Modification of PBSD Procedure for Moderate Shear Walls Subjected to Near-Field Excitation

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Abstract

In the near-field areas, VCE effectively exists which is so sensitive depending on the distance from a source and the earthquake magnitude. This has remarkable effects when shear wall is to be in moderate size which causes it to face wide diversity modes of failure. So, a modified procedure is conceived to ensure the response of the shear wall subjected to biaxial excitation. Thereby, there is an evaluation process that is based on the intersection of capacity and demand curves commonly called the performance point. The modification factors are developed based on the validation of performance points from which are derived demand and capacity curves.

Introduction

The main scope of the performance-based seismic design (PBSD) method is conceptually formed based on the development of structural and component performances with the utilization of the nonlinear static analysis instead of nonlinear dynamic analysis which its goal is to capture a reliable result by reduction of the computational effort. Meanwhile, a rational procedure which can provide a reliable result in an area that a structure is subjected to synchronous vertical (VCE) and horizontal (HCE) earthquake excitations (biaxial excitation) has not been clarified yet ((H. J. JIANG et al., 2011, He and Agrawal, 2008, Ellys Lim and Chouw, 2018, Laila Elhifnawy et al., 2017, Collier and Elanashai, 2001, Naeim, 1998, S., 1997, Huy T. Tran et al., 2016). Researchers indicated that in the near-field area due to intensities of VCE and HCE and change of their characteristics, the interaction between them and distance from a source, performances of components and structures may be considerably affected (Nikolaos Simos et al., 2018, Sinan Akkar et al., 2018, Jalal Kiani et al., 2018, Yang Xiang et al., 2017, Heng Li and Chen, 2017, Laila Elhifnawy et al., 2017, He and Agrawal, 2008, Bozorgnia, 2004, Naeim, 1998, S., 1997, Aki, 1980, Bommer, 2001, Ghatee et al., 2007, Haibo Yang, 2014, Aruna Rawat. et al., 2017). Since VCE effectively exists in near-field area sensitively depending on the distance from a source and the earthquake magnitude (Collier and Elanashai, 2001, Asgarian Behrouz et al., 2012); There are a few methods that the VCEs are commonly transformed to an additional weight which is vertically distributed in different levels of a structure. Correspondingly, the effect of vertical component in demand spectral acceleration response of a single degree of freedom is shown to be significant by a study on the Hyogo-ken Nanbu earthquake (Loh, 1997). And also, Bousias et al. (2002) have shown the effect of near-field on a capacity curve of the column (Bousias, 2002). Since biaxial excitation may also produce different inelastic (damage and/or plastic) surfaces in tensorial material matrices space can produce different elastic/inelastic load-deflection manner (Su and Wong, 2007, Sima et al., 2008); From a different point of view, the performance of components which are governed by biaxial stress in a material matrix such as shear walls and structures consist of them can be impacted significantly by biaxial excitation. The flexibility of shear wall structure is lesser than the other structural systems (actually lesser inter-story drift) but the inter-story drifts can be affected by vertical and horizontal excitations simultaneously. These effects may be amplified when shear wall is to be in moderate size; Walls are considered moderate if their aspect ratio is between 1.5 to 3 (FEMA-273, 1996), hence, they face wide diversity modes of failure (Sheu and Huang, 1992). The capacity-demand evaluation process that is based on the intersection of capacity and demand curves could be affected by considering the static analysis procedure in a near-field area where it has different excitation characteristics corresponding to distance from a source. So, a modified procedure is conceived to ensure the response of the shear wall subjected to biaxial excitation. In spite of all above mentioned, a study by analytical and experimental procedures shows that the nonlinear static analysis may be applicable for the near-field area with the decent response of structure (Wuchuan Pu et al., 2018, Basu, 2007, Ghatee et al., 2009a, Ghatee et al., 2009b, Ghatee et al., 2010). Thus, the present study is formed in such a way to develop modification factor in the nonlinear static procedure to achieve a reliable response. The modification factors are developed based on the validation of a pseudo performance point and the differentiation of pseudo and actual performance points which are derived from demand and capacity curves. The modification factors are formed based on distance from a source and steel ratio of moderate shear wall. Four earthquakes are considered in the following text such as Northridge, Lomaperita, Kobe, and Landers in 3 distances as 0, 15, 30 kilometers. Finally, verification procedures with experimental data have presented that the modification factors can effectively provide reliable outcomes.

Materials And Methods

Earthquake loading

The selection of a suitable set from the collected earthquake events plays an important role in developing general results. As the nonlinear response of a structural system strongly depends on characteristics of motion such as frequency content, magnitude, strong motion duration, and pulse sequencing; therefore, several ground motions representing a range of amplitudes and frequencies should be utilized to anticipate the upper and lower bounds of the nonlinear response. Considering the characteristics of the earthquakes, which are tabulated below, show that the four earthquake records of Northridge, 1994, Loma Prieta, 1989 and Landers, 1992(Iwan and Gates, 1997) Kobe, 1995 are able to generalize the results. Besides the target drift straightly depends on the performance level. So, there should be a reliable statistical study, for instance, the SEAOC has presented the values of earthquake loadings and the corresponding drift targets for the structures, i.e., in Life Safety (LS), the drift is 1.5% while in Collapse Prevention (CP) is 2.5%. Although all these values are not accurate, it has no significant impact in comparison with the actual performance point and the pseudo performance point that is the overall procedure of the present study. It should be noted that for shortening of the sentences in the graphs and tables, the probability of exceedance 2% and 10% per 50 years are demonstrated by 2-50 or 10-50, respectively.

It is obvious due to the table that the effect of near-field characteristics on the response of structures almost vanishes after 30 km. Therefore, the performance points are captured in 0, 15, and 30 Km distances. Besides, it is difficult to record the VCE from the exact distances from a source. Hence, the vertical records are scaled based on the statistical values of V/H ratios which are developed based on the 104 worldwide records by Ambraseys et.al. In 1996(Ambraseys, 1996, Peer.Berkeley.edu).

Material model

When static horizontal and vertical cyclic loadings are imposed on a structure, nonlinear characteristics, and damage aspects of a material matrix within each component may produce different performances (Su and Wong, 2007). In most mathematical models that represent the behavior of concrete, the stress-strain relationship is considered linear in plastic surfaces before damage criteria. Although this definition of concrete behavior can be a good estimation, it can be totally different for the structures and elements subjected to biaxial stress, vertical and horizontal earthquakes, damage state, and damage mode. In other words, a pair of the same component which is affected by different protocols of bidirectional cyclic loadings may have disparate performances due to differences in decreasing stiffness, hardening and/or softening in the material matrix and diminishing of energy absorption capacities because of different cyclic loading protocols (Mo and Chan, 1996, Loh, 1997). All the above mentioned are shown schematically in Figure 1.

The performance of components, which are governed by biaxial stress in the material matrix, can be impacted significantly by biaxial excitation. Since biaxial excitation may also produce different inelastic (damage and/or plastic) surfaces in tensorial material matrices space afterward produce different elastic/inelastic load-deflection manner (Su and Wong, 2007, Sima et al., 2008).

