Jurnal
Teknologi

Full Paper

IMPACT ON STRUCTURAL BEHAVIOR DUE TO INSTALLATION OF BILLBOARD

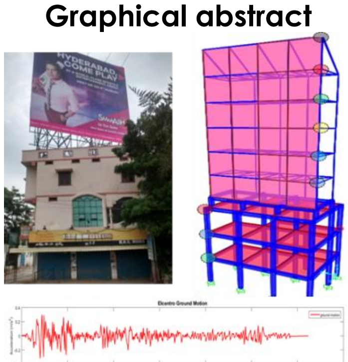
Sairam Neridu[a*], Venkata Dilip Kumar Pasupuleti[b], Archanaa Dongre[a]

[a]Department of Civil Engineering, Vidya Jyothi Institute of Technology, Aziz Nagar, Hyderabad, 500075, Telangana, India
[b]School of Civil Engineering, Anurag Group of Institutions, Hyderabad, 501301, Telangana, India

Article history
Received
16 December 2016
Received in revised form
17 June 2017
Accepted
10 August 2017

*Corresponding author
nsairam@vjit.ac.in

Graphical abstract



Abstract

Installation of billboards on various structures adjacent to busy roads has become common practice as they provide high economic to the local municipal corporation or private business organisations. Till recent, design of billboards and its installation on a structure was of less importance, but recent large wind cyclones had led to the collapse of billboards and structural cracks. This incident has raised doubts in structural engineering community for the resistance of buildings with billboards during earthquakes. In this study, an existing building with the recent installation of a billboard has considered, and dynamic analysis is carried out for three different ground motions viz. El Centro earthquake, Loma Prieta earthquake and Uttarkashi earthquake for understanding the change in its behaviour with and without billboard. The structure has shown an increment of response due to the installation of a billboard during earthquakes.

Keywords: Building with billboard, time history analysis, structural response, modal analysis

1.0 INTRODUCTION

An outdoor advertising sign in the form of a billboard consists of at least one display panel and the supporting framework. Billboards may be freestanding, mounted to buildings, or attached to other structures as seen in Figure 1. Modern billboards conform to engineering standards and are constructed of steel, while older billboard structures are made of wood or angle iron frames. A billboard may be smaller than the permitted size. This allows for the addition of a cutout or extension within the square foot envelope of the permitted area [1].

Various sizes of billboards generally used for all kinds of advertisements raging from new products release to political/government messages to all the public, few standard dimensions are mentioned in Table 1. Types of billboards based on the materials used for construction are classified to be a. Wood, b. Steel A-frame, c. Multi-mast steel, d. Monopole and e. Digital billboards [2]. Wood structure billboards are constructed with wood post or pole supports with dimensional lumber as the secondary support (A-frame) with a wood or metal catwalk and display panel(s). Supports may be imbedded in the ground. There may be a foundation of concrete or gravel. Steel a-frame structure billboards are constructed with angle iron or steel supports with metal framing, catwalk, and display panel(s). Supports may be imbedded in the ground. There may be a foundation of concrete or gravel. Monopole structure is constructed with a tubular steel support (of various circumferences), tubular steel framing, metal catwalk and display panel. The foundation is concrete arrangements of display faces include 1) Single face, 2) Back-to-back, 3) V-build, side-by-side, 4) Stacked, and 5) Tri-build configurations. Digital billboard is an outdoor advertising sign with a light-emitting diode (LED) face.

Billboards are also categorized based on size, viz., a. Gantry Bill Board, b. Large Bill Board, c. Medium Bill Board, and d. Small Bill Board [3]. A Gantry Billboard consists of a double-sided bill-board panel positioned on a gantry structure that span the entire width or only part of the road and which are constructed for the sole purpose of displaying advertisements. Gantry structures support billboards ranging between 18 square meters to 81 square meters. Large billboards area range from 41 square meters to 81 square meters. Whereas medium billboard size ranges from 19 square meters to 40 square meters. Small billboards size range from 9 square meters to 18 square meters and are widely used outdoor. They normally consist of a double-sided billboard panel.

Table 1 Geometric Specifications of Billboards widely used

No.	Dimensions (feet's)	Area (square feet)
1	6 x 12	72
2	10.5 x 36	378
3	8 x 12	96
4	12 x 40	480
5	10 x 22	220
6	14 x 48	672
7	10 x 24	240
8	16 x 60	960
9	12 x 25	300
10	20 x 50	1000

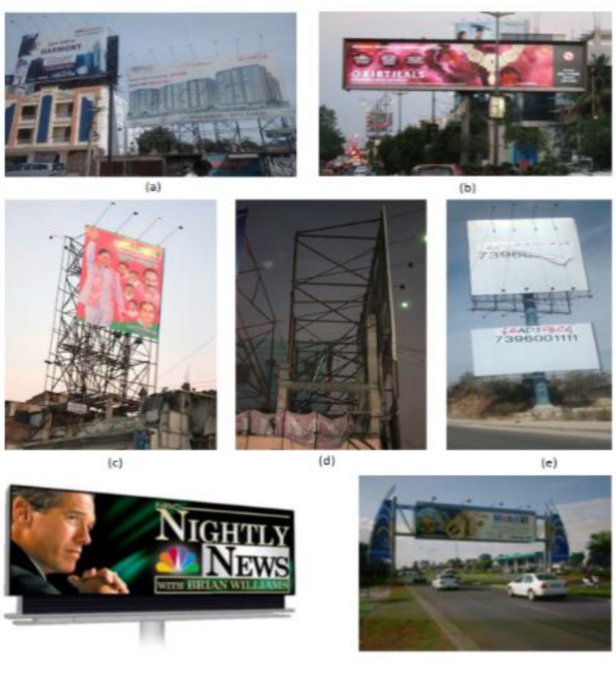


Figure 1 Different type of Billboards installed at sites

There have been many studies in the past related to the mounting of a steel tower on the RCC structures [4, 5] but research on mounting of a billboard or hoarding on RCC structure for understanding structural response is almost negligible even for wind analysis, which is predominant during the life span of a billboard.

