesized by superimposing narrow-band time histories in the time domain to control the velocity peak (Zhao and Zhang, 2006). The main characteristics of thus constructed artificial GMTHs are: (1) their response spectra approach that of the corresponding record; (2) their velocity time histories contain no significant pulses.

Fig.2 shows three samples of artificial GMTHs whose response spectra match that of the record of JFP station, Northridge earthquake, including the acceleration and velocity histories. From the velocity histories, it can be seen that as compared with the natural records in Fig.1, the artificial GMTHs do not contain velocity pulse any more. The matching precision of the first artificial GMTH in Fig.2 to the response spectrum of the JFP, Northridge earthquake record is given in Fig.3, from which can be seen that they are very close. The spectral matching precision of the other artificial GMTHs is similar to that shown in Fig.3.

2.2 Models of Reinforced Concrete Frame

In this paper, six reinforced concrete frame models are used, which are divided into two groups, each containing three models. The first group contains three simulated structures, with the number of stories being 5, 8, and 12, respectively. The site and loading conditions, the plane layouts and heights etc. are determined by reference to a practical structural design documents of an office building, which was designed based on the Chinese Code for Seismic Design of Buildings (GB50011-2001) issued in 2001, with the fortification intensity being Ⅶ, the fundamental design acceleration being 0.15g, design earthquake group being the first one, and the site class being class Ⅱ. The models of the second group come from the already built reinforced concrete frames, with their storey numbers being 5, 8, and 13, respectively. These three structures were all designed according to the

Chinese Code for Seismic Design of Buildings (GBJ11-89) issued in 1989, with the design earthquakes being near-field and site classes being class Ⅱ. The fundamental natural periods of the above six structural models all fall between 0.4s and 1.5s.

3. STUDY ON THE ENGINEERING PROPERTIES OF VELOCITY PULSE

3.1 Influence of Velocity Pulse on the Seismic Responses of Structure

The calculations of structural seismic responses were performed by use of the non-linear response analysis program for plane structures, IDARC, issued by the State University of New York, US (Reinhorn et al, 1996). And the parameters used in this paper to describe seismic response of structure include the storey shear (SS), the inter-storey drift (ISD), the storey displacement (SD), the storey velocity (SV), and the storey acceleration (SA), where the SS refers to the horizontal shear force underwent by the whole storey, the ISD the relative displacement between adjacent floors, and the SD, SV, and SA the displacement, the velocity, and the acceleration of the corresponding floor, respectively. In calculating, the presumption that the stiffness of floor is infinite in its plane is introduced.

In order to keep the structures at their elastic or elastic-plastic states, the peak accelerations of input ground motions need to be scaled to different levels. Here given are only the results corresponding to peak accelerations 49cm/s^2 and 98cm/s^2. When the peak acceleration is scaled to 49cm/s^2, most structures are at the elastic state. However, because the VPC ground motion contains rich long-period components, some individual long-period structures might step into weak elastic-plastic state under the input of VPC ground motion with peak acceleration 49cm/s^2. Whereas, as to peak acceleration 98cm/s^2, all structures are in elastic-plastic state. Here the results corresponding to the record of JFP station, Northridge earthquake, and its corresponding artificial GMTHs will be presented. The results of the other input pairs are similar to them. In addition, the response mechanisms of all structure models are consistent, thus only the results of two models in the first group will be discussed. In all of the charts, the symbol “ori0.05” and “ori0.1” represent the results corresponding to the VPC records scaled by 49cm/s^2 and 98cm/s^2, respectively, and the symbol “0.05g1”, “0.05g2”, “0.05g3”, and “0.1g1”, “0.1g2”, “0.1g3” represent these corresponding to three NVPC artificial GMTHs scaled by 49cm/s^2 and 98cm/^{2}, respectively.

Fig.4 through Fig.8 give the maximum values of the five parameters SS, ISD, SD, SV, and SA during the whole process of structural seismic response. From Fig.4 to Fig.6, it can be seen that the variations of SS, ISD, and SD demonstrate the following distinct characteristics:

(1) The maximum values of SS and ISD generally occur in the bottom stories, and decrease with the increase of storey number. While the SD increases from the bottom to top of structure, with the maximum value occurring at the top storey.

(2) When the peak acceleration is scaled to 49cm/s^2, the structures are in their elastic states. Under such circumstance, the structural responses under the input of VPC natural ground motion and these under the input of NVPC artificial ground motions do not differ significantly, which demonstrates the fact that when the response spectra of inputs are same, the velocity pulse does not impose distinct influence on the elastic seismic responses of structures.

