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Investigation of seismic behavior of steel structure with mass variation in height

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ABSTRACT

Irregular buildings constitute most of the existing buildings in urban areas. These irregularities may be formed because of architectural, economic or building-type issues. Mass irregularity in height is one of the irregularities in a structure. In this research, seismic behavior of a regular 7-storey moment frame steel structure along with two moment frame steel structure having mass irregularities are analyzed (non-liner time-history dynamic analysis) using CSI SAP 2000 U.17.3. Results indicate that reducing mass in upper stories increases total displacement as well as damage concentration. Also, mass irregularity disturbs the ductility and performance of the structure.

1. Introduction

In some cases, mass irregularity in height, such as different usage of stories or mass concentrations due to architectural considerations is inevitable. Non-uniform geometrical, physical and strength-related properties of the building which are attributed to the so-called phenomenon can cause unfavorable concentrations of deflections during earthquake, resulting in a local or complete collapse structures are built for various purposes in which ascetic and architectural considerations are incorporated, causing irregularities. In recent years, numerous studies and seismic codes have tried to propose a method to estimate the real responses of different earthquakes with simple methods. Based on codes, structured are categorized into regular and irregular structures in plan and height. Structural irregularities vary significantly with one another, making their characterization process very difficult. It is worth noting that despite slight and superficial differences, criteria required to determine irregularity are of the same pattern in different codes. According to Iran's seismic code, 2800, mass regularity is fulfilled if distribution of mass in height is almost uniform and in no storey mass variation compared to its lower storey exceeds 50%. On the other hand, based on the above-mentioned codes, equivalent static analysis is only permitted for irregular building of up to 5-storeys or 18m (Valizadeh and Yaghmayi, 2011). Assessment of earthquake-induced damage in existing buildings has revealed that structural and non-structural failure due to seismic excitations have been significantly high in irregular buildings than that of regular ones, causing complete failure in some cases. This is the case when undesirable dissipative mechanisms followed by non-liner deformations are formed in some parts of the structures (Younesi and Tarverdi 2008); first only on seismic behavior of buildings irregular in height dates back to 1982. In 1990s tendency to this field met its peak. Most of these studies are based on a comparison made between the non-liner dynamic responses of regular buildings a reference with that of irregular ones while changing mass, stiffness, capacity or all in height. Valizadeh and Yaghmayi (2011) conducted some researches on seismic behavior of moment-resisting RC frames with mass irregularities in height through non-liner dynamic analysis. Damage index of the fore-mentioned buildings was based on the index introduced by Philippacopoulos and Wang (1984) and was compared with that of the regular buildings (Valizadeh and Yaghmayi, 2011).

In this research three 5-9 and 13-storey structural models with different irregularities have been analyzed based on NO.9 national code and 2800 seismic standard (4th edition) via non-liner dynamic analysis. Results indicated that, analysis type and effect of irregularity is significant in higher modes with notable differences between the first and second mode in most of the models. The ratio of mass irregularity have a negligible effect on damage index, in a way that damage index remains almost constant in various ratios. However, applying the irregularity in mid stories increases the damage index. This increase becomes more evident in near-fault applied records of BAM and Tabas. Moreover,

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mid-storey irregularity disturbs the displacement pattern in height (making non-uniform) when compared with similar cases for upper and lower stories. This behavior is consistent with increased damage index.

Max relative displacement is always attributed to the irregularities in upper stories. In all the models max relative displacement has occurred in three top stories signifying the damage concentration (Valizadeh and Yaghmayi, 2011). The effect of height irregularity in stiffness and seismic behavior of 2 ten-storey structural models considering several intensities was studied. In each storey a regular reference model is defined, then alterations are carried out on the stiffness of its stories, making it irregular. Models geometry includes 2D shear frame, several degrees of freedom and a bay. In this study strong beam-weak column criterion is assumed. In this regard, the stiffness of the beams was considered infinite (e.g. rigid). Therefore, any degradation in stiffness was created by increasing the length of the columns. 10-storey structural models were designed by static or spectral-dynamic and 20-storey models were designed by spectral-dynamic methods of the 2800 design code.

Analysis results reveal that in 10-storey models, using static analysis and considering seismic provisions such as controlling liner-drift, concluded in a regular model despite being significantly irregular in terms of stiffness distribution. Additionally, first storey was more sensitive to irregularity than other stories (Younesi and Tarverdi 2008). Valmundsson and Nau, (1997) evaluated the sensitivity of the structure to mass, stiffness and capacity variations.

It was concluded that, altering time period in irregular structures (having mass irregularity) gives a better estimation of seismic demands in these structures (Valmundsson and Nau, 1997). In 1998, Al-alikrawinker did some parametric studies on seismic response of irregular frames in height. Regular models were based on even distribution of mass in stories and equal liner drift in all stories caused by a triangular lood (stemming from stiffness distribution). Irregular models were created by multi-playing a reduction amplifying factor to mass, stiffness and capacity of the stories before being compared with that of their regular ones. They showed that mass irregularity have minor effect on the relative displacement of stories and ductility demands when compared with the reference regular model. Therefore, a soft story with major changes in its stiffness increases the relative displacement in the storey level; high sensitivity to minor changes modeling on storey beam-weak column mechanism. They sought to intensify the detrimental effects of height irregularity by limiting the yielding distribution in the storey and achieving more destructive effect. Other researchers have also studied on similar irregularities such as geometrical irregularity in height and irregularities stemming from non-continuous lateral resisting frames on seismic performance of structure (Al-ali and Krawinkler, 1998). In UBC97 code (Uniform building code, 1997) and Nehrp (2003) structures have been categorized regular or irregular taking into account the capacity rates, stiffness rates, mass rates and recession of a storey relative to its adjacent storey. These criteria and limitations have been expressed based on previous experience in seismic behavior of structures. Some of criteria are: (stiffness irregularity or soft storey), when the lateral stiffness of a storey is less than 70% of its upper storey or less than 80% of the mean stiffness of three upper stories (mass irregularity), if the weight of a storey is more than 150% of its adjacent storey (capacity irregularity or weak storey), if shear strength of a storey is less than 80% of its upper storey (shear strength of a storey is the sum of all the components of a storey, participating in storey shear during earthquake in a particular direction). If the structural is deemed irregular based on these criteria, equivalent static analysis is not solely allowed and more precise methods such as dynamic methods (e.g. response spectrum or history of the response).

