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RESEARCH ARTICLE

COMPARATIVE STUDY OF RESPONSE OF IRREGULAR STRUCTURES AND EFFECT OF SHEAR WALLS ON IRREGULAR BUILDINGS

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Abstract

A structure is “regular” if the distribution of its mass, strength, and stiffness is such that it will sway in a uniform manner when subjected to ground shaking – that is, the lateral movement in each storey and on each side of the structure will be about the same. Regular building configurations are almost symmetrical (in plan and elevation) about the axis and have uniform distribution of the lateral force-resisting structure such that, it provides a continuous load path for both gravity and lateral loads. A building with absence of symmetry and has discontinuity in geometry, mass or load resisting elements is called irregular. These irregularities may cause interruption of force flow and stress concentrations. Asymmetrical arrangements of mass and stiffness of elements may cause a large torsional force because the centre of mass does not coincide with the centre of rigidity. In this study L-shape plan of G+7 storey reinforced concrete building have been selected. The models are analyzed in two phases, in First Phase the building is analyzed without shear walls and soft-storey in Ground floor and Second Phase the same building is analyzed with shear walls and having soft-storey in Ground floor. In the Second Phase also the shear walls are added to the model in two different cases, to study the best location of shear walls in the building.The models are analyzed by STAAD. Pro V8i SS6 software using IBC-2012[9] code (International building code 2012), by Linear Static Method. As the IBC-2012 Draft Code (Afghanistan Building Code-2012) is used for structures in Afghanistan, so the IBC-2012 code has been sleeted for analysis. The aim of this paper is to study the effect of shear walls on soft-storey and compare the response of irregular building having shear walls with irregular buildings without shear walls. The results are summarized on basis of the response of building.

Introduction:-

A weak storey is defined as one in which the story’s lateral strength is less than 80 percent of that in the storey above. The storey lateral strength is the total strength of all seismic resisting elements sharing the storey shear for

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the direction under consideration, i.e. the shear capacity of the column or shear walls or horizontal component of the axial capacity of diagonal braces. Inadequate strength of frame columns usually make storey weak. A soft storey is one in which the lateral stiffness is less than 70% of that in the storey immediately above, or less than 80% of the combined stiffness of the three stories above (see Fig.1.1). The important characteristics of a weak or soft storey consist of a discontinuity of strength or stiffness, which occurs at the second storey connections. This discontinuity is caused by lesser strength, or increased flexibility, the structures results in large deflections in first storey of the structure, which in turn consequences in concentration forces at the second storey connections. The result is a connection of inelastic actions.

In reinforced concrete building in addition to slabs, beams and columns the vertical plate-like reinforced concrete wall is called shear wall, which is constructed from foundation level and continues throughout the building height and shear walls act like vertically oriented wide beam which carry lateral loads to the foundation of building. During past earthquake the buildings which are properly designed and detailed with shear walls have shown very good resistance to the seismic loads. In most earthquake prone countries, like USA, New Zealand and Chile shear walls buildings are common choice. In addition shear walls can be constructed easily, since the detailing of reinforcement is straight forward and its placing at site is easy. Shear walls are effective due to construction cost and minimizing the damage of earthquake in structural and non-structural elements of the building.

In this study L-shape plan of G+7 storey reinforced concrete building have been selected. The models are analyzed in two phases, in First Phase the building is analyzed without shear walls and soft-storey in Ground floor and Second Phase the same building is analyzed with shear walls and having soft-storey in Ground floor.