(3) When the peak acceleration is scaled to 98cm/s^2, the structures are in their elastic-plastic states. Under such circumstance, as compared with the NVPC artificial ground motions, the maximum values of these three response parameters under the input of the VPC natural ground motion increase significantly. And such increase effect presents itself more distinct with respect to the parameters of ISD and SD.

The above mechanisms can be observed in all the six models. From Fig.7 it can be seen that from the bottom to the top storey of structure, the SV also has the increase tendency, and the elastic-plastic maximum SV induced by the VPC ground motion is a little higher that these by the NVPC ground motions, but such difference is not distinct compared with the above three parameters. Different from Fig.4 through Fig.7, the maximum SA in Fig.8 varies complicatedly between different stories, and the fact that the input ground motion contains velocity pulse or not does not have clear influence on this response parameter.

Therefore, the three parameters of SS, ISD, and SD can reflect better the influence of velocity pulse on the elastic-plastic seismic responses of structures and can thus serve as the reference parameters that are resorted to in the study of the influence of velocity pulse on the dynamic responses of structures. From Fig.4 through Fig.6, it can be concluded that the parameter of response spectrum can reflect faithfully the influence of ground motion on the elastic dynamic responses of structure, however, it cannot reveal comprehensively the influence of VPC ground motion on the elastic-plastic dynamic responses of structure.

3.2 Analysis of the Increase Effects of Velocity Pulse

To clearly discover the increase effects of velocity pulse on the elastic-plastic seismic responses of structure, the structural maximum SS, ISD, and SD are used as reference parameters whose values corresponding to the input of VPC ground motions and of NVPC ground motions are calculated respectively, where the values to the artificial ground motions is the mean of three samples. And then their ratio can be obtained to quantify the increase effect of velocity pulse. The above data are shown in Table 2 through Table 4. In calculating, the peak acceleration of input ground motion is scaled to 98cm/s^2.

The quantifying values in Table 2 through Table 4 demonstrate the same disciplines as Fig.4 through Fig.6, which shows that if the input response spectrum were fixed, the ground motion containing velocity pulse would induce much higher elastic-plastic deformation of structure than these not containing velocity pulse. For example, in Table 3, the ratio of maximum ISD between VPC and NVPC ground motion varies between 1.003 and 2.713, with the mean 1.448. Therefore, in the seismic design of near-fault structures, in addition to response spectrum, some effective measures should be taken to consider the influence of near-fault velocity pulse.

4. CONCLUSIONS

By comparing the elastic and elastic-plastic seismic responses of reinforced concrete frames under the inputs of VPC and NVPC ground motions whose response spectra are same, this paper reveals the influence of near-fault velocity pulse on the seismic responses of structure under the condition of consistent response spectrum. It can be concluded that if the input response spectra are same, the structural elastic seismic responses induced by these two kinds of ground motions do not differ distinctly, whereas, as compared with the NVPC ground motion, the VPC one can invoke higher elastic-plastic deformations of structure even if their elastic response spectra are same. Therefore, the response spectrum can reflect faithfully the influence of VPC ground motion on the elastic seismic responses of structure, however, when the structural seismic responses enter into elastic-plastic phase, it cannot grasp totally the contribution of velocity pulse to the responses of structure. Based on this observation, it is suggested that as to the seismic design of near-fault structures, besides using the response spectrum describe the ground motion, the increase effects of near-fault velocity pulse on the elastic-plastic deformation of structure should be taken into account.

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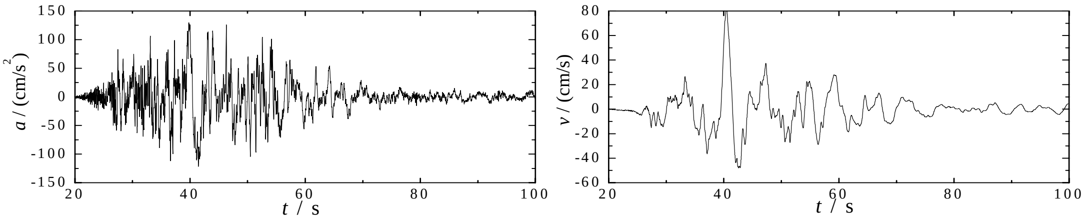
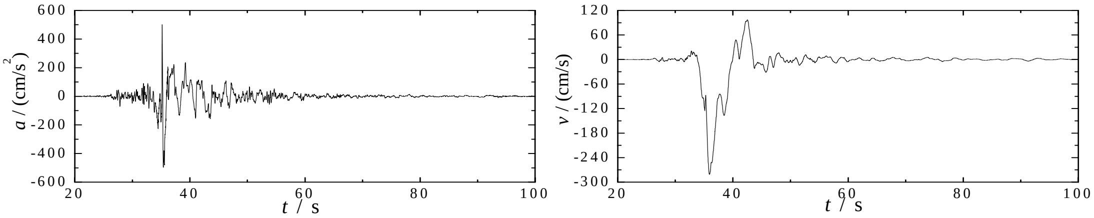
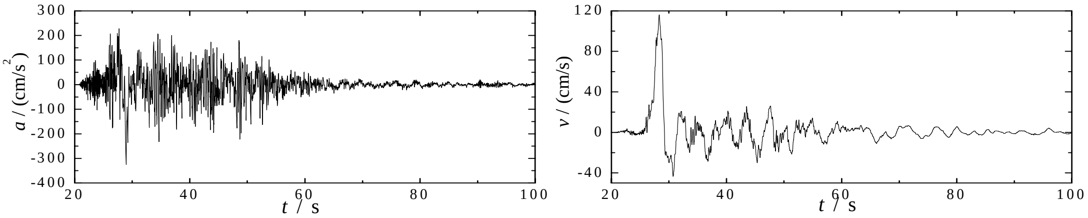


