COST MODELING OF A RCC RESIDENTIAL BUILDING WITH & WITHOUT SOFT STOREY IN ZONE-IV (INDIA)

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ABSTRACT-*Due to decrease in parking spaces the concept of parking at Stilt level of a building has been introduced in various Municipal/Authorities bye-laws. Provision of Stilt level leads to formation of soft storey because of various structural configurations and irregularities. As per Indian codal provisions IS:1893 (2002) the columns, beams and shear walls of the soft storey are to be designed for higher storey shear forces. Higher the storey forces more sectional concrete and steel area will be required to resist forces for a given grade of Concrete. This research paper compares the structural forces through Dynamic analyses of a residential building in Zone IV of Indian Earthquake Zone with and without Stilit/Soft storey and calculates the structural cost of both the buildings in terms of reinforcement consumption keeping the size of the structural members same. The study is broadly validated from the historic data of seismically designed and constructed buildings. The results of the study would be useful for design professionals and quantity surveyors.*

Keywords: Stilt Floor, Soft storey, Cost, Reinforcement, Concrete, ETABS, load combinations

I. INTRODUCTION

Since many of the planning authorities & boards have permitted additional FAR by providing covered parking facilities in the "stilit" or "open ground storey". It has been observed that there is increase in construction of such type of residential buildings. The absence of infills walls/panels along with reduced floor height of the open stilit floor leads to formation of soft or extreme soft storey at that level which is considered as structural vertical irregularity {Table 5 of clause 7.1 and 7.10 of IS:1893(2002)}. As per IS:1893(2002), the soft storey is defined as one which has lateral stiffness less than 70% of the storey above or less than 80% of average lateral stiffness of the three storey above. Clause 7.10.3 of IS:1893(2002) defines the design procedure of soft storey buildings. i.e. to increase the storey shear by a factor of 1.5 times for shear walls and 2.5 times for columns and beams of the soft storey. The modified factor of safety increases the forces viz a viz additional stress in the members which could be resisted either by enhancing the material properties (concrete or steel) or by increasing the moment of inertia of members or a combination of the above.

This research paper compares cost modeling considering only structural cost of a building having basement, ground and 6 upper floors with and without open storey/stilt. The cost comparison is done in terms of cost involved in constructing soft storey for extra reinforcement that needs to be provided to resist additional stresses as discussed earlier. The moment of inertia of the structural members are kept same for comparison of buildings in respect of the steel reinforcement required in Shear Walls, Columns and Beams of the two buildings.

II. SOFT STOREY AND ITS CODAL PROVISIONS

One of the vertical irregularity defined in IS:1893(2002) is "soft storey" which is caused by discontinuous sizes and stiffness. IS:1893(Part1):2002 defines soft storey as stiffness irregularity. A soft storey is one in which the lateral stiffness is less than 70 percent of that in the storey above or less than 80 percent of the average lateral stiffness of the three storeys above.

A extreme soft storey is one in which the lateral stiffness is less than 60 percent of that in the storey above or less than 70 percent of the average stiffens of the three storeys above.

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

Provisions made in IS:1893(Part 1): 2002 (clause 7.8) regarding analysis and design of soft storey are:

- Dynamic analysis to be performed on buildings with soft storey lying in zone 4 and 5 and height greater than 12 m.
- Columns and beams to be designed for 2.5 times the storey shear
- Shear walls to be placed symmetrically in both directions of building and should be as far as possible from the center of the building and be designed for 1.5 times the storey shear.

III. DESCRIPTION OF STRUCTURAL MODEL

In the present study two buildings one regular and other with vertically irregularity (soft storey at ground level) is modelled using ETABS (9.7.1) and analyzed. The properties of the considered building configuration are summarized in Table 1 below.

Table 1: Description of building

Modelling details of building	
Plan dimension	10 x 30 m
No. of storeys	Basement + Ground + 6 storeys
Building frame system	Special Moment Resisting Frame
Basement Height	5 m
Ground storey height	2.7 m
Typical storey height	3.15 m
Building use	Residential
Foundation type	Fixed
Seismic Zone	Zone – IV
Soil Type	Medium soil
Importance Factor (I)	1
Response Reduction Factor (R)	5
Damping Ratio	5 %
Time period in X direction	0.84 sec {Clause 7.6.2 of IS:1893(Part 1): 2002}
Time period in Y direction	0.50 sec {Clause 7.6.2 of IS:1893(Part 1): 2002}
Material Properties	
Grade of steel for longitudinal/main reinforcement	Fe500
Grade of steel for shear/ties reinforcement	Fe415
Grade of concrete and its Young's Modulus (E)	M25 – 25 x 10^6 KN/m^2
Density of concrete	25 KN/m^3
Poisson's ratio (of concrete)	0.20
Structural members	
Slab Thickness	130 mm
Wall thickness	115 and 230 mm thick
Shear wall thickness	230 mm thick
Beam sizes	0.115 x 0.45 m

