Simulation of Near-Fault Ground Motions With Equivalent Pulses & Compare Their Effects on MRF Structures

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ABSTRACT

According to the recent earthquakes Near-Fault ground motions in the vicinity of quake field caused many damages. There is evidence indicating that ground shaking near a fault rupture may be characterized by an impulsive motion that exposes structures to high input energy at the beginning of the record. This pulse-type motion is particular to the forward direction, where the fault rupture propagates toward the site at a velocity close to the shear wave velocity, causing most of the seismic energy to arrive at the site within a short time. Near-fault Earthquake (NFE) come in large variations and this variety complicates evaluation or prediction of structural response unless they can be represented by a small number of simplified motions that can reasonably replicate important Near-Fault response characteristics. In this study, three pulse type models (which proposed by Makris & Agrawal previously) is used to simulate the Near-Fault records and their effect of this simulated motions on structures are compared to the actual NFE ones. For this reason, Four Near-Fault records are selected and we conduct this research by doing time history analysis & selecting 5,8 &12 stories steel buildings designed according to IRAN 2800 code. The results show that, with limitations, Near-Fault records can be represented by equivalent pulses to understand structural response but applying this result to design process is not recommended.

KEYWORDS:

Near-Fault Earthquakes, IRAN 2800 code, Pulse-type motions, Simulated motions, Simplified equivalent pulses, Time history analysis.

1. INTRODUCTION

An inspection of the time history records (especially velocity and displacement) of Near-Fault ground motions reveals their impulsive characteristics. Near-Fault ground motions come in large variations, which make a consistent evaluation of Near-Fault effects difficult and cumbersome. If simple pulse models can be found that represent Near-Fault ground motions with reasonable accuracy, the process of design or response evaluation will be significantly facilitated.

The study of similarities between the response of structures subjected to Near-Fault records and simple pulses provides much evidence that, help us to know better about this phenomenon and its effect on the response of the structures located in the near source zones. The study of the dynamic response of structures to impulsive loading dates back to the mid 20th century, when input pulses were first utilized to model the impact forces imposed by bomb blast. Biggs (1964) evaluated the response of elastic & inelastic SDOF systems to one-sided force pulses of various shapes, i.e., rectangular and ramp-like pulses. He observed that for each pulse shape, the maximum elastic response is a function of the pulse intensity and td/T ratio, where td is the duration of the pulse and T is the natural period of the system. Simple pulse shapes have been used in the literature also to represent earthquake ground motions (Veletsos et al., 1965). The response of elastic SDOF systems to a half-cycle sinusoidal force pulse is discussed in Chopra (1995).

Chopra demonstrated that the effect of damping on the maximum response to pulse-type forces is not significant unless the system is highly damped. Makris and Black introduced two pulse type models (Type A, B) to show pulse-like essence of Near-fault earthquakes. In Agrawal's article (2002) a simplified closed-form approximation using decaying sinusoids is proposed to model long period velocity pulses in Near-fault ground motions. The objective of his formulation is to represent dominant kinematic characteristics of ground motions instead of modeling ground motions accurately.

The validity and usefulness of the proposed approximation is demonstrated using Near-Fault earthquakes measured during Northridge(1994) and landers (1992) earthquakes. Researchers introduced remoteness & nearness to the earthquake resource as the defining indicator of Near-Source waves. Alavi & Krawinkler defined the Near-Source phenomenon for the structures which are located at 10-15 Km from earthquake resource. Douglas & Ambraseys chose 15Km distance from fault but Chopra & Chintanapakdee considered the registered records up to 10 Km from earthquake resource as the Near-Fault ground motions.

2. EMPLOYED NEAR-FAULT RECORDS & SIMPLIFIED EQUIVALENT PULSE TYPE MODELS

4 Near-Fault records of the rest of the world are employed in this research. The registered records less than 15km are chosen as the Near-Source criterion. All records are provided from PEER internet site. According to ground type classification of IRAN 2800 code, which is divided into four zones, one Near-Source record is selected from each type, all the records scaled according to the IRAN 2800 Code which their specifications are represented in the Table 2.1.