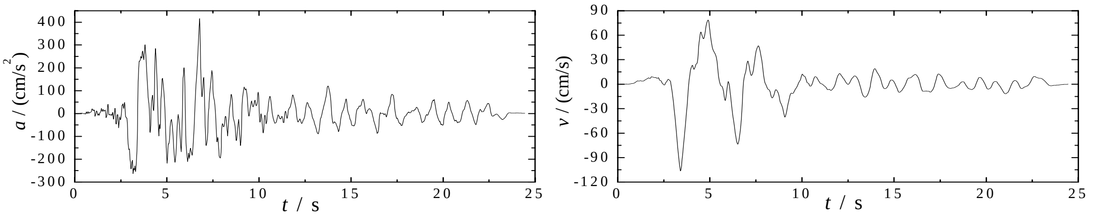
(a) TCU063 station, Chi-Chi earthquake, 1999



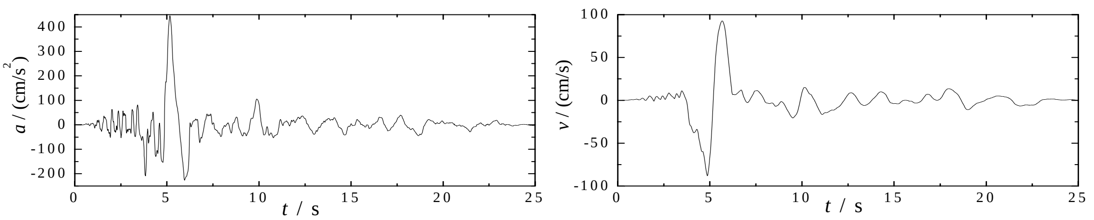
(b) TCU068 station, Chi-Chi earthquake, 1999



(c) TCU075 station, Chi-Chi earthquake, 1999



(d) JFP station, Northridge earthquake, 1994



(e) NWPCR station, Northridge earthquake, 1994

Figure 1 Five recorded acceleration and velocity time histories
(Left: acceleration time histories; Right: velocity time histories)

Table 1 Parameters of seismic recordings and simulated ground shaking time histories
(Unit: PGA, cm/s2; PGV: cm/s; T_p: s)

Record	Natural record			Artificial ground motions			
	PGA	PGV	T_p	PGA	PGV1	PGV2	PGV3
TCU063, Chi-Chi, 1999	129.9	82.2	4.61	130.1	53.7	60.0	60.0
TCU068, Chi-Chi, 1999	501.5	280.8	9.68	507.9	140.0	140.0	140.0
TCU075, Chi-Chi, 1999	325.4	113.1	5.26	325.1	56.4	60.0	59.9
JFP, Northridge, 1994	415.5	106.2	2.64	415.9	53.0	53.5	53.0
NWPCR, Northridge, 1994	445.9	92.8	2.55	447.0	46.0	46.3	47.9

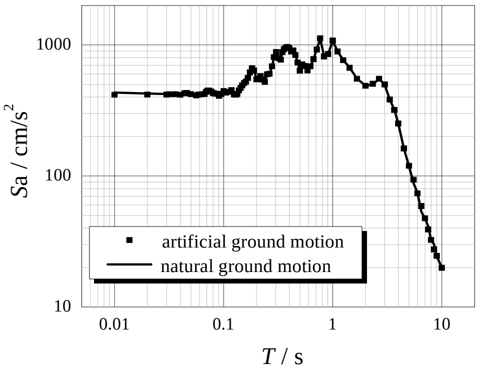


Figure 3 Matching precision to the target spectrum of the artificial ground motion