Figures 2-5, show the recent damages of both building which suffered partial damage and complete collapse of billboards. Pictures have been taken by the authors themselves.

Figure 2 Damage of Billboard and partial damage of building (Langarhouse, Hyderabad, 17 April 2016)

Figure 3 Damage of Billboard and partial damage of building (Raidurgam, Hyderabad, 20 May 2016)

Figure 4 Damage of Billboard and partial damage of building (Jubilee Hills check post, Hyderabad, 20 May 2016)

Figure 5 Damage of Billboard and partial damage of building (Tolichowki, Hyderabad, 20 May 2016)

The main objective of this study is to understand the change in behavior of existing structure after installation of billboard. Due to huge demand of elevated places for advertising boards in growing cities on the sides of road, the existing buildings are not checked structurally whether they could really carry an extra load of billboards, especially during huge winds or earthquakes. If winds could make billboard collapse and partial damage to buildings, the earthquake risk would be much higher for all the structures will billboards situated in higher seismic zones in any country. And it would be much higher in the absence of proper guidelines or design check. So, this study provides important information regarding the percentage change in structural response due to installation of billboard.

2.0 METHODOLOGY

For this study a G+2 structure with billboard located at Raidurg, Hyderabad is considered, which is shown in Figure 6 from two different views. Structural details of building are shown in Figure 8 and geometrical specifications are mentioned in Table 2, similarly details of billboard are shown in the Figure 9 and geometrical specifications of the channels used for numerical modeling are given in Table 2.

(a) (b)

Figure 6 Existing structure considered for this study

Figure 8 shows the plan of the structure consisting the location of columns, beams and span lengths or bay lengths in both x and y directions. All the dimensions mentioned in the figure are in meters. The current joints or connections between building and billboard are shown in the Figure 7. Currently they are attached to the raised platform or columns. In the case of no columns or location where column is absent, a lump of concrete poured on the footings of billboard directly on the slab as seen in the Figure 7.

(a) (b)

Figure 7 Billboard connections on the structure

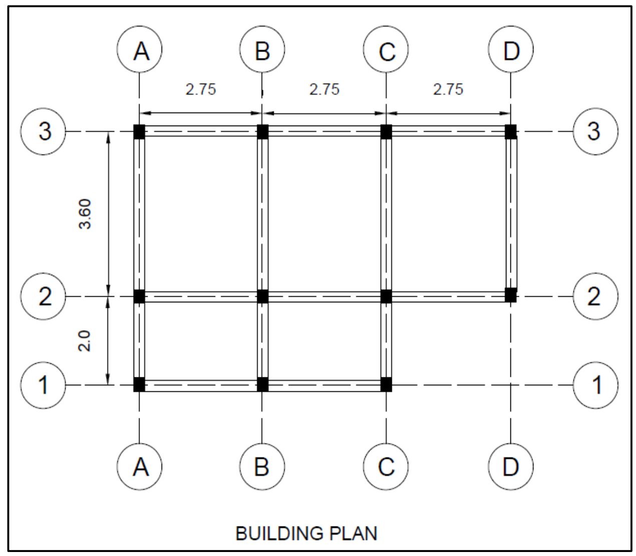


Figure 8 Plan of the building considered for this study and used to develop numerical model

Table 2 Geometrical specifications of building and billboard considered for numerical modeling

	Existing structural details	Geometry Details
1	Bays along X-Direction	3
2	Bays along Y-Direction	3
3	Column Dimension	230 x 300 mm
4	Beam Dimension	230 x 300 mm
5	Grade of Concrete	M_{20}
6	Grade of Steel	Fe 415
7	Thickness of Slab	120 mm
8	Bill Board Chord	ISA 60 x 60 x 8 mm
9	Bill board bracings	ISA 50 X 50 X 8 mm
10	Thin membrane	2 mm

Billboard considered for this study is of dimensions 9m wide and 13m height. The sections considered, vertical column angle of size 60 mm x 60 mm x 8 mm, horizontal and inclined bracings angle are of sizes 50 mm x 50 mm x 6 mm. The plan of the billboard and elevation of the billboard are mentioned in the Figure 9. This billboard consists of a thin sheet or thin membrane of thickness 2 mm and covers 9 meters in width and 11 meters in height. In reality, the billboards or hoardings which are mounted on any structure have to be tested mainly for two loads, first for wind loads and second for seismic loads, apart from the consideration of normal dead and live loads. As the surface area of billboard is higher, they have to transfer lateral loads to the beams of the structure and these loads are directly proportional to the wind speeds of the region.

One of the important points to be noticed is the damping ratios of RC buildings and steel billboards are 0.05 and 0.01 respectively, s o a steel hoarding topping an RC building comprises a non-proportional damping system.

