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Response of a 3-Dimensional 2 X 3 Bays Ten Storey RC Frame with Steel Bracings as Lateral Load Resisting Systems Subjected To Seismic Load

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Abstract— A natural hazard like Earthquake causes damage to or collapse of buildings if not designed for lateral loads resulting due to Earthquake. Hence for seismic resistance for high rise structures it is important to provide exclusive Lateral Load Resisting System (LLRS) which will supplement the behavior of moment resisting frames in resisting the lateral load. Some of the LLRS commonly used are shear walls, infill frames and steel bracings. In the present study, an attempt is made to study the difference in structural behavior of 3-dimensional (3D) two-bays - three-bays, 10 storey basic moment resisting RC frames when provided with steel bracings as LLRS. The detailed investigations are carried out for zone V of Seismic zone of India, considering primary loads and their combinations. Three models are analyzed consisting of one basic moment resisting RC frame and other two include basic moment resisting RC frame with external and internal steel bracings. The results obtained from the linear dynamic analysis are thoroughly investigated for maximum values of joint displacements, support reactions, beam forces and forces in steel bracings. The results indicate better resistance to lateral load of the frames in the presence of steel bracings.

Index Terms—Earthquake, Lateral loads, LLRS, RC frame, Retrofit, RSM, Steel bracings.

1 Introduction

Earthquakes are perhaps the most unpredictable and devastating of all natural disasters. They not only cause great destruction in terms of human causalities, but also have a tremendous economic impact on the affected area. Many existing buildings lack the seismic strength and detailing requirements as per Indian standard codes of practice at present and thus need to upgrade if the structure was initially not designed and constructed to resist an earthquake i.e. designed only for gravity loads but still has not undergone failure. For structures, which have undergone failure due to earthquake, it is essential to retrofit for future use.

2 Present Investigation

Depending upon the local guidelines and for commercial purpose 10 storey buildings are common in practice .Thus, the present investigation is concerned with detailed 3D study of results of analysis of a ten storey Moment Resisting Frame having two bays along X and three bays along Z provided with steel bracings as Lateral Load Resisting Systems (LLRS), in comparison with identical Moment Resisting Bare Frame (without any special LLRS feature) subjected to gravity load, seismic load and their combinations. Two types of steel bracings, External and Internal are considered in the present investigation. The study is hoped to be helpful during retrofitting of such structures which are initially designed only for gravity loads and found unsafe for seismic loads and any combination of loads.

3 METHOD OF ANALYSIS

The present study undertaken deals with Linear Dynamic analysis i.e Response Spectrum Method.

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3.1 Modeling of the Structure

For the present 3D study STAAD.Pro software package is used.

4 DETAILS OF THE PROBLEM CHOSEN

The details and dimensions of the frames and structural elements considered in the present study are given below.

4.1 Plan and Height of the Frames

The plan consists of two bays of span 7.5 m along X direction, three bays of span 3.0 m each along Z direction. The typical Ten-Storey building has each storey height of 3.0 m along Y direction.

4.2 Beam Cross-Sections	**Plinth Beam Size**	**Floor Beam Size**
B1 (Primary) (Z x Y)	300mm X 450mm	300mm X 750mm
B2 (Secondary) (X x Y)	300mm X 300mm	300mm X 375mm

4.3 Column Size

Square column: 636mm X 636mm.

4.4 Steel Section

ISLC 225

4.5 Seismic Zone

Zone V as per IS code [1] for which zone factor (Z) is 0.36.

4.6 Types of Primary Loads and Load Combinations

The structural systems are subjected to three types of Primary Load Cases as per IS code [2], they are:

1. Dead Load case (Gravity load), "DL"
2. Live Load case (Gravity load), "LL"
3. Seismic (Lateral) Load in X-direction, "ELx"
4. Seismic (Lateral) Load in Z-direction, "ELz".

In addition, the structural systems are subjected to 13 different Load Combinations, they are:

5. 1.5(DL + LL)
6. 1.2(DL + LL +ELx)
7. 1.2(DL + LL - ELx)

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8. 1.2(DL + LL +ELz)
09. 1.2(DL + LL - ELz)
10. 1.5(DL + ELx)
11. 1.5(DL - ELx)
12. 1.5(DL + ELz)
13. 1.5(DL - ELz)
14. (0.9DL + 1.5ELx)
15. (0.9DL - 1.5ELx)
16. (0.9DL + 1.5ELz)
17. (0.9DL - 1.5ELz)

The dead load consists of self-weight of structural elements and masonry wall load of thickness 230 mm (The lateral load resistance effect of infill wall is not considered for analysis). The live load considered is as adopted for medium office, hospital or hostel building i.e. 4 kN/m^2 as per IS code [2]. The Response Spectrum Method of analysis is adopted for the calculation of the lateral load at each floor level as per IS code [3]. The lateral loads applied are given in Table1.