2. Case studies

In this research, three 7-storey moment-resisting steel structures which have been analyzed (non-liner time-history dynamic analysis) in CSI SAP 2000 V.17.3 are compared with each other (Table 1).

One of the models is regular in plan and height, which the other two are regular in plan and irregular in height (mass irregularity). In irregular models, the mass of the storey is 50% reduced after the 4th storey. Models were analyzed using the time-history loading of three earthquakes based on the 4th edition of the 2800 standards. These data are Kobe, Nortridge and Manjil's data. In this analysis, overall displacement of the stories has been compared with that of the regular plan. Earthquakes were scaled based on the 4_{th} edition of the 2800 standard and were shown in Figs 1 to 6. Non-liner time history dynamic analysis was performed on 3D models in CSI SAP 2000 V.17.3 axis-to-axis distance of column is 4.5 m and was shown in Figs 7 to 34.

Table 1: Properties of stations for from the fault

Earth quake	year	section	MGA	PGA	PGV(cm/s)	PGD(cm)	S-Duration(s)
COBE	1992	Fortuna	7.3	1.00g	250.201	164.039	18.66
NORTH	1994	Sunland	6.7	0.999g	117.951	31.254	15.85
MANJ	1990	Abbar	7.4	0.999g	82.29	28.767	28.66

