A STUDY ON THE BEHAVIOUR OF 15 STOREYS 2 X 3 BAYS WITH AND WITHOUT EXTERNAL SHEAR WALL

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Abstract

The word "structural system" is nothing but load tolerating sub system of a structure. A shear wall is a division of the structural system composed of shear panel to withstand earthquake load acting on structures. RC structural -shear walls are used as LLRS in high earthquake zones because they offer large lateral strength, major stiffness and momentous deformation capability. Sensitive character of shear-walls when added to RC frame is important to know which gives us idea about what parameters chosen would be best for reliable designs. In the current study, investigation has been carried out to obtain details of the structural behaviour of 3D model having [2 x 3] bays moment- resisting RC frames with sloped and without sloped shear wall at various locations to tolerate earthquake load. The investigation is carried out in zone- V of "Seismic zones of India as per IS 1893 (part 1):2002, considering loads (dead, live and seismic loads) and their seismic load combinations". Three [3] forms of structural systems for fifteen [15] storey with and without Sloped external shear wall were considered for Equivalent Linear Static analysis and Dynamic or Response spectrum analysis. Totally 6 models are analyzed. The models chosen for analysis are 1] Basic moment resisting RC frame i.e. Bare frame and 2] Bare frame with external sloped shear wall at middle and ends. The results obtained analytically are meticulously investigated for higher values of axial force, shear force, bending moment and displacement. The results signify better resistance to lateral loads in the existence of External sloped shear wall at the middle mainly when the shear walls are located symmetrically in two mutually perpendicular directions.

Keywords: *RC Frame, Earthquake Load, Equivalent Static Analysis, Response Spectrum Analysis, Shear Wall*

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1. INTRODUCTION

Buildings on the ground are basically subjected to load of two types" static and dynamic". Static loads are stable with time whereas dynamic loads changes with time. Most commonly the civil engineering buildings are "designed with assumptions that all applied loads are static the consequence of dynamic loads is not taken because the building is not often subjected to dynamic loads; and also in some cases dynamic consideration makes the solution more complicated and also takes more time. This aspect of neglecting the dynamic calculation becomes the main reason for disaster to occur in many cases, mainly in the case of earthquake. There is an emerging awareness in the process of designing structures able to hold up dynamic loads, chiefly, seismic induced load. The dynamic loads are caused below the earth's crust due to displacement of tectonic plates known as faults. The displacement of fault results in more energy release as seismic waves transferred to the building through its foundation which results in movement of structure. The movement is very severe resulting in to and fro motion or oscillation horizontally and vertically. This oscillation gives displacements, velocities and accelerations in the building. The resulting accelerations generate forces in building which is inertial forces "which are proportional to the acceleration of the mass and acting opposite to the ground motion". The energy generated in the building due to ground movement is dissipated all the way to structural and nonstructural members through internal friction. This dissipated energy to building is called damping. The building always has some built-in damping, which stops with time with stopping of seismic excitation. During seismic excitation the displacement is produced which is proportional to resisting force this proportionality constant is stiffness. Stiffness is important factor to be taken care of due to which structures are differentiated as brittle or ductile. Brittle structures are stiffer and they are less durable while ductile structures are less stiff and perform well during earthquake excitation which allows displacement of structure but not allowing it to reach the state of collapse. "The basic equation of static equilibrium under displacement method of analysis is given by F (ext) = ky Where, F (ext) is the external applied static force, k is the stiffness resistance, and y is the resulting displacement. The restoring force (ky) resists the applied force, F (ext). Now, if the applied static force changes to dynamic force or time varying force the equation of static equilibrium becomes one of the dynamic equilibrium and has the form

"$F_{(t)} = m\ddot{y}_{(t)} + c\,\dot{y}_{(t)} + ky_{(t)}$"

Where, $m\ddot{y}_{(t)}$ = inertia forces acting in a direction opposite to that of seismic motion applied to the base of the structure, whose magnitude is the mass of the structure times its acceleration, m is the mass (kg) and $\ddot{y}_{(t)}$ is the acceleration (m/sec^2). The equation above is a second order differential equation that needs to be solved for the displacement $y_{(t)}$.

The number of displacement components required specifying the position of mass points is called the number of degrees of freedom to obtain an adequate solution. For some structures, single degree of freedom may be sufficient where as for others several hundred degrees of freedom may be required".

1.1. Shear wall

When earthquake force acts on the building it is subjected to displacement or sway, in order to minimize the sway in the building horizontal force resisting systems should be provided, commonly used lateral load resisting system is shear wall. Providing shear wall is one method to limit sway in building and give stability to building. Many papers related to study on finding the best position for placing shear wall is carried as shear wall is used as one of the global retrofitting technique which can be provided both internally and externally depending on the requirements without disturbing the occupants and surrounding environment . In this paper study on sloped type of shear wall which is placed in two positions is carried out. First position is at corners and the other position is at middle. Shear wall are placed externally and analysis is conducted to find best performing shear wall location.