TABLE 1
JOINTS LOAD AT EACH STOREY IN KN.

Level	Bare Frame/Steel bracing	
	End- frame	Mid-frame
Plinth	26.25	33.75
Floor	79.92	122.34
Terrace	53.97	72.69

4.7 Physical Properties Considered for Present FEA

Density of brick wall = 18.85 kN/m^3
Density of R.C.C = 25 kN/m^3
Young's modulus of concrete = 2.17185x10^7 kN/m^2
Poisson's Ratio of concrete = 0.17

4.8 Connection details of bracing

The external steel bracings are connected at the junction of the beam column and the ground. In case of internal steel bracings, connection at the beam center is through a vertical steel shear link as shown in Fig. 1, proposed by Ghobarah A., Abou Elfath H. [1]. This arrangement is considered as the concrete beams are incapable of performing as a ductile link for the steel bracing system that is inserted in the frame bays.

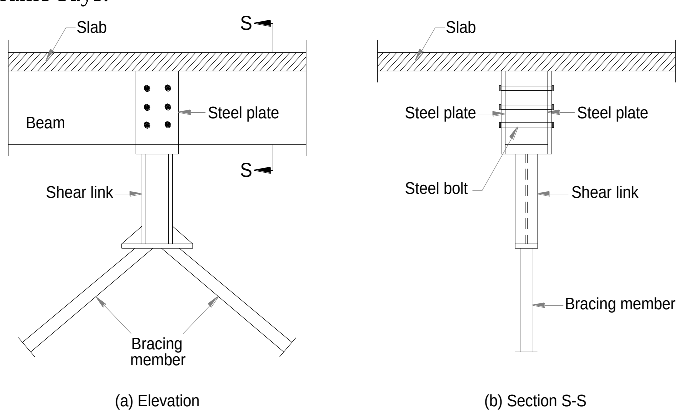

Fig. 1 Connection details of a vertical steel link.

Based on experimental data, the formula for calculating the length of a cantilever link to ensure that the link yields primarily in shear is

$$e_{crit} = 2b_f t_f / t_w$$

Where, b_f and t_f are the width and thickness of the flange and t_w is the web thickness of a wide flange section link.

In the present work, steel bracing section considered is ISLC225, whose section properties are

