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Seismic Analysis and Design of Building Structures in STAAD Pro

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ABSTRACT: Structural designing requires structural analysis and earthquake or seismic analysis of any structure prior to construction. Earthquake or seismic analysis is the calculation of the response of a structure subjected to earthquake excitation. Various seismic data are necessary to carry out the seismic analysis of the structures

In this study, the seismic response of the structures is investigated under earthquake excitation expressed in the form of member forces, joint displacement, support reaction and story drift. The response is investigated for g+10 building structures by using STAAD PRO designing software. We observed the response reduction of cases ordinary moment resisting frame. In this case we have taken earthquake zone 2, response factor 3 for ordinary moment resisting frame and importance factor 1.

KEYWORDS: seismic analysis, earthquake excitation, ordinary moment resisting frame, member forces, joint displacement, support reaction, storey drift, STAAD PRO V8i.

I. INTRODUCTION

When an earthquake struck any residential area, Hundreds of people get killed and many get injured when an earthquake struck any residential area. Tremors can be felt from at hundreds of kilometers from the epicenter of the earthquake. An earthquake is a phenomena in which Earth's surface shakes due to the release of seismic energy from large blocks of the crust along a fault. Faults are cracks in the crust.

The point under the earth crust on the fault surface where the processes of earthquakes begins, it is the source of earthquake and it is termed as the focus. Focus is the center from where Seismic waves radiates outward.

Earthquake Epicenters

The point which is directly above the focus on earth surface is called the epicenter. If we join all the earthquake epicenter on map it shows a well-defined regions of the Earth which is long and narrow and sometimes referred to as earthquake belts.

Tectonic plates

Movement of tectonic plates is one of the major reasons of earthquakes. The lithosphere, is divided into many tectonic plates which are moving slowly with respect to each other. There are 7-8 major plates and many minor plates. Movement of plates vary between 0 to 100mm per year, these plates float on the underlying hot and viscous mantle.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

Measuring the Size of an Earthquake Seismographs

Seismograph is the instrument which records vibrations of seismic waves generated by earthquakes that travel through the Earth. Seismographs record a zig-zag trace that shows the varying amplitude of ground oscillations beneath the instrument. Some of high sensitive seismographs can detect strong earthquakes from sources anywhere in the world by magnifying the ground motions at a great extent. The time, locations, and magnitude of an earthquake can be known from the seismograph stations.

The Richter scale

Charles F. Richter developed the Richter magnitude scale in 1935 in California. The magnitude of an earthquake is determined by analyzing the waves recorded by seismographs. On the Richter scale, the magnitude of earthquake is expressed as whole numbers in decimal fractions. Because of the logarithmic basis of the scale, each increase in magnitude represents a tenfold increase in measured amplitude. Earlier, the Richter scale could be applied only to those records which are from instruments manufactured by same company. Now, instruments are carefully calibrated with respect to each other. Thus, Richter scale can be applied to record of any calibrated seismograph.

Impact of Earthquake

Earthquake has a huge impact on our day-to-day life. The following things are affected due to earthquake:

- Life and Society
- Property (Structures and their content)
- Civic Amenities (schools, hospitals)
- Lifeline Amenities (roads, bridges, power)
- Heritage
- Economy and development

...virtually almost everything.

II. MATERIALS AND METHOD

In order to study the effect of earthquake on a g+10 building a computer aided designing software namely staad pro v8i has been used. This software is very fast as compared to manual designing.

Input data: The staad pro provides an input file which is a text file and it consists all the commands executed in a sequence. This text file consist instructions for analysis and design.

Modeling of structure: The structure is modeled by giving coordinates, by providing building height, floor height, material constants, supports etc.

Materials: Materials selection was done by the software itself.

Mat	Name	E (kN/mm ²)	ν	Density (kg/m ³)	α (/°C)
1	STEEL	205.000	0.300	7.83E+3	12E -6
2	STAINLESSSTEEL	197.930	0.300	7.83E+3	18E -6
3	ALUMINUM	68.948	0.330	2.71E+3	23E -6
4	CONCRETE	21.718	0.170	2.4E+3	10E -6

Supports: All the supports provided in the structure are fixed.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

Loads

Load Cases: Load cases are generated by software and are accordance with Indian standards.