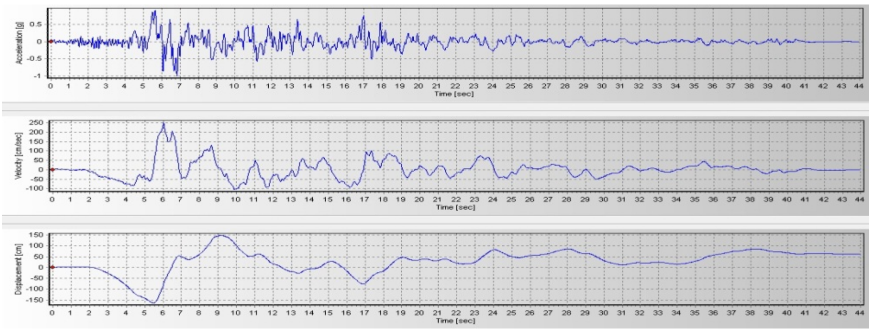


Fig. 1: Scaled accelero Fig (tog) of Kobe earthquake in X direction

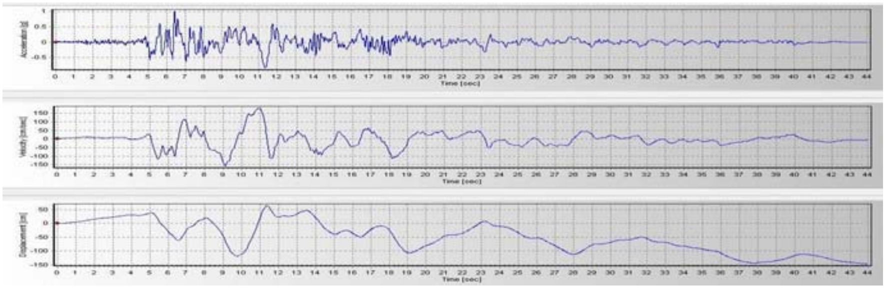


Fig. 2: Scaled accelero Fig (tog) of Kobe earthquake in Y direction

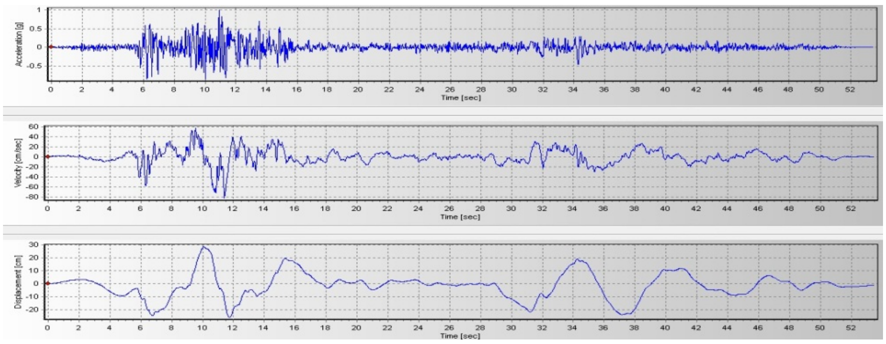


Fig. 3: Scaled accelero Fig (tog) of Manjil earthquake in X direction

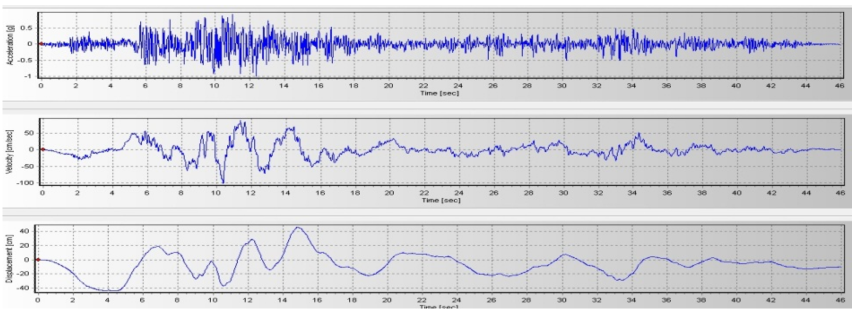


Fig. 4: Scaled accelero Fig (tog) of Manjil earthquake in Y direction

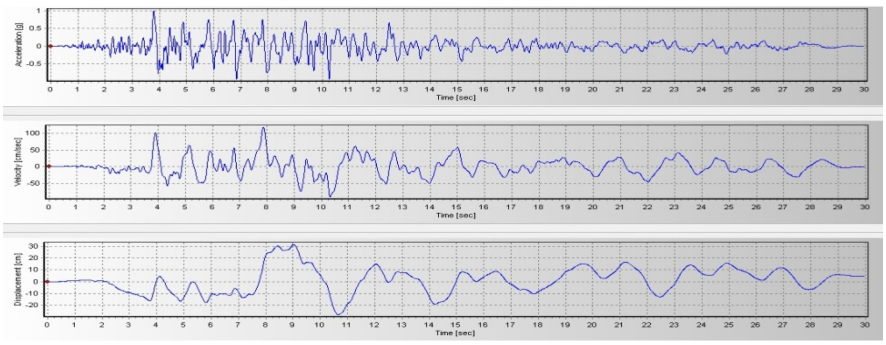


Fig. 5: Scaled accelero Fig (tog) of Nortridge earthquake in X direction

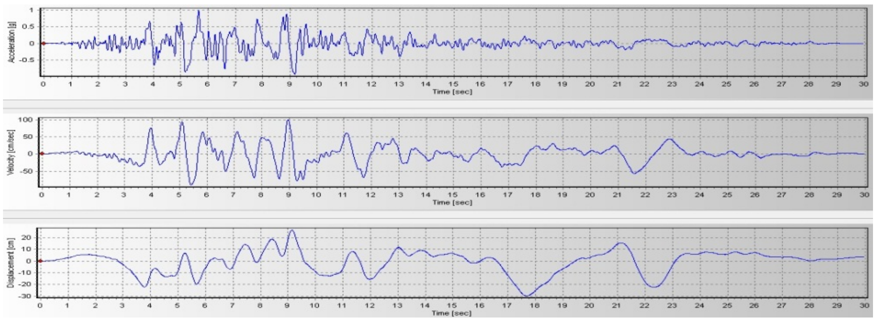


Fig. 6: Scaled accelero Fig (tog) of Nortridge earthquake in X direction

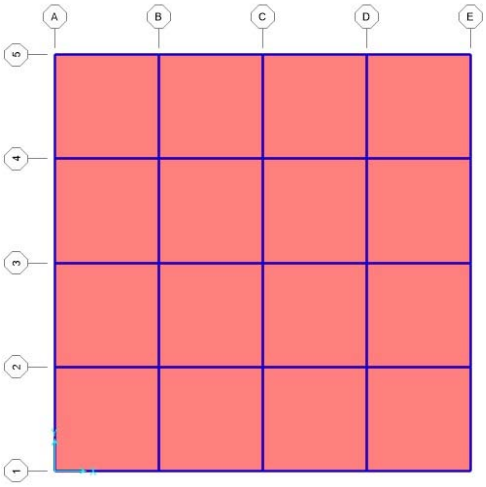


Fig. 7: Plan of models

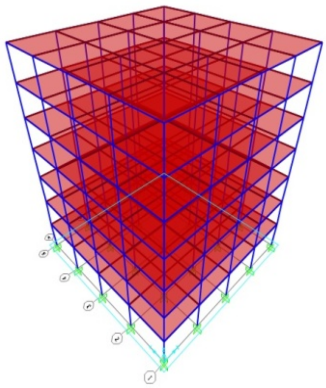


Fig. 8: 2nd irregular model

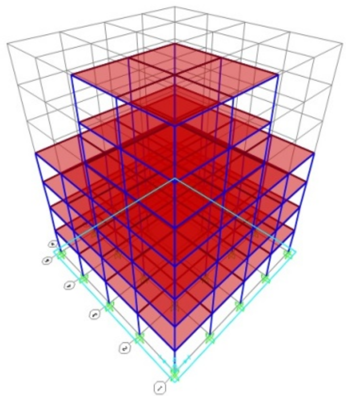


Fig. 9: 1th irregular model

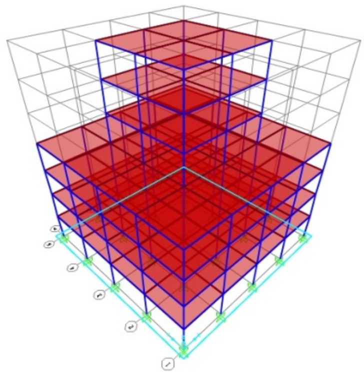


Fig. 10: Regular model

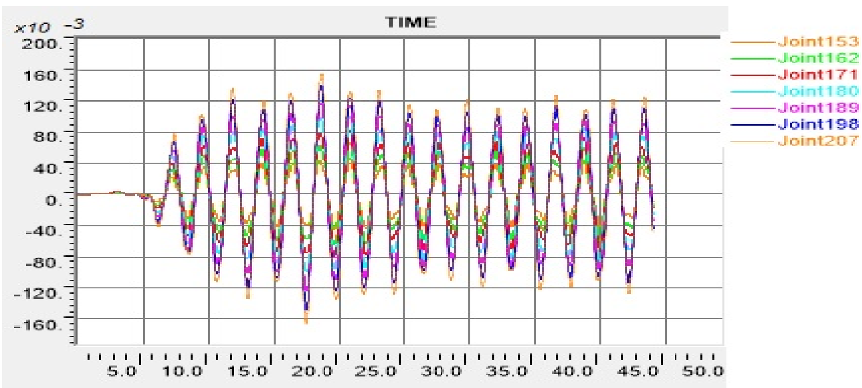


Fig. 11: Cyclic displacement curve of the regular model for the Kobe's earthquake in X direction