The nonlinear behavior of the moderate aspect ratio of shear wall is more complex and involves different modes of failure in comparison with the other aspect ratios. This leads to different aspects of damage, behavior, and performance of the shear wall which is correlated with the different aspects of reinforced concrete damage. Hence, an appropriate material model that is able to consider different aspects of damages and failure modes should be utilized in a numerical simulation to produce acceptable performance points. Therefore, a material model has been developed by authors (Ghatee et al., (Ghatee et al., 2018, in press)) which is capable of handling the characteristics of near-field earthquakes (the partial unloading/reloading effects), their effects on concrete material matrices for the multitude of damage modes, and realistic stress-strain relationships of concrete under crack closure-reopening phenomenon, is adopted for this study. This model has been developed based on the damage formulations which has covered all cyclic loading conditions including partial and complete unloading/reloading ones; the program of the model has been generated via ABAQUS which has been published separately (Ghatee et al., 2017, Ghatee et al., 2018, in press)

Development of performance points

As discussed before, VCE has a significant impact on the behavior of the structure. In order to develop the modification factor this effect should be taken into account by considering it as an additional mass for a preliminary NDA analysis. The design is done with respect to VCE and HCE, distance from a source, and certain reinforcements of moderate shear wall to reach drift target of the top of the wall to a limitation value corresponding to performance level (Botta and Mezzi, 2008). Within the iteration procedure, the mass has changed, from 8950 kg to 9250, which makes the drift change of 0.08m to 0.1m to capture the actual performance point. In this way, to reach the actual performance point, the wall was allowed to reach the drift target which is 1.5% in LS. After the mass causes the drift limitation, the mass and the actual performance point is captured. This procedure is shown in Figure 2. Hereafter the mass is transformed into a force and applied to the shear wall to reach the displacement under a cyclic procedure to displacement target which results in pseudo performance point. For generating pseudo performance points, the nonlinear static analysis is adopted in such a way that the increasing horizontal displacement loading history in presence of constant vertical load in compression state is applied to the top of the shear wall until the drift of the wall reached limitation values (drift targets) in different performance levels. This procedure is shown in Figure 3. With an evaluation of actual and pseudo performance point, the modification factor is developed.

Verification procedure

Considering the time interval between peak vertical and horizontal accelerations effects on the response of the structure, the first part of the records cannot be dropped. Hence, in the present study, the end part of the records is only dropped out based on the 95 percent of delivered seismic energy.

Due to this verification procedure, five experimental results of shear walls (SW21 to SW25) with moderate aspect ratio and different concrete and steel properties are adopted. These shear walls have been monotonically tested by Lefas et.al. (Lefas . L et al., 1990) and the corresponding results have been used also in the verification procedure of the other material models by Vecchio (Vecchio, 1992) and Wu et.al.(Wu et al., 2006). The experiment setup, boundary conditions, material properties, which have been used in the experiments, and finite element models are shown in Figure 5, Tables 2 and 3.

The finite element modeling and mesh discretization, which is adopted in the present study, is illustrated in Figure 6. The present material constitutive law was adopted due to simulation. The maximum top displacements of the walls, which have been reached due to experiments procedure in CP are adopted as targets of displacement loadings which are applied to the models via finite element analyses. The target displacements are presented in Table 4.

Considering Table 4. All analytical simulations, which have been done via the other or present studies, are developed based on the target displacements with small variations but are not developed based on the exact values. It is because of the fact that the target displacements, which have been developed by experiments, are located in the collapse limit of the shear walls. These targets may cause some numerical instability in finite element simulation based on constitutive law capability, material properties (such as damage indices and steel ratio), convergence rates, number of iterations, and time intervals. The variation of imposed displacement on top of the walls is also presented in Table 4.

Results And Discussion

In this study, the modification factors are presented in such a way that can be directly applied in capacity curves of moderate shear wall in a modified PBSD procedure. Since the modification factors are developed based on the evaluation procedure of performance points, there is a capacity-demand evaluation process that is based on the intersection of capacity and demand curves commonly called the performance point. Besides the actual performance points can be captured from drift demand curves, if the displacement of the top of the shear wall reaches displacement objectives. While the pseudo performance point can be captured from the push of hysteresis behavior of the shear wall which is illustrated in Figures 7 to 9. The final results are presented in tables 5, 6, and 7. The base shear value of the pseudo performance point should reach the actual one that has been presented in Figure 10.

Considering above mentioned, the modified shear capacity of the moderate shear wall is adopted which can be developed based on the following formulation:

$$V_{Cm} = V_C - \left(1 - M_f\right)V_C$$

where;V_{cm} is modified shear capacity, V_c is provided shear capacity and M_f is modification factor for moderate shear wall subjected to performance level, steel ratio, and distance from a source, respectively.

The PBSD method for moderate shear walls is conceptually modified to enhance its accuracy and reliability subjected to near-field excitation. This modification is done by application of some general modification factors which may be applied in the capacity of a moderate shear wall. The modification factor's values corresponding with different sizes of moderate shear walls are different. Nevertheless, the modification factors, which may be developed by other sizes of moderate shear walls, should be located in a narrow band of variations. This is the most important issue for the achievement of reliability on the estimation of moderate shear wall performance with different size subjected to near-field excitation.

The modification factors can also be generated by a trend-surface, which passes through the modification factor points in three-dimensional spaces. The Cartesian axes X, Y, and Z of the three-dimensional spaces are steel ratio, distance from a source, and the modification factors, respectively. The trend-surfaces are calculated by MATLAB software. The generalized modification factors can be achieved by averaging the previously developed modification factors. It is not recommended that the modification factors greater than one to be utilized in the practical case of shear wall design. Because the modified performance points will be located in the greater safety margin limit if the maximum values of the modification factors are adapted equally to one. This issue is just a recommendation to keep a greater safety limit in practical cases.

The surfaces of modification factors generally show that the effects of near-field characteristics on the moderate shear walls are reduced if the steel ratios of the moderate shear wall increase and vice versa. It is deduced from the effect of the partial unloading-reloading state of plain concrete on the overall response of the moderate shear wall which is decreased by overcoming the behavior of the steel layer. Moreover, the axial demand loads subjected to one of the distances are commonly decreased, if the steel ratio increases. Since the self-weight of the shear walls are participated in their inelastic responses, while the axial demand forces are calculated based on lumped masses only. Also, the total demand masses subjected to one of the distances are commonly increased, if the steel ratio increases; because the axial force demand of a shear wall with a high steel ratio should be greater than a shear wall with a low steel ratio.

Considering the capacity curves, in a condition that the steel ratio of the wall is not small, hardening of steel reinforcement can play an effective role in diminution or even enhance shear wall performance. Considering the terminology of PBSD, the demand force of a component is defined as a minimum requirement of component force resistance, which the component remains in the performance level. When distance goes to a large extent, total demand masses on the top of the moderate shear wall commonly increases, and the axial demand forces of moderate shear walls commonly decrease. It is because, first due to updating of the shear wall design in the iteration procedure, the steel ratios increase. Hence, the weights of shear walls increase; and the axial force demand in close distance to a source should be greater than the far distance from the source.