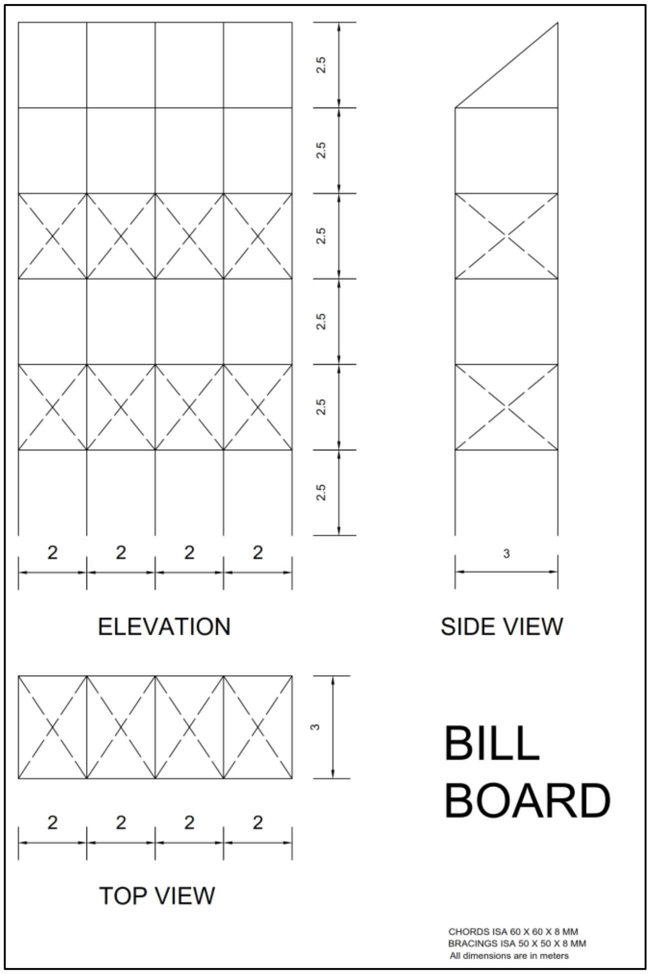


Figure 9 Plan and elevation details of the billboard installed on the considered structure

3.0 RESULTS AND DISCUSSION

As a characteristic behavior of any structure depends on its mode shapes, which actually depends on the geometry, material and boundary conditions, the same has been done for the structure considered. The modal analysis is carried separately for all the three cases. First modal analysis is carried for the building as shown in the Figure 10. Before understanding the modal analysis, few assumptions have been taken for making the actual structure simple to be modeled using finite element based software SAP2000 [6]. In reality there were lumps of concrete on the slab and billboard base were fixed to these lumps of concrete in cylinder shaped as seen in Figure 7(a). There are other cases were column heights were increased up to a meter, and billboard bases are fixed to these extended columns as shown in Figure 7(b). This is a complex or confused boundary conditions for numerical model. Complex only means consideration of contact analysis between the billboard angle sections and column with bolts fixed as seen in the Figure 7.

3.1 Modal Analysis of Building

As building material is reinforced concrete, the damping of the structure is considered to be 5%.

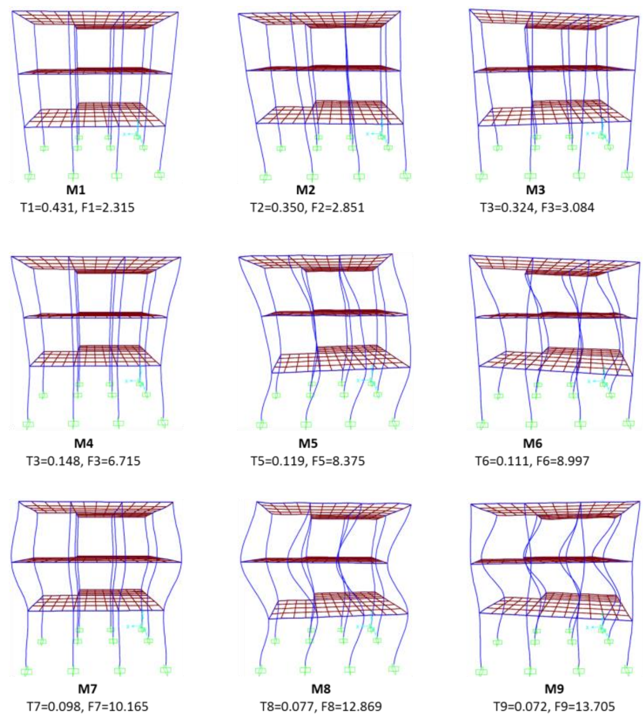


Figure 10 First nine mode shapes of building (M = mode number, F = frequency of the concerned mode)

The first ten mode shapes obtained for the building are shown in the Figure 10. The first mode indicates the building has a natural frequency of 2.315 Hz, which is approximately 0.431 seconds of time period. The height of the building is 9 meters height. As described earlier the mode shapes are directly related to geometry, material and boundary conditions, apart from the complete height and complete width of the structure. As seen in the Figure 10, as the mode number is increasing, the frequency is also increasing till the tenth mode. For every three mode shapes the frequency increase is very high, that could be due to directional change.

3.2 Modal Analysis of Billboard

As billboard material is steel, the damping of the structure is considered to be 1%. As the modal analysis helps in determination of natural frequencies and the corresponding mode shape of the structure, this essentially depends on distribution of stiffness and mass within the structure. In the analysis natural frequencies obtained are shown in Figure 11. The fundamental frequency of the billboard is obtained to be 0.506 Hz or time period of 1.973 seconds. The variations in time periods of obtained ten mode shapes is gradually decreased except the time period of first and second mode shape which is differed by almost 56 %.