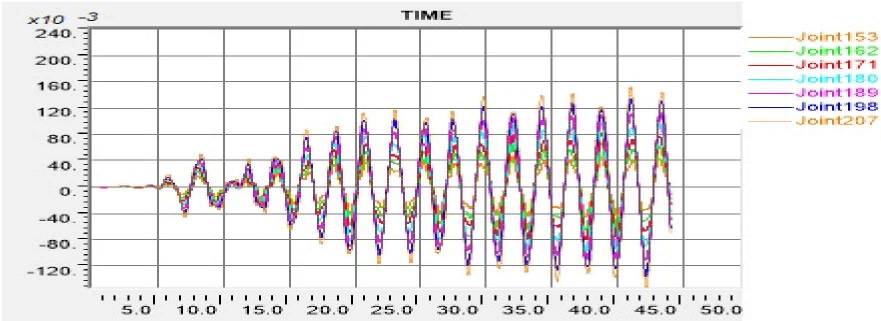


Fig. 12: Cyclic displacement curve of the regular model for the Kobe's earthquake in Y direction

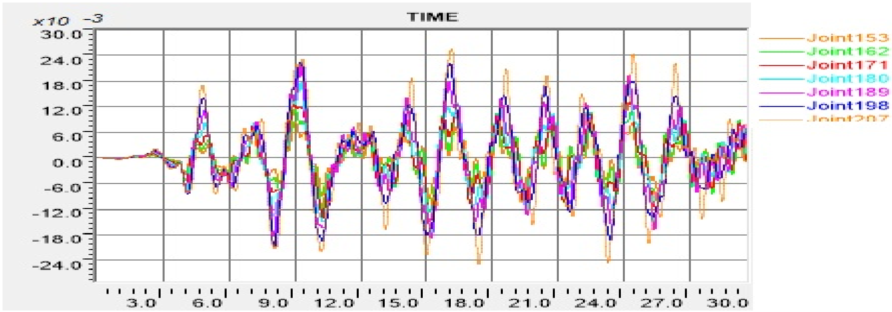


Fig. 13: Cyclic displacement curve of the regular model for the Nortridge's earthquake in X direction

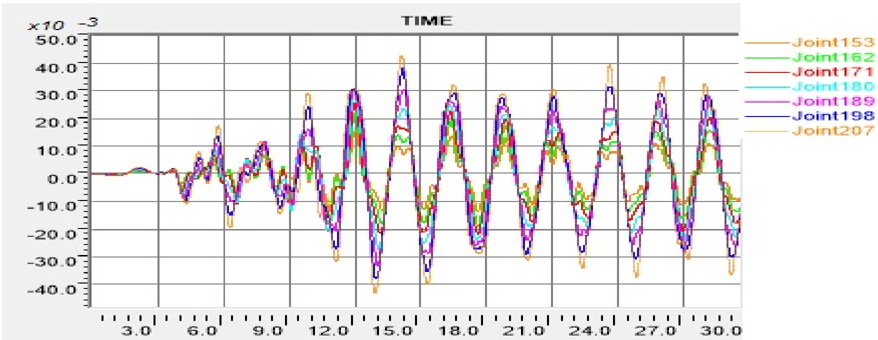


Fig. 14: Cyclic displacement curve of the regular model for the Nortridge's earthquake in Y direction

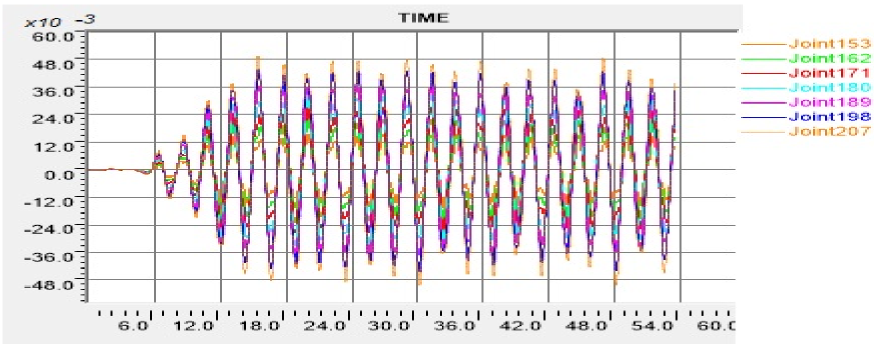


Fig. 15: Cyclic displacement curve of the regular model for the Manjil's earthquake in X direction

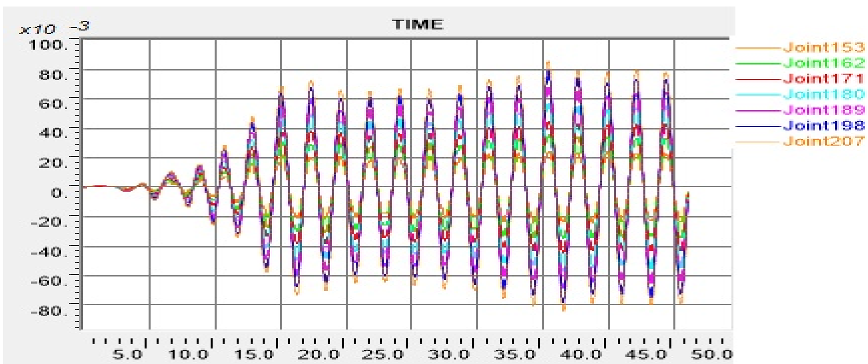


Fig. 16: Cyclic displacement curve of the regular model for the Manjil's earthquake in Y direction