$b_f = 90mm$, $t_f = 10.2mm$ and $t_w = 5.8mm$

Therefore, $e_{crit} = 2 \times 90 \times 10.2 / 5.8$

$$e_{crit} = 320\,mm = 0.32\,m$$

4.8 Frames considered

4.8.1 Bare frame (Fig.2 and Fig. 3).

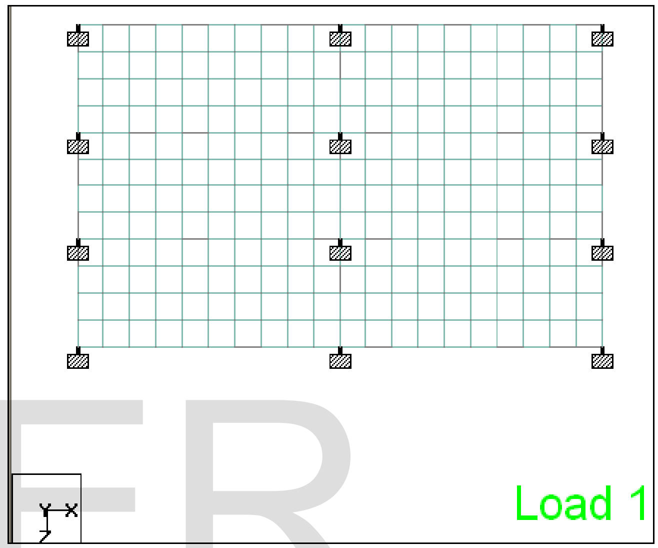

Fig.2 BF – Plan

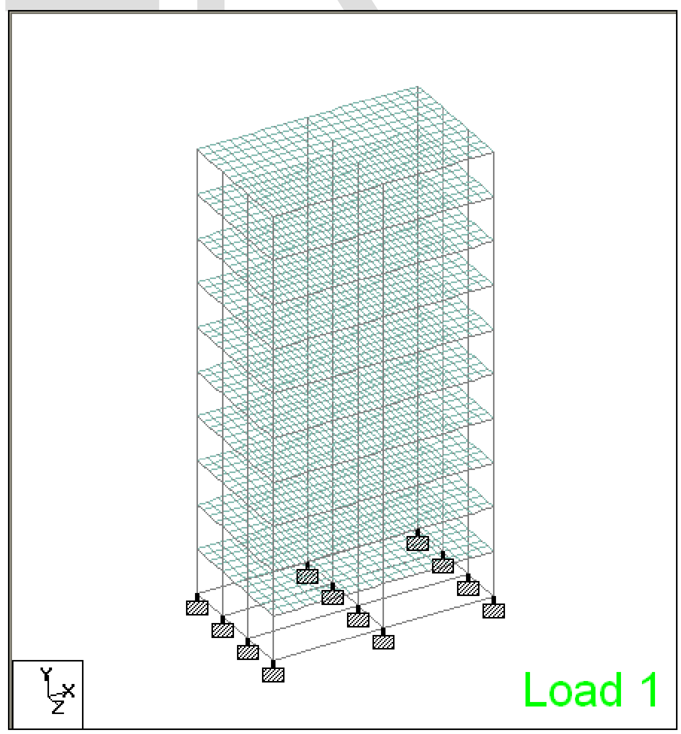

Fig.3 BF – 3D

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4.8.2 Frames with External Steel Bracing (ESB), provided at end bays along X and Z directions. External steel bracing is provided upto five storeys only due to practical considerations. (Fig.4 and Fig.5).