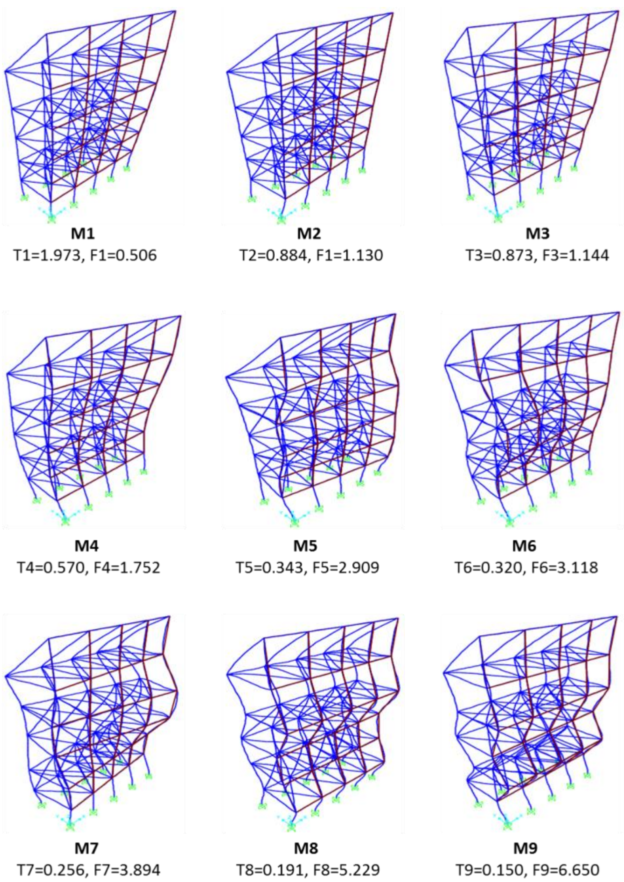


Figure 11 First nine mode shapes of building (M = mode number, F = frequency of the concerned mode)

3.3 Modal Analysis of Building with Billboard

The damping ratios of RC building and steel tower are 0.05 and 0.01 respectively, so a steel frame mounted on reinforced concrete building comprises a non-proportional damping system. Combining both the structures would deal with a combined damping ration which in general would be more than 0.01 and less than or equal to 0.05. In this analysis, 0.05 damping ratio is considered and obtained mode shapes are seen in Figure 12. The first natural frequency of the combined structure i.e., building with billboard is observed to be 0.451 hz or time period of 2.212 seconds, which actually means the time period of the combined structure is greater than the individual structures. There is approximately 10 % increase in time period of the combined structure compared to only billboard and 81 % increases in time period when compared to only reinforced concrete building. The considered case directly indicates the change in time period by a large amount. This could be one of the main reasons for complete structural behavior change of the building with and without billboard. Also, it proves to study the building before installing a billboard or a steel tower on the structure.

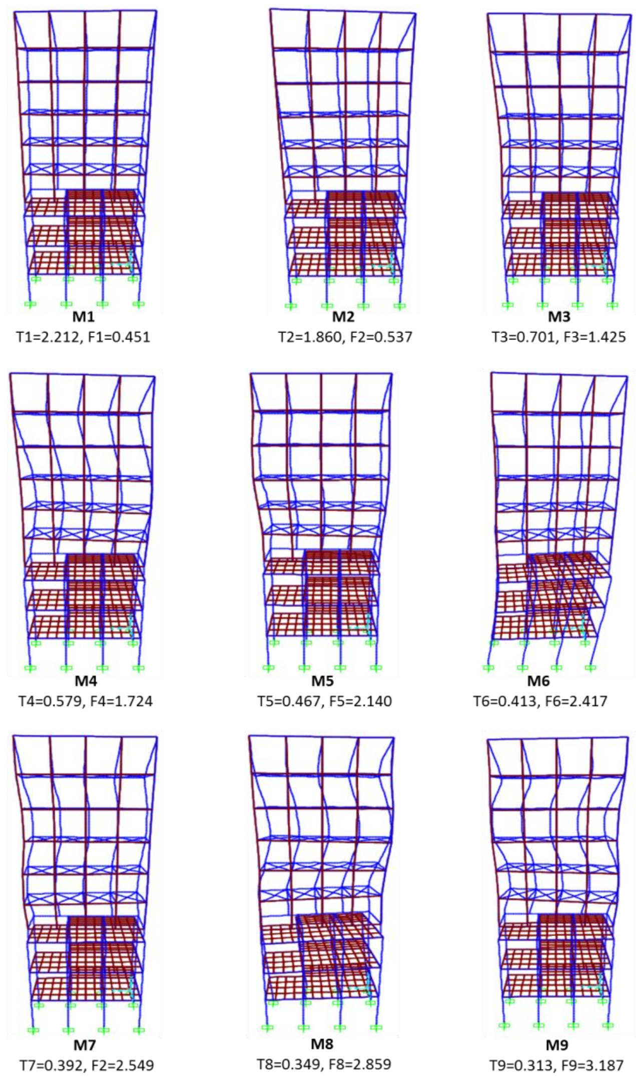


Figure 12 First nine mode shapes of building (M = mode number, F = frequency of the concerned mode)

The comparison first ten modes with and without billboard are listed in Table 3.

