ISSN 2229-5518

Non-linear seismic analysis of high raised RC buildings with outrigger systems

Nehal M. Ayash, Mohamed H. Agamy

Abstract – The construction of the super - tall buildings are rapidly increasing worldwide. As the buildings become taller and narrower, the structural engineer faces challenges to meet the imposed drift requirements due to lateral load. The outriggers are the structural elements that connecting the outer columns to the central core at different levels to increase the stiffness of the structure and to control the excessive drift. The optimum location of outrigger system is the main scope of this research. Linear elastic analyses were applied in most of previous researches focused on this field. Although, it is widely recognized that the nonlinear time-history in-elastic analysis constitutes the most accurate way for simulating response of structures subjected to seismic excitation. The nonlinearity effects are taken in consideration. A 55 story R.C. buildings having outrigger structural systems are analyzed using Etabs. The optimum location for one or double internal outriggers with cap outrigger is studied. Results showed that the response spectrum analysis underestimated the responses; while the linear time history analysis overestimated the results when compared with non-linear time history. The optimum locations for single and double internal outriggers with cap one are at (0.67, 1) and (0.67, 0.75, 1) of building height, respectively.

Index Terms – Tall Building, Outrigger System, Geometric Nonlinearity, Material Nonlinearity, Time History Analysis

1. INTRODUCTION:

The structural design of high-rise structures is based on limiting the drift due to lateral loads to acceptable limits without extra cost. These requirements can be done by adopting certain techniques such as the outrigger systems. The idea of outriggers in building structures is to couple the perimeter and the internal structure as a whole to act as a single unit for resisting lateral load. The concept of this system is that when the central core tilts, its rotation at the outrigger level causes a tension- compression coupling forces in the outer columns to resist this deformation (Fig.1).

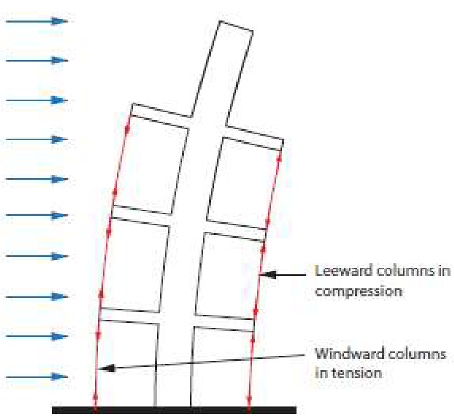


Figure 1 Behavior of Outrigger Structural system

- ***Nehal M. Ayash*** *is assistant professor at Civil Engineering Department, Faculty of Engineering at Mataria, Helwan University11718, Cairo, Egypt, E-mail: Nehalnehal82@yahoo.com, PH- 00201006351251*
- ***Mohamed H. Agamy*** *is assistant professor at Civil Engineering Department, Faculty of Engineering at Mataria, Helwan University11718, Cairo, Egypt, E-mail: Mohammedhelmy@m-eng.helwan.edu.eg, PH- 00201003817511*

2. LITERATURE REVIEW

P.M.B. Raj Kiran Nanduri et. al. (2013) studied the optimized location of outrigger and the efficiency when three outriggers are used in the structure. Nine thirty-story 3D models of outrigger and belt truss system are subjected to wind and earthquake load are analyzed. It is noted that there is reduction when placing of outrigger at top story as a cap truss is 4.8% and 6% with and without belt truss; respectively. The optimum altitude of the second outrigger is at a mid-height of the building. Using second outrigger with cap truss reduces the drift of building by 18% and 23% for cases with and without belt truss, respectively. MOHAMMADKHANI et. al. (2015) investigated the seismic behavior of outrigger and belt truss systems. They examined 3D models using SAP2000 software for a 40-storey steel building with central core braced with and without outrigger effects. The structural models with single and double outrigger levels are analyzed using three sets of ground motion records. The main scope is comparing the optimum locations of outrigger using response spectrum analysis (RSA) and linear time history analysis (THA). They found that the optimized location of outrigger using THA is occurred in upper levels compared with RSA method. There is 40% reduction when using a single outrigger at its optimum level, while 60% reduction is achieved when using double outriggers levels at their optimum levels. Sarfaraz I. Bhati et. al. (2016) examined the behavior of a 42 story RCC model for earthquake and wind loadings using ETABS software. The response spectrum method was carried out as linear dynamic analysis. The comparative study has been carried out for models without and with outriggers at different story. The results indicated that the outrigger is effective in reducing the displacements and drifts significantly, while the base shear showed no significantly changes when introducing outriggers. Akash Kala et. al. (2017) identified the optimum outrigger location in high rise concrete building under wind load. Buildings with different locations of outrigger are analyzed by using a structural analysis software ETABS. The results showed that the optimum location of the outrigger is at between 0.33-0.38 times the building height.

3. OBJECTIVE:

The main objective of this study is identified the optimum location of single and double outrigger systems in addition to cap outrigger in structures which are undergoing inelastic behavior.

4. MODELING AND ANALYSIS:

4.1. Description of building and Modeling

The building considered is 165m high-rise R.C. building as three-dimensional model. The building represents a 55 storied building. The Plan area of the Structure is 42m x 42m with columns spaced at 6m from center to center. The height of each story is 3m. Buildings are modeled as multi – story concrete frames with a 5% damping ratio. The outer and inner columns sizes are considered as 600*600 mm with steel reinforcement 16φ 20 and shear wall thickness is considered as 350 mm. All beams are 300mm*600mm. The cross bracing outriggers are 300mm*300mm with steel reinforcement 8φ20. Grade 40 concrete (Compressive strength 40 N/mm²) is considered throughout the height of the building. Fig. 2 showed the elevation and plan of structure with outriggers. The analyses are based up on the assumptions that the outriggers are pinned attached to the core; Neglecting soil-structure interactions (fixed supports) for all columns and core.