2. CURRENT INVESTIGATION

In the current study [15] fifteen storeys 3D model is considered. First Basic model which is a moment resisting reinforced concrete bare frame having 2x3 bays ["with 2 bays in x-direction and 3 bays in z-direction"] is selected for analysis. The other 2 models are bare frame with sloped shear wall provided externally at corners [ESLOPSWE] and middle [ESLOPSWM] in both x- direction and z-direction. The Bare frame along with sloped shear walls provided externally is subjected to same type of loading conditions and seismic load combinations. The analytical study conducted for zone V may be helpful in deciding which location acts as best performing lateral load resisting system.

3. ANALYSIS METHODOLOGY

Once the model is selected, the parameters are implimented, load applications are incorporated as per code and load combination for analysing the model is keyed. The model is subjected to analysis in zone V using STAAD. Pro V8i [SELECT series5] 2007 software. Analysis is carried out by 2 methods:

i. Equivalent Lateral force method or Liniear Static analysis

ii Dynamic analysis or Response Spectrum analysis.

The analysis is carried out with reference to code specified for earthquake analysis i.e.; IS 1893 [Part-1]:2002.

3.1. Equivalent Lateral force method or Linear Static analysis:

As the name suggests Linear means the structures response whether it is in the form of strain, reactions, stress or displacement it is linear with the force applied to structure. Static means that the time effect is not accounted, it only deals with static load case. Static loads are placed on the structure at different floor levels and base shear is calculated applying empirical formula. Base shear depends on natural frequency, ground motion, and soil type, and damping. The Base shear obtained at bottom of building is distributed throughout the building height at each storey level by applying formula it is found that the storey force distribution is maximum at the top floor while minimum at bottom as a result maximum displacement occurs at top storey.

3.2. Dynamic method or Response spectrum method

It takes time into effect together with load. Time or period is inverse of frequency based on frequency and mode shape modal analysis is performed. When lateral load acts on the building, building vibrates with its own natural frequency. The oscillation which occurs during vibration results in maximum displacement. This maximum displacement with time factor into consideration is plotted and converted to pseudo spectral acceleration by multiplying with natural frequency. [$Sa = W^2 \times y_{max}$]. Sa points are plotted on ordinate against period of oscillator to give Response spectrum curve. The Dynamic analysis is based on Modal analysis. "[Mode shape and natural frequency]". The deformed shape at a particular natural frequency is called the mode shape. Normal modes analysis is also called Eigen value analysis. Building response to lateral forces and gravity forces does not occur in one mode. Peak response of each mode is combined to give total building response. Absolute results assume that peak response occurs at same time which is not reliable so peak modes of entire building is usually combined by [SRSS] Square root of sum of square method".

3.3. Modelling details

In the current study 3D model of the structure is generated using STAAD. Pro v8i ss5 software.

3.3.1. Frame element

Beam and column elements are longitudinal member which carry axial load they may be subjected to shear and bending in STAAD. Pro software, it is defined from the required property specification. Beam and column has six degrees of freedom at each node [Ux, Uy, Uz, Mx, My, Mz]

3.3.2. Plate element

Plate element may be modelled using Finite element.
Some rules should be followed while modelling a plate element such as aspect ratio it should be of order 1:1 and preferably less than 4:1, Angle between two adjacent elements should be 90 degree, Nodes for elements should be specified in clockwise direction. The plate elements are taken as quadrilaterals having nodes at corner and each node has 6 degrees of freedom.

4. DEFINING PROBLEM

4.1. Plan

It is 2 bays in x-direction and 3 bays in z-direction each bay having 7.5 m in x-direction and 3.0 m in z-direction. [Overall 15.0 m x 9.0 m] the Plan is shown in dig. [1, 1.a & 1.b.]

4.2. Height

The fifteen [15] storeys building has each storey height of 3.0 m in Y-direction. Overall height of building is 45.0 m.

4.3. Cross section of Frame elements

Beam at plinth level in x-direction	0.30m x 0.45m
Beam at plinth level in z-direction	0.30m x 0.30m
Main beam in x-direction [X x Y]	0.30m x 0.75m
Main beam in z-direction [X x Y]	0.30m x0.375m
Column size [X x Z]	0.90m x0.45m
Colum height [Y]	3.0m

4.4. Frame with LLRS

4.4.1. Bare frame

Basic Bare frame taken is a 15 storey moment resisting reinforced concrete frame with 2x3 bay of length 7.50 m in x-direction and 3.0 m in z-direction.

4.4.2. External Sloped shear wall at ends

External sloped shear wall at ends [ESLOPSWE] with basic bare frame is provided at exterior of the frame at corners in both x and z directions of length at base as 1.875 m sloping to a height of 45.0 m having a length of 0.375 m at top.

4.4.3. External Sloped shear wall at middle

External sloped shear wall at middle [ESLOPSWM] with basic bare frame is provided at exterior of the frame at middle in both x and z directions of length at base as 1.875m sloping to a height of 45.0m having a length of 0.375 m at top.