In order to simulate the Near-Fault ground motions, three pulse type models which proposed by Makris & Agrawal is used. Makris proposed a one-sin acceleration pulse as a Type-A cyclical pulse which models the forward ground motion and a one-cosine acceleration pulse as a Type-B cyclical pulse that models a forward-and-backward motion. These pulses are given by the Eqns. 2.1 to 2.6. The pulse parameters are: $\boldsymbol{V_p}$, the amplitude of velocity pulse and is $\omega_p=2\pi/T_p$ the circular frequency of the pulse, which are selected judiciously to approximate the main displacement and velocity pulse.

Pulse Type-A:[7]

$$\ddot{u}_g(t) = \omega_p \frac{v_p}{2} \sin(\omega_p t) \quad ; \quad 0 \le t \le T_p \tag{2.1}$$

$$\dot{u}_g(t) = \frac{v_p}{2} - \frac{v_p}{2} \cos(\omega_p t) \quad ; \quad 0 \le t \le T_p \tag{2.2}$$

$$u_g(t) = \frac{v_p}{2} \mathrm{t} - \frac{v_p}{2\omega_p} \sin(\omega_p t) \quad ; \quad 0 \le t \le T_p \tag{2.3}$$

Pulse Type-B:[7]

$$\ddot{u}_g(t) = \omega_p v_p \cos(\omega_p t) \quad ; \quad 0 \le t \le T_p \tag{2.4}$$

$$\dot{u}_g(t) = v_p \sin(\omega_p t) \quad ; \quad 0 \le t \le T_p \tag{2.5}$$

$$u_g(t) = \frac{v_p}{\omega_p} - \frac{v_p}{\omega_p}\cos(\omega_p t) \quad ; \quad 0 \le t \le T_p \tag{2.6}$$

Agrawal proposed a simple approach for modeling velocity pulses by using decaying (damped) sinusoidal pulses (Type D pulse). The model is for forward rupture directivity conditions, which produce a strong pulse in the fault-normal direction. The pulse parameters that have been modeled are the natural frequency (ω_p), amplitude of velocity pulse (v_p), and damping factor of ground motion (ξ_p) which controls the shape and duration of the velocity pulse. The proposed decaying sinusoidal pulse can be modeled as type A pulse using a high value of ξ_p and it can be modeled as type B pulse by assuming smaller value of ξ_p. In the proposed Type D pulse, the velocity component $\dot{u}_g$ of the pulse is modeled by a decaying sinusoid as follows [1]:

$$\dot{u}_g = v_p e^{-\xi_p \omega_p t} \sin\left(\omega_p \sqrt{(1-\xi_p^2)}.t\right) \tag{2.7}$$

Where ξ_p is the damping factor of the decaying sinusoid, ω_p is the frequency of sinusoid and v_p is the initial amplitude of the pulse. Differentiating Eqn. 2.7, the acceleration $\ddot{u}_g$ of the pulse obtained as:

$$\ddot{u}_g = v_p e^{at}[a\sin(bt) + b\cos(bt)] \tag{2.8}$$

And the displacement u_g of the pulse can be obtained by integrating Eqn. 2.7 as follows:

$$u_g = [v_p e^{at}(a\sin(bt) - b\cos(bt)) + v_p b]/\omega_p^2 \tag{2.9}$$

Where : $a = -\xi_p.\omega_p$; $b = \omega_p\sqrt{1-\xi_p^2}$

Recent studies have shown that the input energy of ground motion depends mainly on the peak ground velocity (PGV) and the seismic index I_D representing the effective duration of the ground motion [e.g., Manfredi (2001)]. These 2 parameters depend on v_p and ξ_p in the proposed approximation in Eqn. 2.7.