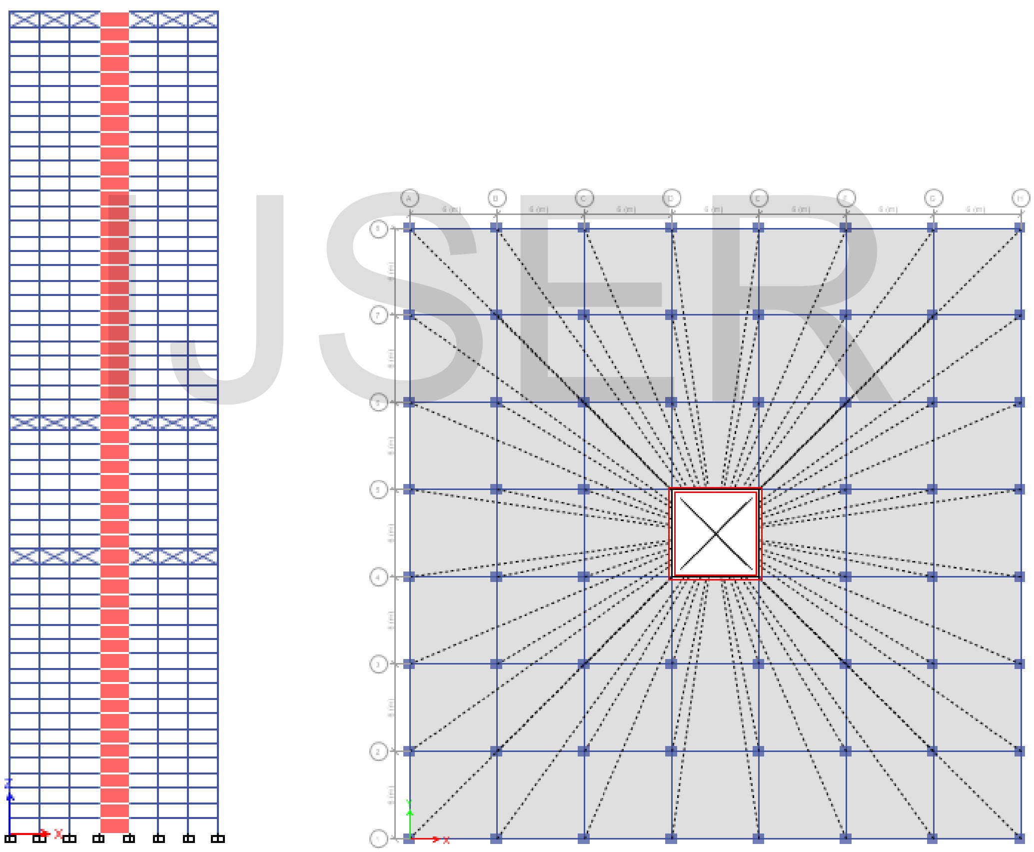


Figure 2 Elevation and plan of structure with outriggers

4.2. Different Arrangements of Outriggers

A total of 16 different arrangements of outriggers analyzed are:

1- Structural Model without Outrigger
2- Structural Model with internal single Outrigger in addition to cap outrigger
   1. Internal single Outrigger at 0.33H
   2. Internal single Outrigger at 0.25H
   3. Internal single Outrigger at 0.50H
   4. Internal single Outrigger at 0.67H
   5. Internal single Outrigger at 0.75H
3- Structural Model with internal double Outrigger in addition to cap outrigger
   1. Internal double Outriggers at 0.25H and 0.33H

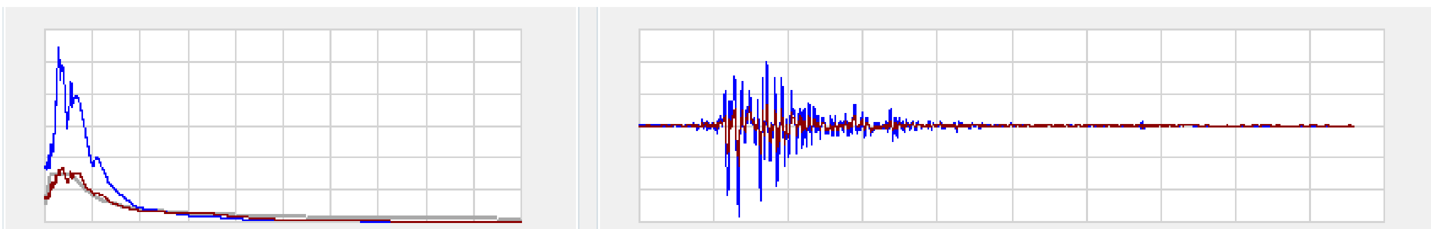
ISSN 2229-5518

2. Internal double Outriggers at 0.25H and 0.50H
3. Internal double Outriggers at 0.25H and 0.67H
4. Internal double Outriggers at 0.25H and 0.75H
5. Internal double Outriggers at 0.33H and 0.50H
6. Internal double Outriggers at 0.33H and 0.67H
7. Internal double Outriggers at 0.33H and 0.75H
8. Internal double Outriggers at 0.50H and 0.67H
9. Internal double Outriggers at 0.50H and 0.75H
10. Internal double Outriggers at 0.67H and 0.75H

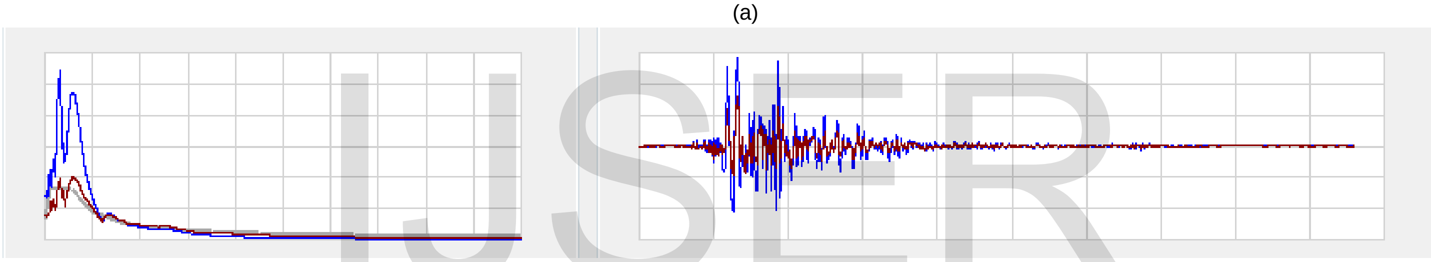
4.3. Description of loadings

The dead load is the own weight of building. The flooring finishing and live load are considered distributed on slabs as 1.5 KN/m2, 3 KN/m2, respectively and the wall load is distributed along all beams as 6 KN/m. The North – South (NS) and East –West (EW) components of Kobe JMA 1995 earthquake is applied as acceleration time history in X and Y directions.

This earthquake was matched to response spectrum established according with UBC 97 as target. The seismic zone "3" is selected with factor (Z) = 0.30. The importance factor (I) of the building is taken as 1.0. The soil profile type is Stiff Soil Profile "SD" with coefficients Ca= 0.36 and Cv = 0.54. The reduction factor R is taken as 5.5 for wall frame interaction system. Fig. 3 showed the Response spectrum and acceleration time history for reference and matched to target for Kobe earthquake.



(a)



(b)

Figure 3 Response spectrum and acceleration time history for reference (blue) and matched (red) to target for Kobe earthquake in (a) X-direction and (b) Y-direction.

4.4. Analysis Model Types

All types of nonlinearity are taken in analyses. The material nonlinearity is modeled using formation of Plastic hinges in all elements. The geometric nonlinearity is considered based on P-Delta effect based on mass source; while defining "mass source" is a mass multiplier for live load as "0.25"; i.e. only 25% of live load is to be considered for calculation of seismic weight.

The plastic behavior models for all beams, columns, wall and outriggers are concentrated in points where the deformations can involve large excursions into the plastic range of the constituent materials, these points are called "plastic hinges" where are restricted to both ends. Each hinge represents a concentrated post-yield behavior that based on a capacity curve with five values A- B- C- D- E, as shown in Fig.4.