Conclusion

The modification of the PBSD method subjected to near-field excitation is successfully developed by directly applying the modification factors in the capacity curves. All of the modification factors are developed based on different sizes (3*3m, 3*8.4m, 5*10m), aspect ratios (2, 2.8), and the same conditions (Northridge earthquake, CP 2-50, ρ=4.4%, distance from a source 15km) can be compared as presented in Table 8. Considering Table 8, there are two comparison procedures between the modification factors for different sizes. The modification factors can be compared, firstly, by the modification factors which have been produced by similar earthquake imposed to the models, secondly, by the general modification factors which have been developed by the response's average of three different earthquakes loading for generalization. The variations of modification factors in the second comparison procedure are greater than the first comparison procedure (Table 8). Because the comparison procedure should be done in such a way that all boundary conditions to be similar. The second comparison procedure has been presented for a demonstration of the fact that the variations of modification factors in the second comparison procedure are even small. Considering modification factor ratios within Table 8, average variations of the modification factors affected by different size of shear wall in the first comparison procedure (subjected to Northridge earthquakes) are 4.9% (COV=0.18%) in presence of tensile vertical loads and 6.6% (COV=0.33%) in presence of compressive vertical loads. The average variations of the modification factors in the second comparison procedure are 11.4% (COV=0.97%) in presence of tensile vertical loads and 9.9% (COV=0.74%) in presence of compressive vertical loads. Considering the results of the present study, the axial demand forces of moderate shear walls are commonly decreased, when the distance goes to a large value. It is because the axial force demand in close distance to a source should be greater than a far distance from the source. For instance, in Loma Prieta PE-10-50 and steel ratio 4.4%, the axial demand loads subjected to different distances 0, 15, and 30 km are provided as 91245.38, 84313.4, and 70337.64 N, respectively. The minimum of the factors for CP and LS is equal to 0.737 and 0.802, respectively. The values declare that, in the worst condition, the performance point of moderate shear wall can be affected up to 26.3% by near-field characteristics. The modification factors have greater values than 1.0 if the steel ratios are large and the performance level, which is adapted to be, low. I mean that the capacity of moderate shear wall in LS may be increased from provided capacity depending on the distance from a source and steel ratio. In case of a greater modification factor than 1, an increase of the distance from a source may consequently increase the effect of near-field characteristics, when a large amount of steel ratio and the low-performance level such as LS is selected. The effects of near-field characteristics on moderate shear wall are almost reduced when the distance from a source is increased. Clearly, the modification factors should be different, if the size of moderate shear walls is changed. However, based on the fact that the PBSD method is an estimation method, the proposed modification factors are acceptable, if the difference of the values or ratios of the modification factors produced by other moderate aspect ratios below. The results of the present study show that the modification of the PBD method for moderate shear wall should be accounted for in a wide range of steel ratios and distances from a source earthquake if the collapse-prevention performance level has been adopted. However, in life-safety performance level, this modification should be accounted for in a narrow range of low steel ratio intermingled with a small distance from a source of an earthquake. The variations show that the general modification factors, which are presented in the present study in the last part for moderate shear wall, can be utilized for different sizes of moderate shear wall with relatively high confidence (88.6% captured from the maximum case of average variation).

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Tables

Table 1. Collection of horizontal components of near field earthquakes and their major characteristics and their Scaled vertical earthquakes records

Horizontal earthquakes loading collection (Iwan, 1997, SAC, 1997) and their Scaled vertical earthquakes records												
		2-50						**10-50**				
Index	Record	**Magnitude (Richter)**	**Distance (Km)**	**PGA (m/s^2)**	**PGA (m/Sec^2)** ***(Scale factor)***			Index	Record	**Magnitude (Richter)**	**Distance (Km)**	**PGA (m/s^2)**
					d=0 km	d=15km	d=30km					
LA26	Northridge, 1994, California, Rinaldi RS	6.7	7.5	9.253	13.01 ***(2.713)***	11.77 ***(6.61)***	10.53 ***(7.52)***	LA16	Northridge, 1994, California, Rinaldi RS	6.7	7.5	5.686
LA22	Kobe, 1995, Nishi-Akashi	6.9	3.4	9.027	13.02 ***(3.58)***	11.77 ***(4.42)***	10.53 ***(6.79)***	LA12	Loma Prieta, 1989, San-Francisco, Gilroy, Ary 3, Gilroy sewage plant	7	3.5	4.638
LA24	Loma Prieta, 1989, San-Francisco, Gilroy, Ary 3, Gilroy sewage plant	7	12	9.509	13.88 ***(3.11)***	12.55 ***(5.65)***	11.22 ***(12.08)***	LA07	Landers,1992, Los-Angeles, Barstow-Vineyard & H	7.3	36	4.129

Table 2. Shear wall specimens' properties- Concrete(Lefas .L et al., 1990).

Shear walls Indices	Axial load (KN)	f'_c (MPa)	f_t (MPa)	E_c (MPa)
SW21	0	36.4	2.00	30,150
SW22	182	43.0	2.16	32,800
SW23	343	40.6	2.10	31.850
SW24	0	41.1	2.12	32,050
SW25	325	38.3	2.04	30,950
$\vartheta_0 = 0.15$ assumed for all walls				

Table 3. Shear wall specimen properties- Reinforcement (Lefas .L et al., 1990).

Zone	ρ_x (%)	f_{yx} (MPa)	ρ_y (%)	f_{yy} (MPa)
1	0.820	520	2.090	470
2	0.820/0.336*	520/420*	3.312	470
3	0.818	520	0.810/0.203*	470/420*
4	1.022	520	0.810/0.203*	470/420*
$\vartheta = 0.33$ * Belong to the additional reinforcements				

Table 4. Comparisons of displacement results of the moderate shear walls Analyses with experiments and other corresponds analyses results

Shear walls	Experimental results	Present study	Variation %
	D_{u-EXP} (mm)	D_{u-PM} (mm)	$\frac{D_{u-EXP} - D_{u-PM}}{D_{u-EXP}} * 100$
SW21	20.6	20.685	-0.4126214
SW22	15.3	15.298	0.0130719
SW23	13.2	13.183	0.1287879
SW24	18.1	18.278	-0.9834254
SW25	9.5	9.396	1.0947368
Mean%	--	--	-0.03189
COV	--	--	0.00587
D_{u-EXP}: Tested by (Lefas .L et al., 1990)			

Table 5.The results of actual performance points (CP, 2-50).

		CP, 2-50			LS, 10-50		
ρ %	Distance From Source (km)	Northridge Earthquake	Kobe Earthquake	Loma Prieta Earthquake	Northridge Earthquake	Lenders Earthquake	Loma Prieta Earthquake
		F_V=Vertical Force (N) =m*PGAv			F_V=Vertical Force (N) =m*PGAv		
		V=Shear demand (N)			V=Shear demand (N)		
		M_L=Lumped Mass (kg)			M_L=Lumped Mass (kg)		
0.39%	0 km	73788.04	67217.07	60269.74	72828.76	92654.43	77555.09
		272803.2	291496.2	308619.8	279057.1	292612.3	311216.4
		5671.64	5230.90	4342.20	9092.23	14872.30	11455.70
	15 km	63462.75	60364.80	57069.87	67631.59	97070.40	75100.36
		286032.1	308129.1	309398.1	280682.6	263551.8	303268.6
		5387.33	5128.70	4547.40	9354.30	17120.00	12271.30
	30 km	57081.84	58083.05	53328.66	60507.57	85667.84	77610.00
		282880.4	278046.6	287481.6	260717.1	250749.6	246407.6
		5426.03	5433.40	4753.00	9352.02	16732.00	14188.30
1.05%	0 km	64345.51	34844.06	28330.47	88111.92	129814.50	103039.40
		954956.0	954956.0	954956.0	689454.0	954956.0	954956.0
		4945.85	2711.60	2041.10	11000.24	20837.00	15220.00
	15 km	64482.31	59258.42	51324.48	80253.07	117168.80	97285.36
		719993.8	727293.3	797164.3	737016.6	695086.8	745276.5
		5473.88	5034.70	4089.60	11100.01	20664.70	15896.30
	30 km	62513.10	66974.99	64962.68	72347.54	99904.00	94555.51
		765492.5	736372.8	720699.5	809901.7	804038.4	756286.8
		5942.31	6265.20	5789.90	11182.00	19512.50	17286.20
4.4%	0 km	21232.32	20575.42	16830.89	69353.94	117978.10	91245.38
		700082.0	679436.9	788501.7	756999.1	602647.3	693695.6
		1632.00	1601.20	1212.60	8658.42	18937.10	13477.90
	15 km	17367.14	19213.35th	15833.08	62070.92	105848.10	84313.40
		733671.3	673542.6	775905.9	764031.3	605517.2	676748.2
		1474.29	1632.40	1261.60	8585.19	18668.10	13776.70
	30 km	15704.89	17928.20	16402.52	52452.10	77152.77	70337.64
		799451.0	683448.2	709168.8	678293.8	648212.5	632984.2
		1492.86	1677.10	1461.90	8106.97	15068.90	12858.80