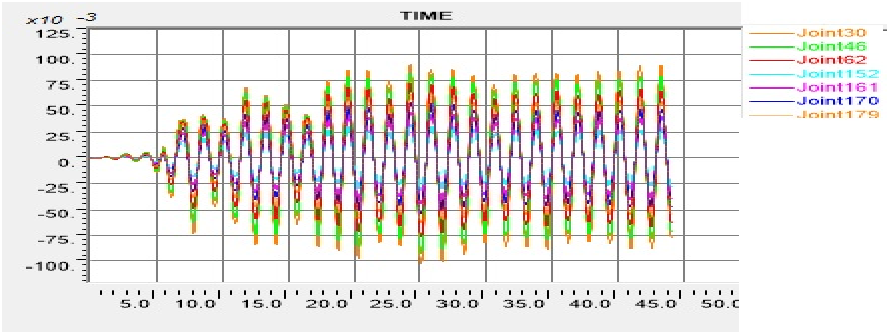


Fig. 17: Cyclic displacement 1th irregular model for the Kobe's earthquake in X direction

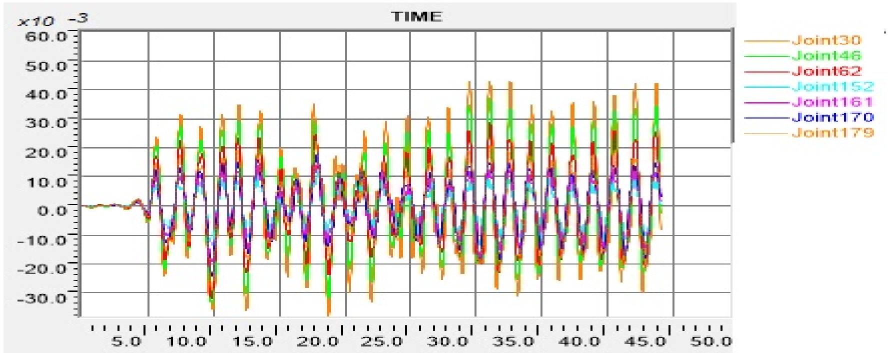


Fig. 18: Cyclic displacement 1th irregular model for the Kobe's earthquake in Y direction

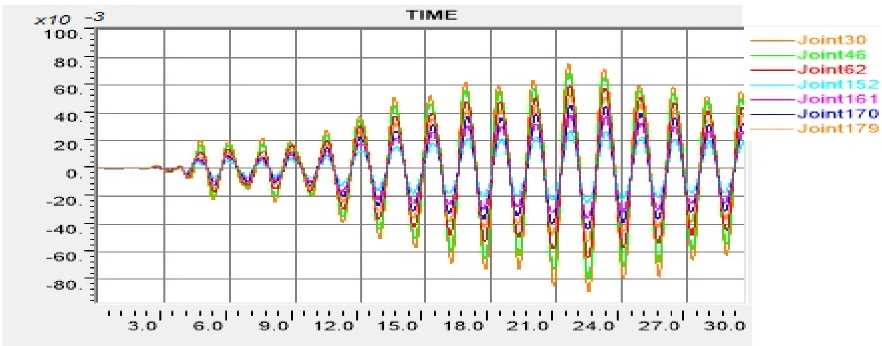


Fig. 19: Cyclic displacement 1th irregular model for the Nortridge's earthquake in X direction

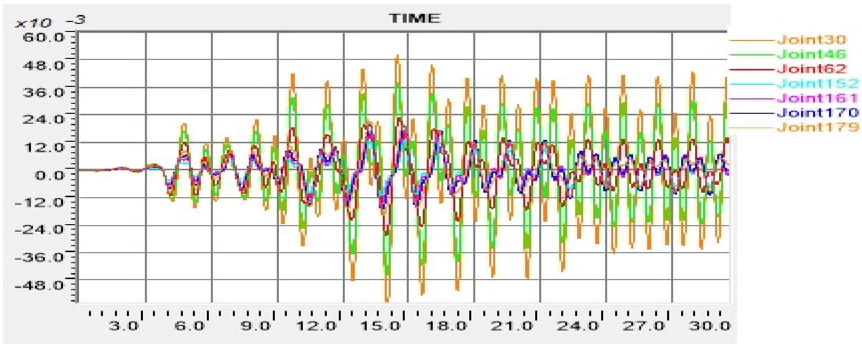


Fig. 20: Cyclic displacement 1th irregular model for the Nortridge's earthquake in Y direction

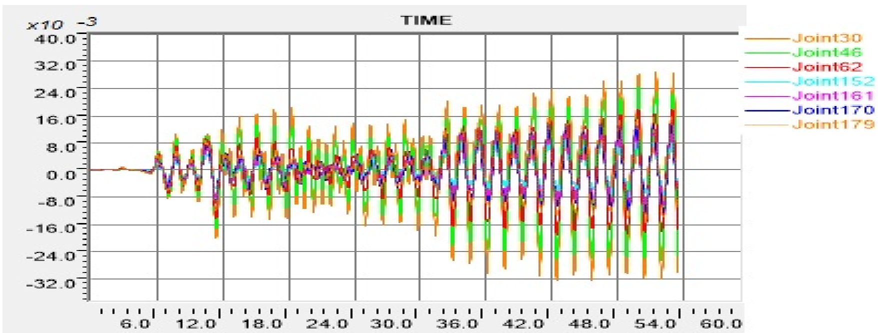


Fig. 21: Cyclic displacement 1th irregular model for the Manjil's earthquake in X direction