Point A is the origin, Point B represents yielding, Point C shows the ultimate capacity, Point D represents the residual strength and Point E represents the total failure. Between B and C; three levels of plasticity are occurred. IO is an immediate occupancy that the Minor hairline cracking, limited yielding is possible at few locations-No crushing, LS is the life safety that the Spalling of cover, shear cracking and Joint cracks formed and CP is a collapse prevention (Extensive cracking). The auto hinge properties is axial P hinges for concrete outriggers, moment M3 hinges for concrete beams and interacting P – M3 hinges for concrete columns and there are based on deformation controlled.

The Comparative studies have been carried out based on the lateral story displacements, story drifts, story and base shear, story and base moment and time period.

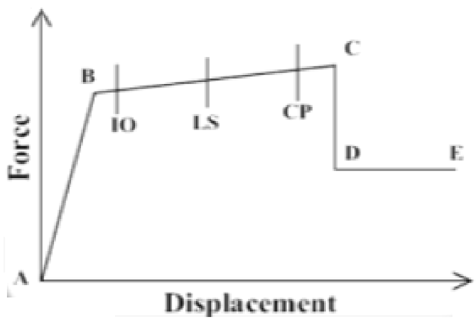


Figure 4 Force vs. Displacement in a plastic hinge according to NEHRP (1994) recommendation

5. RESULTS:

5.1. Comparison between types of analysis

In this part the comparative study has been carried out between response spectrum analysis, linear time history analysis (neglecting geometric and material nonlinearities) and non-linear time history analysis (when the geometric and material nonlinearities into consideration). Fig.5 showed the displacement (a) and drift (b) for building using response spectrum analysis, linear time history analysis and non-linear time history analysis for building without or with outrigger system.

Using response spectrum analysis, outrigger system reduced building displacement and story drift while the opposite behavior is occurred when using either linear time history analysis or nonlinear time history analysis. The response spectrum analysis underestimated the story drift; while the linear time history analysis overestimated the story drift when compared with non-linear time history.

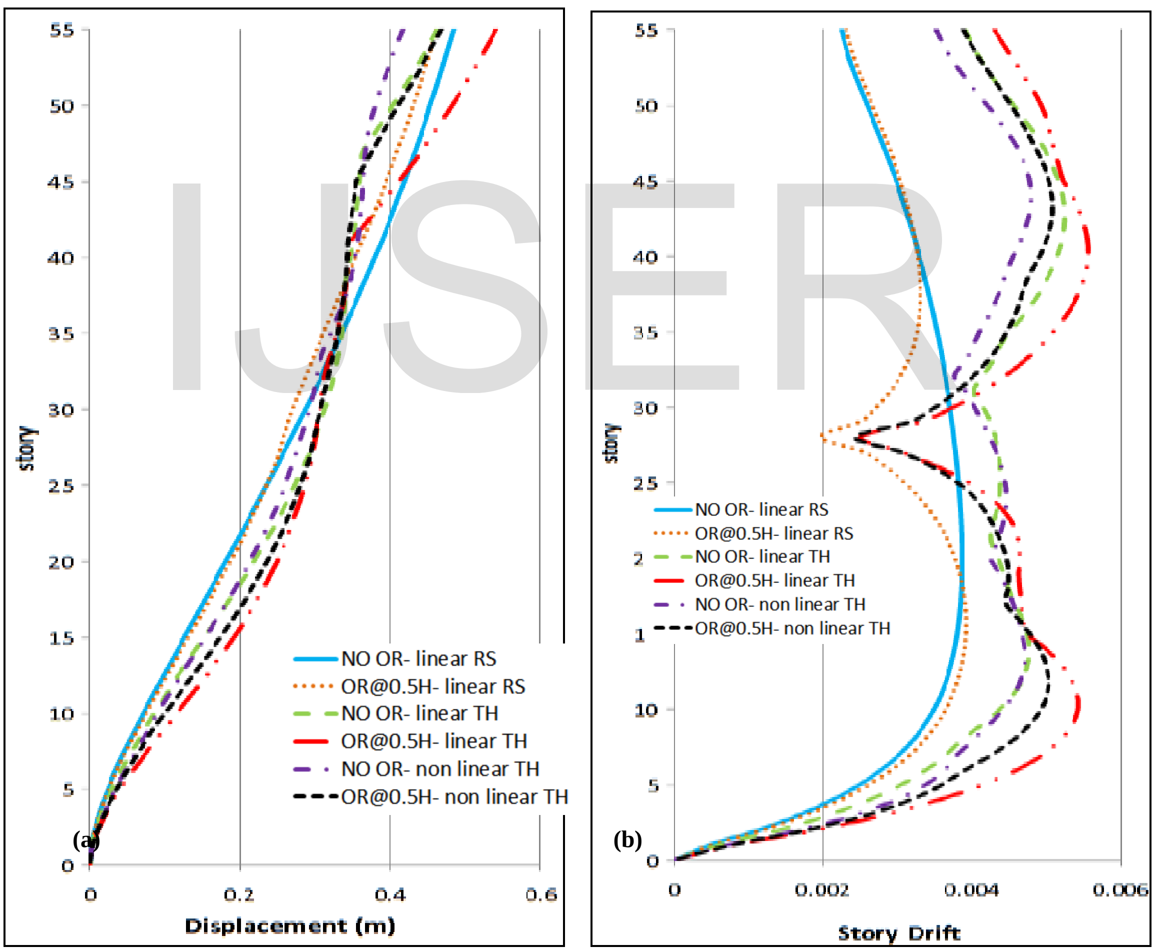


Figure 5 displacement (a) and drift (b) for building using response spectrum analysis, linear time history analysis and non-linear time history analysis for building with and without outrigger system

5.2. Single internal outrigger in addition to cap outrigger:

Figure 6 showed the time period and Figure 7 and Figure 8 showed the displacement, drift, shear and moment and for buildings with single outrigger at different levels in addition to cap outrigger compared to building without outrigger system.

It is observed that the Existing internal single outrigger in addition to cap outrigger reduced building time period; that is meaning that the building stiffness increased when compared with building with only cap outrigger. Building with only cap outrigger has less difference in stiffness than building without outrigger system. In the case of existing cap outrigger and internal outrigger; with increasing the level of internal outrigger; the time period of building is increased i.e. building stiffness is reduced.

In addition, with increasing the level of internal outrigger; the top displacement, story drift, variation in story drift above and below outrigger level, base shear, shear amplification at location of outrigger, base moment and moment amplification at location of outrigger are reduced.

Table (1) and Fig.10 presented the percentage of displacement, drift, shear and moment for buildings with single outrigger at different levels in addition to cap outrigger relative to building without outrigger system. It is observed that the optimum location for single internal outrigger with cap outrigger is at 0.67 building height.

Fig.9 showed the plastic hinges formation for buildings with single outrigger at different levels in addition to cap outrigger. It is shown that the main location of failure occurred at connection between outrigger and core. As the height of internal outrigger increased, the formation of plastic hinges above level of outrigger diminished. The failure points are shown mostly at cap outrigger; and the failure points are formed in internal outrigger at its level is raised.