	0.23 x 0.45 m
	0.3 x 0.45 m
	0.35 x 0.45 m
Column sizes	0.3 x 0.75 m
	0.35 x 0.75 m
Dead Load Intensities	
Wall 230 mm thick	13.5 KN/m
Wall 115 mm thick	7.5 KN/m
Parapet Wall load	5.61 KN/m
Railing Load	3.0 KN/m
Floor finish and plaster on ceiling	1.45 KN/m^2
Brick coba and plaster on ceiling	2.75 KN/m^2
Sunk load (450 mm sunk)	4.05 KN/m^2
Staircase loading	9.2 KN/m^2
Live Load Intensities	
Living room, Kitchen, Toilet	2 KN/m^2
Corridor, Staircase, Lobbies, Balcony	3 KN/m^2
Terrace (Accessible)	1.5 KN/m^2
Terrace (Non- Accessible)	0.75 KN/m^2
Parking	5 KN/m^2

IV. MODELLING OF BUILDING

The building model comprising of basement, ground and 6 storeys is modelled in ETABS (9.7.1). Structural system comprises of beam-column and shear wall system. Beam and column are modelled as lines elements connected between two points having 6 degree of freedom (DOF) at each node whereas shear wall and slabs are modelled as area elements. Slabs being rectangular in plan are connected by 4 nodes. Slabs are designed as shell properties and are connected so that they act as a rigid diaphragm whereas shear walls have been assigned member property. Other non-structural components that doesn't have a major role in analysis are not modelled. Load combinations for analysis of structure as per IS 1893 (Part 1): 2002 is defined. Also, conditions for lumping of mass at floor levels according to the code is defined which helps in getting the storey shear. Figure 1 shows 3D view of building having basement, ground and 6 storeys along with plan of the building. Both the buildings are similar except that there is no wall load on ground storey in building with soft storey.

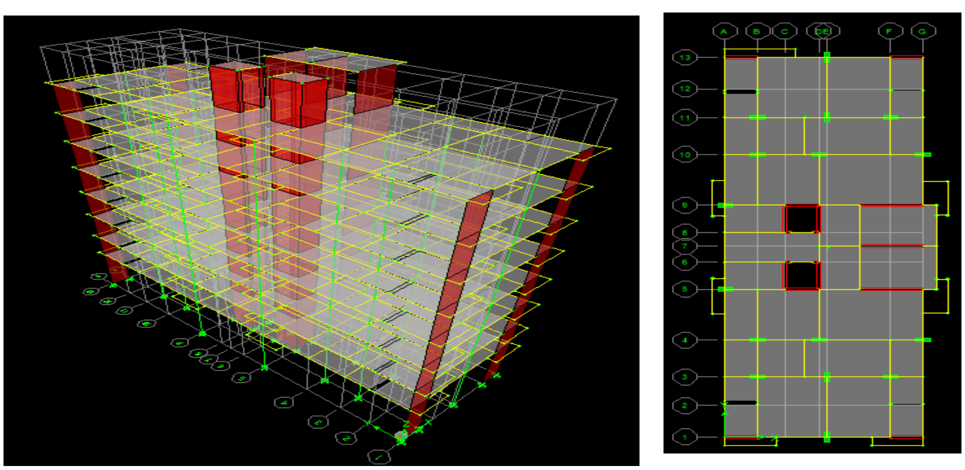


Figure 1 – 3 D view of building with basement, ground and 6 storeys along with plan of the building

Models considered for analysis and design:

- Basement + Ground + 6 storeys with soft storey
- Basement + Ground + 6 storeys without soft storey

V. SOFT STOREY CHECK

Before analysis and design of building with soft storey, it is to be ensured that soft storey is formed in a building where wall load is not applied and at the same time it has to be checked that soft storey effect does not exist in building where wall load is applied. For this the method suggested by (Aslam Faqeer Mohammed, 2012) is followed. As per codal provisions if the stiffness is less than 70 % of above storey then it will be classified as soft storey, so a maximum variation of 30 % is required between the two adjacent storeys. Table 2 and 3 calculates the stiffness of each storey for building where wall load is not applied at stilit/open storey level in X and Y direction respectively and then determines the percentage difference between the stiffnesses of each storey with respect to top and bottom storey. Similarly Table 4 and 5 determines the stiffness in X and Y direction respectively for building where wall load is applied at stilt/open ground storey level.