4.5. Seismic Zone

The response of the models for Self weight, Live load, Lateral load [both x & z direction] and Earthquake load combinations are studied in zone V i.e. very sever zone having seismic zone factor of 0.36 as per IS 1893:2002 code.

4.6. Shear wall thickness

Thickness is taken as 230mm

4.7. Physical properties

Density of concrete	23.5616 KN/m^3
Poison's ratio	0.17
Density of masonry	18.75 KN/m^3
E of concrete	2.17185x10^7 KN/m^3

4.8. Loads and Seismic load combination

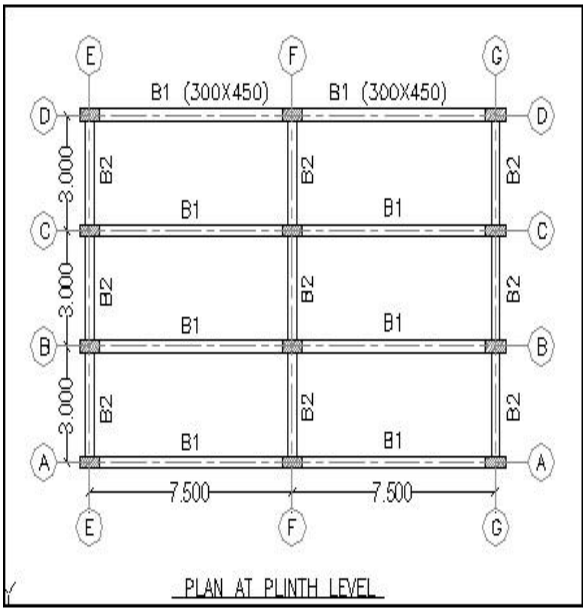
The model is subjected to primary load cases as per provisions of Indian Standard code of Practice for Structural safety of buildings, Loading standards [IS 875-1987] [Part-1] they are:

1. Dead load [Vertical or Gravity load], denoted as 'DL'
2. Live load [Vertical or Gravity load], denoted as 'LL'
3. Seismic load in x-direction [Lateral or Earthquake load] , denoted as 'Elx'
4. Seismic load in z-direction [Lateral or Earthquake load], denoted as 'Elz'
   In addition, the structural systems are subjected to 13 different load combinations as per provision of IS 1893:2002] they are:
5. 1.5[DL+LL]
6. 1.2[DL+LL+ELx]
7. 1.2[DL+LL-ELx]
8. 1.2[DL+LL+ELz]
9. 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 - 1.5 ELx]
16. [0.9DL + 1.5 ELz]
17. [0.9DL – 1.5 ELz]

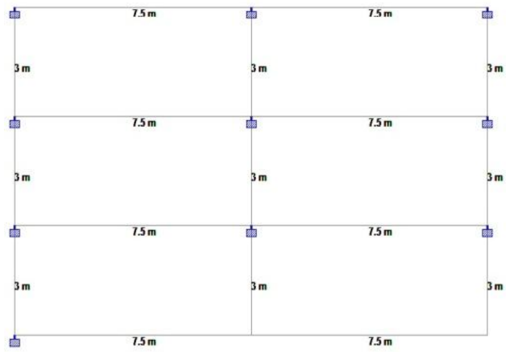
The primary loads on the frame have been calculated on The basis of Indian Standard code of practice IS 875[Part1] 1987. The dead load consists of self weight. The live load Considered is as adopted for medium office, hospitals or hostel buildings i.e. 4KN/m^2.

4.9. Response Spectrum Base Shear Values

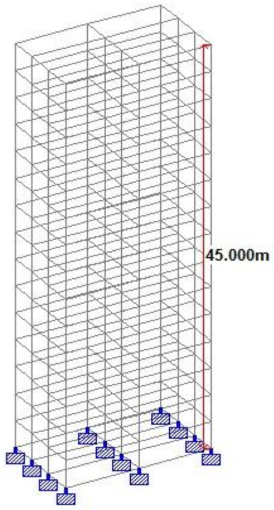
The Linear static method of analysis is adopted for the calculation of lateral load at each storey level as per IS 1893:2002.