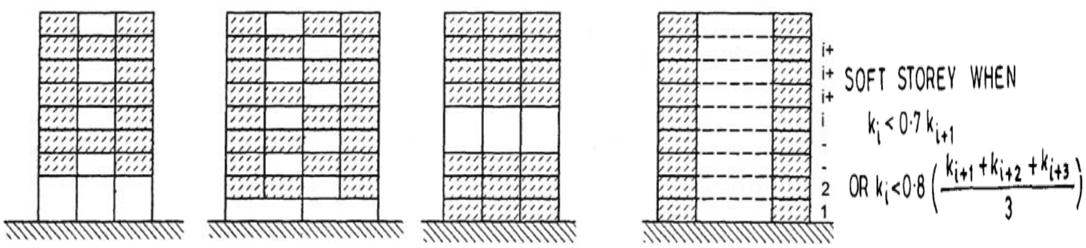


Fig. 1:-Stiffness Irregularities-Soft Storey

In a study of a residential building of G+15 irregular high-rise building without shear wall and with shear wall was considered to compare lateral loads, torsion effects and storey drifts. In comparison, it was summarized that the lateral forces are decreasing if the shear walls are located in proper location of frame and the values of lateral forces are minimum [5]. Eccentricity cause torsion in structures and structural in case of large torsion the elements or the entire structure may be deflect beyond its lateral deflection limit. If the adjacent buildings are not separated from each other properly, so torsional irregularity may cause pounding. If strength of structural elements increase on weak direction or decrease on strong direction, the effects of torsion on structures can be prevented. The best solution is that the structural systems should be designed without irregularities including torsional irregularity [8]. With refuse area beams, mass irregular building deflection will be more than without mass irregular building. The mass irregular building moment is 67% more than without mass irregular building. The size of member and amount of reinforcement increase in building that have mass irregularity [4].

Irregular and Regular Classification of Structures:-

Structures can be classified due to various structural irregularities. Such classification shall be based on their structural configurations. Generally structures irregularities as per IBC-2012 (ASCE-7-10) code are defined as under.

Horizontal irregularity: -Horizontal irregularities are divided into five categories.

1. (a) Torsional Irregularity: Torsional irregularity is exist, where the maximum storey drift, computed including accidental torsion with Ax = 1.0, at one end of the structure transverse to an axis is more than 1.2 times the average of the storey drifts at the two ends of the structure. Torsional irregularity requirements in the reference sections apply only to structures in which the diaphragms are rigid or semi-rigid.

1. (b) Extreme Torsional Irregularity:Extreme torsional irregularity is exist, where the maximum storey drift, computed including accidental torsion with Ax = 1.0, at one end of the structure transverse to an axis is more than 1.4 times the average of the storey drifts at the two ends of the structure.

2. Reentrant Corner Irregularity**:** Reentrant corner irregularity is defined to occur where both plan projections of the structure beyond a reentrant corner are greater than 15% of the plan dimension of the structure in the given direction.
3. Diaphragm Discontinuity Irregularity: Diaphragm discontinuity irregularity is defined to exist where there is a diaphragm with a sudden discontinuity or variation in stiffness, including one having open area more than 50% of the gross enclosed diaphragm area, or an alteration in effective diaphragm stiffness of more than 50% from one of the next storey.
4. Out-of-Plane Offset Irregularity: Out-of-plane offset irregularity is that to present where there is a discontinuity in a lateral force-resistance path, such as an out-of-plane offset of at least one of the vertical elements.
5. Non-parallel System Irregularity: Non-parallel system irregularity is exist, where vertical lateral force-resisting elements are not parallel to the major orthogonal axes of the seismic force-resisting system.

Vertical Irregularity: -Vertical irregularities are divided into five types.
1. (a) Stiffness-Soft StoreyIrregularity: Stiffness-soft storey irregularity is defined, if a storey lateral stiffness is less than 70% of the storey above or less than 80% of the average stiffness of the three stories above.
1. (b) Stiffness-Extreme Soft StoreyIrregularity: Stiffness-extreme soft storey irregularity is defined, if a storey lateral stiffness is less than 60% of the storey above or less than 70% of the average stiffness of the three stories above.
2. Weight (Mass) Irregularity: Weight (mass) irregularity is defined where the effective mass of any storey is more than 150% of the effective mass of an adjacent storey. Generally roof is lighter than the floor below is not to be considered.
3. Vertical Geometric Irregularity: Vertical geometric irregularity is defined, where the horizontal dimension of the seismic force-resisting system in any storey is more than 130% of adjacent storey.
4. In-Plane Discontinuity in Vertical Lateral Force-Resisting Element Irregularity: In plane discontinuity in vertical lateral force-resisting elements irregularity is if there is an in-plane offset of a vertical lateral force-resisting element which causing in overturning demands on a supporting column, beam, slab, or truss.
5. (a) Discontinuity in Lateral Strength–Weak Storey Irregularity: Discontinuity in lateral strength–weak storey irregularity is that, where lateral strength of a storey is less than 80% of the above storey. The storey lateral strength is the total lateral strength of all seismic-resisting elements that sharing the storey shear for the direction under consideration.
5. (b) Discontinuity in Lateral Strength–Extreme Weak Storey Irregularity: Discontinuity in lateral strength–extreme weak storey irregularity is where the storey lateral strength is less than 65% of the storey above. The storey strength is the total strength of all seismic-resisting elements that sharing the storey shear for the direction under consideration.

