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Research Article

Investigating of Damage Indexes Results Due To Presence of Shear Wall in Building with Various Stories and Spans

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ABSTRACT

The fundament of using shear walls that are considered seriously during the last two decades is to use the diagonal tensional field that emerges after buckling of the steel plate. In the system of these walls due to expansion of connection materials, tension balancing is done much better than other resistance systems such as frames and types of braces in which materials usually are clustered and connections are concentrated, and system's behavior, especially in plastic zone, is more suitable. Steel shear walls is applicable in different structural forms and is capable of creating new structural forms as well. The main responsibility of shear walls is to resist horizontal story shear and overturning moments induced by lateral forces. In this paper, the results of three damage indexes namely Park and Ang, lateral deformation and 2800 design code to the implementation of shear wall in building with different stories and spans is examined. To this goal, one of experimental studies, which are conducted before, is taken as the reference and after verification of the modeling, results for buildings with 5, 3, 7, 15 and 25 stories and 1 or 2 spans are represented.

Keywords Finite Element; Shear Wall; Steel Sheet.

1- INTRODUCTION

The idea of using steel shear walls with thin plates based on studies on plate beams was discussed for the first time in 80's in Alberta University, Canada. They focused their investigations and theoretical and experimental studies merely on steel shear walls with thin plates and during some experiments, to define their ultimate capacity, replaced the thin web with a series of tensile angled rods. studies on effectiveness and performance of these type of walls is well established but the matter left in shadow is studying of performance of these walls using well-known damage index around the world.

To examine shear wall's performance, several indexes are available, among which Park and Ang, Lateral Deformation and Energy are notable though the first one is more famous. This damage index is calculated by this equation:

$$D = \frac{\delta_m}{\delta_u} + \frac{\beta}{Q_y \delta_u} \int dE$$

In this equation, δ_m is the amount of maximum deformation under earthquake load, δ_u is the maximum bearable deformation under uniform laoding, Q_y is yielding resistance (shear, bending or axial resistance), β is a constant and $\int dE$ is the cumulative energy absorbed by structure's strain. D could be calculated under static or dynamic loading. The following table illustrates Park & Ang damage index which is presented for different performance levels. The definition of this performance level is as following: 1- IO: in this stage the building is at service with no considerations. 2- LS: this performance level depicts that some damages are happened to the building but life safety is available. 3- CP: is the sign of collapse initiation. 4- Building's collapse.

Because of its simplicity, lateral deformation is among the most popular indexes which is determined through this equation:

$$\Delta_{DR} = \frac{\Delta_m}{H}$$

In which Δ_m is maximum roof displacement (corresponding to performance point) and H is building's height.

The third damage evaluation index is based 2800 design code. The relative displacement of each story is the displacement that, by assuming linear behavior of the structure, is calculated under earthquake loading.

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The real relative displacement of the design, the non-elastic lateral displacement of the design, at each story is the displacement that is obtained while analyzing the structure, in case that the real behavior of structure is given. In cases that structural analyze is done while linear behavior is assumed, the displacement can be attained through this relation:

$$\Delta_m = 0.7R\Delta_w$$

In this relation, R is the response modification factor and taken equal to 7.5. also Δ_w is the real relative displacement of the design in story.

Using pushover analysis, we get the maximum displacement of the structure and by placing in equation 3 the relative displacement of the design in story is attained which it shouldn't overpass the following criteria:

Δ_a = 0.025times the height ofthe floor (forup to 5 floor buildings)

Δ_a = 0.020times the height ofthe floor (forother buildings)

Table 1- displacement damage index

Performance levels	Park and Ang's damage index nonlinear dynamic analysis	Park and Ang's damage index nonlinear static analysis
IO	0.1-0.2	0
LS	0.2 – 0.5	0 – 0.3
CP	0.5 – 0.8	0.3- .5
Collapse	>0.8	>0.5

Table 2- displacement damage index

Performance levels	The limit of displacement/ story height ratio (%)	The limit of the residual displacement/story height (%)
IO	0.7	-
LS	2.5	1
CP	5	5

In this study the effect of shear wall presence in 3, 5, 7, 15, 25 stories buildings that have one and two spans is investigated on Park and Ang's damage index (D).