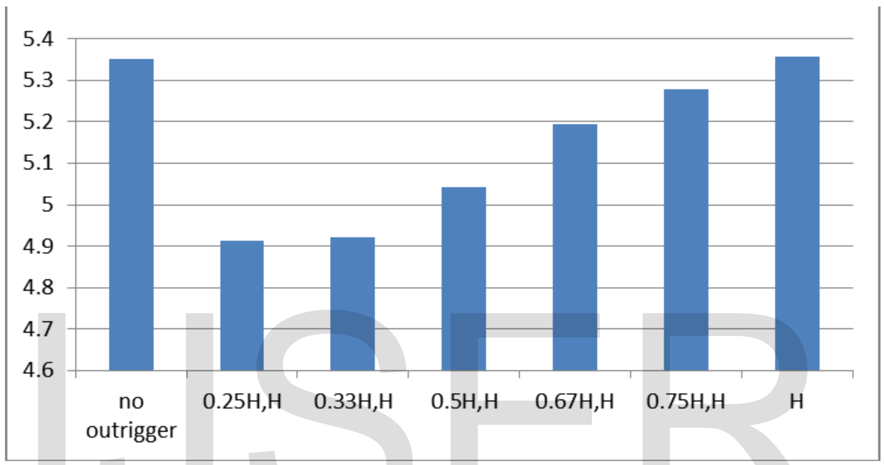


Figure 6 time period for buildings with single outrigger at different levels in addition to cap outrigger compared to building without outrigger system

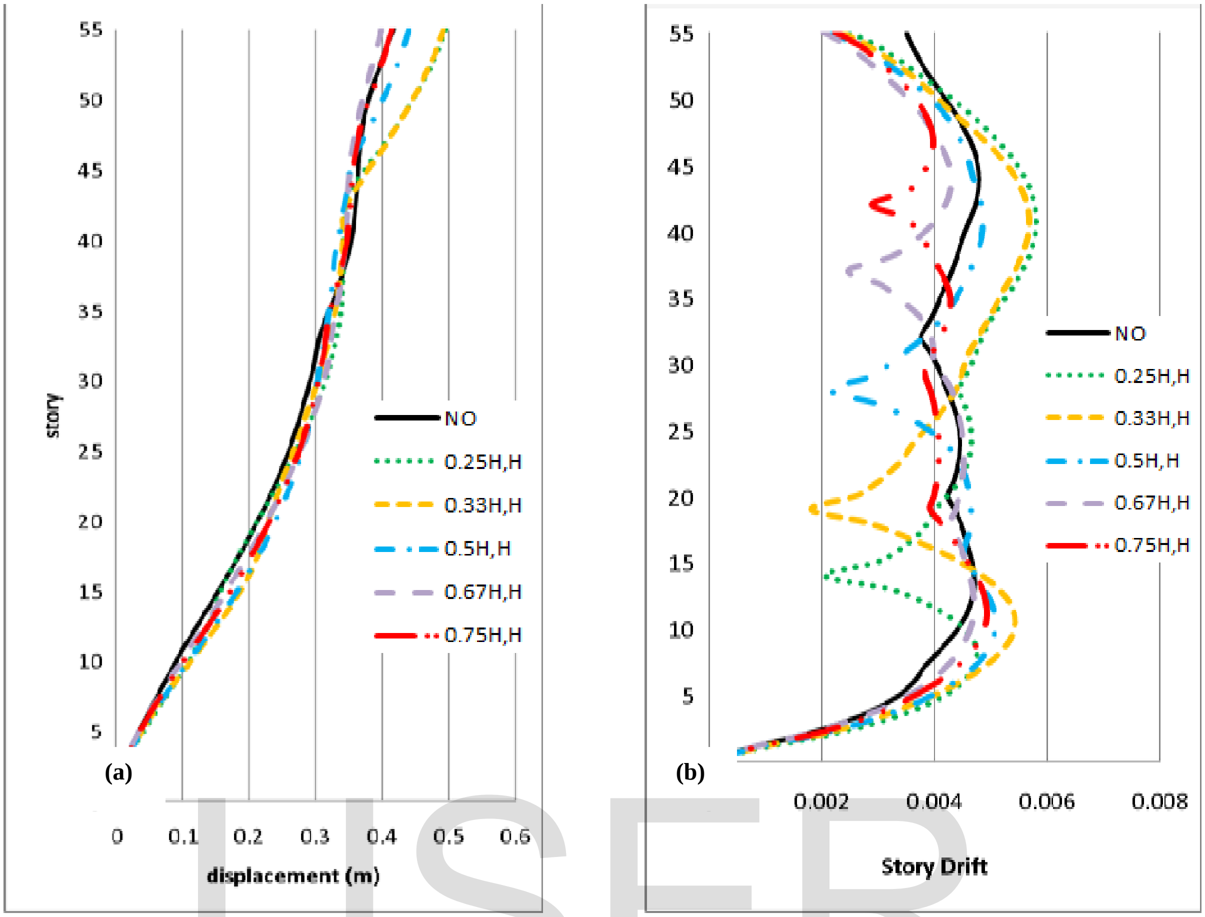


Figure 7 (a) Displacement and (b) drift for buildings with single outrigger at different levels in addition to cap outrigger compared to building without outrigger system