Table 2.1- Spesification of Near Fault Ground Motions [4]

Quake	Year	Station	Component	PGA(g)	PGV(cm/s)	PGD(cm)	Distance(Km)	Soil class	Ms	Time of quake	PGV/PGA	PGD/PGV
Landers	6/28/1992	24 Lucerne	V	0.818	45.9	22.23	1.1	I	7.4	48.12	0.057	0.484
			H1	0.721	97.6	70.31					0.138	0.720
			H2	0.785	31.9	16.42					0.041	0.515
Kobe2	1/16/1995	0 KJMA	V	0.343	38.3	10.29	0.6	II	6.9	47.98	0.031	0.269
			H1	0.821	81.3	17.68					0.022	0.217
			H2	0.599	74.3	19.95					0.034	0.269
Chi-Chi, Taiwan	9/20/1999	TCU068	V	0.486	187.3	266.55	1.09	III	7.6	89.995	0.393	1.423
			H1	0.462	263.1	430					0.581	1.634
			H2	0.566	176.6	324.11					0.318	1.835
Imperial Valley	10/15/1979	5057 El Centro	V	0.127	8.7	4.7	9.3	IV	6.9	39.54	0.070	0.540
			H_1	0.266	46.8	18.92					0.179	0.404
			H_2	0.221	39.9	23.31					0.184	0.584

3. MATCHING OF NEAR-FAULT GROUND MOTIONS TO EQUIVALENT PULSES

In order to establish an equivalent pulse for a Near-Fault record, three parameters need to be evaluated; pulse type(A, B, or D), pulse period T_p, and pulse intensity. These three parameters completely characterize the equivalent pulse, and therefore its time history and response properties can be derived accordingly.

3.1 Procedure for matching

Mostly judgment is employed to decide on the pulse type, based on an inspection of the time history trace, and on a comparison between ground motion and pulse spectral shapes (primarily velocity spectra). In this study, according to the time history traces of the selected records, we use three pulse types A, B & D models to simulate the selected Near-Fault records. The pulse period (T_p) for a Near-Fault record is identified from the location of a global and clear peak in the velocity response spectrum.
For records, in which the peak is not clear or there are two or more peaks, judgment has to be employed to decide on a final value of the T_p [2]. Pulse intensity is chosen as the maximum of the time history velocity of the Near-Fault records and will be introduced as a V_p. According to the pulse parameters definition for the pulse models, each record is equivalent by the parameters which come in Table 2.2. Figure 2 shows the simplified equivalent pulses of Type A, B & D for the H_1 component of the Landers (1992) earthquake recorded at the 24Lucerne station.

Table 2-2-Equivalent Pulse Parameters

Record	Landers						Kobe2						ChiChi						Imperial valley					
Pulse Parameters	T_p(sec)		V_p(Cm/s)		ζ_p		T_p(sec)		V_p(Cm/s)		ζ_p		T_p(sec)		V_p(Cm/s)		ζ_p		T_p(sec)		V_p(Cm/s)		ζ_p	
Pulse Type	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2
A	4.1	3.54	150.78	45.25	-	-	0.89	0.8	73.26	91.79	-	-	8.91	9.36	364.93	199.76	-	-	2.23	4.27	117.84	120.92	-	-
B	4.1	3.54	150.78	45.25	-	-	0.89	0.8	73.26	91.79	-	-	8.91	9.36	364.93	199.76	-	-	2.23	4.27	117.84	120.92	-	-
D	4.1	3.54	150.78	45.25	0.08	0.05	0.89	0.8	73.26	91.79	0.08	0.05	8.91	9.36	364.93	199.76	0.08	0.05	2.23	4.27	117.84	120.92	0.08	0.05

4. ANALYSIS METHOD AND RESULTS

In this research, three MRF steel structures with 5, 8 & 12 stories are employed. These buildings are geometric regular and their typical story height & bays width are 3.20m & 3m, respectively (figure 1).
The designed sections are considered as plate girder. In order to modeling the nonlinear response of structures trilinear behaviour model of SAP2000 software is employed in which FEMA273 code provides the hinges specifications .P-M-M hinges in columns & M hinges in beams are used. Damping factor of structure is proportional to the structure's period ($\xi = 5\%$).
To compare the structural response to the records and their equivalent pulses, the distribution of the maximum story displacement & maximum story shear are selected in two directions (x, y) as the comparable response parameters. Using nonlinear time history analysis of SAP2000 software, structure's response parameters under Near -Fault ground motions and their equivalent pulses are examined which the conclusions are expressed later. Analysis results for 5, 8 &12 stories building are presented in coming pages.