Table 3 Comparison of Time periods obtained of different modes for only building and building with billboard

Mode shape	Building without Bill board (Time period, S)	Building with Bill board (Time period, S)
1	0.431	2.212
2	0.350	1.860
3	0.324	0.701
4	0.148	0.579
5	0.119	0.467
6	0.111	0.413
7	0.098	0.392
8	0.077	0.349
9	0.072	0.313
10	0.042	0.272

3.4 Time History Analysis

Linear time history analysis (THA) is carried out for three ground motions viz. **a.** 1940 El Centro earthquake ground motion which occurred in the Imperial Valley having a moment magnitude of 6.9 and maximum perceived intensity of X on the Mercalli intensity scale and first major earthquake recorded by a strong-motion seismograph [7-9]. **b.** Second earthquake ground motion considered for this study is Loma Prieta earthquake occurred in Northern California on 17th October 1989 with a moment magnitude of 6.9 on a section of San Andreas Fault system. **c.** Third ground motion is of 1991 Uttarkashi earthquake of moment magnitude 6.8 occurred within the main thrust system of Himalayas [10, 11]. All three ground motions are shown in Figure 13. To understand the response for building, billboard and for combined structure few joints have been selected. Figure 14 shows the building, billboard and combined structural with highlighted joint locations where response is taken and plotted. Three joints 6, 7 and 8 are taken for the building. Six joints 68, 69, 70, 71, 72 and 73 for billboard. And the same joints have been considered for combined structure as for building. Even though joints are same, but when structure has been combined joint numbers have been changed to 39, 57, 75, 99 and 109 which are similar to joints 68, 69, 70, 71, 72 and 73 respectively. The major assumption of the study is the joint connection between the building and billboard is assumed to be rigid. Since, this study mainly focused towards the change in behavior after installation of the billboard on a new structure or on an existing structure. Apart from joint connection, the total analysis is linear which actually give the fundamental behavior of the structure up to a limit.

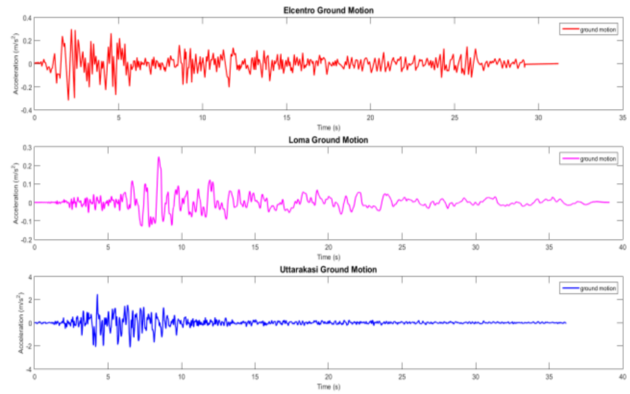


Figure 13 Three ground motions considered for this study, a. El Centro earthquake, b. Loma Prieta earthquake and c. Uttarkashi earthquake

For all the three ground motions considered, the responses of building with and without billboard are calculated in terms of x and y displacements, as both the stiffness are completely different. And these responses are compared within the building and building with billboard.

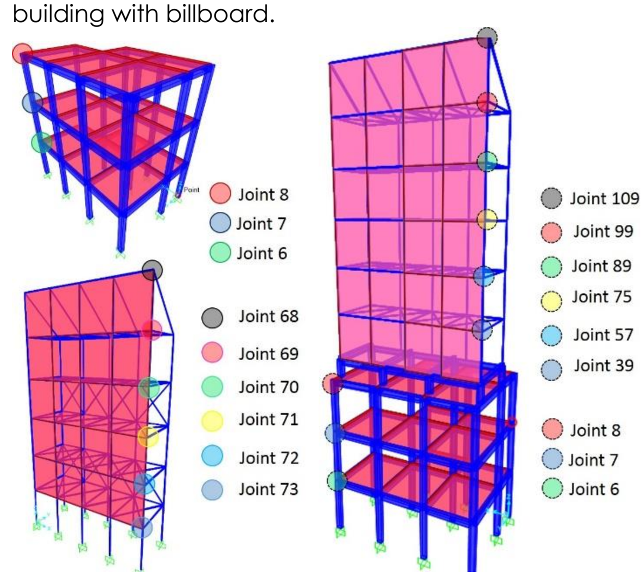


Figure 14 Numerical models developed for building, bill board and building with billboard. Joints shown indicate the considered response for further comparison

Figure 14 shows three numerical models developed using SAP200 with extruded view. And time history of all three ground motions are carried for all three numerical models, even though only few important and significant results are presented in this paper.

3.5 Response for El Centro Ground Motion

In most time history analysis of research community, El Centro ground motion is considered for its uniqueness.

Figure 15 shows the comparison of building response at three joints in terms of displacements.

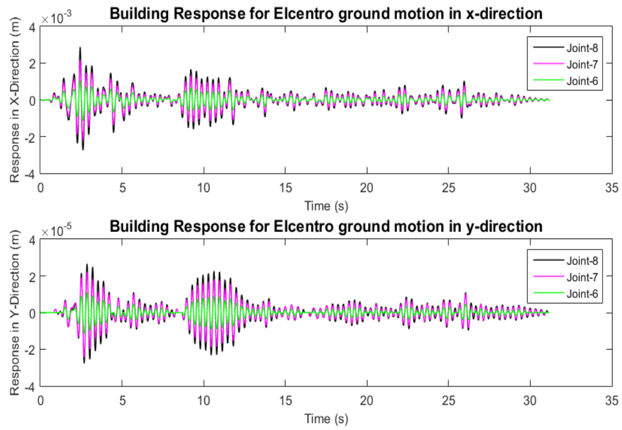


Figure 15 Comparison of response within the building at three joints shown in Figure 13 for both x and y directions

The maximum displacement of the structure in x-direction at joint 6, joint 7 and joint 8 are 1.05 mm, 2.18 mm and 2.88 mm respectively. Where as in y-direction for the same joints 6, 7, and 8 are 0.010 mm, 0.022 mm and 0.026 mm respectively. In fact the response of the building in y-direction is almost negligible.