ISSN 2229-5518

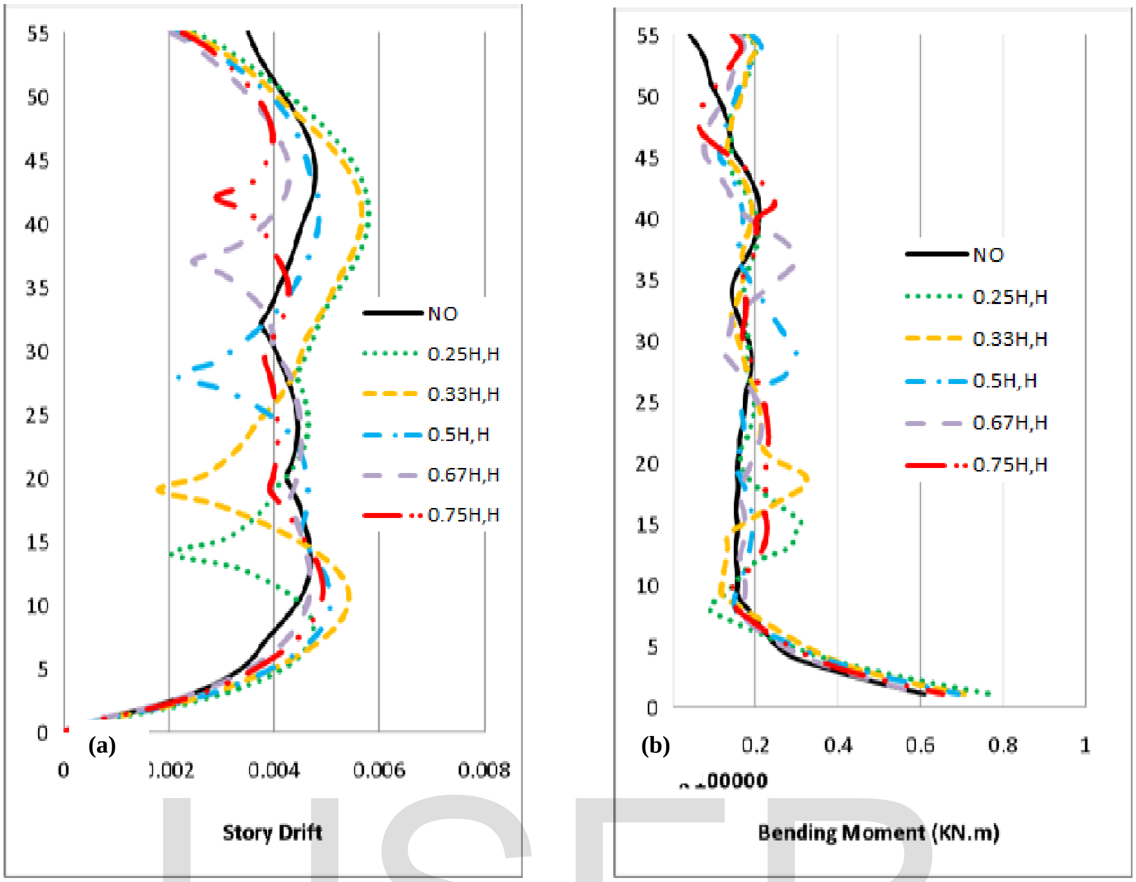


Figure 8 (a) shear and (b) moment for buildings with single outrigger at different levels in addition to cap outrigger compared to building without outrigger system

Table 1
Percentage of displacement, drift, shear and moment for buildings with single outrigger at different levels in addition to cap outrigger relative to building without outrigger system

	Displacement	Drift	Shear	Moment
0.25H,H	118.7%	121.1%	366.6%	125.9%
0.33H,H	118.0%	118.4%	292.0%	115.4%
0.5H,H	105.5%	106.1%	278.4%	113.5%
0.67H,H	95.7%	98.0%	245.8%	99.7%
0.75H,H	99.5%	102.8%	218.7%	107.0%

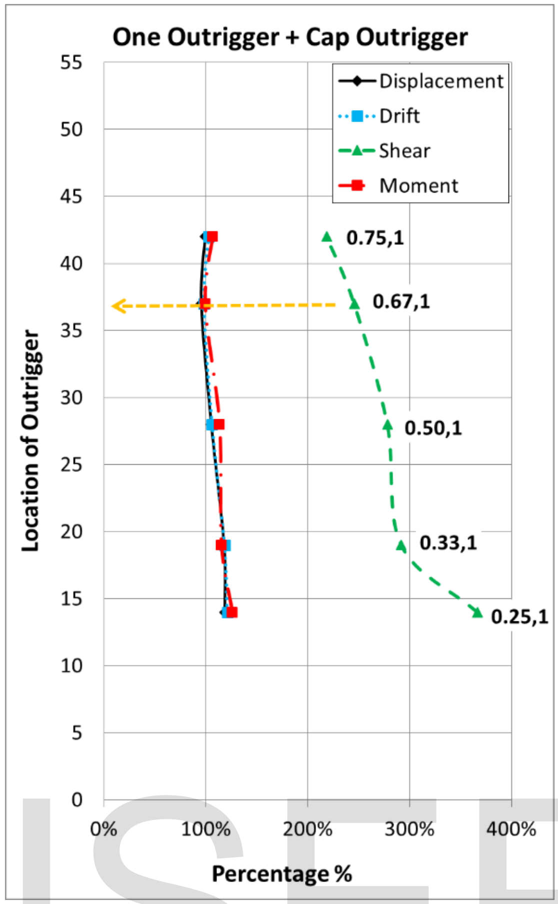


Figure 9 Percentage of displacement, drift, shear and moment for buildings with single outrigger at different levels in addition to cap outrigger relative to building without outrigger system

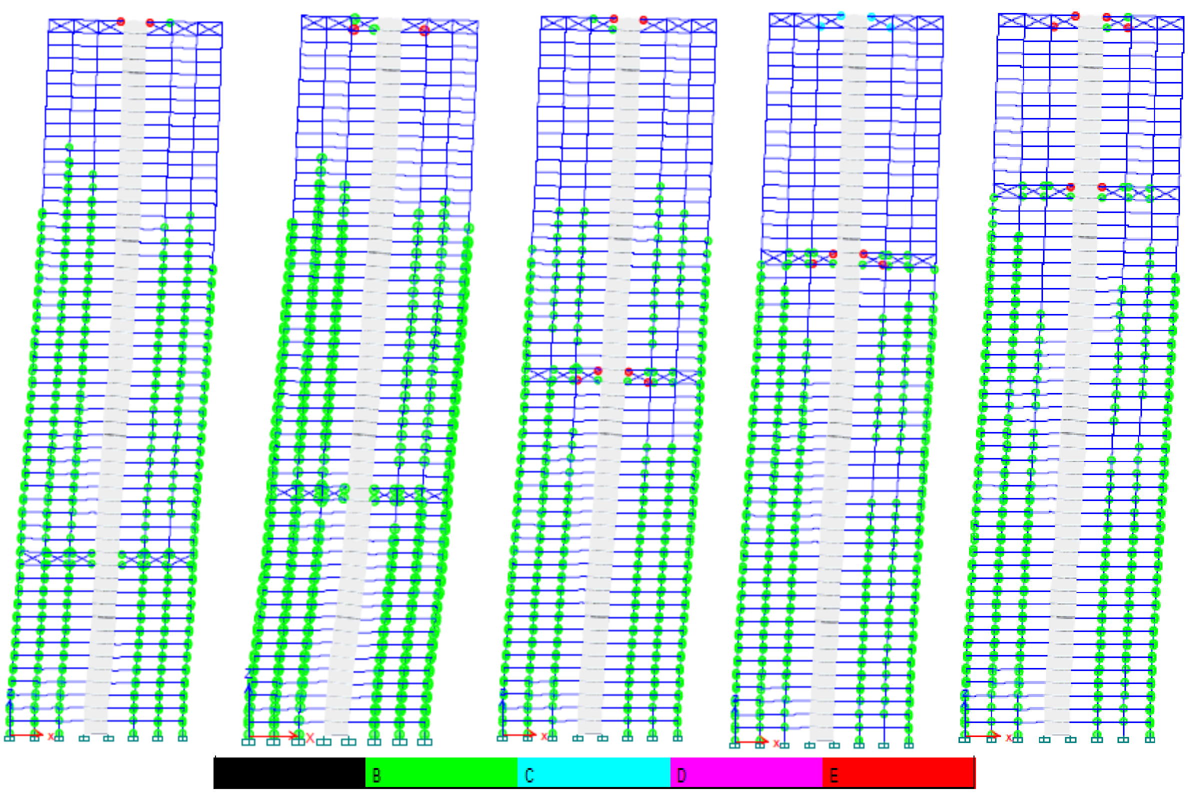


Figure 10 plastic hinges formation for buildings with single outrigger at different levels in addition to cap outrigger

5.3. Double internal outriggers in addition to cap outrigger

The studied cases in this part are arranged from case (1) to case (10) as double internal outriggers with cap one are at (0.25, 0.33, 1), (0.25, 0.5, 1), (0.25, 0.67, 1), (0.25, 0.75, 1), (0.33, 0.5, 1), (0.33, 0.67, 1), (0.33, 0.75, 1), (0.5, 0.67, 1), (0.5, 0.75, 1), (0.67, 0.75, 1) of building height, respectively.