Table 6. The results of pseudo performance points

ρ %	Distance From Source (km)	Northridge Earthquake					
		2-50			10-50		
		Vertical load	V'=Shear capacity		Vertical load	V'=Shear capacity	
			Compressive vertical load	Tensile vertical load		Compressive vertical load	Tensile vertical load
0.39%	0km	±73788.04	196807	196585	±72828.76	202445	215566
	15km	±63462.75	196917	200002	±67631.59	195664	207579
	30km	±57081.84	189580	178111	±60507.57	177951	174988
1.05%	0km	±64345.51	666856	671074	±88111.92	478382	501197
	15km	±64482.31	479674	483077	±80253.07	496205	517023
	30km	±62513.10	499118	469757	±72347.54	543853	537376
4.4 %	0km	±21232.32	499641	500759	±69353.94	451084	462507
	15km	±17367.14	495775	497023	±62070.92	448378	454611
	30km	±15704.89	496130	495342	±52452.10	486934	462003

Table7. The results of modification factors

ρ %	Distance From Source (km)	Northridge Earthquake, CP (2-50)							Northridge Earthquake, LS (10-50)						
		V_d=Shear demand (N)	V_c=Shear capacity (N)		Shear ratio (SR)		Modification factor		V_d=Shear demand (N)	V_c=Shear capacity (N)		Shear ratio (SR)		Modification factor	
		Absolute values	Compressive vertical load V_{cc}	Tensile vertical load V_{ct}	$\frac{V_d - V_{cc}}{V_{cc}}$	$\frac{V_d - V_{ct}}{V_{ct}}$	V_{cc}	V_{ct}	Absolute values	Compressive vertical load V_{cc}	Tensile vertical load V_{ct}	$\frac{V_d - V_{cc}}{V_{cc}}$	$\frac{V_d - V_{ct}}{V_{ct}}$	V_{cc}	V_{ct}
							$\frac{SR}{SR_{30km}}$	$\frac{SR}{SR_{30km}}$						$\frac{SR}{SR_{30km}}$	$\frac{SR}{SR_{30km}}$
0.39%	0km	272803.2	215139	208987	0.268034	0.305362	0.54463	0.51912	279057.1	202445	215566	0.378437	0.294533	0.81365	0.60119
	15km	286032.1	215140	207691	0.329517	0.377202	0.66956	0.64125	280682.6	195664	207579	0.43451	0.352171	0.93421	0.71884
	30km	282880.4	189580	178110	0.49214	0.58823	1	1	260717.1	177951	174988	0.46511	0.489916	1	1
1.05%	0km	954956	729375	705402	0.309279	0.353776	0.57951	0.56195	689454	478382	501197	0.441221	0.375614	0.90194	0.74065
	15km	719993.8	524425	504382	0.372921	0.427477	0.69876	0.67902	737016.6	496205	517023	0.485307	0.425501	0.99206	0.83902
	30km	765492.5	499118	469757	0.53369	0.62955	1	1	809901.7	543853	537376	0.489191	0.507141	1	1
4.4%	0km	700082	499641	500759	0.40117	0.398042	0.65618	0.64834	756999.1	451084	462507	0.678178	0.63673	1.72569	1.36007
	15km	733671.3	495775	497023	0.479847	0.476131	0.78487	0.77554	764031.3	448378	454611	0.703989	0.680627	1.79137	1.45384
	30km	799451	496130	495342	0.611374	0.613937	1	1	678293.8	486934	462003	0.392989	0.468159	1	1

Table 8.Calculation of modification factor ratios of moderate shear walls (CP-2-50, ρ=4.4%).

Model	Size	Thick-ness	Aspect ratio	Modification factor		Modification factor ratio	
				Compressive vertical load	Tensile vertical load	Compressive vertical load	Tensile vertical load
1*	3m*6m	0.25m	2	0.78487	0.77554	1	1
2	3m*8.4m	0.3m	2.8	0.84371	0.85259	1.0749678	1.0993501
3	5m*10m	0.35m	2	0.8421	0.8525	1.0729165	1.0992341
Mean of variations%:						1.049295	1.066195
Cov (%):						0.1824	0.3286
1**	3m*6m	0.25m	2	0.98651	0.97975	1	1
2	3m*8.4m	0.3m	2.8	0.84371	0.85259	1.169253	1.149146
3	5m*10m	0.35m	2	0.8421	0.8525	1.171488	1.149267
Mean:						1.11358	1.099471
Cov (%):						0.9677	0.7421

* Northridge earthquake,15km

** General modification factors based on the average of moderate shear wall subjected to different earthquakes

Figures

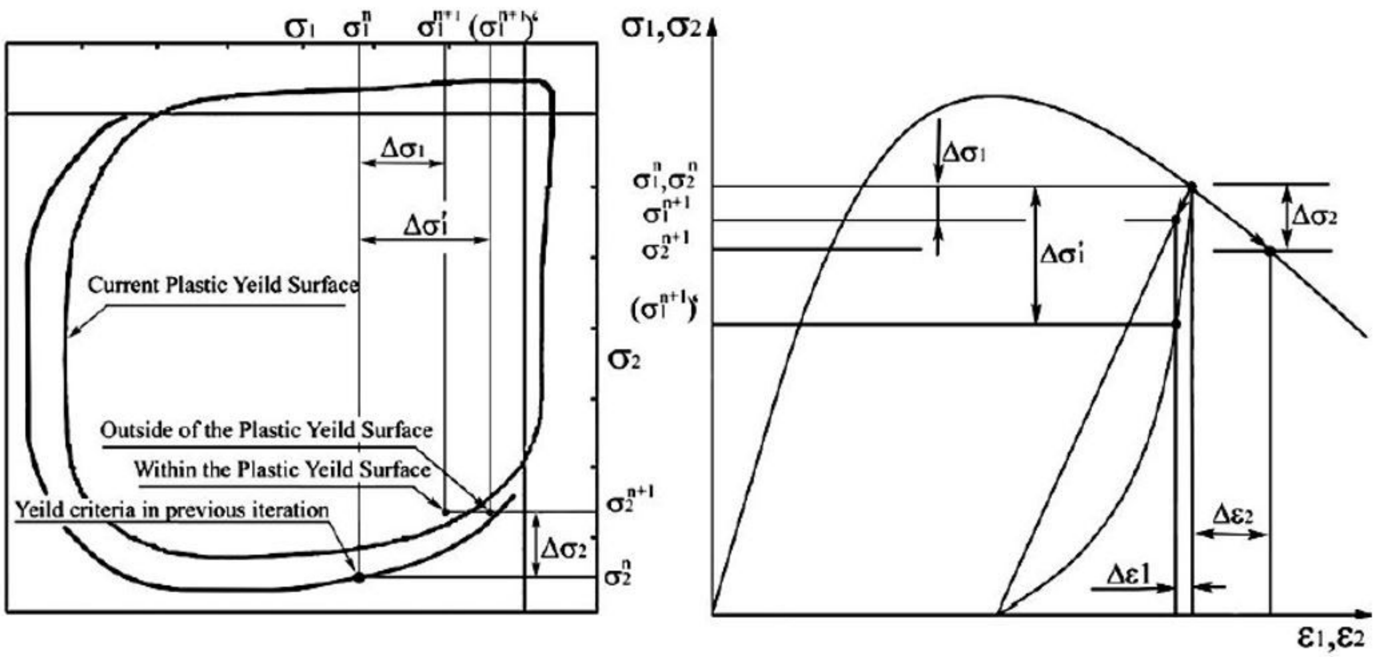

Figure 1

Schematically illustration of differences between actual and linearized unloading curves Consideration within an example of biaxial analysis