Details of RCC Buildings Selected for study:-
In this study L-shape plan of G+7 storey reinforced concrete building have been selected. The models are analyzed in two phases, in first phase the building is analyzed without shear walls and soft-storey in Ground floor and second phase the same building is analyzed with shear walls and having soft-storey in Ground floor. The plan of Building is shown in Fig. 2. The data for analysis of the selected building is given in the Table 1.

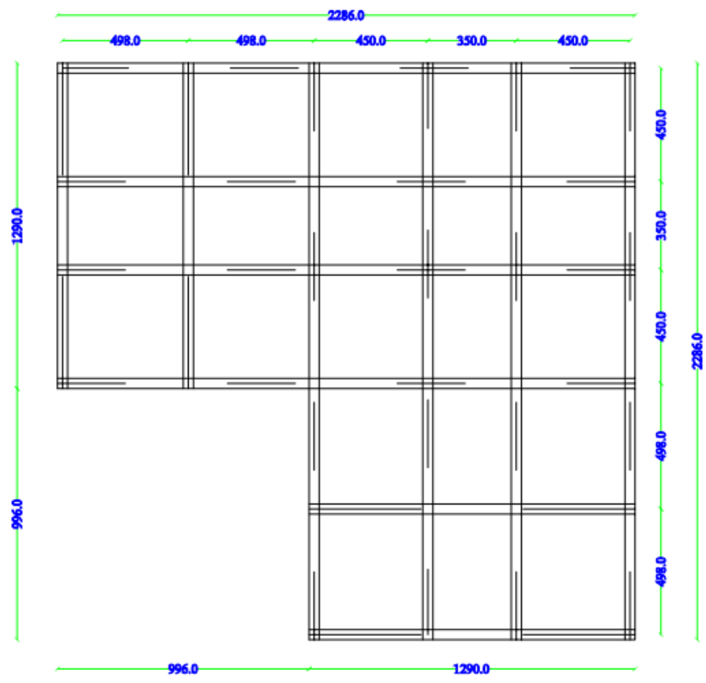


Fig. 2:-Plan of G+7 Storey RCC Buildings

Table 1:- Data for the Building

Live load	4.0 kN/m^2 at typical floor 1.5 kN/ m^2 on terrace
Floor finish	1.0 kN/ m^2
Water proofing	2.0 kN/ m^2
Terrace finish	1.0 kN/ m^2
Seismic zone	3rd
Important factor	1
Type of soil	Medium
Storey height	Typical floor: 3m, GF: 3m, and height of column from base to Ground floor level: 2m
Floors	G.F. + 7 upper floors
Columns size	400mm*400mm
Beams size	400mm*500mm
No. of Columns	32
Slab thickness	100mm
Thickness of all masonry Walls	230mm
Parapet wall height	1.2m
Grade of concrete	M35 for plinth columns and ground floor columns, M30 from first floor to the 7th floor columns, M30 for all other components
Grade of steel	Fe 415 HYSD
Floor Area	423.3 sqm

The horizontal spectral response acceleration for 0.2 second period (5 percent of critical damping) is for Khost Province in Figure 311.4.1-1 of ABC-2012 code (Afghanistan Building Code-2012) is 60% (S_s=0.6g) and horizontal spectral response acceleration for 1.0 second period (5 percent of critical damping) is for KhostProvince in figure 311.4.1-2 of ABC code is 25% (S_1=0.25g).