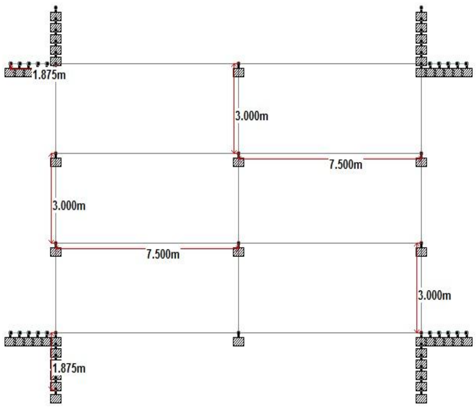
Dig. 1.1. PLAN AT PLINTH LEVEL



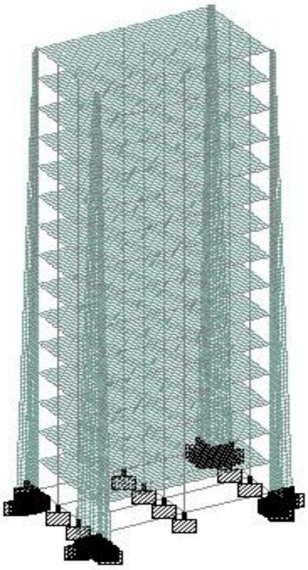
Dig. 1. a. PLAN OF BF



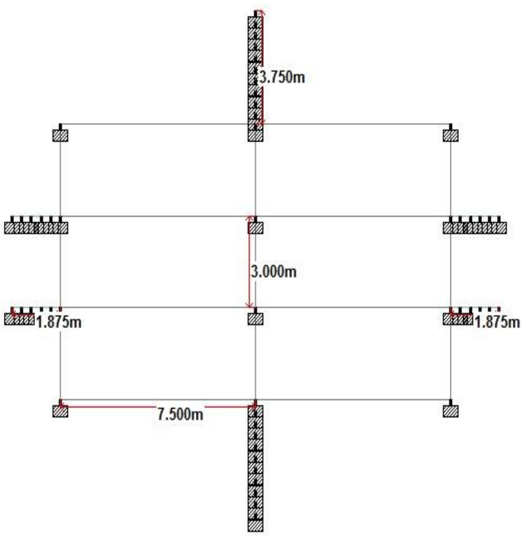
Dig. 1. b. ELEVATION OF BF



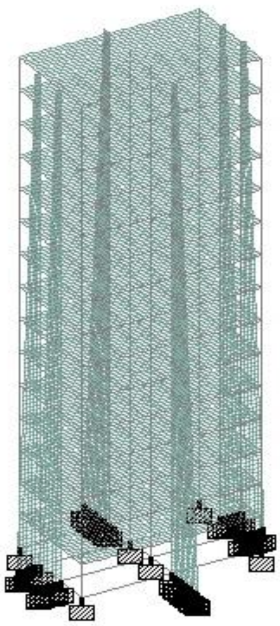
Dig. 2. a PLAN OF ESLOPSWE



Dig.2.b.ELEVATION OF ESLOPSWE



Dig. 3. a. PLAN OF ESLOPSWM



Dig.3.b. ELEVATION OF ESLOPSWM

The Base shear [V_B] analysed from Dynamic analysis [RSM] is less than the Base shear [Vb] calculated from empherical formula by ESLM method. As of which a multiplying factor [Vb/VB] is multiplied to calculate Base Shear [VB] in x direction as shown in Table.1

Table 1 - 15 Storey, zone V- Base Shear values of ESLM & RSM method

Frame type	BASE SHEAR [Vb] - ESLM	MULTIPLYING FACTOR	TOTAL SRSS SHEAR	BASE SHEAR [VB] - RSM
Bare Frame	1659.946	1.695	979.090	1659.949
ESLOPSWE	1750.909	1.594	1098.690	1750.872
ESLOPSWM	1750.909	1.598	1095.980	1750.938

4.10. Equilibrium Check

Bare frame and LLRS [ESLOPSWE & ESLOPSWM] considered are checked for equilibrium in case of Lateral forces Fx and Fz, Vertical force Fy and Moment Mx & Mz.

And it is found that Manual calculation matches with Software Calculation. The details of Equilibrium check in case of bare frame and External sloped shear wall at corners and middle is given in Table .2

Table.2 EQUILIBRIUM CHECK for [Fx, Fy, Fz, Mx & Mz] both Manual and by Staad.Pro software.

Reactions & Moments		Bare Frame-x	Bare frame -z	ESLOPSWE-x	ESLOPSWE-z	ESLOPSWM-x	ESLOPSWM-z
Fx KN	Manual calculation	1659.960		1750.911		1750.911	
	Values obtained from Staad	-1659.960		-1750.912		-1750.912	
Fy KN	Manual calculation	40056.590	40056.590	42251.378	42251.378	42251.378	42251.378
	Values obtained from Staad	40056.580	40056.580	42251.342	42251.342	42251.349	42251.349
Fz KN	Manual calculation		1659.957		1750.911		1750.911
	Values obtained from Staad		-1659.960		-1750.906		-1750.914
Mx KNm	Manual calculation		4262.400		1252.325		820.114
	Values obtained from Staad		-4262.390		-1252.376		-820.134
Mz KNm	Manual calculation	5229.630		2703.147		2785.625	
	Values obtained from Staad	5229.620		2703.194		2785.652	

5. RESULTS AND DISCUSSION

The results obtained from the 3D analysis of 15 storey framed structure considered in zone V in case of Sloped Shear wall at ends and middle are observed for Vertical load and Lateral load Equilibrium, which are presented in Table 1 and 2. The maximum values obtained among all the load cases and load combinations [L/C] considered are presented in Tables 3 to 7, along with the corresponding node number and load case for both ESLM & RSM method. The Tables indicate the results of frames with both types of LLRS [i.e. ESLOPSWE & ESLOPSWM]. Corresponding values obtained for the moment resisting Bare frame [BF] are also included. The discussions focus on the comparison between the two LLRS considered with the basic bare frame in the following parameters.