LC	TYPE	NAME
1	PRIMARY	SEISMIC X+
2	PRIMARY	SEISMIC Z+
3	PRIMARY	DEAD LOAD
4	PRIMARY	LIVE LOAD
5	COMBINATION	1.5(DL+LL)
6	COMBINATION	1.2(DL+LL)
7	COMBINATION	1.2(DL+LL+SX+)

Seismic load: These loads are applied in X-direction and in Z-direction in staad pro. These loads will simulate the building as in actual condition during earthquake. All the loading is done with the accordance with IS – 1893.

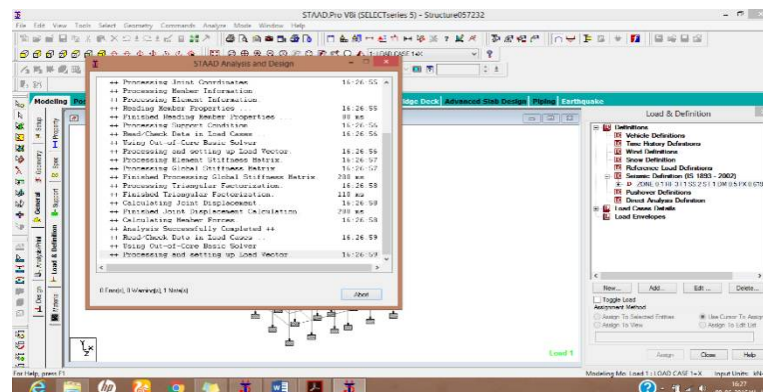
Dead load: These loads are non-movable loads and are fixed like weight of beams and columns, floor weight, slab weight etc.

Live load: These loads are movable load like human being in building.

Design parameter: The designing is performed as per IS: 456 for concrete design, IS: 13920 for ductile detailing of reinforced concrete design and IS: 1893 for seismic parameter.

Analysis of structure: The whole structure was analyzed by the staad pro software under consideration of IS: 1893 for seismic parameter.

IV. RESULT AND DISCUSSION



Concrete design

Beam design: In this section beam design is discussed. In the process of building designing three types of beams are being used which have same cross section of 0.60mX0.30m and have three different spans which are 3m, 5m and 6.5m. The design output of staad pro is shown below for each type of beams.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

(i) 3m span

B E A M N O. 620 D E S I G N R E S U L T S					
M30	Fe415 (Main)		Fe415 (Sec.)		
LENGTH: 3000.0 mm	SIZE: 300.0 mm X 600.0 mm		COVER: 25.0 mm		
SUMMARY OF REINF. AREA (Sq.mm)					
SECTION	0.0 mm	750.0 mm	1500.0 mm	2250.0 mm	3000.0 mm
TOP REINF.	350.24 (Sq. mm)	350.24 (Sq. mm)	0.00 (Sq. mm)	350.24 (Sq. mm)	350.24 (Sq. mm)
BOTTOM REINF.	0.00 (Sq. mm)	0.00 (Sq. mm)	350.24 (Sq. mm)	0.00 (Sq. mm)	0.00 (Sq. mm)

SUMMARY OF PROVIDED REINF. AREA					
SECTION	0.0 mm	750.0 mm	1500.0 mm	2250.0 mm	3000.0 mm
TOP REINF.	5-10i 1 layer (s)	5-10i 1 layer (s)	5-10i 1 layer (s)	5-10i 1 layer (s)	5-10i 1 layer (s)
BOTTOM REINF.	5-10i 1 layer (s)	5-10i 1 layer (s)	5-10i 1 layer (s)	5-10i 1 layer (s)	5-10i 1 layer (s)
SHEAR REINF.	2 legged 8i @ 200 mm c/c	2 legged 8i @ 200 mm c/c	2 legged 8i @ 200 mm c/c	2 legged 8i @ 300 mm c/c	2 legged 8i @ 300 mm c/c