The storey numbers are given to the portion of the building between two successive grids of beams. The storey numbers are defined as follows:

Portion of the building	**Storey No.**
Foundation top to first floor	1
First Floor to second floor	2
Second floor to third floor	3
Third floor to fourth floor	4
Fourth floor to fifth floor	5
Fifth floor to sixth floor	6
Sixth floor to seventh floor	7
Seventh floor to roof	8

Analysis of Models:-

Since in these day in most multi-storey building the ground flooris considered for parking, or the height of ground floor columns is more than the above storeys, for this to study the effect of soft-storey in seismic areas, therefore in this study Ground floor is selected as soft-storey. In plinth level of Ground floor, tie beams are not considered, so the column height for Ground floor increase than upper storeys and the lateral stiffness of this floor decreases.

Calculation of Stiffness:-

The lateral stiffness of the storey is calculated, to know that the Storey-1 (Ground floor) is soft-storey or not. As Ground floor column height is 5 m and the upper each storey height is 3m, so the stiffness of Ground floor (Storey-1) and First floor (Storey-2) are calculated.

Stiffness of Ground floor (Storey-1):-

Stiffness of storey column is calculated as below,

$$K = \frac{12\ EI}{L^3}$$

where, E = Elastic modulus of concrete

I = Moment of inertia of column

L = Height of column.

For M30 grade of concrete E,

$$E = 5000\sqrt{f_{ck}} = 5000\sqrt{30} = 27386\frac{N}{mm^2} = 27386 \times 10^3 kN/m^2$$

For M35 grade of concrete E,

$$E = 5000\sqrt{35} = 29580\frac{N}{mm^2} = 29580 \times 10^3 kN/m^2$$

Moment of inertia of column,

$$I = \frac{1}{12}bd^3 = \frac{1}{12} \times 0.40 \times 0.40^3 = 0.002133\ m^4$$

Total number of columns of Ground floor is 32 and all the columns are same size and column height is 5m. The grade of concrete in these columns is M35.

$$\text{StiffnessofGroundfloor} = 32 \times \frac{12 \times 29580 \times 10^3 \times 0.002133}{5^3} = 193825.198\ kN/m$$

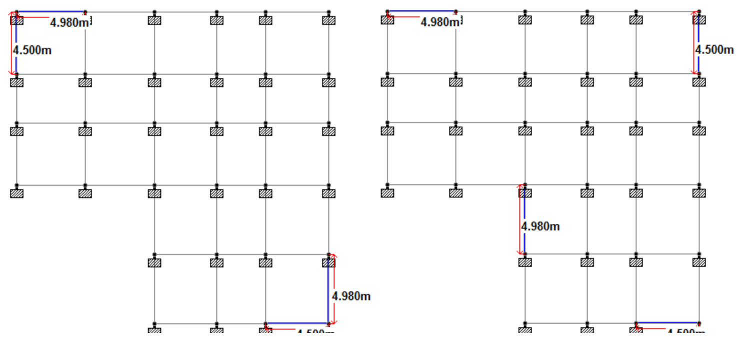
Stiffness of First floor (Storey-2): Total number of columns of is 32, all the columns are same size and its height is 3m. The cross section dimensions of First floor columns are same as Ground floor column, but grade of concrete in from Fist floor to Roof of building is M30.

$$\text{Stiffnessoffirstfloor} = 32 \times \frac{12 \times 27386 \times 10^3 \times 0.002133}{3^3} = 830781.69\ kN/m$$

The stiffness of Ground floor is 23.33% of stiffness of First floor, so the stiffness of Storey-1 is less than 60% of the stiffness Storey-2. As per Table 12.3.2, clause 12.3.2 of ASCE-7-10, “an extreme soft-storey is one in which the lateral stiffness is less than 60 percent of that in storey above or less than 70 percent of the average stiffness of the three storeys above”. So the selected model has soft-storey in Ground floor.