5. CONCLUSION

Simple pulses of different shapes are utilized here to represent Near-Fault ground motions. This representation proves to be very efficient for an evaluation of imposed seismic demand to the structures. However, it is not

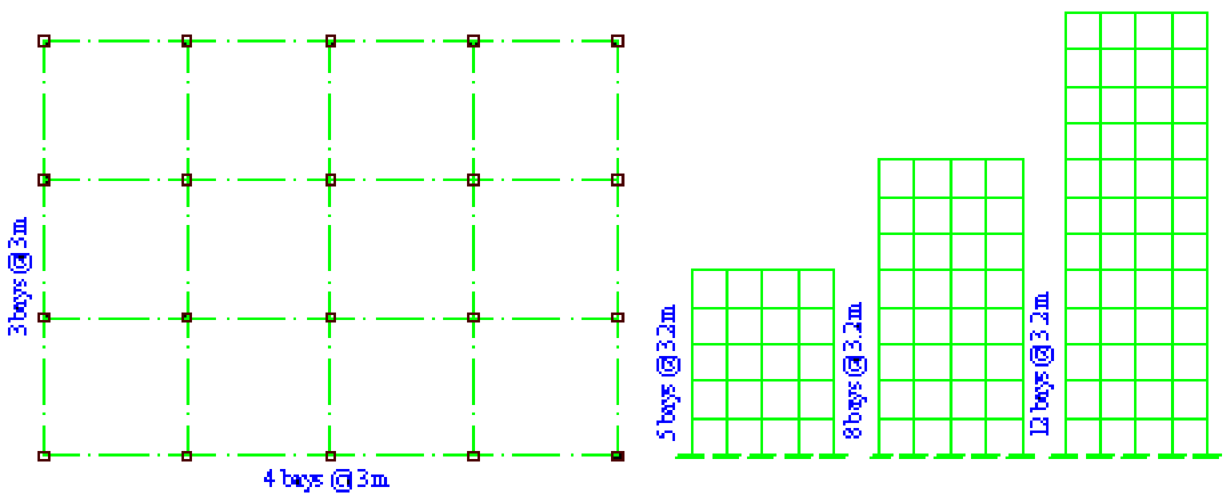
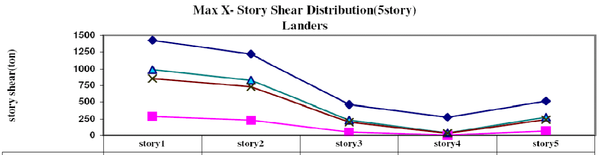
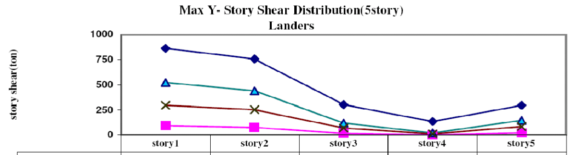


Figure 1 Plan & Elevation of employed buildings.

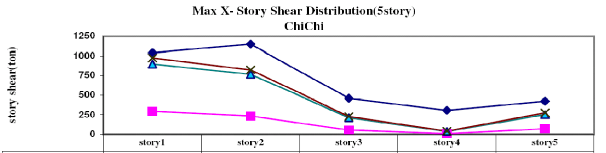
Figure 2 Simplified Equivalent Pulses of Landers (1992) Earthquake



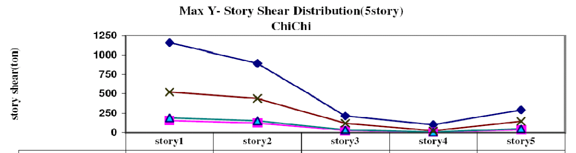
	story1	story2	story3	story4	story5
Actual record	1425	1219	464	276	515
Pulse Type A	290	232	54	9	71
Pulse Type B	989	829	231	41	278
Pulse type D	856	731	203	36	241



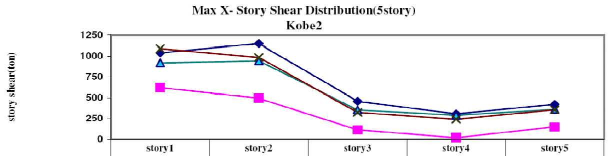
	story1	story2	story3	story4	story5
Actual record	862	757	304	136	295
Pulse Type A	94	76	18	3	23
Pulse Type B	522	440	121	22	148
Pulse type D	297	254	70	13	84