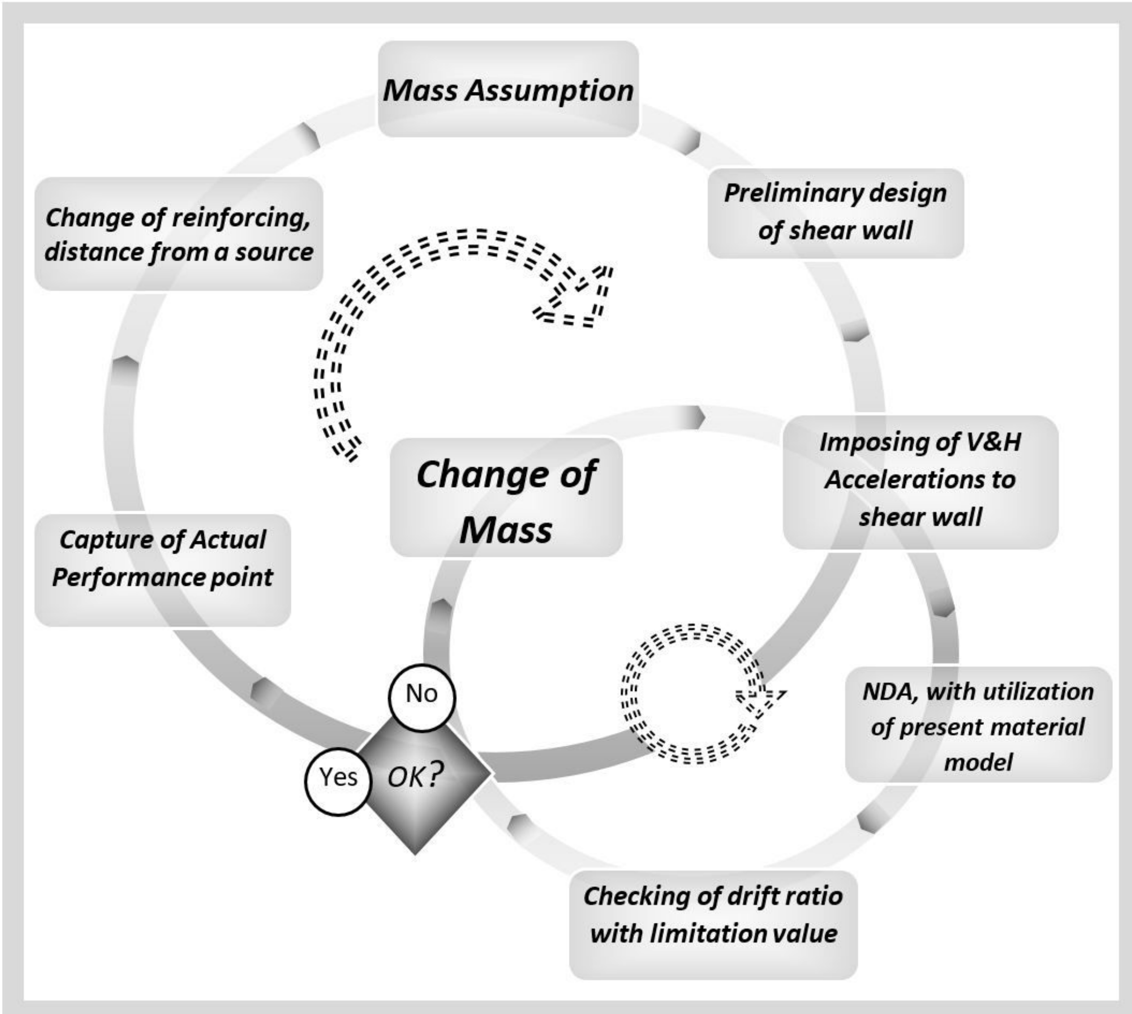

Figure 2

Flowchart of actual performance points determination.

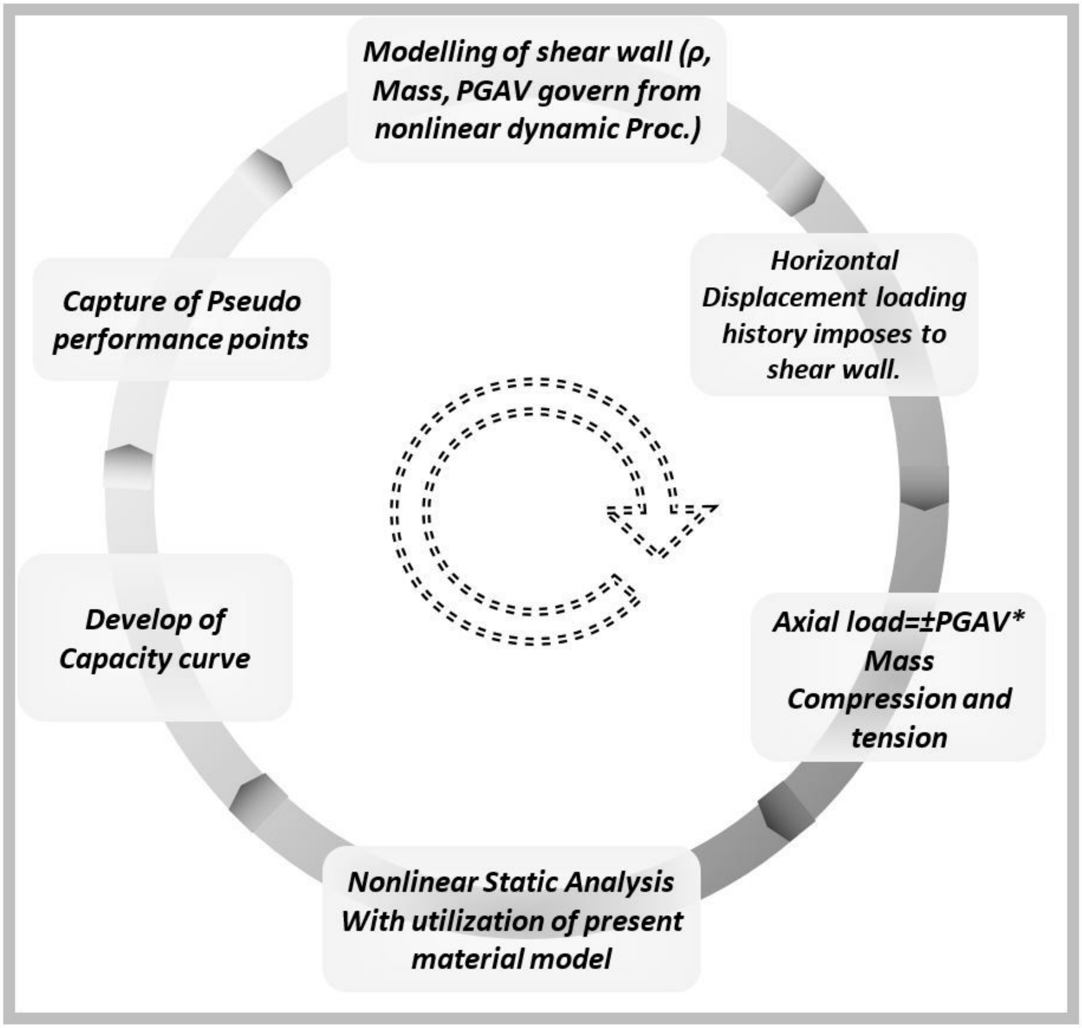

Figure 3

Flowchart of pseudo performance points and capacity curve determination.