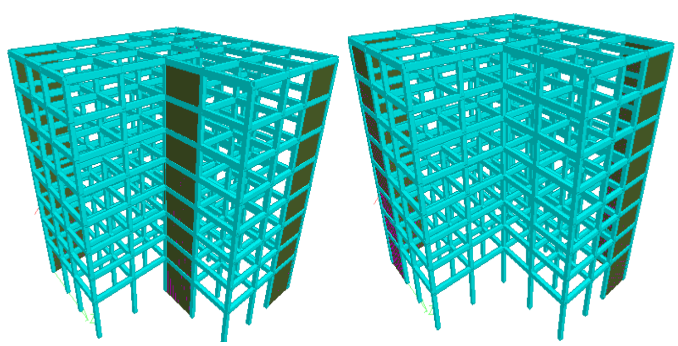
For analysis, theselected G+7 reinforced concrete framed buildings are modeledand analyzed bySTAAD. Pro V8i SS6 software according to the given data using IBC-2012 code and load combinations are prepared according to theIBC-2012 code. The analysis is performed in two phases, in First Phase the model is analyzed without shear walls and Second Phase, it is analyzed with shear walls. Also in Second Phase the shear walls are added in different location of the plan to the irregular building and analyzed the models. The results of the models with shear walls & having soft-storey in Ground floor are compared with the results of model without shear walls and having soft-storey in Ground floor.

As shear walls are added in two different cases. In First Model, four shear walls are considered, two in left corner and two in the opposite right corner and this case the shear walls are arrange in such that two shear walls are located along X-direction and other two shear walls are located along Z-direction, therefore the stiffness of shear in both directions is same (see Fig. 3 (a)). In Second Model, the same size four shear walls are added as in First Model, but in this case the shear walls arranged in four corners, that two shear walls are positioned along X-direction and two shear walls are arranged along Z-direction and the stiffness of shear walls in both direction is equal (see Fig. 3(b)). Thickness of shear walls is 220 mm and the length of shear walls is shown in Fig. 3 below.



(a) Model-1(b) Model-2

Fig. 3:- Location of Shear Walls in L-shape Building.



(a) Model-1 (b) Model-2

Fig. 4:- 3D of Models with Shear Walls.

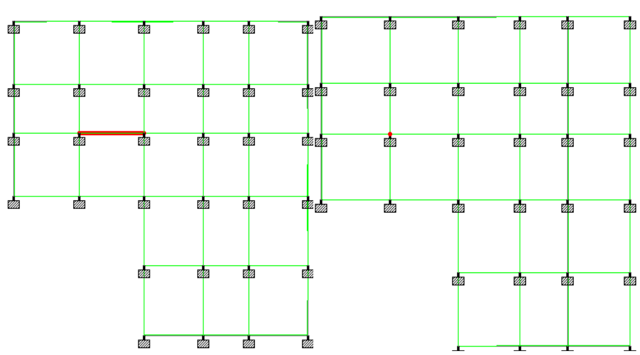


Fig. 5:-Selected Beams Fig. 6 Selected Columns.

Result and Discussion:-

The results of model without shear walls and having soft-storey in Ground floor are compared to the results of models with shear walls and having soft-storey in Ground floor. Also the locations of shear walls are studied in two cases, for selecting the best locations of shear walls in L-shaped RCC Building.

Total Seismic Weight & Base Shear:-

It is clear that the total seismic weight and base shear due to the self-weight of shear walls will be increased as compared to the model without shear walls and total seismic weight and base shear are shown in Table 2 below.

Table 2:-Total Seismic Weight&Base Shear of Buildings

Description	Without Shear	With Shear Wall	
		Model-1	Model-2
Seismic Weight (kN)	30704.5	33260	33260
Base Shear in X-direction (kN)	1397	1729	1729
Base Shear in Z-direction (kN)	1397	1729	1729

Storey Displacement and Storey Drift:-

The displacement and storey drift significantly decrease, when add shear walls to the models.

From the Fig. 7 & Fig 8, it is observed, that displacement & storey drift of models with shear walls is lesser than model without shear walls. Between the two cases, in Model-1 displacement and storey drift is lesser than Model-2. The soft-storey drift by adding shear walls to the building is decreased significantly and it decrease more than 50% in Model-1.