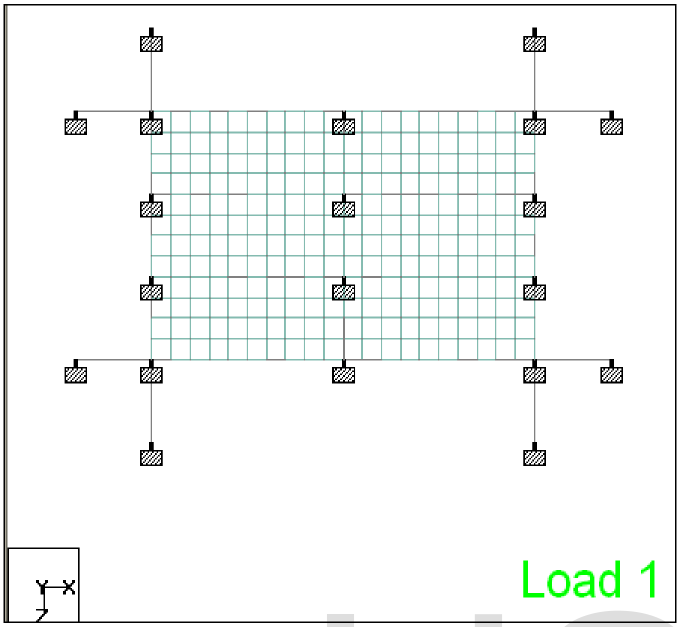

Fig. 4 – ESB – Plan

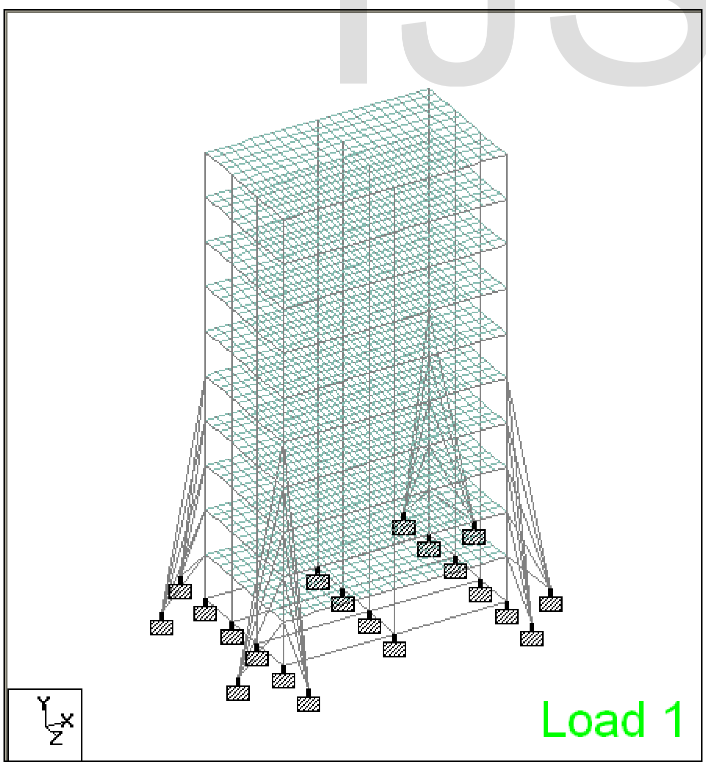

Fig. 5 – ESB – 3D

4.8.3 Frames with Internal Steel Bracing (ISB), provided at end bays along X and Z directions. (Fig.6 and Fig.7).

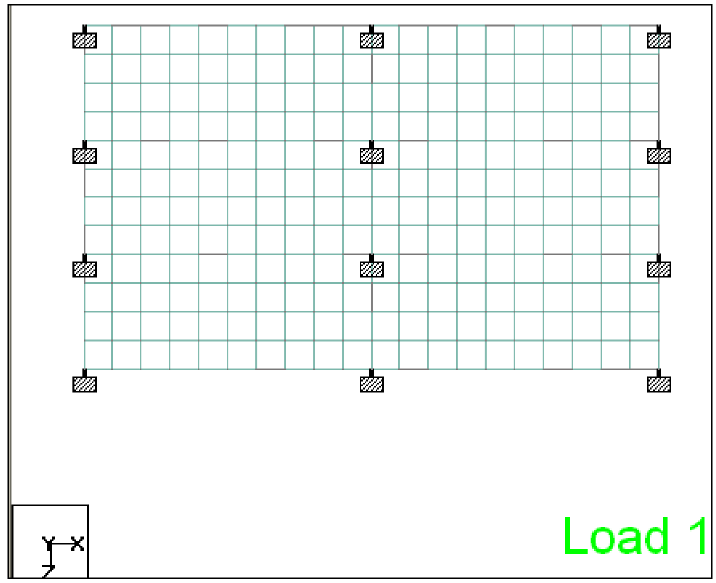

Fig. 6 – ISB – Plan

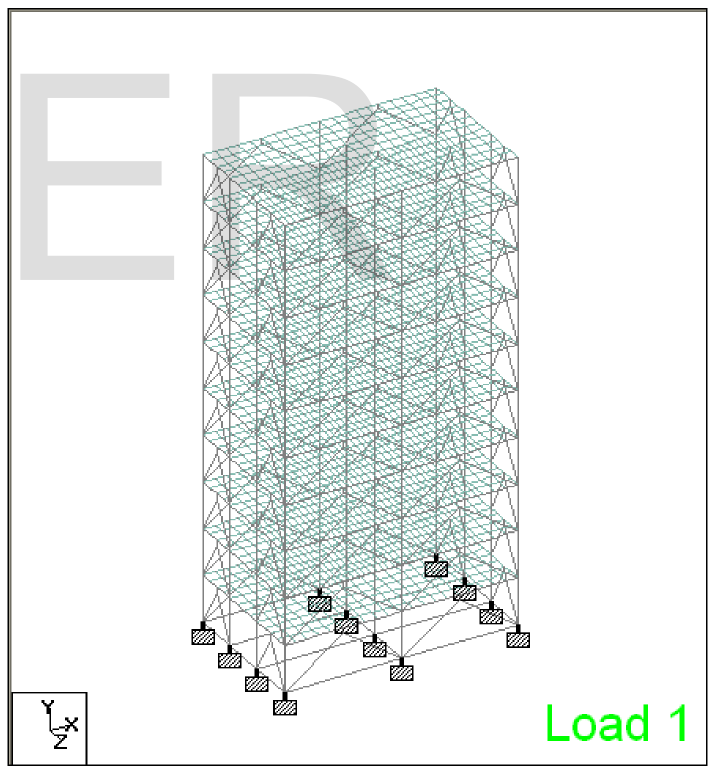

Fig. 7 – ISB – 3D

5 RESULTS AND DISCUSSIONS

The results obtained are observed and the maximum values obtained among all the load cases and load combinations (L/C) considered are presented in Table 2, along with the corresponding load case. The Table indicates the results of frames with both types of LLRS considered (i.e. ISB and ESB) and for the moment resisting Bare Frame (BF). The discussions focus on the comparison between the two LLRS considered and the basic Bare Frame with respect to Maxi-

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mum Joint Displacements, Maximum Support Reaction, Maximum beams Forces, Maximum axial forces and axial stresses in steel bracings.