SHEAR DESIGN RESULTS AT DISTANCE d (EFFECTIVE DEPTH) FROM FACE OF THE SUPPORT					
SHEAR DESIGN RESULTS AT 910.0 mm AWAY FROM START SUPPORT					
VY = 37.31 MX = -0.04 LD= 12					
Provide 2 Legged 8i @ 200 mm c/c					
SHEAR DESIGN RESULTS AT 910.0 mm AWAY FROM END SUPPORT					
VY = -29.96 MX = 0.03 LD= 9					
Provide 2 Legged 8i @ 200 mm c/c					

(ii) 5m span

B E A M N O. 600 D E S I G N R E S U L T S					
M30	Fe415 (Main)			Fe415 (Sec.)	
LENGTH: 5000.0 mm	SIZE: 300.0 mm X 600.0 mm			COVER: 25.0 mm	
SUMMARY OF REINF. AREA (Sq.mm)					
SECTION	0.0 mm	1250.0 mm	2500.0 mm	3750.0 mm	5000.0 mm
TOP REINF.	350.24 (Sq. mm)	0.00 (Sq. mm)	0.00 (Sq. mm)	350.24 (Sq. mm)	958.98 (Sq. mm)
BOTTOM REINF.	0.00 (Sq. mm)	349.63 (Sq. mm)	377.04 (Sq. mm)	0.00 (Sq. mm)	0.00 (Sq. mm)
SUMMARY OF PROVIDED REINF. AREA					
SECTION	0.0 mm	1250.0 mm	2500.0 mm	3750.0 mm	5000.0 mm
TOP REINF.	3-25i 1 layer(s)	2-25i 1 layer(s)	2-25i 1 layer(s)	3-25i 1 layer(s)	3-25i 1 layer(s)
BOTTOM REINF.	2-16i 1 layer(s)	3-16i 1 layer(s)	3-16i 1 layer(s)	2-16i 1 layer(s)	2-16i 1 layer(s)
SHEAR REINF.	2 legged 8i @ 200 mm c/c	2 legged 8i @ 200 mm c/c	2 legged 8i @ 200 mm c/c	2 legged 8i @ 200 mm c/c	2 legged 8i @ 200 mm c/c
SHEAR DESIGN RESULTS AT DISTANCE d (EFFECTIVE DEPTH) FROM FACE OF THE SUPPORT					
SHEAR DESIGN RESULTS AT 902.5 mm AWAY FROM START SUPPORT					
VY = 69.19 MX = 1.67 LD= 5					
Provide 2 Legged 8i @ 200 mm c/c					
SHEAR DESIGN RESULTS AT 902.5 mm AWAY FROM END SUPPORT					
VY = -118.78 MX = 1.67 LD= 5					
Provide 2 Legged 8i @ 200 mm c/c					

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

(iii) 6.5m span

B E A M N O. 603 D E S I G N R E S U L T S					
M30	Fe415 (Main)			Fe415 (Sec.)	
LENGTH: 6500.0 mm	SIZE: 300.0 mm X 600.0 mm			COVER: 25.0 mm	
SUMMARY OF REINF. AREA (Sq.mm)					
SECTION	0.0 mm	1625.0 mm	3250.0 mm	4875.0 mm	6500.0 mm
TOP REINF.	2397.54 (Sq. mm)	0.00 (Sq. mm)	0.00 (Sq. mm)	0.00 (Sq. mm)	1477.33 (Sq. mm)
BOTTOM REINF.	29.03 (Sq. mm)	350.24 (Sq. mm)	1070.03 (Sq. mm)	413.02 (Sq. mm)	0.00 (Sq. mm)
SUMMARY OF PROVIDED REINF. AREA					
SECTION	0.0 mm	1625.0 mm	3250.0 mm	4875.0 mm	6500.0 mm
TOP REINF.	12-16i 2 layer (s)	2-16i 1 layer (s)	2-16i 1 layer (s)	2-16i 1 layer (s)	8-16i 2 layer (s)
BOTTOM REINF.	5-10i 1 layer (s)	5-10i 1 layer (s)	14-10i 2 layer (s)	6-10i 1 layer (s)	5-10i 1 layer (s)
SHEAR REINF.	2 legged 8i @ 200 mm c/c	2 legged 8i @ 150 mm c/c	2 legged 8i @ 200 mm c/c	2 legged 8i @ 200 mm c/c	2 legged 8i @ 200 mm c/c
SHEAR DESIGN RESULTS AT DISTANCE d (EFFECTIVE DEPTH) FROM FACE OF THE SUPPORT					
SHEAR DESIGN RESULTS AT 891.0 mm AWAY FROM START SUPPORT					
VY = 252.10 MX = -0.50 LD= 5					
Provide 2 Legged 10i @ 180 mm c/c					
SHEAR DESIGN RESULTS AT 899.0 mm AWAY FROM END SUPPORT					
VY = -214.83 MX = -0.50 LD= 5					
Provide 2 Legged 10i @ 190 mm c/c					