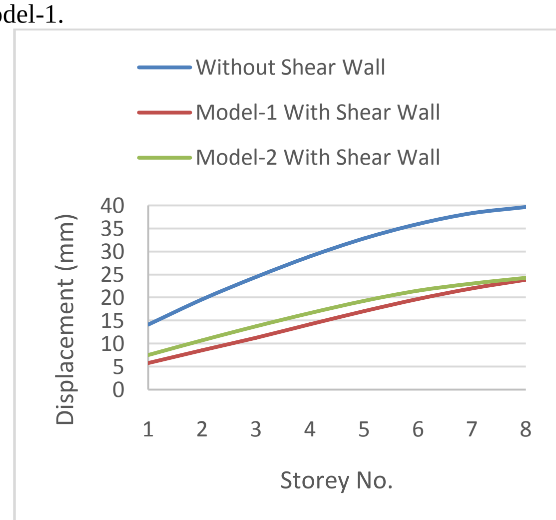


Fig. 7:- Maximum Storey Displacement.

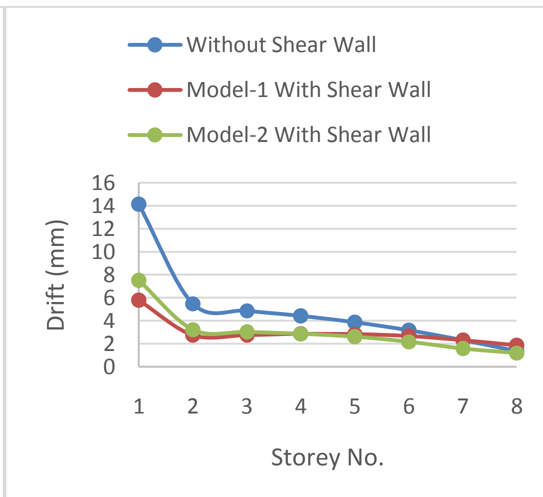


Fig. 8:- Maximum Storey Drift

Maximum Moment and Shear Force in Beams:-

For the models one interior beam in each floor has been selected and the selected beams have been shown in Fig.5. Moments and shear forces in selected beams are compared. The centre to centre span length of selected beam is 4.98 m.

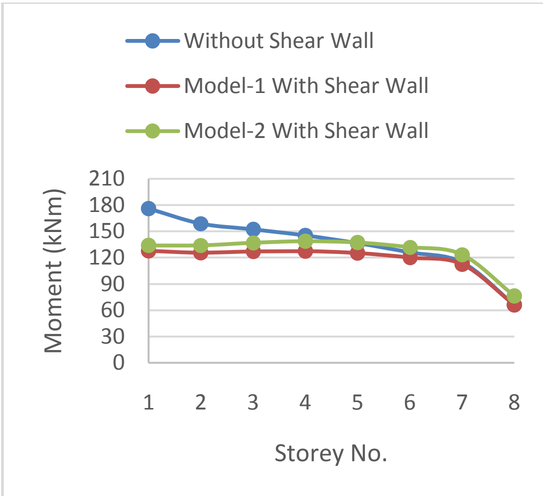


Fig. 9:- Max.Envelope Moments in Beams

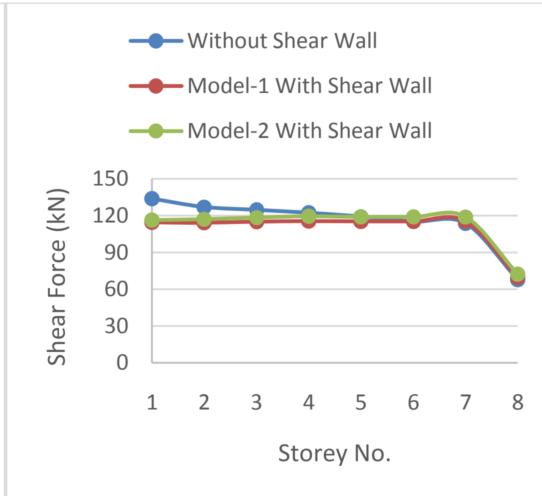
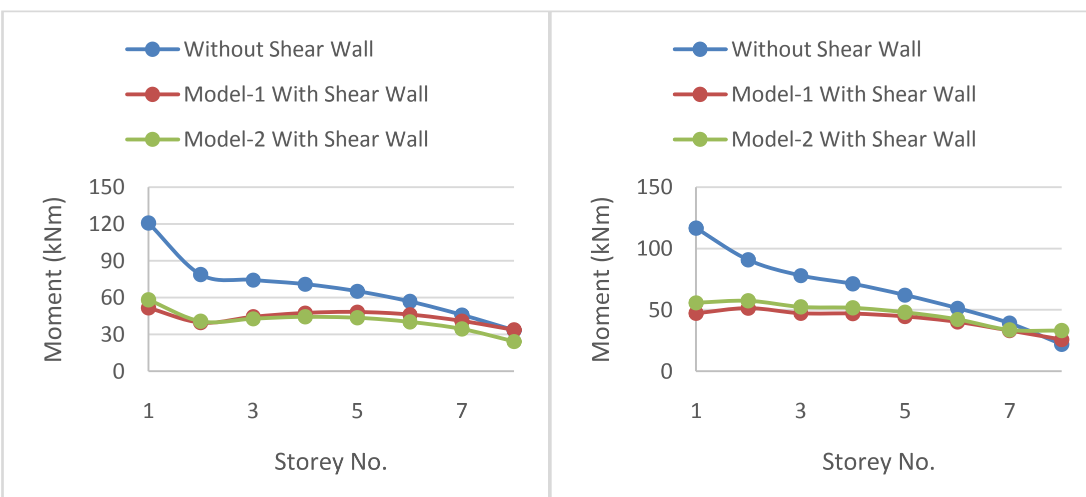