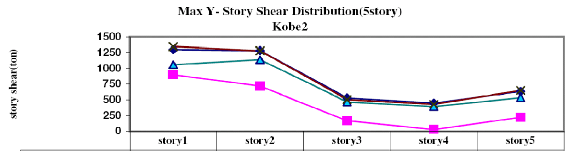
	story1	story2	story3	story4	story5
Actual record	1039	1149	460	308	423
Pulse Type A	297	235	54	9	71
Pulse Type B	897	766	212	37	252
Pulse type D	974	822	229	41	275



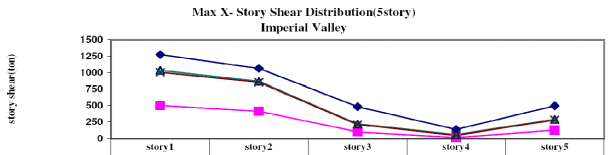
	story1	story2	story3	story4	story5
Actual record	1158	896	216	102	292
Pulse Type A	156	123	28	5	37
Pulse Type B	190	153	35	6	47
Pulse type D	519	439	121	22	147



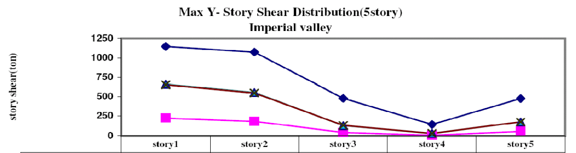
	story1	story2	story3	story4	story5
Actual record	1039	1149	460	308	423
Pulse Type A	620	494	116	18	151
Pulse Type B	918	943	355	290	362
Pulse type D	1089	985	324	242	358



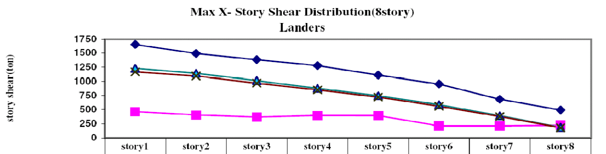
	story1	story2	story3	story4	story5
Actual record	1303	1286	533	453	634
Pulse Type A	901	719	169	28	223
Pulse Type B	1061	1141	469	396	538
Pulse type D	1348	1282	506	432	650



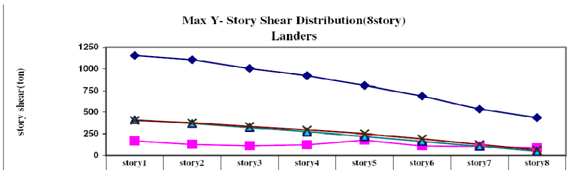
	story1	story2	story3	story4	story5
Actual record	1275	1067	484	134	496
Pulse Type A	503	412	99	15	127
Pulse Type B	1037	868	219	61	287
Pulse type D	1007	855	211	50	281



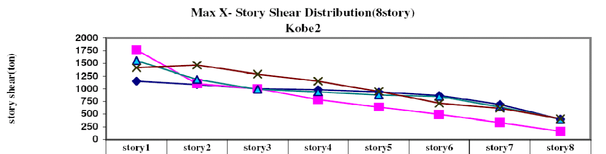
	story1	story2	story3	story4	story5
Actual record	1147	1075	479	140	476
Pulse Type A	224	179	41	7	55
Pulse Type B	660	554	128	31	172
Pulse type D	652	548	131	29	173



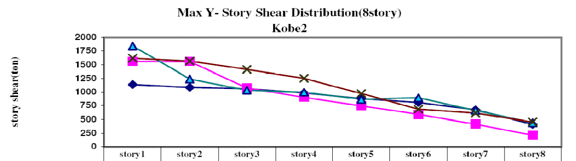
	story1	story2	story3	story4	story5	story6	story7	story8
Actual record	1657	1495	1383	1276	1109	956	685	491
Pulse Type A	464	403	366	394	390	210	210	225
Pulse Type B	1231	1143	1015	879	748	585	392	187
Pulse type D	1167	1093	973	853	721	559	376	181