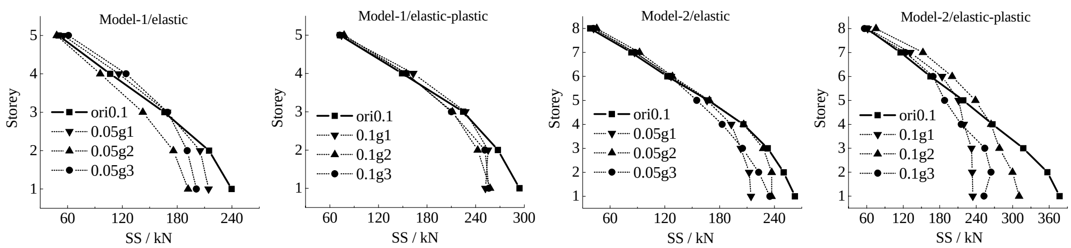


Figure 4 Storey shear force

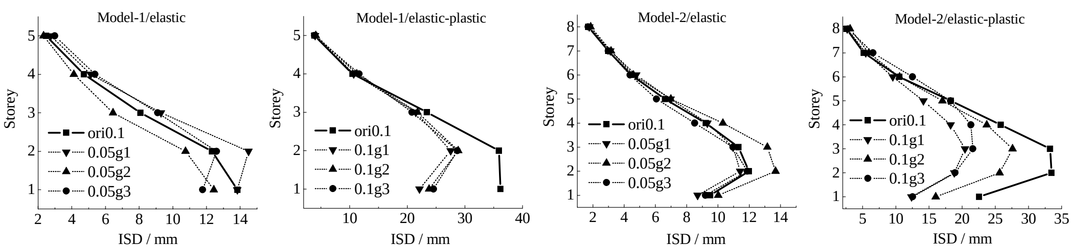


Figure 5 Inter-storey displacement

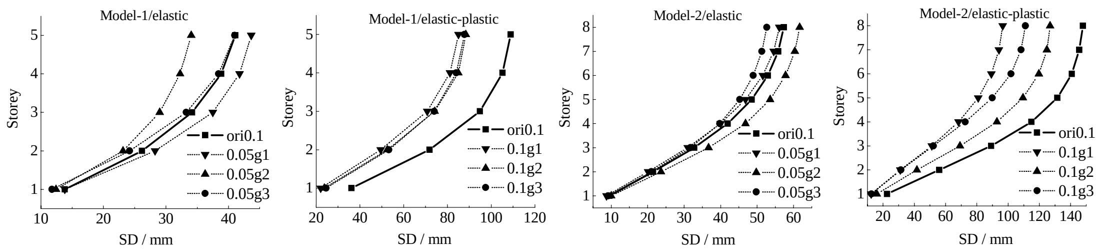


Figure 6 Storey displacement

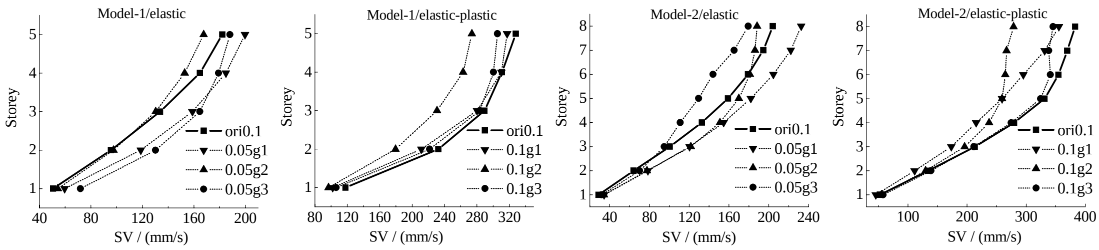


Figure 7 Storey velocity

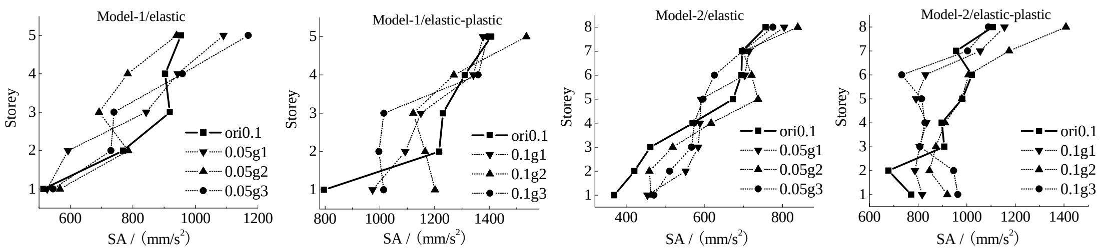


Figure 8 Storey acceleration

Table 2 Comparison of the maximum inter-storey shear force of structure Unit: kN
(V_p: maximum SS to VPC input; V: maximum SS to NVPC input)