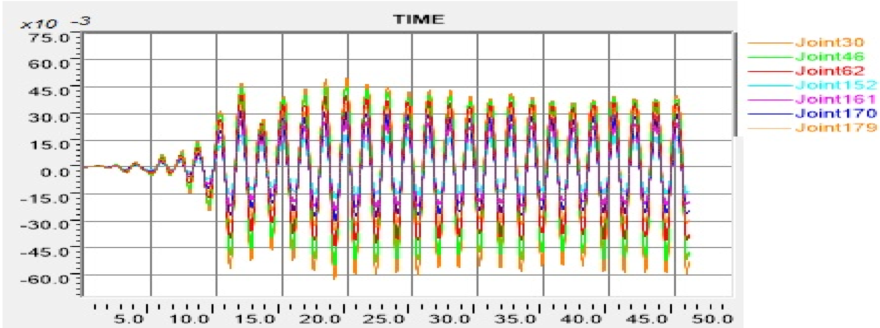


Fig. 22: Cyclic displacement 1th irregular model for the Manjil's earthquake in Y direction

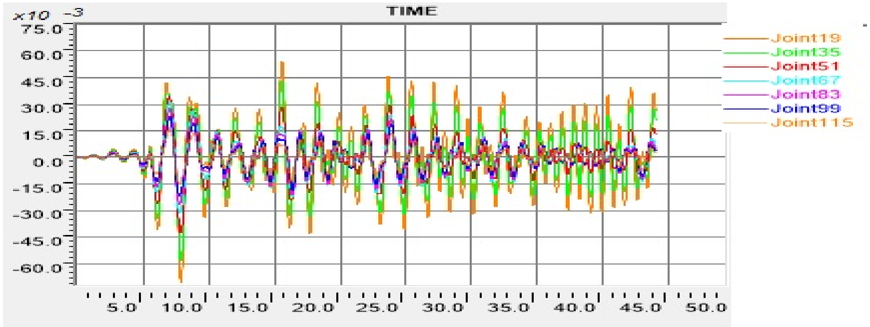


Fig. 23: Cyclic displacement 2nd irregular model for the Kobe's earthquake in X direction

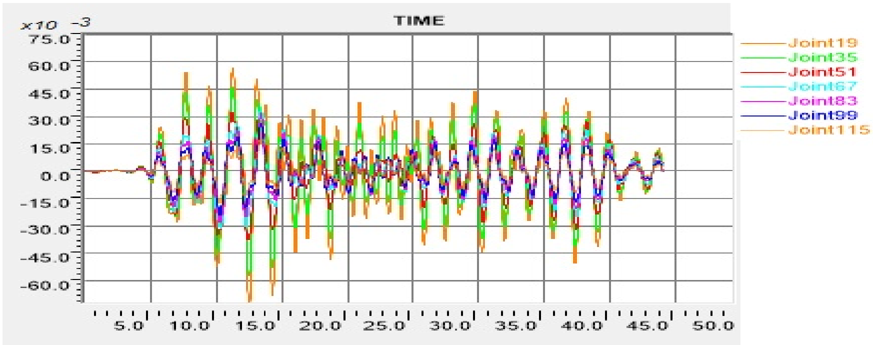


Fig. 24: Cyclic displacement 2nd irregular model for the Kobe's earthquake in Y direction

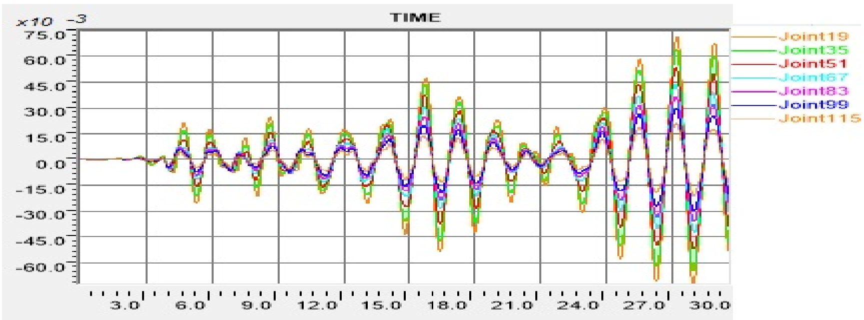


Fig. 25: Cyclic displacement 2nd irregular model for the Nortridge's earthquake in direction

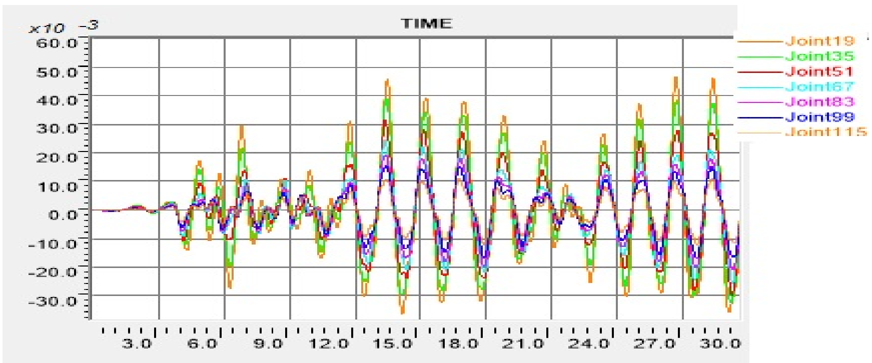


Fig. 26: Cyclic displacement 2nd irregular model for the Nortridge's earthquake in Y direction