Column design: In this section column design is discussed. In the process of building designing three types of columns are being used which have same height of 3m each and have three different cross section which are (0.92mX0.92m), (0.81mX0.81m) and (0.68mX0.68m). The design output of staad pro is shown below for each type of columns.

i. Cross section (0.92mX0.92m)

```
=====
C O L U M N   N O.      28   D E S I G N   R E S U L T S

M30                      Fe415 (Main)                      Fe415 (Sec.)

LENGTH: 3000.0 mm   CROSS SECTION: 920.0 mm X 920.0 mm   COVER: 40.0 mm

** GUIDING LOAD CASE:      5   END JOINT:      1   SHORT COLUMN

REQD. STEEL AREA   :      3426.69 Sq.mm.
REQD. CONCRETE AREA:      428336.66 Sq.mm.
MAIN REINFORCEMENT : Provide 32 - 12 dia. (0.43%, 3619.11 Sq.mm.)
                    (Equally distributed)
TIE REINFORCEMENT  : Provide 8 mm dia. rectangular ties @ 190 mm c/c

SECTION CAPACITY BASED ON REINFORCEMENT REQUIRED (KNS-MET)
-----
Puz : 12446.70   Muz1 : 1591.07   Muy1 : 1591.07

INTERACTION RATIO: 0.11 (as per Cl. 39.6, IS456:2000)

SECTION CAPACITY BASED ON REINFORCEMENT PROVIDED (KNS-MET)
-----
WORST LOAD CASE:      10
END JOINT:      1   Puz : 12503.99   Muz : 1611.64   Muy : 1611.64   IR: 0.17
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International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

ii. Cross section (0.81mX0.81m)

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=====
C O L U M N   N O .   169   D E S I G N   R E S U L T S

M30                      Fe415 (Main)                      Fe415 (Sec.)

LENGTH: 3000.0 mm  CROSS SECTION: 810.0 mm X 810.0 mm  COVER: 40.0 mm

** GUIDING LOAD CASE:    5  END JOINT:    61  SHORT COLUMN

REQD. STEEL AREA   :    3929.43 Sq.mm.
REQD. CONCRETE AREA:   491178.94 Sq.mm.
MAIN REINFORCEMENT : Provide 20 - 16 dia. (0.61%, 4021.24 Sq.mm.)
                    (Equally distributed)
TIE REINFORCEMENT  : Provide 8 mm dia. rectangular ties @ 255 mm c/c

SECTION CAPACITY BASED ON REINFORCEMENT REQUIRED (KNS-MET)
-----
Puz : 10027.34  Muz1 : 934.91  Muy1 : 934.91

INTERACTION RATIO: 0.15 (as per Cl. 39.6, IS456:2000)

SECTION CAPACITY BASED ON REINFORCEMENT PROVIDED (KNS-MET)
-----
WORST LOAD CASE:      5
END JOINT:    61  Puz : 10054.67  Muz : 942.30  Muy : 942.30  IR: 0.15
=====
```

iii. Cross section (0.68mX0.68m)

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=====
C O L U M N   N O .   313   D E S I G N   R E S U L T S

M30                      Fe415 (Main)                      Fe415 (Sec.)