Figure 11, Figure 12 showed the displacement, drift, shear and moment and Figure 13 showed the time period for buildings with single outrigger at different levels in addition to cap outrigger compared to building without outrigger system. The building time period is reduced, and then the building stiffness is increased in case of existing internal outrigger in addition to cap outrigger when compared with building not having outrigger.

With maintaining the levels of first and cap outriggers and arising the level of second outrigger; it is noted that the time period is increased i.e. building stiffness is reduced while the top displacement, story drift, deamplification in story drift at outrigger level, base shear and base moment and shear and moment amplification at location of outrigger are reduced. The same observation can be reached for cases where the levels of double outrigger with closer spacing are increased.

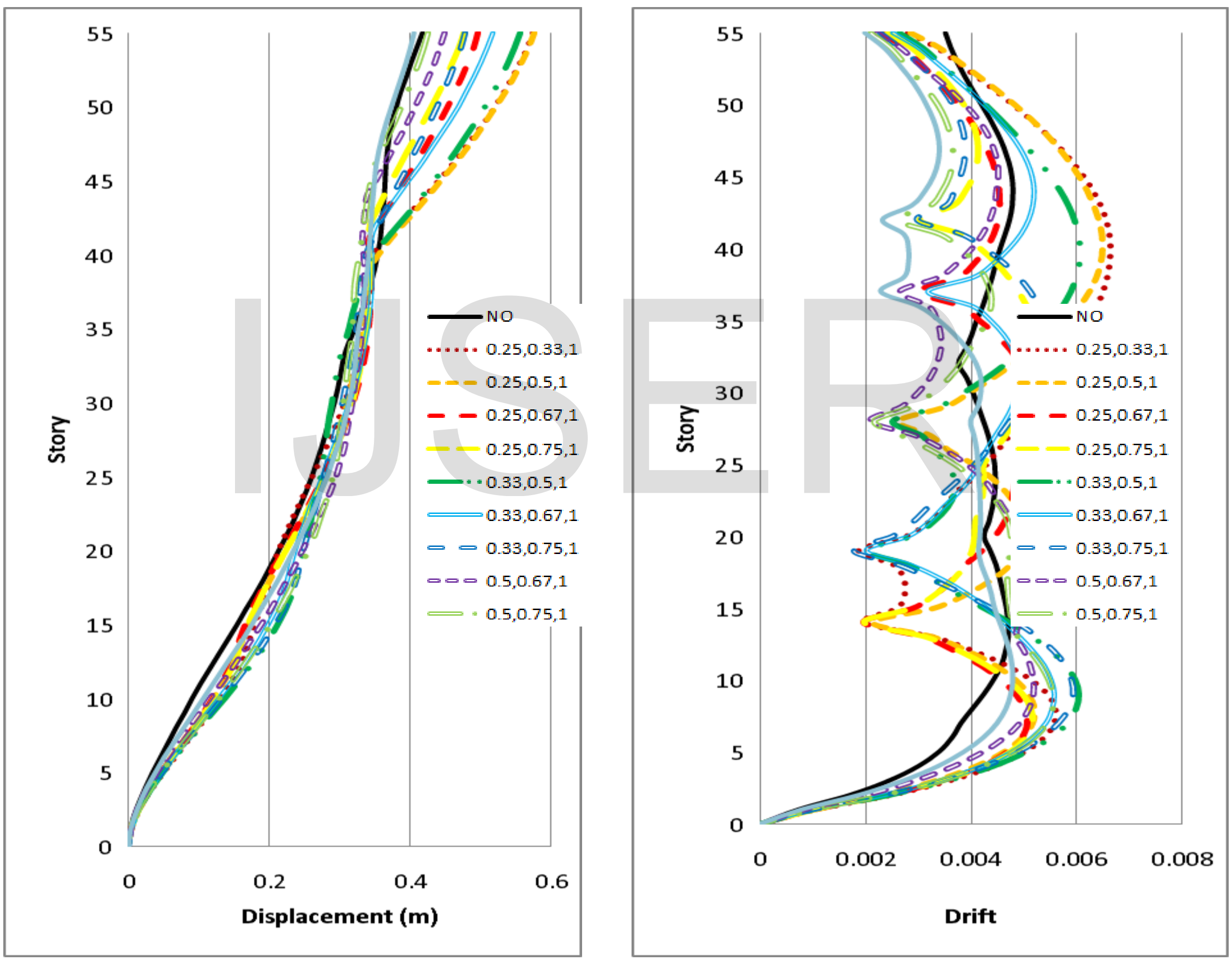


Figure 11 (a) Displacement and (b) drift for buildings with double outriggers at different levels in addition to cap outrigger compared to building without outrigger system