Fig. 10:- Max.Envelope Shear Forces in Beams.

From Fig. 9, it is observed, that in Model-1 moments of beams show decreasing in all storeys as compared to model without shear walls, but in Model-2 moments of beams show decreasing in soft-storey and near to soft-storey, but in upper storeys they show increasing. In Fig. 10, shear forces of beams in Model-2 also decrease in soft-storey and near to soft-storey, but in upper storeys they increase when it is compared with models without shear walls. The shear forces of beams in Model-1 show decreasing in the lower storeys, but in the above storeys they have about equal values to thebeams of models without shear walls.

Maximum Moment in Columns:-

For the model one interior column in each floor has been selectedand the selected columns have been shown in Fig.6. From Fig. 11, it is cleared, that moment (Mz& My) of columns generally in both models decrease significantly as compared to the models without shear walls.



(a) Mz (b) My

Fig. 11:- Maximum Envelope Moments in Columns

Comparing Support Reactions:-

The selected columns support reactions of models without shear walls are compared with the models having shear walls and the results are shown in Table 3 below.

Table 3:-Maximum Envelop Support Reactions

Description	Without Shear	With Shear Wall	
		Model-1	Model-2
Fy (kN)	2804.8	2759.1	2746.6
Fx (kN)	45.53	19.27	21.85
Fz (kN)	45.08	18.86	21.96
Mx (kNm)	116.6	47.25	55.94
Mz (kNm)	120.77	51.81	58.16

Support reactions (see Table 3) of Model-1 and Model-2 show significantly decreasing as compared to the models without shear walls.

Conclusion:-

In this study L-shape plan of G+7 storey reinforced concrete building have been selected. The models have been analyzed in two phases, in First Phase the building has been analyzed without shear walls and soft-storey in Ground floor and Second Phase the same building has been analyzed with shear walls and having soft-storey in Ground floor. In the second phase also the shear walls were added to the model in two different cases, to study the best location of shear walls in the building. The results are concluded as under:

1. It is observed, that displacement, storey drift, moments and shear forces in beams, moments in columns and support reactions decrease of the building with shear walls and having soft-storey in Ground floor as compared to the buildings without shear walls and having soft-storey in Ground floor.
2. By adding shear walls to irregular building, generally the effect irregularities like soft-storey drift, displacement and moments & shear forces in beams and momentsin columns of soft-storey decrease significantly as compared to the other storeys.
3. The soft-storey drift by adding shear walls to the building is decreased significantly and it decrease more than 50% in Model-1.
4. Stiffness of shear walls in both directions and location of shear walls are very important, if the shear walls are added in proper location and have equal stiffness in both directions, it will be more effective.
5. In L-shape that four shear walls were added to the model in two different cases (see Fig. 3), the location of shear walls in Model-1, in which two shear walls were arranged in left side corner and two shear walls were added in right side opposite corner was better than Model-2.

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