LENGTH: 3000.0 mm  CROSS SECTION: 680.0 mm X 680.0 mm  COVER: 40.0 mm

** GUIDING LOAD CASE:    5  END JOINT:    124  SHORT COLUMN

REQD. STEEL AREA   :    2082.21 Sq.mm.
REQD. CONCRETE AREA:  260275.62 Sq.mm.
MAIN REINFORCEMENT : Provide 20 - 12 dia. (0.49%, 2261.95 Sq.mm.)
                    (Equally distributed)
TIE REINFORCEMENT  : Provide 8 mm dia. rectangular ties @ 190 mm c/c

SECTION CAPACITY BASED ON REINFORCEMENT REQUIRED (KNS-MET)
-----
Puz : 6862.38  Muz1 : 630.02  Muy1 : 630.02

INTERACTION RATIO: 0.22 (as per Cl. 39.6, IS456:2000)

SECTION CAPACITY BASED ON REINFORCEMENT PROVIDED (KNS-MET)
-----
WORST LOAD CASE:      8
END JOINT:    142  Puz : 6915.90  Muz : 667.68  Muy : 667.68  IR: 0.29
=====
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International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

Nodal Displacement Summary

In the above table maximum and minimum node displacements are given with their respective load cases.

	Node	L/C	X (mm)	Y (mm)	Z (mm)	Resultant (mm)	rX (rad)	rY (rad)	rZ (rad)
Max X	199	12:GENERATE	20.860	-6.070	0.095	21.725	0.000	-0.000	-0.000
Min X	204	14:GENERATE	-20.860	-6.070	0.095	21.725	0.000	0.000	0.000
Max Y	205	1:LOAD CASE	13.849	0.215	0.000	13.851	0.000	0.000	-0.000
Min Y	206	5:GENERATEI	0.057	-17.379	0.000	17.379	-0.000	-0.000	-0.000
Max Z	201	13:GENERATE	0.008	-8.198	23.805	25.176	0.001	-0.000	0.000
Min Z	213	15:GENERATE	0.008	-8.198	-23.805	25.176	-0.001	0.000	0.000
Max rX	110	13:GENERATE	0.004	-6.114	15.307	16.483	0.001	-0.000	-0.000
Min rX	122	15:GENERATE	0.004	-6.114	-15.307	16.483	-0.001	0.000	-0.000
Max rY	213	5:GENERATEI	0.009	-9.528	-0.120	9.528	-0.001	0.000	0.000
Min rY	201	5:GENERATEI	0.009	-9.528	0.120	9.528	0.001	-0.000	0.000
Max rZ	84	14:GENERATE	-8.181	-4.537	0.000	9.355	0.000	-0.000	0.001
Min rZ	79	12:GENERATE	8.181	-4.537	-0.000	9.355	0.000	-0.000	-0.001
Max Rst	206	13:GENERATE	0.049	-15.093	23.698	28.096	0.000	-0.000	-0.000

Beam Displacement Detail Summary

Maximum and minimum displacements of beam members are discussed in the above table with accordance to load cases. The maximum resultant displacement is 30.292 mm.

Displacements shown in italic indicate the presence of an offset

	Beam	L/C	d (m)	X (mm)	Y (mm)	Z (mm)	Resultant (mm)
Max X	578	12:GENERATE	3.000	20.860	-6.071	0.095	21.726
Min X	583	14:GENERATE	3.000	-20.861	-6.071	0.095	21.726
Max Y	231	2:LOAD CASE	5.200	0.000	0.393	8.110	8.119
Min Y	457	5:GENERATEI	3.900	-0.014	-22.458	-0.012	22.458
Max Z	598	13:GENERATE	1.500	-0.000	-8.167	23.809	25.171
Min Z	620	15:GENERATE	1.500	-0.000	-8.167	-23.809	25.171
Max Rst	471	13:GENERATE	2.600	0.014	-19.405	23.261	30.292

Maximum and minimum Beam End Displacement

The result shown here in the table shows us the Maximum and minimum Beam end displacement coming under different load cases applied in this study. The maximum beam end displacement in the building is 28.097.

Displacements shown in italic indicate the presence of an offset

	Beam	Node	L/C	X (mm)	Y (mm)	Z (mm)	Resultant (mm)
Max X	578	199	12:GENERATE	20.860	-6.071	0.095	21.726
Min X	583	204	14:GENERATE	-20.861	-6.071	0.095	21.726
Max Y	394	169	1:LOAD CASE	13.140	0.214	0.000	13.141
Min Y	585	206	5:GENERATEI	0.057	-17.379	0.000	17.379
Max Z	580	201	13:GENERATE	0.008	-8.198	23.805	25.177
Min Z	592	213	15:GENERATE	0.008	-8.198	-23.805	25.177
Max Rst	588	209	15:GENERATE	-0.050	-15.094	-23.698	28.097

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

Maximum and minimum Beam End Force

The above table gives us the maximum and minimum Beam end forces coming in different beams at different nodes under different load cases.