2- FINITE ELEMENT MODELING:

For this study, one of experimental studies that has been done by Gholhaki et al. is considered. In their study, they put a 3-story, 1-span frame under dynamic loading to investigate the behavior of moment resistant frame. Figure 1 depicts type of beam, column and respected dimensions.

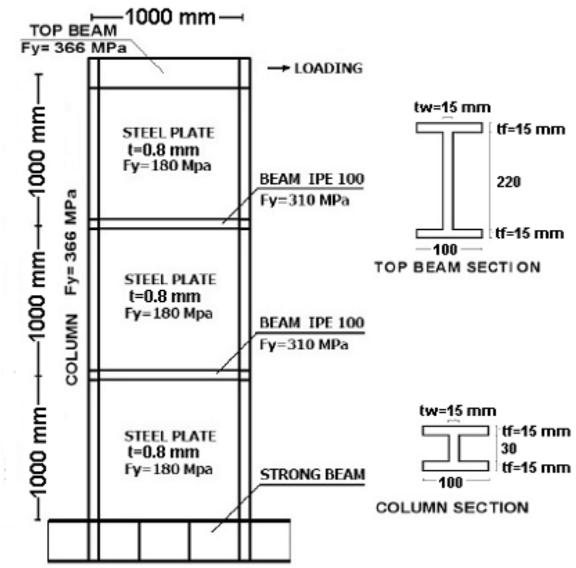

Figure 1- details of shear wall model

To model the steel shear wall, “Shell” elements, and to model beams and columns, “Beam” elements, is used. Materials characteristics are also listed in table 2. In figure 3, the computer model based on experimental work and its meshing is illustrated. Imposed loading is on the roof and is applied to building in a nonlinear static way.

Table 3- the mechanical characteristics of stell used in shear plate

Members	Yielding resistance(MPa)	Elasticity module(GPa)
Shear wall plate	180	210
Column	366	210
Middle beams	310	210
Upper beam	366	210

(B) (A)

Figure 2-meshing of A steel plate B beams and columns in 3-story shear wall

To verify the model, we compare the results from this study to those of Gholhaki and Shirazian’s study in which they modeled their experimental model in ANSYS (Fig 3). The reason for the benign difference between these two results is due to an initial displacement in shear wall’s center, modeled by [3], which is considered because of initial defects in steel plate. But here we ignored this defect.

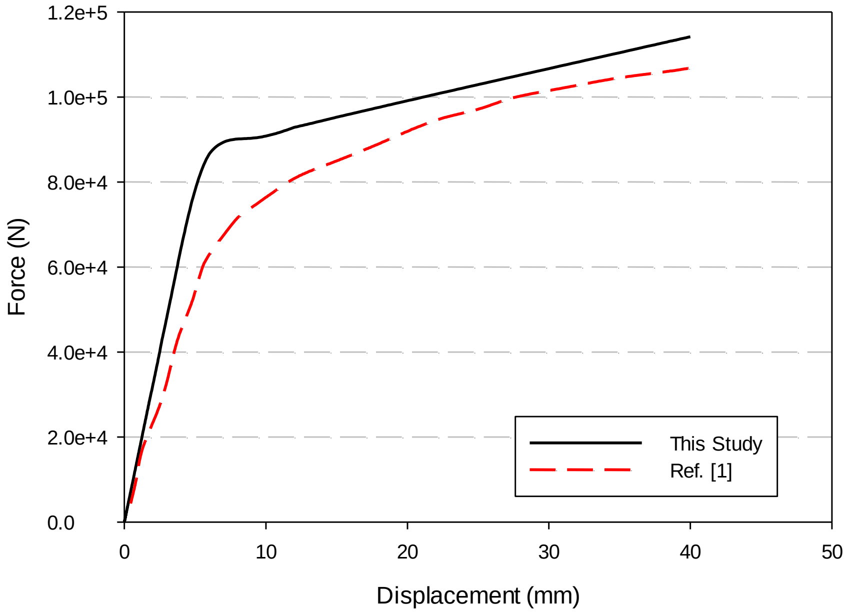

Figure 3- comparing results from this paper and reference [3] for 3-story structure

3- RESULTS:

The effect of shear wall on Park and Ang's damage index (D parameter) is presented in table 3, in which for different loadings the level of performance is defined as well.