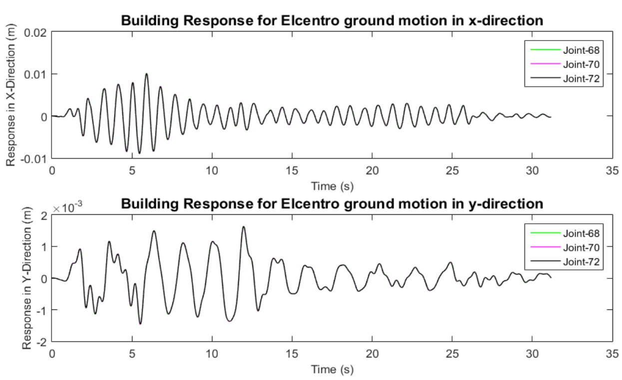


Figure 16 Comparison of response within the billboard at three joints shown in Figure 13 for both x and y directions

Similarly, time history is performed only on billboard with bottom fixed and joint displacements obtained are plotted in Figure 16. Observation of the plot indicates the displacements at various joints considered are same in both the directions. The maximum displacement of the billboard is 10.13 mm in x-direction and 1.64 mm in y-direction.

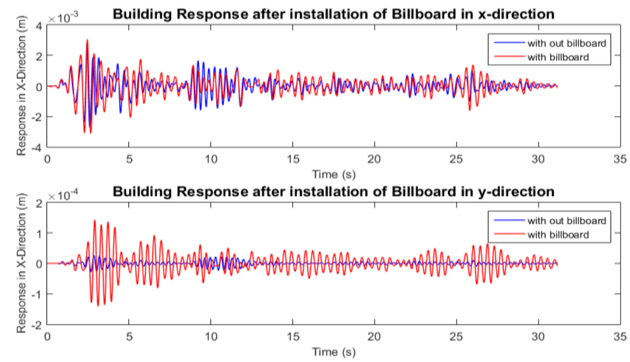


Figure 17 Comparison of response within the building at three joints shown in Figure 13 after installation of billboard for both x and y directions

Figure 17 shows the combined response of the building with and without billboard. The red color line indicates the response of the building with billboard and blue color line indicates the response of the structure of only building. From the plot, it is clear evident that the response of the structure has changed. The percentage change in x-direction is only 6 %, where as in y-direction it is 18 %. The major reason for this change is because of its stiffness.

3.6 Using Lomaprieta Ground Motion

The response of the building due to Loma Prieta ground motion are plotted and showed in the Figure 18. The maximum displacement of the structure in x-direction at joint 6, joint 7 and joint 8 are 0.6 mm, 1.3 mm and 1.69 mm respectively. Where as in y-direction for the same joints 6, 7, and 8 are 0.0055 mm, 0.011 mm and 0.013 mm respectively. In fact the response of the building in y-direction is almost negligible.

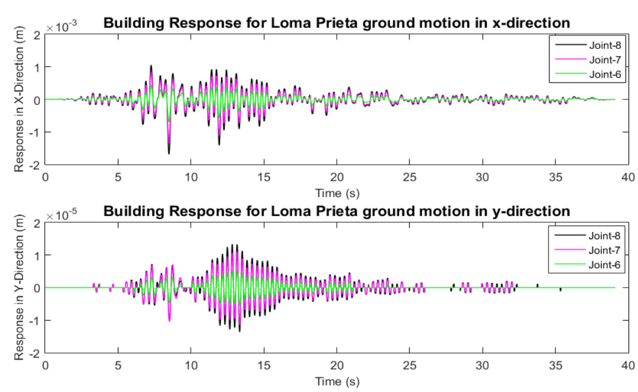


Figure 18 Comparison of response within the building at three joints shown in Figure13 for both x and y directions

Similarly, time history is performed only on billboard with bottom fixed and joint displacements obtained are plotted in Figure 19. Observation of the plot indicates the displacements at various joints considered are same in both the directions. The maximum displacement of the billboard is 12.71 mm in x-direction and 1.94 mm in y-direction.

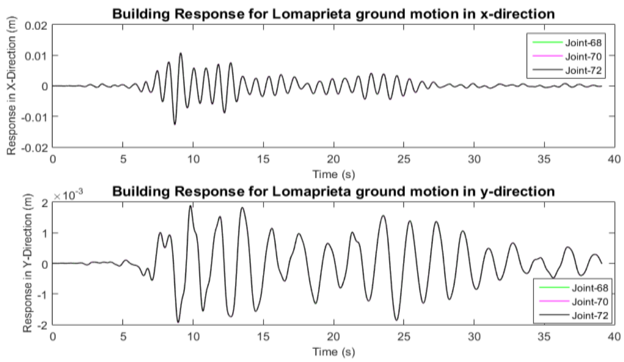


Figure 19 Comparison of response within the billboard at three joints shown in Figure 13 for both x and y directions

Figure 20 shows the combined response of the building with and without billboard. The red color line indicates the response of the building with billboard and blue color line indicates the response of the structure of only building. From the plot, it is clear evident that the response of the structure has changed. The percentage change in x-direction is 30 %, where as in y-direction it is 79.4 %. It is a clear evident that the type of ground motion will change the total response of the structure. The percentage change of billboard response acquired for Loma Prieta is quite different from the response obtained due to El Centro earthquake. These comparisons actually show the importance of this study even for two earthquakes scenarios. One of the major reason for these two earthquake ground motions the response of the billboard is same at all the joints from bottom to top is because of its action like a soft storey. This effect is also seen in the mode shape two. Where its frequency is 1.13 Hz and time period is 0.884 seconds. Apart from that the upper part of the billboard is being rigid.