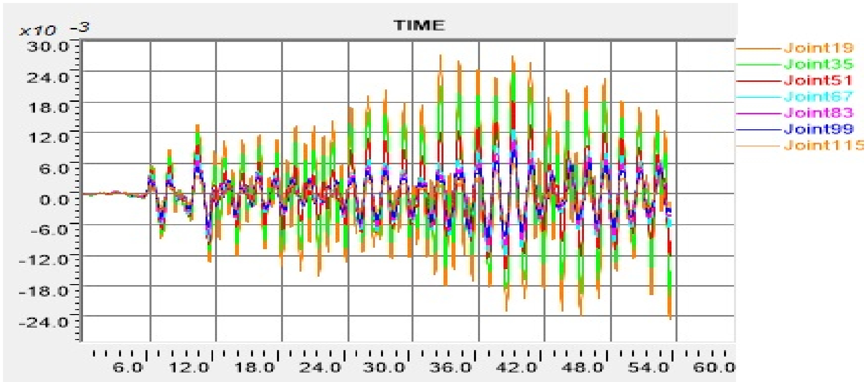


Fig. 27: Cyclic displacement 2nd irregular model for the Manjil's earthquake in X direction

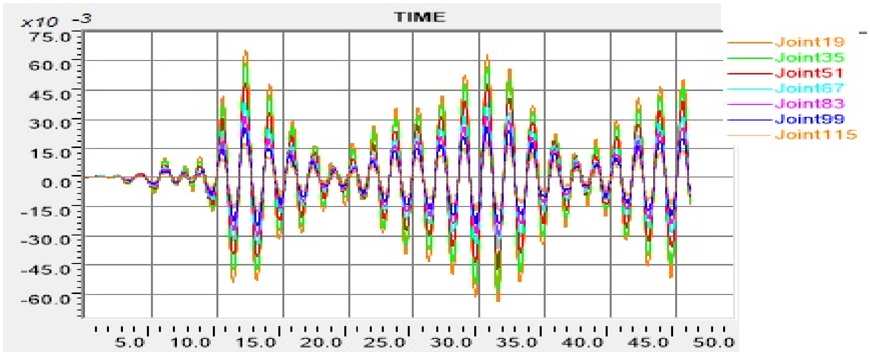


Fig. 28: Cyclic displacement 2nd irregular model for the Manjil's earthquake in Y direction

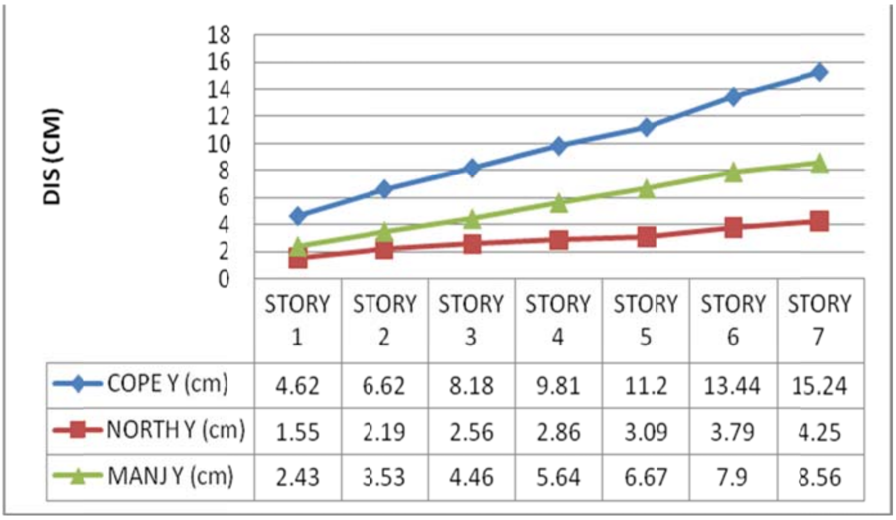


Fig. 29: Total displacement of the regular building in X direction

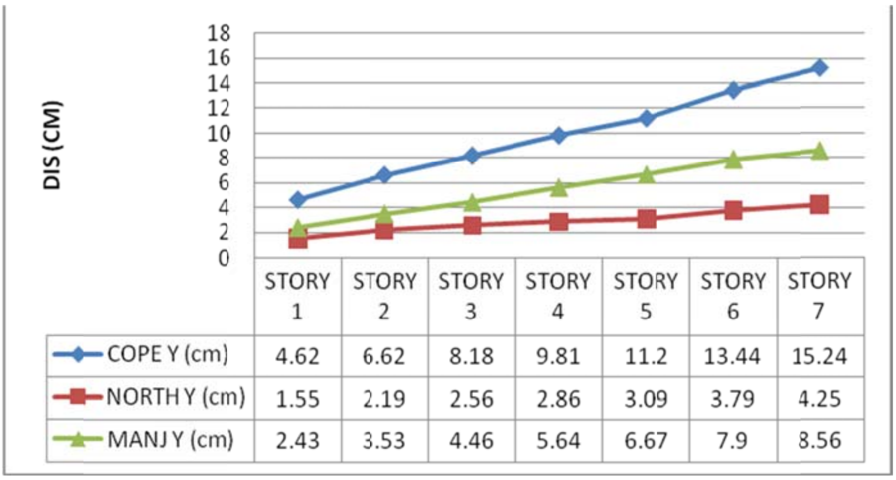
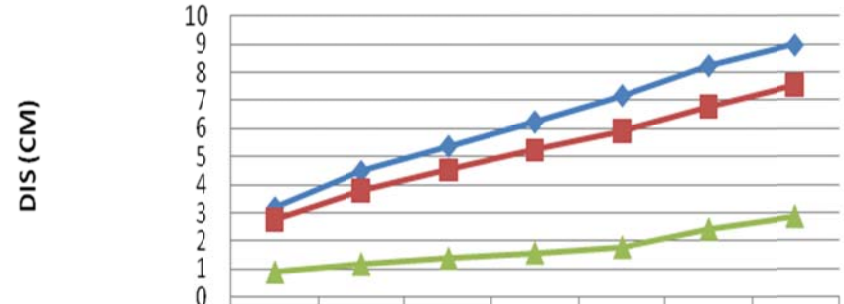
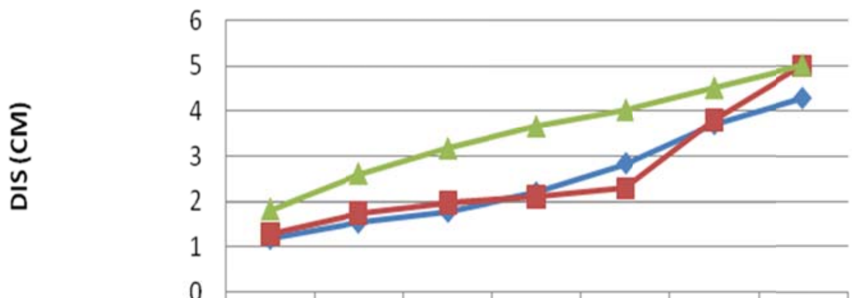