a. "Joint Displacements [Maximum] along X [X-Tran], Z [Z-Tran] and Absolute maximum [Asb-Tran] [Table 3A, 3B].
b. Support Reaction Forces [Maximum] along X [Fx], Y [Fy], Z [Fz] and Support Moments [Maximum] along X [Mx] and Z [Mz] [Table 4A, 4B].
c. Column Forces [Maximum] Axial Force along X [Fx], Shear Forces along Y [Fy] and Z [Fz], Column Moments along X [Torsion] and Z [Mz] [Table 5A, 5B].
d. Beam Forces [Maximum] Bending Moments along Z [Mz], Torsional Moments [Mx] and Shear force (along Y [Fy] and Z [Fz] [Table 6A, 6B].
e. Principal Stresses [Maximum] occurring in shear wall, Maximum [S_{max}], Minimum [S_{min}] and Maximum Shear Stress [T_{max}] [Table 7]".

5.1 JOINT DISPLACEMENT [MAXIMUM]:

Maximum joint displacements that structural systems undergo in x direction [Max x] and z direction [Max z] and Absolute maximum displacement [Max AB] with corresponding node number and Load cases are given in Table.3A, 3B for both

ESLM and RSM respectively. Of all the structural systems considered, as expected, the bare frame [without any LLRS] undergoes the maximum joint displacement namely Max x, Max z, and Max Abs in both ESLM and RSM method of analysis. It is observed that the values obtained by RSM method indicate a large reduction in displacement compared to ESLM and shows the necessity of seismic analysis".

Method of Analysis consequence : With respect to the parameter considered the results obtained from the two methods of seismic analysis considered namely Equivalent Static Lateral Force Method [ESLM] and Response Spectrum Method [RSM] are found to differ by around 19% and maximum of 21% in all Max-x, Max-z translation and Max-Absolute case.

Consequence of LLRS compared to Bare Frame: In both ESLM & RSM method of analysis - ESLOPSWE the values of Max x translation reduces by 14% & reduces by 28% in case of Max z trans & Max Abs respectively. In case of ESLOPSWM Max x translation reduces by 14% & reduces by 43% in case of Max z trans & Max Abs .

Consequence of all loads and earthquake load combination: "For all the LLRS considered for which Max X occurs in load case 10 or 11 i.e. 1.5[DL±ELx] and Max Z occurs in Load case 12 i.e. 1.5[DL+ELz] where as Max Abs occurs for load combination 12 or 13 i.e. 1.5[DL±ELz] for both ESLM & RSM method".

Comparison among External Sloped shear wall at ends and middle acting as LLRS: When the 2 types of LLRS are considered [ESLOPSWE & ESLOPSWM] External Slopped shear wall shows a increase of 0.5 % in x translation, whereas z translation and Max Absolute translation reduced by 22%. The same form of results applies in case of RSM method also.

5.2 SUPPORT REACTION [MAXIMUM]:

"The Maximum Support reaction forces along x [Max Fx], y [Max Fy], z [Max Fz], Maximum support reaction moments along x [Max Mx], z [Max Mz] that occurs in all the structural systems considered with corresponding node number and the load cases are given in Table 4A, 4B [except torsional moments as the values are negligible]".

Method of Analysis consequence: With respect to the parameter considered [i.e., Max Support Reaction] the results obtained from the two methods of Seismic Analysis considered namely ESLM method and Dynamic method [RSM] are found to differ by around 1% minimum to maximum of 6% in all "Max-Fx, Max-Fy, Max Fz, Max Mx, and Max-Mz".

Consequence of LLRS compared to Bare Frame: The greatest values of maximum support reactions Fx, Mz & Fz, Mx, decreases by 32%, 41% & 5% , 71% whereas Fy decreases by 6% in case of ESLOPSWE for both ESLM & RSM methods compared to BF. While in case of ESLOPSWM Fx, Mz, decreases by 19%, 41% and increases in Fz by 13% and decreases in Mx by 80% in case of ESLM method, the same form of results are seen in RSM also except Fx decreases by 14% and Fy in both ESLM & RSM decreases by 16% & 13%.

Consequence of all load and earthquake load combination: "For all the Structural system considered Max support reaction Fx & Max Moment Mz occurs in load case 10 or 11 i.e. 1.5[DL±ELx] whereas Max Fz & Max Moment Mx occurs in Load case 12 or 13 i.e. 1.5[DL±ELz] for both ESLM & RSM method of analysis. Max Fy occurs for load combination 5 i.e 1.5[DL+LL] in all cases except for Bare frame in ESLM method it occurs in load case 12 i.e. 1.5[DL+ELz]"

Comparison among External Sloped shear wall at ends and middle acting as LLRS: When the 2 types of LLRS [ESLOPSWE & ESLOPSWM] are compared among them External sloped shear wall mid [ESLOPSWM] decreases in Fy by 10% & Mx by 28% in both ESLM & RSM method compared to ESLOPSWE, while [ESLOPSWM] increases in Fx by 18% to 21% & by 1% in Mz & by 19% to 26% in Fz for both ESLM & RSM method.