Table 2: Determination of soft storey due to lateral force caused by the earthquake in X direction for building where wall load is not applied at ground level

Storey	Design Base Shear (KN)	Lateral Force (KN)	Diaphragm Displacement (mm)	Stiffness (KN/mm)	% difference in K (30 % required)	
					% difference compared to	
					Above Storey	Below Storey
MUMTY	61.77	61.77	15.12	4.09	-	86.29
TERRACE	460.13	398.36	13.37	29.80	629.32	7.54
SIXTH	839.42	379.29	11.77	32.23	8.16	13.49
FIFTH	1123.65	284.23	10.01	28.39	11.89	13.51
FOURTH	1326.52	202.87	8.11	25.01	11.90	13.80
THIRD	1461.71	135.19	6.15	21.98	12.12	13.97
SECOND	1542.91	81.2	4.21	19.29	12.26	15.87
FIRST	1583.36	40.45	2.43	16.65	13.69	**68.68**
GROUND	1594.61	11.25	1.14	9.87	**40.72**	-

Table 3: Determination of soft storey due to lateral force caused by the earthquake in Y direction for building where wall load is not applied at ground level

Storey	Design Base Shear (KN)	Lateral Force (KN)	Diaphragm Displacement (mm)	Stiffness (KN/m)	% difference in K (30 % required)	
					% difference compared to	
					Above Storey	Below Storey
MUMTY	95.38	95.38	37.81	2.52	-	86.40
TERRACE	710.49	615.11	33.15	18.56	635.56	6.19
SIXTH	1296.16	585.67	29.61	19.78	6.60	15.42
FIFTH	1735.05	438.89	25.61	17.14	13.36	15.54

FOURTH	2048.31	313.26	21.12	14.83	13.45	15.68
THIRD	2257.05	208.74	16.28	12.82	13.55	15.87
SECOND	2382.43	125.38	11.33	11.07	13.69	17.82
FIRST	2444.89	62.46	6.65	9.39	15.12	**73.47**
GROUND	2462.27	17.38	3.21	5.41	**42.35**	-

From Table 2 and 3, It is calculated that the stilit/open ground storey and first floor has a stiffness difference of more than 30% which implies that soft storey effect is taking place in building without walls at ground level. These two stories need to be designed taking into consideration the soft storey effect by considering relevant codal provisions.

Table 4: Determination of soft storey due to lateral force caused by the earthquake in x direction for building where wall load is applied at ground level

Storey	**Design Base Shear (KN)**	**Lateral Force (KN)**	**Diaphragm Displacement (mm)**	**Stiffness (KN/mm)**	**% difference in K (30 % required)**	
					% difference compared to	
					Above Storey	**Below Storey**
MUMTY	64.62	64.62	15.34	4.21	-	86.27
TERRACE	481.36	416.74	13.58	30.69	628.49	7.50
SIXTH	878.16	396.8	11.96	33.18	8.11	13.58
FIFTH	1175.52	297.36	10.18	29.21	11.96	13.82
FOURTH	1387.75	212.23	8.27	25.66	12.14	13.77
THIRD	1529.18	141.43	6.27	22.56	12.10	14.18
SECOND	1614.13	84.95	4.30	19.76	12.42	16.27
FIRST	1656.44	42.31	2.49	16.99	13.99	6.54
GROUND	1675.1	18.66	1.17	15.95	6.14	-

Table 5: Determination of soft storey due to lateral force caused by the earthquake in y direction for building where wall load is applied at ground level

Storey	**Design Base Shear (KN)**	**Lateral Force (KN)**	**Diaphragm Displacement (mm)**	**Stiffness (KN/mm)**	**% difference in K (30 % required)**	
					% difference compared to	
					Above Storey	**Below Storey**
MUMTY	99.78	99.78	39.57	2.52	-	86.41
TERRACE	743.28	643.5	34.69	18.55	635.64	6.18
SIXTH	1355.99	612.71	30.99	19.77	6.58	15.45
FIFTH	1815.14	459.15	26.81	17.13	13.38	15.55
FOURTH	2142.85	327.71	22.11	14.82	13.45	15.65
THIRD	2361.24	218.39	17.04	12.82	13.53	15.89
SECOND	2492.4	131.16	11.86	11.06	13.71	17.80

FIRST	2557.74	65.34	6.96	9.39	15.11	9.53
GROUND	2586.54	28.8	3.36	8.57	8.70	-

From table 4 and 5, it is calculated that due to the presence of walls at stilt/open ground level the soft storey effect does not take place and hence the building can be classified as regular building.