Fig. 30: Total displacement of the regular building in Y direction



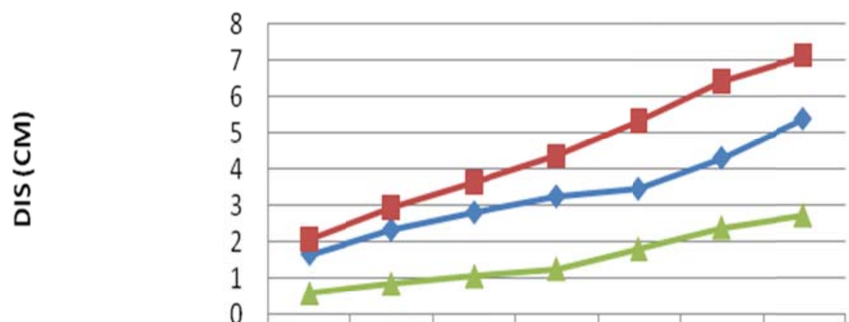
	STORY 1	STORY 2	STORY 3	STORY 4	STORY 5	STORY 6	STORY 7
COPE X (cm)	3.17	4.47	5.37	6.24	7.18	8.25	8.98
NORTH X (cm)	2.74	3.79	4.52	5.23	5.92	6.77	7.52
MANJ X (cm)	0.9	1.19	1.39	1.58	1.79	2.44	2.88

Fig. 31: Total displacement of the 1st irregular building in X direction



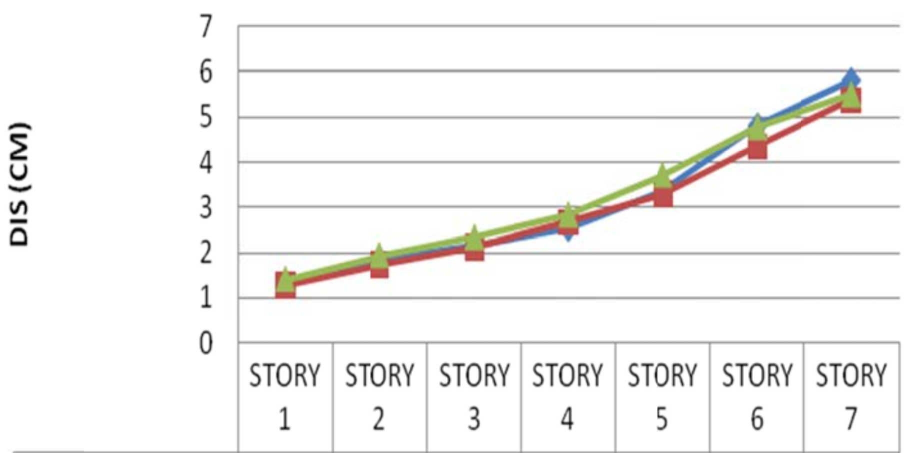
	STORY 1	STORY 2	STORY 3	STORY 4	STORY 5	STORY 6	STORY 7
COPE Y (cm)	1.18	1.54	1.78	2.19	2.84	3.71	4.29
NORTH Y (cm)	1.3	1.75	1.98	2.1	2.29	3.8	5
MANJ Y (cm)	1.83	2.61	3.17	3.66	4.03	4.52	5.01

Fig. 32: Total displacement of the 1st irregular building in Y direction



	STORY 1	STORY 2	STORY 3	STORY 4	STORY 5	STORY 6	STORY 7
DIS COPE X (cm)	1.65	2.32	2.8	3.24	3.45	4.3	5.39
DIS NORTH X (cm)	2.08	2.95	3.64	4.36	5.34	6.42	7.13
DIS MANJ X (cm)	0.59	0.85	1.06	1.26	1.81	2.39	2.72

Fig. 33: Total displacement of the 2nd irregular building in X direction



	STORY 1	STORY 2	STORY 3	STORY 4	STORY 5	STORY 6	STORY 7
COPE Y (cm)	1.34	1.86	2.17	2.52	3.38	4.8	5.8
NORTH Y (cm)	1.27	1.73	2.11	2.67	3.3	4.35	5.37
MANJ Y (cm)	1.41	1.94	2.34	2.84	3.73	4.79	5.52

Fig. 34: Total displacement of the 2nd irregular building in Y direction

3. Discussion and conclusion

The following conclusions can be drawn from the non-liner time history dynamic analysis of the model.

- In irregular models, max displacement is observed in the three upper stories signifying the damage concentration in those stories.
- In the 2nd irregular model where upper stories are located at the edge of the structure, total displacement is reduced when compared to the 1st irregular model where upper stories are at the midst of the structure.
- Total displacement of the lower and mid-stories in the irregular model decreases in relation to the regular one while observing an increase in upper stories.
- Results indicate that irregularity has decreased the ductility in model 1 and 2 when compared to that of the regular ones.

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