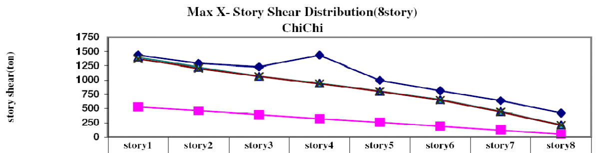
	story1	story2	story3	story4	story5	story6	story7	story8
Actual record	1158	1106	1005	920	810	689	535	437
Pulse Type A	170	130	113	126	180	112	105	88
Pulse Type B	412	368	322	272	220	164	107	49
Pulse type D	404	375	335	295	249	194	131	63



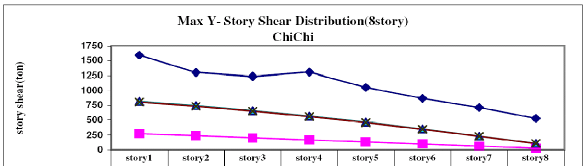
	story1	story2	story3	story4	story5	story6	story7	story8
Actual record	1152	1085	1003	983	936	865	687	397
Pulse Type A	1760	1101	1002	780	634	488	331	165
Pulse Type B	1550	1186	989	938	874	842	637	395
Pulse type D	1409	1460	1285	1152	949	711	607	406



	story1	story2	story3	story4	story5	story6	story7	story8
Actual record	1138	1087	1065	983	877	806	671	410
Pulse Type A	1558	1554	1077	901	744	586	414	215
Pulse Type B	1841	1240	1036	995	865	894	660	440
Pulse type D	1618	1567	1411	1252	973	681	612	451