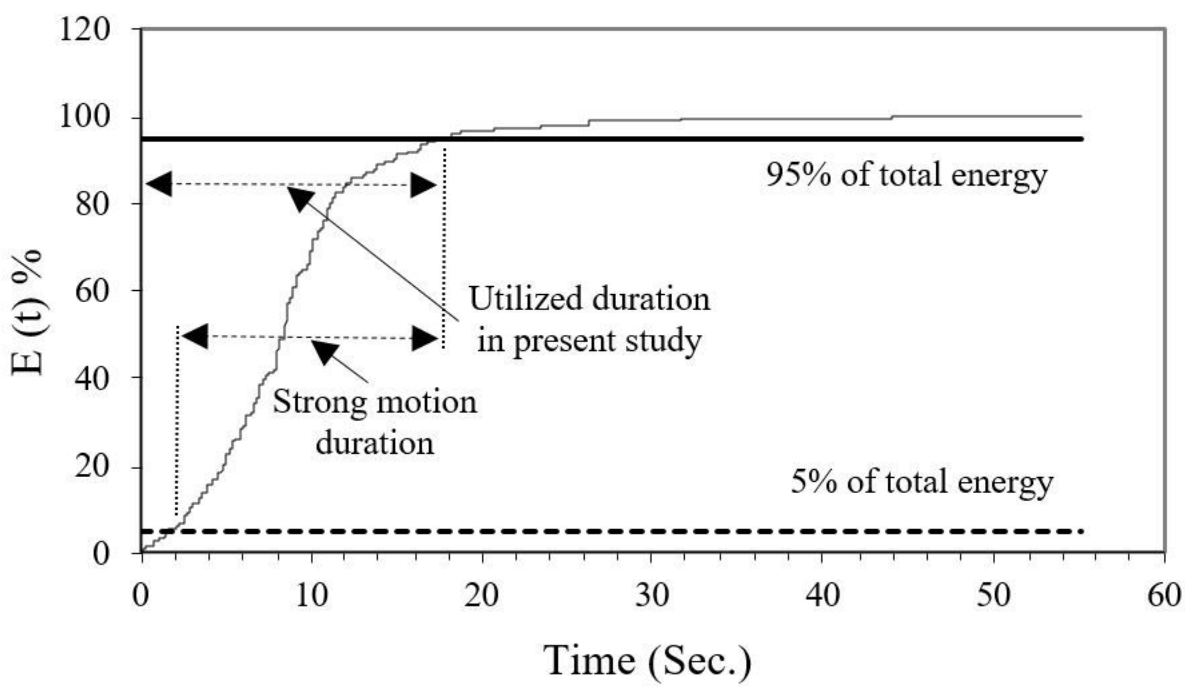

Figure 4

Utilized duration in present study subjected to horizontal component of Northridge earthquake.

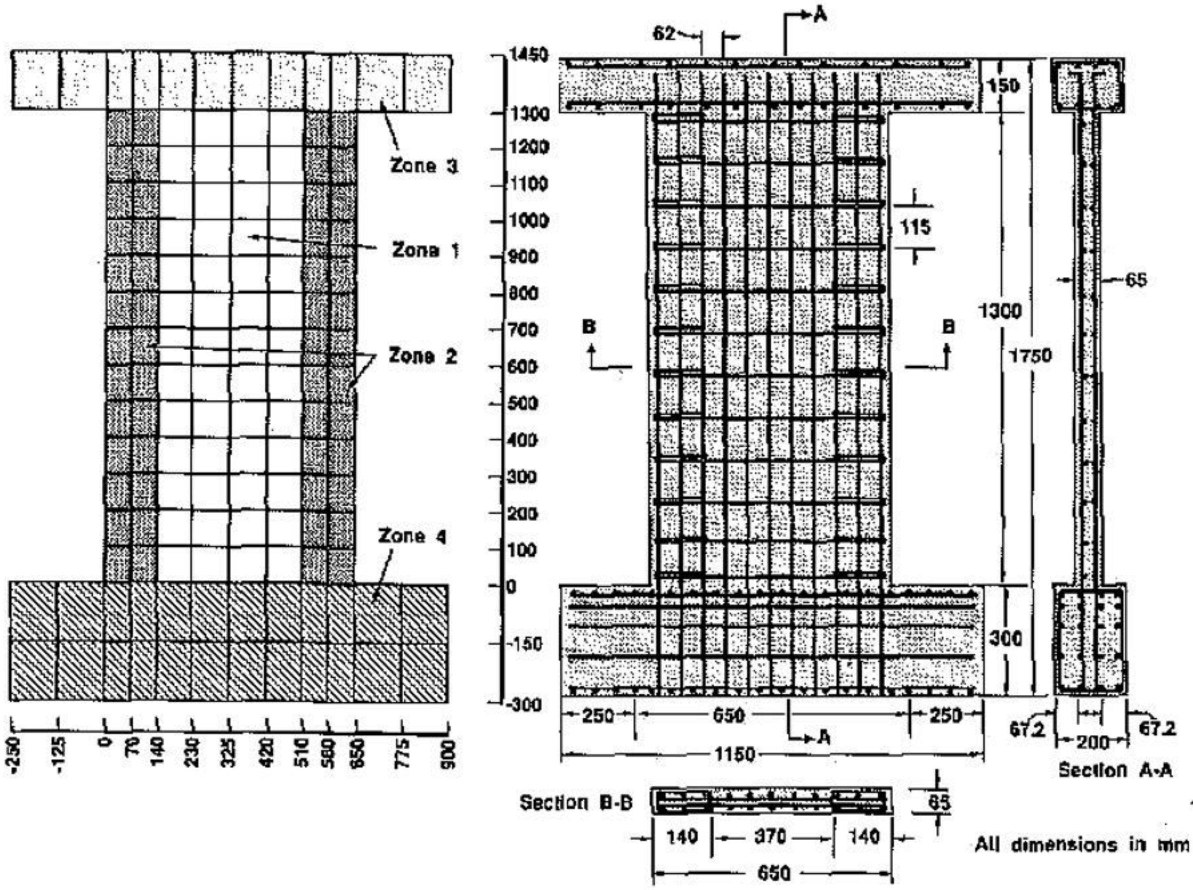

Figure 5

Finite element modeling of moderate shear walls by Vecchio (1992) And its experimental details tested by Lefas et.al (1990)

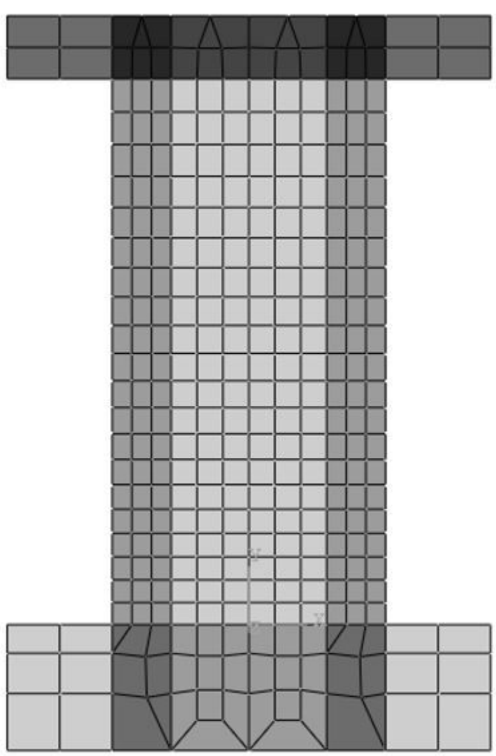

Figure 6

Finite element modeling The moderate shear walls in present study.