5.3 COLUMN FORCES [MAXIMUM]

"The maximum column forces [Axial force Fx, Shear force Fy, and Shear force Fz, Torsional moment Mx and Bending moment Mz] that are found in all the structural systems considered and the corresponding load case are given in Table 5A, 5B."

Consequence of method of Analysis: With respect to the parameter considered [i.e., Max Column Forces] the results obtained from the two methods of Seismic Analysis considered namely ESLM method and Dynamic method [RSM] are found to differ by around minimum 4% to maximum of 16% in all "Max-Fx, Max-Fy, Max Fz, Max Mx and Max-Mz".

Consequence of LLRS compared to Bare Frame: The greatest values of the maximum column forces Fx, and Mz are seen in Bare frame and it decreases in case of ESLOPSWE by 7% & 35% in ESLM and decreases by 3% & 42% in RSM method while in ESLOPSWM Fx and Mz decreases 17% & 34% compared to Bare frame in ESLM and in RSM method decreases by 13% & 40%.
Other max values corresponding to Fy, Fz, and Mx increases compared to bare frame. In case of ESLOPSWE increases by 18%, 14%, 70% almost for both ESLM & RSM method while in ESLOPSWM increases by 30%, 45% & 80% for both ESLM & RSM method.

Consequence of all load and earthquake load combination: "In case of in BF, & two LLRS considered max column force Fx occurs in Load case 5 i.e. 1.5[DL+LL] for all structural systems in both ESLM & RSM except in Bare frame in ESLM method it occurs in Load combination 13 i.e.1.5 [DL-ELZ], The load combination where the max column forces occurs are given below.

'Fy' occurs in L/C 10 & 11 i.e. 1.5[DL±ELX] while 'Fz' occurs in L/C 12 & 13 i.e. 1.5[DL±ELZ], 'Mx' occurs in L/C 12 i.e 1.5[DL+ELZ] & 'Mz' occurs in L/C 14 i.e. [0.9DL+1.5ELX]

Comparison among External sloped shear wall acting as LLRS: Among the two types of LLRS [ESLOPSWE & ESLOPSWM] considered ESLOPSWM decreases by 11% in axial load 'Fx' in both ESLM & RSM method.

In all other cases [Fy, F z, Mx, Mz] values of ESLOPSWM increases in both ESLM & RSM almost by 9%, 27%, 63% & 1%.

Table.3A Max. JOINT DISPLACEMENT in mm [ESLM] - 15 STOREY 2X3 BAY

Frame Type	Max X			Max Z			Max Abs		
	Node No.	LC	X-Trans	Node No.	LC	Z-Trans	Node No.	LC	Abs -Trans
BF	187	10	102.479	182	12	261.185	15225	12	261.885
ESLOPSWE	181	10	87.719	183	12	187.999	15122	12	188.638
ESLOPSWM	187	10	88.225	23857	12	146.895	14776	12	147.449

Table.3B Max JOINT DISPLACEMENT in mm [RSM] - 15 STOREY 2X3 BAY

Frame Type	Max X			Max Z			Max Abs		
	Node No.	LC	X-Trans	Node No.	LC	Z-Trans	Node No.	LC	Abs -Trans
BF	186	11	-82.571	182	12	209.158	191	13	209.946
ESLOPSWE	183	11	-70.757	183	12	150.944	15122	13	151.730
ESLOPSWM	186	11	-71.199	23857	12	115.796	14987	13	116.535

Table.4A Max SUPPORT REACTION [ESLM] - 15 STOREY 2X3 BAY

Frame Type	Max Fx KN			Max Fy KN			Max Fz KN			Max Moment Mx KN-m			Max Moment Mz KN-m		
	Node no.	LC	Fx	Node no.	LC	Fy	Node no.	LC	Fz	Node no.	L C	Mx	Node no.	LC	Mz
BF	5	10	-246.387	11	12	8119.541	8	12	-246.829	8	12	-571.726	3	11	-693.019
ESLOPSWE	15444	10	-167.128	5	5	7603.341	16397	12	-234.210	8	12	-159.307	3	11	-397.707
ESLOPSWM	4	10	-197.935	5	5	6773.559	21045	12	-279.355	2	12	-111.588	6	11	-402.322

Table.4B Max. SUPPORT REACTION [RSM] - 15 STOREY 2X3 BAY

Frame Type	Max Fx KN			Max Fy KN			Max Fz KN			Max Moment Mx KN-m			Max Moment Mz KN-m		
	Node no.	LC	Fx	Node no.	LC	Fy	Node no.	LC	Fz	Node no.	LC	Mx	Node no.	LC	Mz
BF	5	11	-245.837	8	5	7827.911	5	12	246.333	8	13	-565.292	10	10	683.890
ESLOPSWE	10	11	-172.405	8	5	7603.341	16442	12	222.140	8	13	-154.504	10	10	392.204
ESLOPSWM	4	11	-210.625	8	5	6773.559	11	12	280.175	2	13	-112.787	4	10	397.845