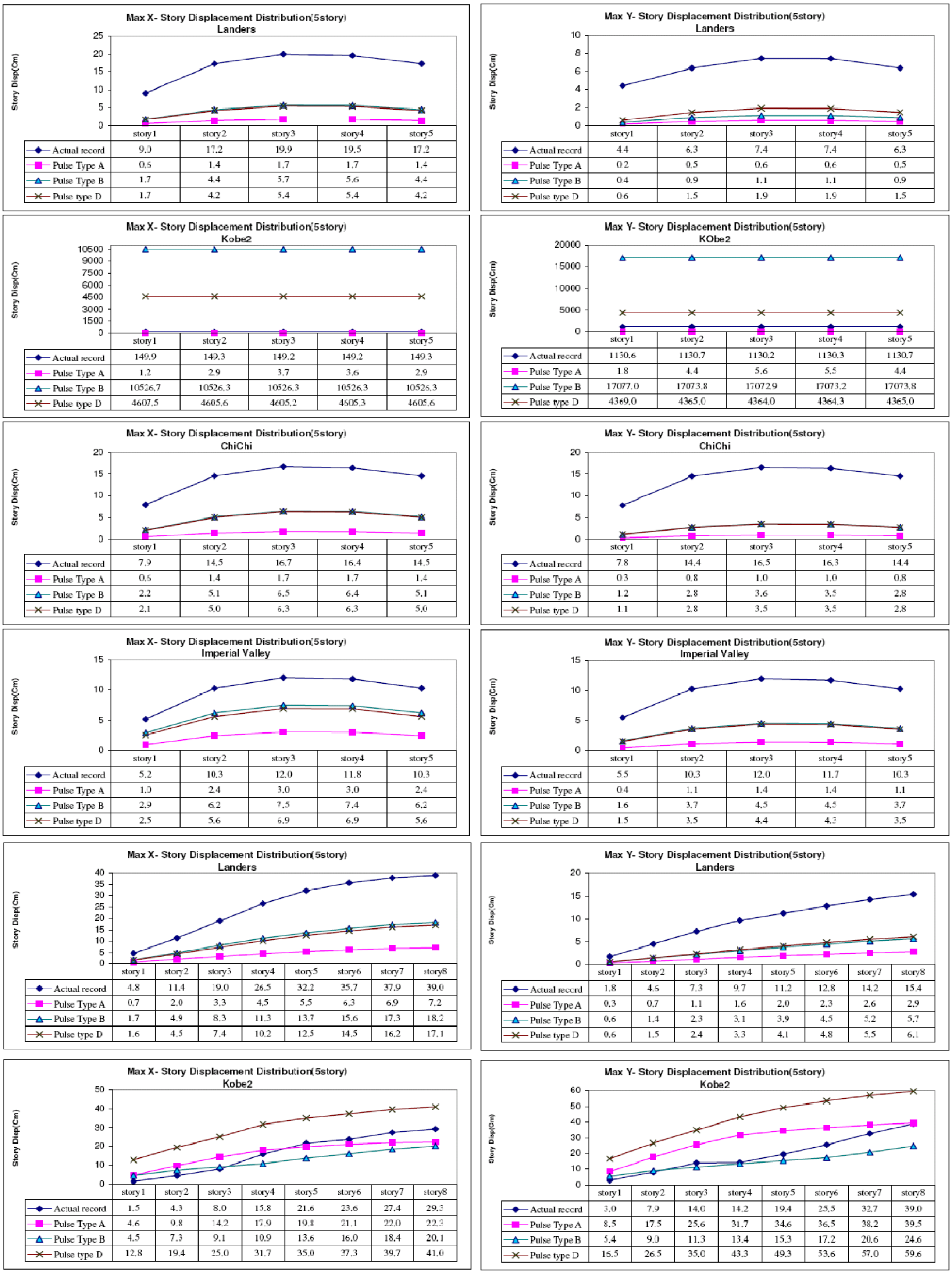


	story1	story2	story3	story4	story5	story6	story7	story8
Actual record	1439	1292	1230	1433	997	812	638	421
Pulse Type A	529	462	394	326	258	189	121	54
Pulse Type B	1397	1227	1069	948	805	655	451	216
Pulse type D	1368	1206	1067	938	799	646	441	210



	story1	story2	story3	story4	story5	story6	story7	story8
Actual record	1592	1300	1234	1306	1051	865	711	529
Pulse Type A	274	239	204	169	133	98	62	28
Pulse Type B	816	743	655	566	467	354	231	110
Pulse type D	803	732	648	558	459	349	228	108

Figure 3 Max Story Shear Distribution (Actual records & Equivalent Pulse Type models)



Max X- Story Displacement Distribution(5story) Landers

	story1	story2	story3	story4	story5
Actual record	9.0	17.2	19.9	19.5	17.2
Pulse Type A	0.5	1.4	1.7	1.7	1.4
Pulse Type B	1.7	4.4	5.7	5.6	4.4
Pulse type D	1.7	4.2	5.4	5.4	4.2

Max Y- Story Displacement Distribution(5story) Landers

	story1	story2	story3	story4	story5
Actual record	4.4	6.3	7.4	7.4	6.3
Pulse Type A	0.2	0.5	0.6	0.6	0.5
Pulse Type B	0.4	0.9	1.1	1.1	0.9
Pulse type D	0.6	1.5	1.9	1.9	1.5

Max X- Story Displacement Distribution(5story) Kobe2

	story1	story2	story3	story4	story5
Actual record	149.9	149.3	149.2	149.2	149.3
Pulse Type A	1.2	2.9	3.7	3.6	2.9
Pulse Type B	10526.7	10526.3	10526.3	10526.3	10526.3
Pulse type D	4607.5	4605.6	4605.2	4605.3	4605.6

Max Y- Story Displacement Distribution(5story) KObe2

	story1	story2	story3	story4	story5
Actual record	1130.6	1130.7	1130.2	1130.3	1130.7
Pulse Type A	1.8	4.4	5.6	5.5	4.4
Pulse Type B	17077.0	17073.8	17072.9	17073.2	17073.8
Pulse type D	4369.0	4365.0	4364.0	4364.3	4365.0

Max X- Story Displacement Distribution(5story) ChiChi

	story1	story2	story3	story4	story5
Actual record	7.9	14.5	16.7	16.4	14.5
Pulse Type A	0.5	1.4	1.7	1.7	1.4
Pulse Type B	2.2	5.1	6.5	6.4	5.1
Pulse type D	2.1	5.0	6.3	6.3	5.0

Max Y- Story Displacement Distribution(5story) ChiChi

	story1	story2	story3	story4	story5
Actual record	7.8	14.4	16.5	16.3	14.4
Pulse Type A	0.3	0.8	1.0	1.0	0.8
Pulse Type B	1.2	2.8	3.6	3.5	2.8
Pulse type D	1.1	2.8	3.5	3.5	2.8