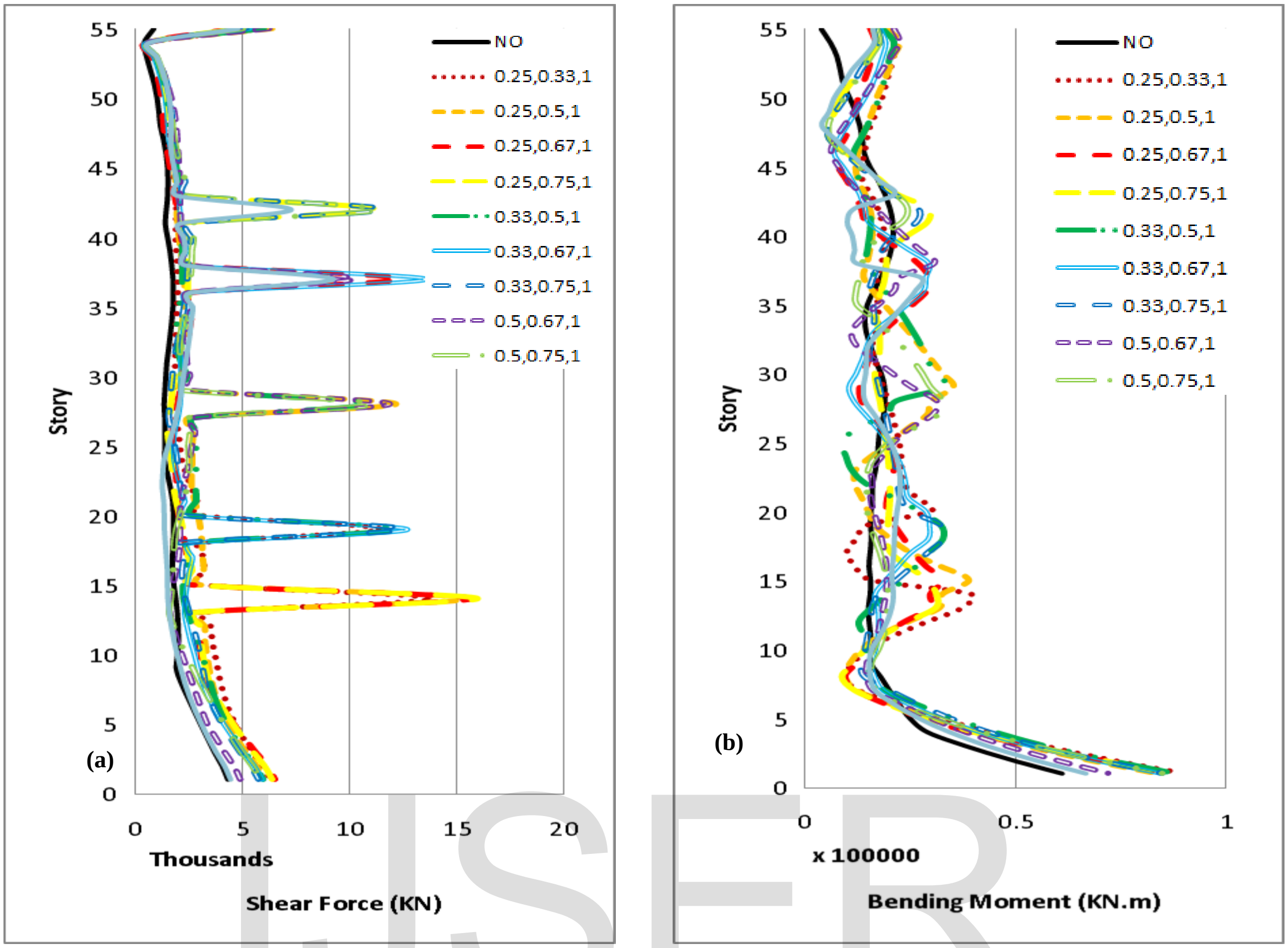


Figure 12 (a) shear and (b) moment for buildings with double outriggers at different levels in addition to cap outrigger compared to building without outrigger system

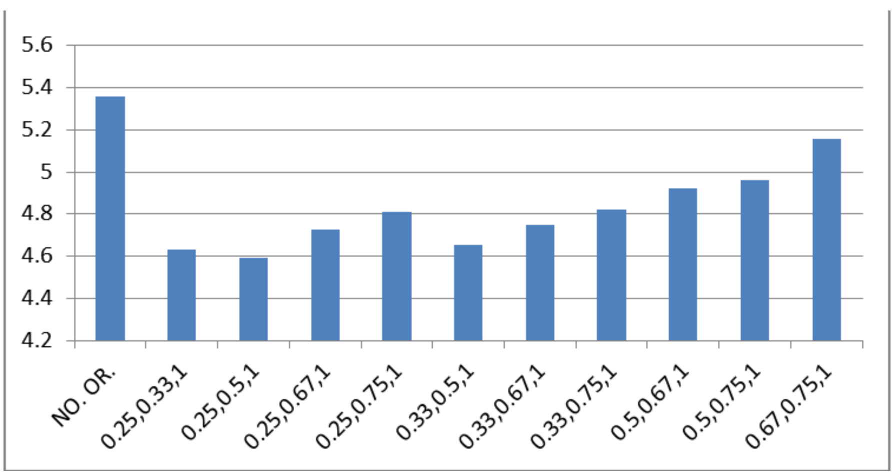


Figure 13 time period for buildings with double outriggers at different levels in addition to cap outrigger compared to building without outrigger system

Table (2) and Fig.15 presented the percentage of displacement, drift, shear and moment for buildings with double outriggers at different levels in addition to cap outrigger relative to building without outrigger system. It is observed that the responses of building with double outrigger in addition to cap outrigger i.e. top displacement, story drift, story shear and story moment are amplified than the case without outrigger except the case where the outriggers at (0.67, 0.75, 1 H); the responses are reduced or at least they have very small amplifications. So; it is reached that the optimum location for double internal outriggers with cap outrigger is at 0.67, 0.75 of building height.

Table 2
Percentage of displacement, drift, shear and moment for buildings with double outriggers at different levels in addition to cap outrigger relative to building without outrigger system

CASE	Outrigger at	displacement	drift	shear	moment
1	0.25,0.33,1	138%	138%	146%	147%
2	0.25,0.5,1	138%	136%	138%	136%
3	0.25,0.67,1	119%	110%	150%	143%
4	0.25,0.75,1	114%	110%	148%	143%
5	0.33,0.5,1	133%	126%	138%	143%
6	0.33,0.67,1	124%	116%	137%	139%
7	0.33,0.75,1	115%	124%	133%	139%
8	0.5,0.67,1	108%	108%	114%	118%
9	0.5,0.75,1	102%	116%	134%	139%
10	0.67,0.75,1	97%	100%	103%	109%

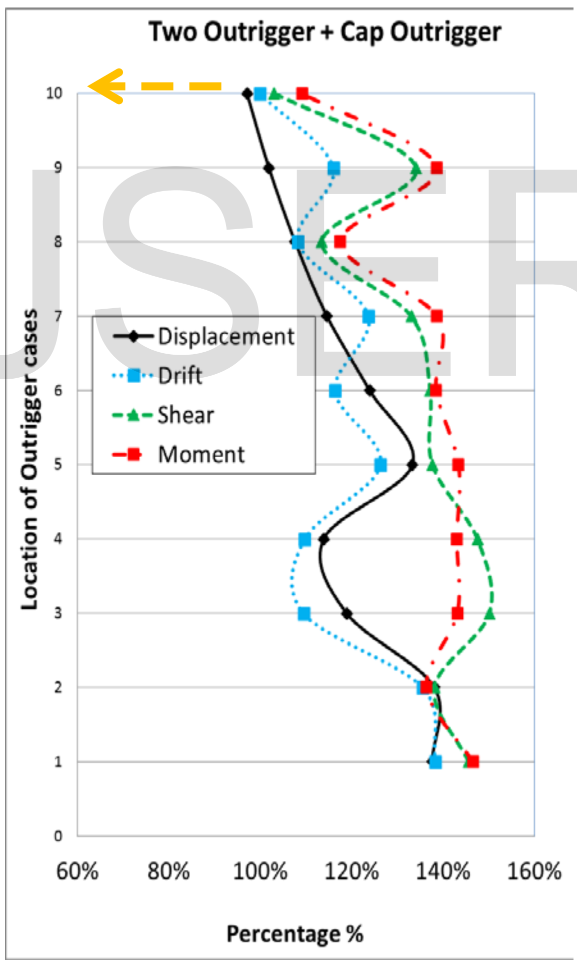


Figure 14 Percentage of displacement, drift, shear and moment for buildings with double outriggers at different levels in addition to cap outrigger relative to building without outrigger system

Figure 15 showed the plastic hinges formation for buildings with double outrigger at different levels in addition to cap outrigger. It is shown that as the level of double internal outriggers with closer spacing between them increased, the formation of plastic hinges intermediate between two levels of outriggers and the plastic hinges above the second level of outrigger are diminished.