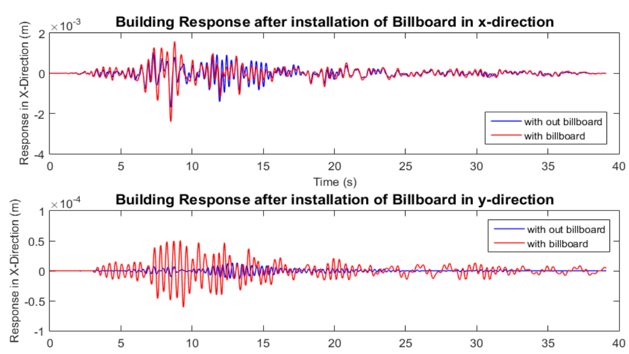


Figure 20 Comparison of response within the building at three joints shown in Figure 13 after installation of billboard for both x and y directions

3.7 Using Uttarkashi Ground Motion

Uttarkashi earthquake has occurred in 1991 in the northern part of the country nearer to the higher Himalaya. The response of the building due to Uttarkashi ground motion are plotted and showed in the Figure 21. The maximum displacement of the structure in x-direction at joint 6, joint 7 and joint 8 are 5.47 mm, 11.02 mm and 14.23 mm respectively. Where as in y-direction for the same joints 6, 7, and 8 are 0.055 mm, 0.11 mm and 0.14 mm respectively.

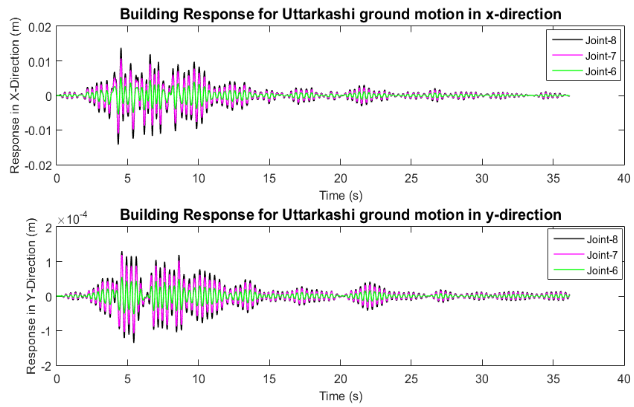


Figure 21 Comparison of response within the building at three joints shown in Figure 13 for both x and y directions

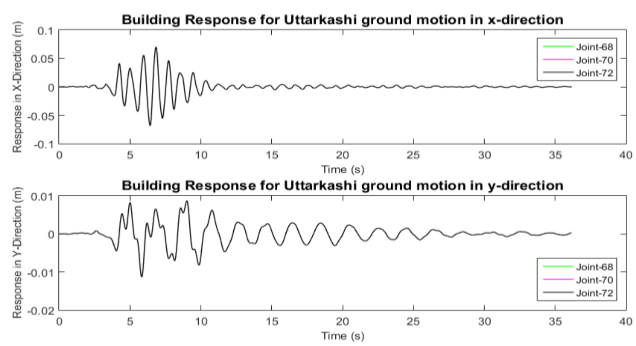


Figure 22 Comparison of response within the billboard at three joints shown in Figure 13 for both x and y directions

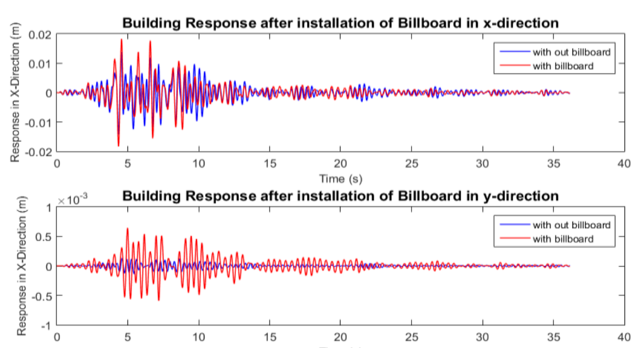


Figure 23 Comparison of response within the building at three joints shown in Figure 13 after installation of billboard for both x and y directions

Figure 22 shows the response of the billboard in both the x and y directions. The maximum displacement of the billboard in x-direction is 70.34 mm and displacement in y-direction is 11.36 mm. In fact this is the highest displacement when compared to other two ground motions. If the predominant frequency of the ground motion match's with the natural frequency of the billboard, then it would increase the response of the billboard. Other reason would be the peak ground acceleration of the Uttarkashi earthquake. And Figure 23 shows the combined response of the building with and without billboard. The red color line indicates the response of the building with billboard and blue color line indicates the response of the structure of only building. The percentage change in the response of the building with billboard in x-direction is 33 %, whereas, the displacement increase on the top of the structure in y-direction with billboard is 77%.

4.0 CONCLUSION

A numerical study has been carried out to understand the behavior of the building with and without installation of a billboard. As there are many cases in Hyderabad, India where buildings are not being checked whether they could withstand the extra loads transferred by the billboards during the huge winds or earthquakes. And continuous installations of billboards are continued on old and new structures without proper design considerations. This type of sudden installation of billboards could be very disastrous in both threat for life and economic loss during natural calamities. This study has indicated that the behavior will change for both building and billboard if combined together, by analyzing them in terms of modal analysis and time history analysis for three different earthquake ground motions.