Max X- Story Displacement Distribution(5story) Imperial Valley

	story1	story2	story3	story4	story5
Actual record	5.2	10.3	12.0	11.8	10.3
Pulse Type A	1.0	2.4	3.0	3.0	2.4
Pulse Type B	2.9	6.2	7.5	7.4	6.2
Pulse type D	2.5	5.6	6.9	6.9	5.6

Max Y- Story Displacement Distribution(5story) Imperial Valley

	story1	story2	story3	story4	story5
Actual record	5.5	10.3	12.0	11.7	10.3
Pulse Type A	0.4	1.1	1.4	1.4	1.1
Pulse Type B	1.6	3.7	4.5	4.5	3.7
Pulse type D	1.5	3.5	4.4	4.3	3.5

Max X- Story Displacement Distribution(5story) Landers

	story1	story2	story3	story4	story5	story6	story7	story8
Actual record	4.8	11.4	19.0	26.5	32.2	35.7	37.9	39.0
Pulse Type A	0.7	2.0	3.3	4.5	5.5	6.3	6.9	7.2
Pulse Type B	1.7	4.9	8.3	11.3	13.7	15.6	17.3	18.2
Pulse type D	1.6	4.5	7.4	10.2	12.5	14.5	16.2	17.1

Max Y- Story Displacement Distribution(5story) Landers

	story1	story2	story3	story4	story5	story6	story7	story8
Actual record	1.8	4.5	7.3	9.7	11.2	12.8	14.2	15.4
Pulse Type A	0.3	0.7	1.1	1.6	2.0	2.3	2.6	2.9
Pulse Type B	0.6	1.4	2.3	3.1	3.9	4.5	5.2	5.7
Pulse type D	0.6	1.5	2.4	3.3	4.1	4.8	5.5	6.1

Max X- Story Displacement Distribution(5story) Kobe2

	story1	story2	story3	story4	story5	story6	story7	story8
Actual record	1.5	4.3	8.0	15.8	21.6	23.6	27.4	29.3
Pulse Type A	4.6	9.8	14.2	17.9	19.8	21.1	22.0	22.3
Pulse Type B	4.5	7.3	9.1	10.9	13.6	16.0	18.4	20.1
Pulse type D	12.8	19.4	25.0	31.7	35.0	37.3	39.7	41.0

Max Y- Story Displacement Distribution(5story) Kobe2

	story1	story2	story3	story4	story5	story6	story7	story8
Actual record	3.0	7.9	14.0	14.2	19.4	25.5	32.7	39.0
Pulse Type A	8.5	17.5	25.6	31.7	34.6	36.5	38.2	39.5
Pulse Type B	5.4	9.0	11.3	13.4	15.3	17.2	20.6	24.6
Pulse type D	16.5	26.5	35.0	43.3	49.3	53.6	57.0	59.6

Figure 4 Max Story Displacement Distribution (Actual records & Equivalent Pulse Type models)

reasonable to expect that perfect equivalence can be established between Near-fault ground motions and simple pulses for the full range of interest.
The pulse representation of the Near-Fault earthquakes is not perfect but is believed to be helpful to have a better comprehension of the structural response to Near-Fault records. The following conclusions are drawn:

1) There are clear similarities between the response of frame structures to Near-Fault ground motions and the response to pulse-type excitations.

2) An inspection of the time history traces of the selected records and according to the analysis results, we can conclude that the pulse Type B,D models have a reasonable results in compare with pulse Type A model, i.e. the pulse Type B,D models can be used to simulate the selected records.

3) With the difference in the period of the structures, the nearness of the simplified equivalent pulses' results and the actual records ones changes and will be closer.

4) The simplified equivalent pulses can capture the most important characteristics of the structure's response which help us to have a better understanding of the Near-Fault ground motion's effects on the frame structures.

5) The results show that, with limitations, Near-Fault records can be represented by equivalent pulses to understand structural response of the buildings but applying this result to design process is not recommended.

6) It is emphasized that the objective of the proposed approximation is to model dominant features of ground motions and should not be used to replace recorded ground motions to investigate structural behaviour.

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