Table.5A Max. COLUMN FORCES [ESLM] - 15 STOREY 2X3 BAY

	Max Axial Force Fx KN				Max Shear Force Fy KN				Max Shear Force Fz KN				Max Torsion Mx KNm				Max Moment Mz KNm			
Frame Type	Beam no.	LC	Node no.	Fx	Beam no.	LC	Node no.	Fy	Beam no.	LC	Node no.	Fz	Beam no.	LC	Node no.	Mx	Beam no.	LC	Node no.	Mz
BF	274	13	2	7943.985	316	11	56	302.018	313	13	41	300.219	284	12	24	0.856	277	14	5	689.218
ESLOPSWE	280	5	8	7400.514	19925	11	73	365.572	20273	13	17693	357.430	18177	12	15527	2.827	331	14	50	443.514
ESLOPSWM	280	5	8	6570.732	21081	11	79	396.563	20322	13	17829	458.162	21269	12	88	8.404	325	14	53	450.779

Table.5B Max. COLUMN FORCES [RSM] - 15 STOREY 2X3 BAY

	Max Axial Force Fx KN				Max Shear Force Fy KN				Max Shear Force Fz KN				Max Torsion Mx KNm				Max Moment Mz KNm			
Frame Type	Beam no.	LC	Node no.	Fx	Beam no.	LC	Node no.	Fy	Beam no.	LC	Node no.	Fz	Beam no.	LC	Node no.	Mx	Beam no.	LC	Node no.	Mz
BF	280	5	8	7625.084	301	10	29	288.422	301	12	29	285.253	282	12	10	0.848	280	14	8	679.374
ESLOPSWE	280	5	8	7400.514	18937	10	70	335.284	19925	12	17345	314.098	18177	12	15527	2.680	310	14	38	392.105
ESLOPSWM	280	5	8	6570.732	19104	10	67	369.366	20235	12	17655	396.534	21222	12	93	6.800	316	14	44	403.157

Table.6A Max. BEAM FORCES [ESLM] - 15 STOREY 2X3 BAY

	MAX BM IN BEAMS								MAX SHEAR FORCE IN BEAMS							
	Max M_Z				Max Torsion M_X				Max F_Y in KN				Max F_Z in KN			
Frame Type	Beam no.	LC	Node No.	Moment Mz	Beam no.	LC	Node No.	Torsion Mx	Beam no.	LC	Node No.	Fy	Beam no.	LC	Node No.	Fz
BF	90	11	67	695.541	73	12	3742	-124.751	88	11	64	288.592	17452	5	187	-11.610
ESLOPSWE	120	11	85	706.307	124	12	6781	-113.497	120	11	85	274.519	263	5	181	-12.832
ESLOPSWM	105	11	76	726.020	159	12	8966	-94.768	105	11	76	302.756	263	13	191	-25.817

Table.6B Max. BEAM FORCES [RSM] - 15 STOREY 2X3 BAY

	MAX BM IN BEAMS								MAX SHEAR FORCE IN BEAMS							
	Max M_Z in KNm				Max Torsion M_X in KNm				Max F_Y in KN				Max F_Z in KN			
Frame Type	Beam no.	LC	Node No.	Moment Mz	Beam no.	LC	Node No.	Torsion Mx	Beam no.	LC	Node No.	Fy	Beam no.	LC	Node No.	Fz
BF	54	10	40	647.270	56	12	43	115.360	54	10	40	276.462	17452	5	187	-11.610
ESLOPSWE	109	10	82	632.185	124	12	91	95.213	90	10	67	256.636	264	5	181	-12.832
ESLOPSWM	90	10	67	658.554	159	12	116	77.857	105	10	76	284.341	263	13	191	-25.810

Table. 7 Max. PRINCIPAL STRESS, Min. PRINCIPAL STRESS & Max TENSILE STRESSES - 15 STOREY 2X3 BAY

Frame Type	Plate	LC		S_{max} N/mm^2	Plate	LC		S_{min} N/mm^2	Plate	LC		T_{max} N/mm^2
ESLOPSWE [ESLM]	19102	16	Top	18.314	19102	13	Top	-25.010	19107	13	Top	11.707
ESLOPSWE [RSM]	19142	16	Top	17.033	19102	13	Top	-23.404	19107	13	Top	10.976
ESLOPSWM [ESLM]	24874	16	Top	16.258	24874	13	Top	-25.597	24884	13	Top	11.855
ESLOPSWM [RSM]	24874	16	Top	14.682	24874	13	Top	-23.266	24884	13	Top	10.803

5.4 BEAMS FORCES [MAXIMUM]

"The maximum Bending moment Mz, Torsional moment Mx, Shear force Fy & Fz of beams that occur in all the Structural systems considered and the corresponding load cases are given in Table 6A, 6B".