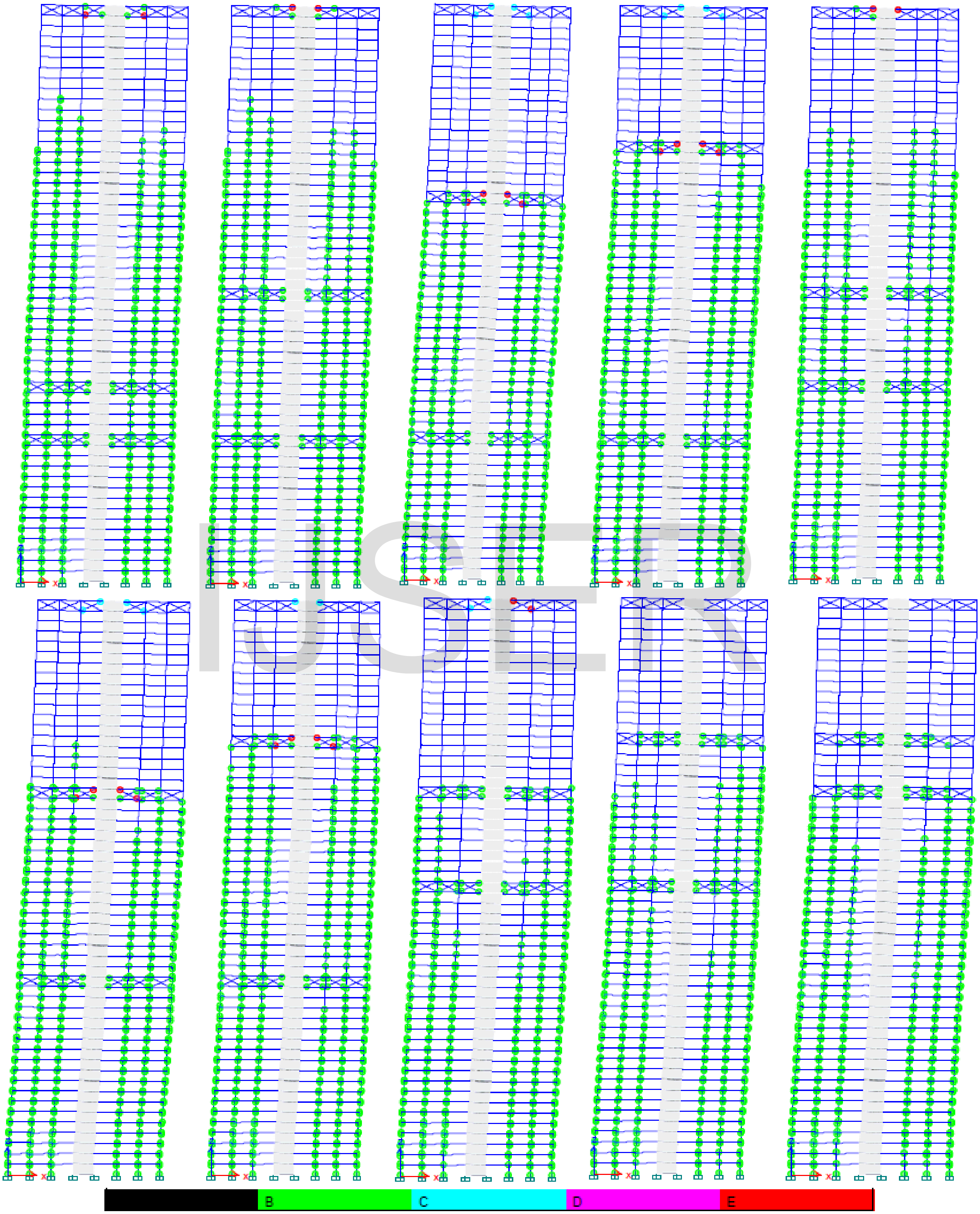


Figure 15 plastic hinges formation for buildings with double outrigger at different levels in addition to cap outrigger

6. CONCLUSIONS:

The main conclusions are:

The response spectrum analysis underestimated the building responses; while the linear time history analysis overestimated the results when compared with non-linear time history.

Existing outriggers systems increased the building stiffness. Increasing number of internal outrigger systems increasing building stiffness. Existing cap outrigger system has less effect on building stiffness and responses.

In the case of existing single or double internal outriggers in addition to cap outrigger; with increasing the level of internal outriggers; the building stiffness is reduced and the building responses also are reduced.

The failure mechanisms are located at connections between outrigger bracing and central core, so it is more important to focus on designing this connection. In addition, as the level of internal outrigger increased the failure points are diminished.

The optimum location for single internal outrigger with cap one is at (0.67, 1H).

The optimum locations for double internal outriggers with cap one is at (0.67, 0.75, 1 H) i.e. closely to each other and closely to top portion of building.

REFERENCES

[1] Akash Kala, Madhuri Mangulkar, Indrajeet Jain (2017) The use of outrigger and belt truss system for high-rise RCC building. International Journal of Civil Engineering and Technology (IJCIET) Volume 8, Issue 7, July 2017, pp. 1125–1129, Article ID: IJCIET_08_07_119 ISSN Print: 0976-6308 and ISSN Online: 0976-6316.

[2] Alok Rathore, Dr. Savita Maru (2017) The behavior of outrigger structural system in high-rise building: reviews. International Journal of Science, Engineering and Technology Research (IJSETR) Volume 6, Issue 11, November 2017, ISSN: 2278 -7798.

[3] Alpana L. Gawate, J.P. Bhusari (2015) Behavior of Outrigger Structural System for High-rise Building. International Journal of Modern Trends in Engineering and Research, e-ISSN No.:2349-9745, Date: 2-4 July, 2015

[4] Kasi Venkatesh , B.Ajitha (2017) BEHAVIOR OF A BUILDING WITH OUTRIGGER SYSTEM . Proceedings of 6th International Conference on Recent Development in engineering science, humanities and management 14 May 2017.

[5] Mohammad Hosein MOHAMMADKHANI, Hossein TAHGHIGHI (2015) On the seismic performance evaluation of outrigger and belt truss systems for steel high-rise buildings . proceedings of 7th International Conference on Seismology & Earthquake Engineering 18-21 May 2015.

[6] Nishit Kirit Shah, N.G.Gore (2016) Review on Behavior of Outrigger System in High Rise Building. International Research Journal of Engineering and Technology (IRJET) Volume: 03 Issue: 06 | June-2016 e-ISSN: 2395 -0056 p-ISSN: 2395-0072.

[7] P.M.B. Raj Kiran Nanduri, B.Suresh, MD. Ihtesham Hussain (2013) Optimum Position of Outrigger System for High-Rise Reinforced Concrete Buildings under Wind and Earthquake Loadings .American Journal of Engineering Research (AJER) e-ISSN: 2320-0847 p-ISSN: 2320-0936 Volume-02, Issue-08, pp-76-89.

[8] Sarfaraz I. Bhati, Prof. P. A. Dode, Prof. P. R. Barbude (2016) Analysis of High Rise Building with Outrigger Structural System . International Journal of Current Trends in Engineering & Research (IJCTER) e-ISSN 2455–1392 Volume 2 Issue 5, May 2016 pp. 421 – 433.

[9] Krunal Z. Mistry, Proff. Dhruti J. Dhyani (2015) OPTIMUM OUTRIGGER LOCATION IN OUTRIGGER STRUCTURAL SYSTEM FOR HIGH RISE BUILDING International Journal of Advance Engineering and Research Development Volume 2,Issue 5, May -2015