The signs of the forces at end B of each beam have been reversed. For example: this means that the Min Fx entry gives the largest tension value for an beam

	Beam	Node	L/C	Axial	Shear		Torsion	Bending	
				Fx (kN)	Fy (kN)	Fz (kN)	Mx (kNm)	My (kNm)	Mz (kNm)
Max Fx	35	8	5:GENERATEI	14.1E+3	-4.374	0.000	0.000	-0.000	-5.609
Min Fx	34	7	1:LOAD CASE	-236.660	47.936	-0.000	-0.000	0.000	219.254
Max Fy	457	182	5:GENERATEI	-18.068	540.024	-0.004	0.130	0.016	740.195
Min Fy	468	194	5:GENERATEI	-18.068	-540.024	0.004	-0.130	0.016	740.194
Max Fz	579	182	5:GENERATEI	678.102	-22.661	277.839	0.593	-398.609	-26.408
Min Fz	591	194	5:GENERATEI	678.102	-22.661	-277.839	-0.593	398.609	-26.408
Max Mx	455	185	5:GENERATEI	-8.336	162.320	0.005	1.765	-0.016	109.294
Min Mx	451	181	5:GENERATEI	-8.336	224.144	-0.005	-1.765	0.009	263.853
Max My	579	200	5:GENERATEI	583.850	-22.661	277.839	0.593	434.909	41.574
Min My	591	212	5:GENERATEI	583.850	-22.661	-277.839	-0.593	-434.909	41.574
Max Mz	457	182	5:GENERATEI	-18.068	540.024	-0.004	0.130	0.016	740.195
Min Mz	37	10	14:GENERATE	10.4E+3	-121.107	-0.000	0.000	0.000	-373.813

Maximum beam displacement

The maximum beam displacement coming for span 3m, 5m and 6.5m are 0.0044mm, 1.023mm and 3.048mm respectively. The allowable limits as per IS: 456 are 12mm,20mm and 26mm respectively for 3m, 5m and 6.5m.

BEAM	L/C	LENGTH (m)	Max (mm)	Distance (m)	allowable limits(mm)
598	5 combination 1.5(DL+LL)	3	0.044	2.250	12
600	5 combination 1.5(DL+LL)	5	1.023	2.083	20
601	5 combination 1.5(DL+LL)	6.5	3.048	3.250	26

Storey drift

STORY	HEIGHT	LOAD	AVG. DISP (CM)		DRIFT (CM)		RATIO	STATUS
	(METE)		X	Z	X	Z		
BASE=	0.00						ALLOW. DRIFT = L / 1	
12	33.00	5	0.0000	0.0000	0.0000	0.0000	L / 999999	PASS
		6	0.0000	0.0000	0.0000	0.0000	L / 999999	PASS
		7	1.6619	0.0000	0.0267	0.0000	L / 11238	PASS
		8	0.0000	1.8959	0.0000	0.0362	L / 8293	PASS
		9	-1.6619	0.0000	0.0267	0.0000	L / 11238	PASS
		10	0.0000	-1.8959	0.0000	0.0362	L / 8293	PASS
		11	0.0000	0.0000	0.0000	0.0000	L / 999999	PASS
		12	2.0774	0.0000	0.0334	0.0000	L / 8990	PASS

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

After the analysis we get the maximum drift in the building is 2.077 cm under different combinations of load which is safe as per IS 1893-2002.

V. CONCLUSIONS

The main conclusion of the study is as follows

- The fundamental natural period calculated by staad pro matches with that calculated by IS 1893:2002.
- The displacement of beam coming in the building is within the limits of Indian standards.
- This building is safe for area coming under earthquake zone II.
- The maximum drift in the building is 2.077 cm which is safe as per IS 1893-2002.
- The maximum beam displacement of 3m span beam is 0.044mm and allowable displacement is 12mm.

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