Consequence of method of Analysis: With respect to the parameter considered [i.e., Max Beam Forces] the results obtained from the two methods of seismic analysis considered namely ESLM method and Dynamic method [RSM] are found to differ around minimum 4% to maximum of 18% in all [Max-Mz, Max-Mx, Max Fy, Max Fz]

Consequence of LLRS compared to Bare Frame: Among the 2 LLRS [ESLOPSWE &ESLOPSWM] considered, it is seen that both LLRS increases in case of Bending moment 'Mz' by 2% to 4% for ESLM method of analysis while the same Mz by RSM method of analysis decreases in ESLOPSWE by 2% and increases in ESLOPSWM by 2%.compared to Bare frame.

The Torsional moment 'Mx' decreases in ESLOPSWE by 9% in ESLM and 18% in RSM while in ESLOPSWM decreases by 24% in ESLM and 32% in RSM methods compared to bare frame.

The Shear force 'Fy' decreases in ESLOPSWE by 6% in both ESLM and RSM method of analysis while in ESLOPSWM 'Fy' increases by 3-5% in both ESLM & RSM method compared to bare frame.

The Shear force 'Fz' increases in ESLOPSWE by 10% and increases by 35% in ESLOPSWM in both ESLM and RSM method.

Consequence of all load and earthquake load combination:" For all the Structural system considered Max Bending moment 'Mz', occurs for load case 11 & 10 in both ESLM & RSM i.e1.5 [DL±ELX], Torsional moment 'Mx' occurs for load case 12 i.e.1.5 [DL+ELZ] for both ESLM & RSM and Maximum shear force 'Fy' occurs in Load case 10& 11 i.e. 1.5[DL±ELX], Max shear force 'Fz' occurs for load case 13 i.e.1.5 [DL-ELZ] in both ESLM and RSM for ESLOPSWM, while 'Fz' for Bare frame and ESLOPSWE occurs in Load case 5 i.e. 1.5[DL+LL] for both methods of seismic analysis'.

Comparison among External sloped shear wall acting as LLRS: When the two types of LLRS [ESLOPSWE & ESLOPSWM] considered, among them ESLOPSWM increases in 'Mz' ,'Fy', & 'Fz' by 3-4% , 10% , 25% in both ESLM & RSM method of analysis compared to ESLOPSWE, While ESLOPSWM decreases in Torsional moment 'Mx' by 17-18% in ESLM & RSM method of analysis compared to ESLOPSWE.

5.5 MAXIMUM-PRINCIPAL & SHEAR STRESS AND MINIMUM PRINCIPAL STRESS

The values corresponding to Principal stress [Max] S_{max}, Principal stresses [Minimum] S_{min} and Shear stress [Maximum] T_{max} that occur in both types of shear wall are considered [except Bare frame] and given in Table 7.

Consequence of Vertical Load and Earthquake Load combination: In ESLOPSWE & ESLOPSWM the Maximum Principal Stress [Smax] occurs in load case 16 i.e. [0.9DL+1.5ELZ] while Minimum Principal stress [Smin] and Max Shear stress [Tmax] occurs in load case 13 ie 1.5[DL-ELZ] for both ESLM & RSM method.

Occurrence of Stress: In both ESLOPSWE & ESLOPSWM stresses occur at Top of plates.

Comparison among External sloped shear wall acting as LLRS: When the values of ESLOPSWE is compared with ESLOPSWM the ESLOPSWM reduces by 11% in ESLM & 14% in RSM method of analysis for Max principal stress [Smax] compared to ESLOPSWE, While ESLOPSWM increases by 2% in ESLM for both Minimum Principal stresses [Smin] and Max Shear stress [Tmax] and decreases by 1% in RSM method of analysis for both Smin & Tmax.

6. CONCLUSION

From the analytical study of 3D model of 15 storeys – 2 x 3 bays the following conclusions are drawn:

1. Max joint displacement reduces in both types of Shear wall provided i.e., [ESLOPSWE & ESLOPSWM] compared to bare frame.
2. Max. Joint displacement in Z and Absolute direction reduces to a considerable extent [nearly 45%] in ESLOPSWM.
3. Provision of ESLOPSWM reduces the support reaction 'Fy' by 17% and reduces Column Axial force 'Fx' also by 17% it also reduces torsional moment in Beams by 25%.
4. Even though there is increase in X-translation, and increase in Beam bending moment and Beam Shear force, the percentage increase is negligible (2%).
5. External Sloped shear wall middle [ESLOPSWM] can be considered as better LLRS by comparing the results with Bare frame and ESLOPSWE. Since the shear wall is

provided externally sloped type of shear wall at ends can also be adopted as one of retrofitting technique.

6. It can also be noticed that the Axial force in column in case of RSM method of seismic analysis occurs at the same beam member, same node and same load case for Bare frame and both LLRS [ESLOPSWE & ESLOPSWM] which shows that the Bare frame parameters taken can withstand the forces acting on structure for both gravity and seismic load but with addition of LLRS it can perform much better.

7. Since Maximum joint displacement occurs for earthquake load combination it shows the necessity of seismic analysis and consideration of seismic load combination in addition to gravity load.

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