Record	Model-1			Model-2			Model-3		
	V_p	V	V_p/V	V_p	V	V_p/V	V_p	V	V_p/V
TCU063	345.83	320.89	1.078	444.03	407.69	1.089	478.01	451.12	1.060
TCU068	321.88	235.97	1.364	353.89	288.81	1.225	397.54	388.35	1.024
TCU075	246.89	208.48	1.184	368.47	299.34	1.231	441.06	358.30	1.231
JFP	294.13	255.40	1.152	377.16	266.01	1.418	421.36	324.52	1.298
NWPCR	307.00	262.57	1.169	349.88	283.48	1.234	409.23	328.55	1.246

Record	Model-4			Model-5			Model-6		
	V_p	V	V_p/V	V_p	V	V_p/V	V_p	V	V_p/V
TCU063	279.22	268.57	1.040	366.68	339.02	1.082	1376.54	1306.95	1.053
TCU068	242.07	205.81	1.176	316.96	251.62	1.260	1089.73	1022.96	1.065
TCU075	172.68	170.76	1.011	242.42	240.34	1.010	1072.51	924.74	1.160
JFP	260.21	233.07	1.116	304.82	280.05	1.089	1048.19	977.92	1.072
NWPCR	258.71	233.34	1.109	304.18	273.25	1.113	979.58	945.91	1.036

Table 3 Comparison of the maximum inter-storey displacement Unit: mm
(SD_p: maximum ISD to VPC input; SD: maximum ISD to NVPC input)

Record	Model-1			Model-2			Model-3		
	SD_p	SD	SD_p/SD	SD_p	SD	SD_p/SD	SD_p	SD	SD_p/SD
TCU063	73.81	73.62	1.003	118.69	68.7	1.728	156.74	113.92	1.376
TCU068	53.92	19.88	2.713	41.16	24.85	1.656	41.85	39.82	1.051
TCU075	15.26	12.79	1.193	28.02	20.97	1.336	54.74	34.29	1.597
JFP	36.17	23.48	1.540	33.46	23.22	1.441	41.82	30.04	1.392
NWPCR	45.25	23.51	1.924	36.01	24.60	1.464	39.28	23.45	1.675
Record	Model-4			Model-5			Model-6		
	SD_p	SD	SD_p/SD	SD_p	SD	SD_p/SD	SD_p	SD	SD_p/SD
TCU063	83.43	53.45	1.561	28.59	22.95	1.246	40.41	21.85	1.859
TCU068	42.58	30.75	1.385	16.77	11.16	1.503	29.21	24.05	1.214
TCU075	19.69	18.90	1.042	8.38	7.15	1.172	30.51	17.30	1.764
JFP	49.99	40.17	1.245	19.23	14.69	1.310	25.69	19.68	1.305
NWPCR	48.76	40.44	1.206	19.45	14.77	1.317	21.53	17.39	1.238

Table 4 Comparison of the maximum storey displacement Unit: mm
(D_p: maximum SD to VPC input; D: maximum SD to NVPC input)

Record	Model-1			Model-2			Model-3		
	D_p	D	D_p/D	D_p	D	D_p/D	D_p	D	D_p/D
TCU063	186.82	217.21	0.860	624.86	363.47	1.719	943.39	705.72	1.337
TCU068	146.15	62.41	2.342	191.88	110.82	1.732	293.53	221.50	1.325
TCU075	40.83	35.04	1.165	128.14	94.04	1.363	308.38	196.24	1.571
JFP	108.96	87.13	1.250	147.90	111.50	1.327	229.98	173.57	1.325
NWPCR	138.66	82.87	1.673	168.51	112.27	1.501	229.22	139.15	1.647
Record	Model-4			Model-5			Model-6		
	D_p	D	D_p/D	D_p	D	D_p/D	D_p	D	D_p/D
TCU063	155.19	102.62	1.512	126.93	110.37	1.150	653.20	580.43	1.125
TCU068	79.28	62.83	1.262	77.98	54.85	1.421	189.56	141.83	1.337
TCU075	44.38	42.76	1.038	39.31	34.10	1.153	172.02	119.11	1.444
JFP	95.93	82.95	1.156	86.25	74.09	1.164	176.09	144.56	1.218
NWPCR	88.10	81.44	1.082	89.09	71.34	1.249	154.32	126.87	1.216