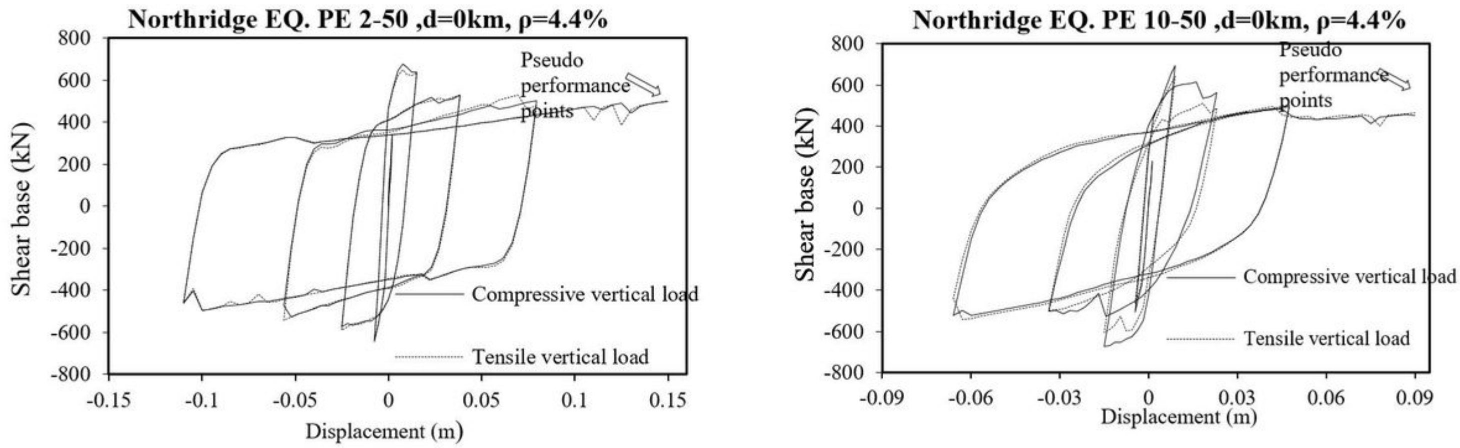

Figure 7

Hysteresis of the moderate shear wall subjected to Northridge earthquake, PE 2-50(left side), PE 10-50 (right side)

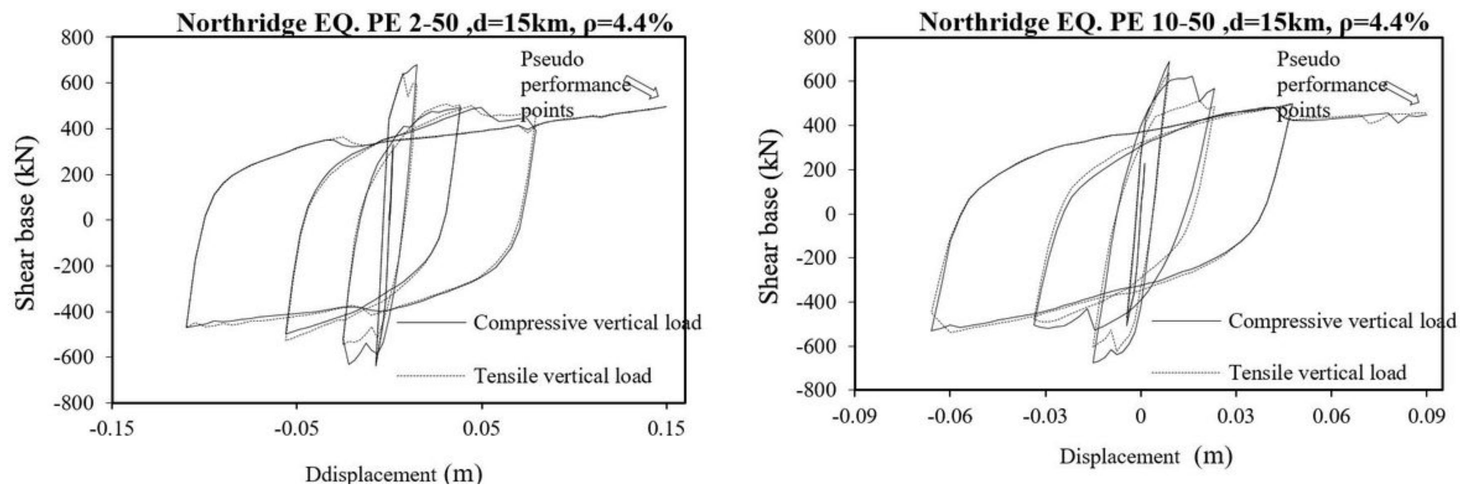

Figure 8

Hysteresis of the moderate shear wall subjected to Northridge earthquake, d=15 km, PE 2-50(left side), PE 10-50 (right side)

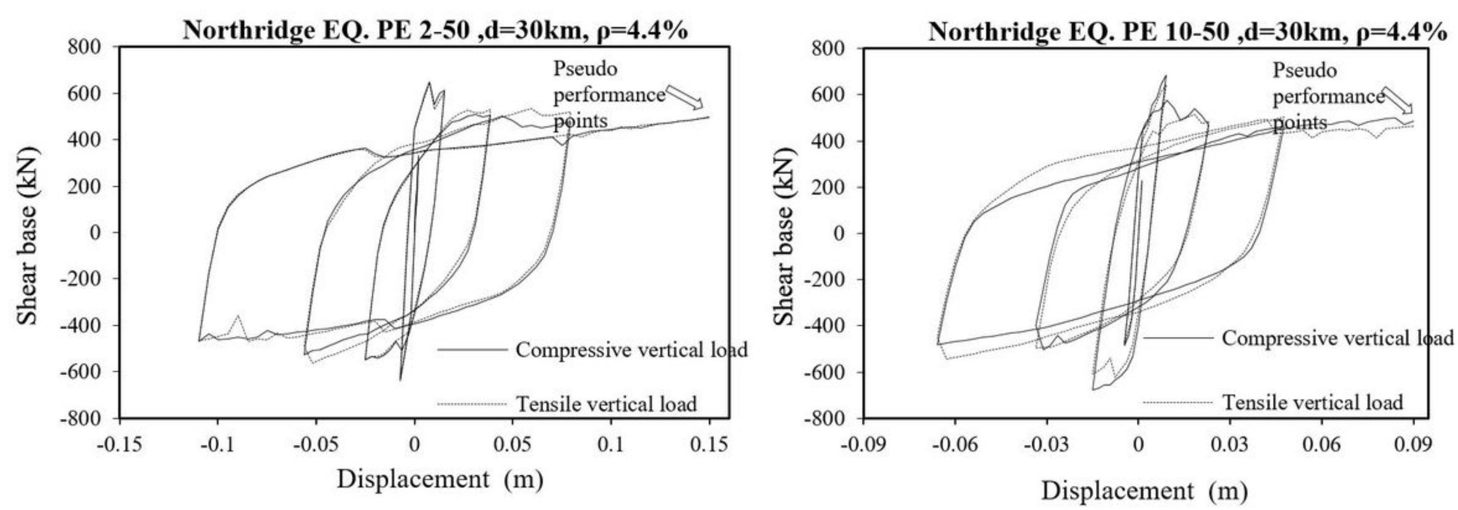

Figure 9

Hysteresis of the moderate shear wall subjected to Northridge earthquake, d=30 km, PE 2-50(left side), PE 10-50 (right side)