The results for 3-story, 1-span frame shows that,based on 2800 design code's damage index, this frame wouldn't suffer from any damages by a 86 KN load, but by increasing it to 96 and 110 KN it would, furthermore, based on displacement damage index, under 86 and 96 KN loadings, this structure performs in IO zone and by rising the load to 110 KN it moves to LS zone. After investigating Park and Ang's index for this structure under 86, 96 and 110 KN loadings, it isconceived that the building would be in Life Safety, Collapse P and collapse, respectively.

The results for 3-story, 2-span frame illustrates that based on 2800 design code's damage index, this frame is not subjected to any damage by 86 KN loading, but increasing it to 190 and 200 KN would cause damages, furthermore, based on displacement index, this structure is in IO zone for 86 and 190 KN loadings, and by increasing it to 200 KN the performance level will move to LS zone. Considering Park and Ang's index for this structure for 86, 190 and 200 KN loadings, performance level is in LS, CP and COLLAPSE zones, respectively.

Comparing the results for 3-story, 1-span frame to 3-story, 2-span frame, it is clear that despite the apparent behavior of the structure in regard of advancing in the performance level associated with the increase in the mentioned tri-loadings, however, considering the fact that in resulted outcomes from each index per each loading, the level of performance for that loading aside, the amount of that index and the proximity of that amount to boundaries of each individual performance level of each method has a great potential to be effecting; because it is possible, for example, that the structure under a certain loading be in LS zone and a slight increase in the loading could push it to the CP zone; hence, ignoring this dilemma while studying vulnerability and defining performance levels could be very effecting.

The results for 5-story, 1-span frame show that the structure, based on 2800 design code's damage index, is not experiencing damage for 80 KN loading, but by increasing it by 10 KN the structure will not meet code's limits and based on 2800 design code the lateral displacement in this structure will be over the allowed displacement range that could lead to seismological vulnerability. Also based on displacement index, this structure is in IO zone for 80 and 90 KN loadings and by increasing it to 100 KN it moves to LS zone. According to the resulted amounts from this index for 80 and 90 KN, it is clear that the 10KN increase in the imposed loading into the building has led displacement damage index to increase to 0.0064 from 0.0368 and then by adding another 10 KN (from 90 to 100 KN) the damage index increases to 0.0101 which causes to performance level change to LS. This result clears that noticing to the number derived from damage index and whether it's near the performance level boundaries could be very determining. By considering Park and Ang's index for this structure under 80, 90 and 100 KN loadings it appears that the structure is in LS, CP and COLLAPSE zones, respectively; which indicates that increasing the loading in the negligible amounts could result in changes in damage index and lead in considerable changes in performance levels.

For 150, 160 and 170 KN loadings, the 5-story, 2-span frame agrees with damage index of 2800 standard in terms of allowed displacement in this code. According to the results it is clear that for those loadings the damage index has increased respectively from 51.29 to 57.75 and 86.1. Behavior of this structure based on displacement damage index for every of three loadings is in IO zone and based on Park and Ang's index it is, respectively, in LS, CP and CP zones.

The results for 5-story, 1-span frame shows that little changes in imposed loading doesn't lead to considerable changes in structure's behavior and it indicates that for assessing vulnerability of structures based on damage index and all methods of it, it is incorrect to generally speak about structures and the final result of vulnerability for each structure is reliable only after specific study on that certain structure; and generalizing the results of other studies to the structure under consideration, especially when that structures is strategically, usage wise or … high-profile, cannot be accurate, because factors such as what is mentioned earlier in this study has effects on different damage index methods.