TABLE 2
MAGNITUDE OF THE PARAMETERS CONSIDERED AND CORRESPONDING LOAD CASE.

Parameter	Notations	Bare Frame		ESB		ISB	
		Magnitude	L/C	Magnitude	L/C	Magnitude	L/C
Storey Sway [mm]	Max-X	49.99	10	39.39	10	2.73	10
	Max- Z	94.44	12	65.70	12	7.63	12
Support Reaction [kN, m]	Max Fx	222.44	14	510.31	10	-122.34	5
	Max Fy	5729.94	5	5709.05	5	5615.13	5
	Max Fz	215.41	12	599.18	12	52.29	12
	Max Mx	-605.24	13	-188.51	13	60.21	12
	Max Mz	-487.22	11	228.60	10	116.24	10
Beam Forces [kN, m]	Axial force	82.37	5	-89.56	13	-145.47	13
	Shear Y	259.04	10	238.78	10	229.02	5
	Max Mx	79.67	12	-63.12	13	34.92	8
	Max Mz	573.82	10	507.92	10	341.83	5
Steel Bracing [Axial]	Force [kN]	-	-	378.53	12	365.10	12
	Stress [MPa]	-	-	123.99	12	119.59	12

5.1 Maximum Joint Displacements

For all the structural systems considered, the maximum joint displacement is observed at the top storey level (Lateral sway in X and Z directions) as expected, the Bare Frame (without any LLRS) undergoes the maximum joint displacement namely Max X & Max Z.

5.1.1 Effect of load and load combinations

For the structural systems considered, load combinations for which Max X and Max Z occur are load case 10 or 11 i.e. 1.5(DL ± ELx) and 12 or 13 i.e. 1.5(DL ± ELz) respectively.

5.1.2 Effect of LLRS

The value of Max X reduces by 21% to 94% in ESB and ISB respectively when compared with bare frame .The values of Max Z reduce by 30% in ESB and 91% in ISB respectively when compared with the bare frame .The main objective of providing LLRS is to control the lateral displacement, which is observed in case of both the LLRS considered.

5.2 Maximum Support Reactions

5.2.1 Effect of load and load combinations

The maximum support reaction Fx occurs when seismic load combination 10 or 11 i.e. 1.5 (DL ± Elx) is applied, except in case of ISB where it occurs when load case 5 i.e 1.5(DL+LL) is applied. The Maximum Support reaction Fy occurs when non-seismic load case 5 i.e 1.5(DL+LL) is applied. The maximum support reaction Fz and maximum support moment Mx occurs when seismic load combination 12 or 13 i.e. 1.5 (DL ± Elz) is applied. The maximum support moment Mz occur when load case 10 or 11 i.e. 1.5 (DL ± Elx) is applied respectively.

5.2.2 Effect of LLRS:

The maximum support reactions Fx and Fz increase by 129% and 178% in case of ESB and reduce by 45% and 75% respectively in ISB. The maximum support reaction Mx reduces by 69% and 90% for ESB and ISB respectively. Also the maximum support reaction Mz reduces by 53% and 76% respectively for frames with LLRS considered.

5.3 Maximum Forces in Beams

Generally the maximum beam forces Fx, Fy, Mx and Mz occur in seismic load combinations.
The greatest value of the maximum Shear force Fy, Torsion moment Mx and Bending moment Mz in beams, of all the structural systems considered, occur in bare frame. Comparing the frames with LLRS with bare frame, the maximum axial force Fx increases. The maximum shear force Fy, moment Mx and Mz decrease for all LLRS considered.

5.4 Forces in Steel Bracings

The forces considered are maximum Axial Force and Axial Stress in Steel Bracings.
The maximum Axial force and axial stress for ESB and ISB occur when load case 12 i.e. 1.5(DL+ELz) is applied. The maximum axial stress values as given in Table 2 in ESB and ISB are less than the permissible stresses in steel as applicable.

6 CONCLUSIONS

It is necessary to consider gravity and seismic loads as well as all the load combinations during analysis of the structure. Provision of both ESB and ISB effectively reduce large joint displacements found in bare frame. The best performing LLRS among the two LLRS considered is ISB as all the parameters considered reduce in this case when compared with bare frame. When these LLRS considered in the study are employed in field for upgrading or retrofitting a structure, it is necessary to ensure proper connections between existing structure and LLRS provided.

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