Few important conclusions from this study are:

1. For the considered ground motions, the response of the building with billboard is greater than only building's response.
2. The variations in responses are directly dependent on the type of grounds motions considered. As it has been clearly observed that the variation is from 6% to 33 % in x-direction and 18 % to 80 % in y-direction.
3. The orientation of the billboard will definitely change the response of the structure, but it might lead to torsional effects.
4. The existing billboard has an effect of soft storey, as its displacements are almost same at all the levels in vertical direction.
5. As the damping percentages are different for reinforced concrete structure and steel structure, a common damping ratio has to be found for better results.

References

[1] Tomas, U. Ganiron. 2014. An Exploratory Study of the Impact and Construction of Billboards and Signage Structures. *Proceedings of Twelfth LACCEI Latin American and Caribbean Conference for Engineering and Technology (LACCEI'2014), July 22-24, 2014 Guayaquil, Ecuador.*

[2] State of North Carolina, Department of Revenue. Billboard Structures Valuation Guide: 2015, Rpt. 2009.

[3] International Association. 1991. Assessing Officers. The Valuation of Outdoor Advertising Structures. Assessment Digest. 13(4).

[4] Konno, T., Kimura, E. 1973. Earthquake Effects on Steel Tower Structures Atop Buildings. *Proceedings of the 5th World Conference on Earthquake Engineering (5WCEE)*, 1973, Rome, Italy, 25-29 June 1973. 184-193.

[5] McClure, G., Georgi, L., Assi, R. 2004, Seismic Considerations for Telecommunication Towers Mounted on Building Rooftop. *13th World Conference on Earthquake Engineering (13WCEE) Vancouver, B.C., Canada. August 1-6, 2004*. Paper No. 1988.

[6] SAP 2000 (Version 14.0.0). 2009. Integrated Software for Structural Analysis and Design. *Computers & Structures*, Inc., Berkeley, California.

[7] Ulrich, Franklin P. 1941. The Imperial Valley Earthquakes of 1940. *Bulletin of the Seismological Society of America (Seismological Society of America)*. 31: 13-30.

[8] Hough, S. E. 2004. *Finding Fault in California: An Earthquake Tourist's Guide*. Mountain Press Publishing. 185.

[9] Gunn, A. M. 2007. Imperial Valley California Earthquake. *Encyclopedia of Disasters: Environmental Catastrophes and Human Tragedies*. Volume 1. Greenwood Publishing Group. 364-365.

[10] Thakur, V. C., Sushil, K. 1994. Seismotectonics of the 20 October 1991 Uttarkashi Earthquake in Garhwal, Himalaya, North India. *Terra Nova.* 6(1): 90-94.

[11] Surendar Kumar and A. K. Mahajan. 1994. The Uttarkashi Earthquake of 20 October 1991: Field Observations. *Terra Nova.* 6(1): 95-99.

[12] Agarwal, P. and Shrikhande, M. 2006, *Earthquake Resistant Design of Structures.* PHI Learning Pvt. Ltd., New Delhi.

[13] IS 456- Indian Standard Code of Practice for Plain and Reinforced Concrete.

[14] IS 875. 1987. Indian Standard Code of Practice for Design Loads for Buildings and Structure.

[15] Indian Standards IS: 800. 2007. Code of Practice - General Construction Steel. New Delhi: BIS; 2007.

[16] IS: 1893 (Part I). 2002. Criteria for Earthquake Resistant Design of Structures. Fifth Revision. Indian Standards, New Delhi.

[17] Amiri, G., Barkhordari, M. A., Massah, S. R. 2004. Seismic Behaviour of 4-Legged Self-Supporting Telecommunication Tower. *13th World Conference on Earthquake Engineering (13WCEE) Vancouver, B.C., Canada. August 1-6, 2004.*

[18] Amiri, G., Barkhordari, M. A., Massah, S. R., Vafaei, M. R., 2007. Earthquake Amplification Factors for Self-supporting 4-legged Telecommunication Towers. *World Applied Sciences Journa*. 2(6): 635-643

[19] Khedr, M. A, McClure, G. 1999. Earthquake Amplification Factors for Self-supporting Telecommunication Towers. *Canadian Journal of Civil Engineering*. 26(2): 208-215.

[20] Khedr, A., McClure, G. 2000. A Simplified Method for Seismic Analysis of Lattice Telecommunication Towers. *Canadian Journal of Civil Engineering.* 27(3): 533-542.

[21] Galvez, C., McClure, G. 1995. A Simplified Method for a Seismic Design of Self-supporting Lattice Telecommunication Towers. *Proceedings of the 7th Canadian Conference on Earthquake Engineering (7CCEE)*, Montreal, Canada. 541-548.

[22] Marsantyo, R., Shimazu, T., Akari, H., Kabayama, K., and Kobayashi, M. 1998. Experimental Work on the Seismic Horizontal Force for Nonstructural Systems Mounted on the

Buildings. *Proceedings of the 10th Earthquake Engineering Symposium*, Yokohama, Japan, November 25-27. 2635-2640.

[23] Kanazawa, K., and Hirata K. 2000. Seismic Analysis for Telecommunication Towers Built on the Building. *Proceedings of the 12th World Conference on Earthquake Engineering*, Auckland, New Zealand, on CD-ROM. Paper 0534.

[24] Nitin Bhosale, Prabhat Kumar, A. D. Pandey. 2012. Influence of Host Structure Characteristics on Response of Rooftop Telecommunication Towers. *International Journal of Civil and Structural Engineering*. 2(3): 737-748.

[25] Chopra, A. K. 2001. *Dynamics of Structures – Theory and Application to Earthquake Engineering*. Prentice Hall.