The results from analyzing the 7-story, 1-span indicates that this structure has suffered from excessive displacement over the allowed limits in 2800 standard, which in comparison to 5-story, 1-span frame under the same loading that based on 2800 standard had an acceptable behavior, it is safe to say that by increase in stories of building, notable measures should be considered for designing the building, because by considerable increase in story levels, compared to medium and short buildings, affecting elements multiple and it is not possible anymore to design tall buildings with idealized assumptions of design codes that has been issued years ago.

After studying damage index derived for 7-story, 2-span structures based on 2800 standard, it is indicated that the increase in spans and consequently increase in resistant members against lateral loads induced on structure causes in reduction of lateral displacement of the 2-span frame against 1-span frame and hence getting to keep the lateral displacement results in the allowed zone by 2800 standard code. It is necessary to point out that the 1-span frame under the mentioned lateral forces has lateral displacement more than allowed amounts by 2800 standard.

In the predefined limits for Park and Ang, for example, for damage index of 0.3 both LS and CP are eligible to choose, a dilemma that needs notice and investigation and probably some modification.

2800 standard has chosen one single boundary and the resulted number and its distance from the boundary should be considered if this standard is the only index used in design process .

In investigations for 15 and 25-story, 1-span structures, since they are located in COLLAPSE zone even in their elastic behavior stage, the second term in Park and Ang's index is equal to zero.

Damage index for structures up to 5 stories has similar performance zones and in agreement with other discussed indexes, but rising the structure's height, since this index is only reliant on displacement and height parameters, for the studied 7, 15 and 25-story structures, it will have significant differences with the other two discussed damage indexes in terms of defining performance level zones.

The defined performance levels for displacement index are chosen in the manner that for most cases, structures are in IO or LS performance levels and the boundary limit from LS to CP is apparently too big which shows the fact that in this index structures are unlikely to reach CP and COLLAPS stages.

The studied 25-story structure in 1-span and 2-span moods under 20 KN loading has not the same behavior, based on 2800 standard and Park and Ang's index. 1-span structure under 20 KN loading, experiences an excessive displacement over the limits of 2800 standard, but in 2-span structure, due to presence of shear walls, the mentioned displacement is undoubtedly in the allowed zone. Moreover, based in Park and And's index,this structure is in CP and LS zones for 1 and 2-span modes, respectively, which is the result of steel shear wall's presence.

In the studied 25-story structure in 1-span mode under 40 KN loading the performance zone is COLLAPSE but the performance level of the structure in 2-span mode is CP which is improved by the performance of steel shear walls in second span.

Table 4- static analysis results summary for studied structures

Story No.	Span No.	Loading (KN)	Park and Ang's index
3	1	86	LS
		96	CP
		110	COLAPSE
	2	86	LS
		190	CP
		200	COLAPSE
5	1	80	LS
		90	CP
		100	COLAPSE
	2	150	LS
		160	CP
		170	CP
7	1	70	LS
		80	CP
		90	COLAPSE
	1	70	LS
		100	LS
		120	CP
15	1	30	LS
		40	CP
		60	COLAPSE
	2	120	LS
		140	CP
		170	CP
25	1	10	LS
		20	CP
		40	COLAPSE
	2	20	LS
		40	CP
		60	CP

4-CONCLUSION:

1- Displacement performance index has defined the boundary limits in the manner that fewer structures could be categorized in CP zone, which in comparison with the other two considered damage index might be seen as a shortcoming of this method.

2- In 2800 standard, load bearing system and lateral displacement under induced loads are considered as effecting parameters of this index. Its applicability to structures with different heights and changing frames is among its advantages, but lack of different performance levels is one of its disadvantages.

3- Investigating the behavior of structures with different stories in 1 or 2-span modes, and also investigating their performance levels based on implied loadings, concludes that the number of spans, due to presence of more members and of course more resistant and due to the concept of distributing the imposed loading between members by their stiffness ratio, has a significant role and consequently, 2-span frames have much better performance levels in compare to 1-span frames, given the same loading; and are capable of bearing even more loading in the same performance level zone in compare to their compatible 1-span structures.

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