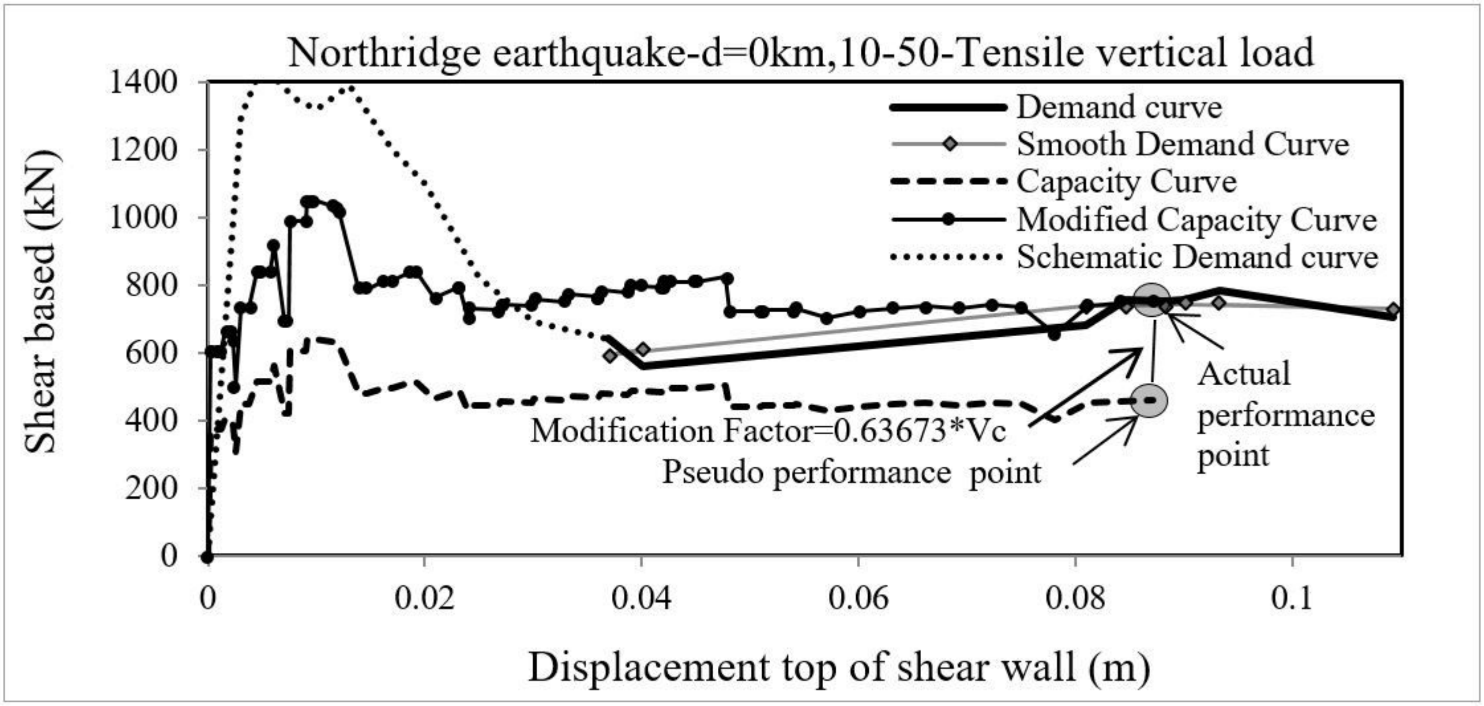

Figure 10

Demand-Capacity curve and modification factors For Northridge earthquake, CP (10-50), steel ratio 4.4%, In presence of tensile vertical load.

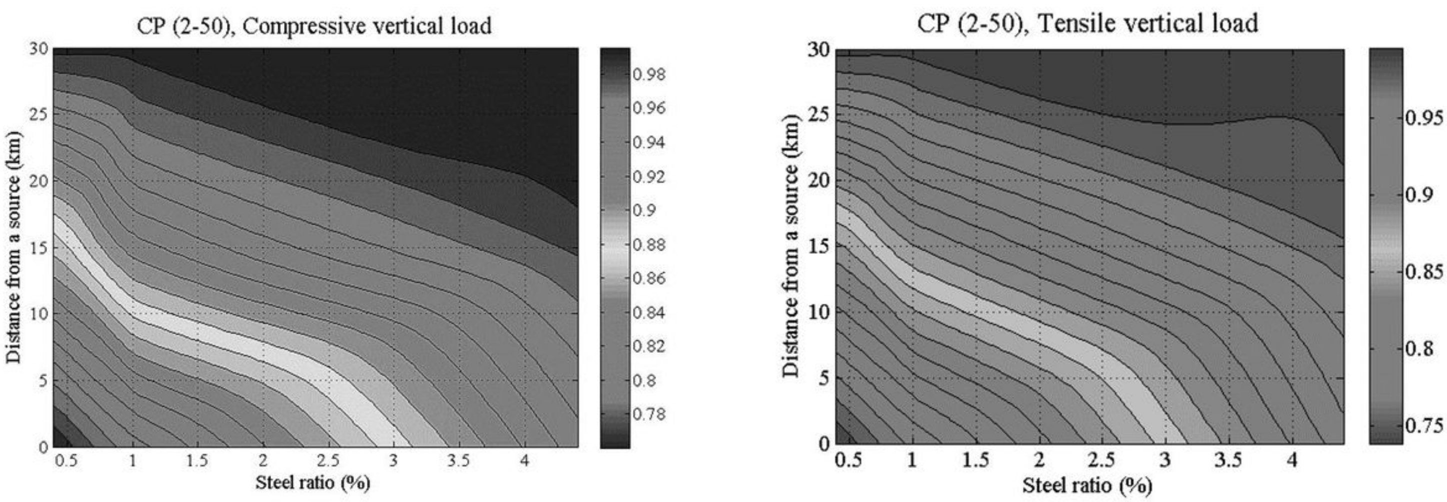

Figure 11

Two-dimensional surface of the generalize modification factors In CP (2-50)

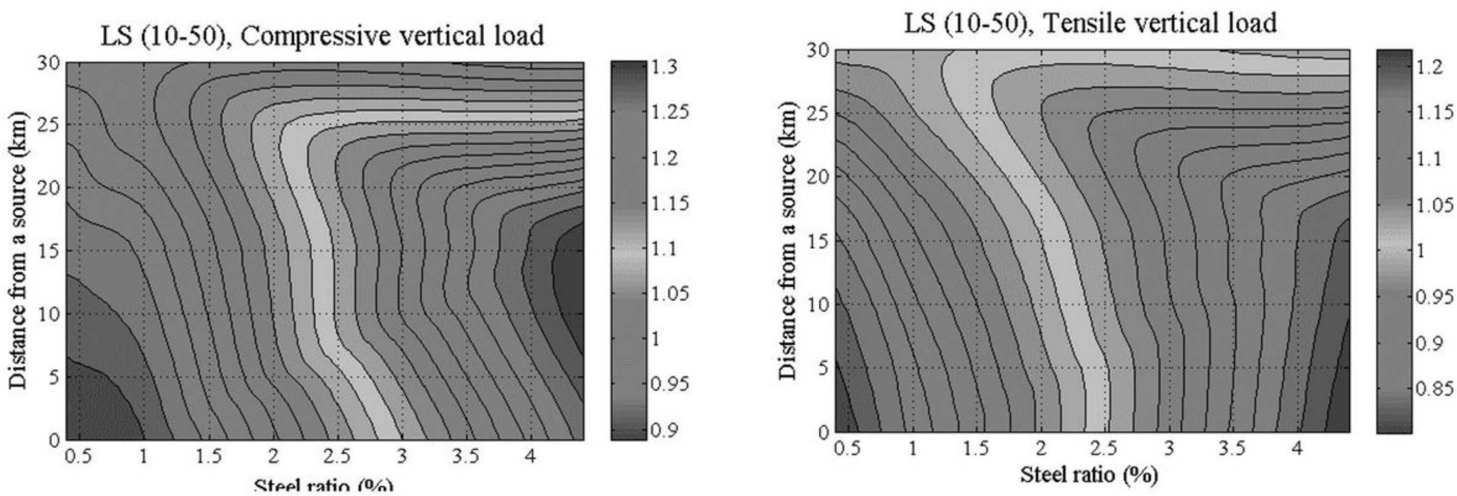

Figure 12

Two-dimensional surface of the generalize modification factors In LS (10-50)