VI. LOAD COMBINATIONS

Buildings with soft storey needs to be designed as per the provisions laid down in the code. the code requires to design the Beams and Columns of the soft storey for modified storey shear by increasing it to 2.5 times of the initial forces and shear walls for 1.5 times the storey shear. So for analysis in ETABS 9.7.1 this condition is met by defining the load combinations such that the earthquake load component in each load combination is multiplied by 2.5 times for beams and columns and for shear walls the earthquake load component is multiplied by 1.5 times.

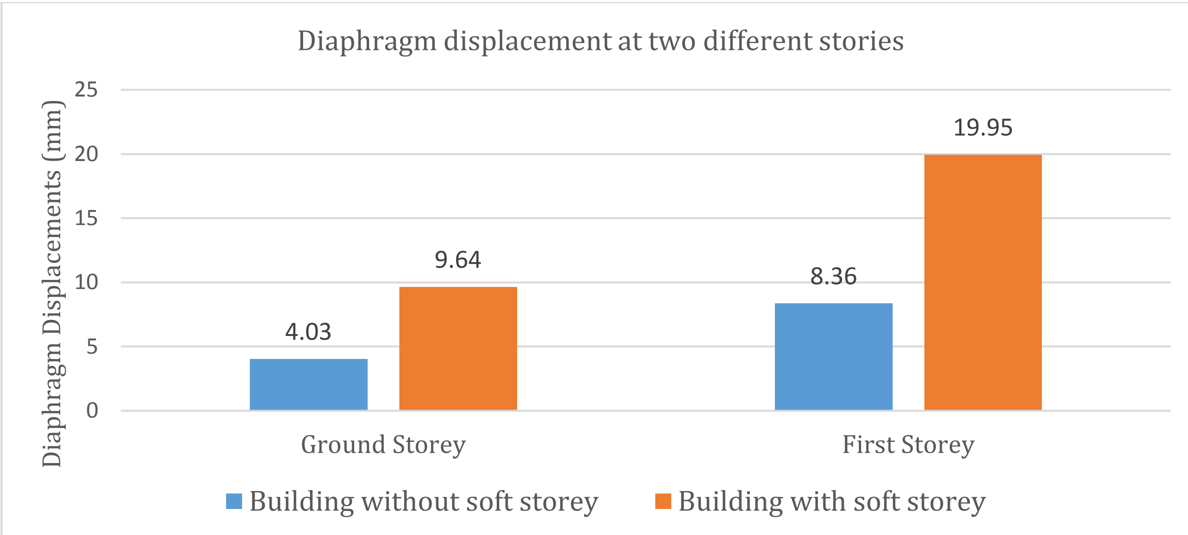
For ex. if a load combination for a regular building is 1.2 (DL + LL + EQ) where DL is Dead Load, LL is Live Load and EQ is Earthquake load then for building with soft storey the load combination for beams and columns would become 1.2(DL + LL + 2.5 EQ) or 1.2(DL + LL) + 3EQ and for shear wall the load combination would be 1.2(DL + LL + 1.5 EQ) or 1.2(DL + LL) + 1.8 EQ. The modified load combinations are only applied for soft storey while all other storeys are designed for standard load combinations. Table 6 provides a list of load combinations used for analysis and design of both the buildings.

Table 6: List of load combinations used for analysis and design of both buildings

Load combinations for regular building and for storeys other than soft storey	**Load combinations for beams and columns present in soft storey**	**Load combinations for shear walls present in soft storey**
1.5(DL + LL)	1.5(DL + LL)	1.5(DL + LL)
1.2(DL + LL + EQX)	1.2(DL + LL) + 3 EQX	1.2(DL + LL) + 1.8EQX
1.2(DL + LL - EQX)	1.2(DL + LL) - 3 EQX	1.2(DL + LL) - 1.8EQX
1.2(DL + LL + EQY)	1.2(DL + LL) + 3 EQY	1.2(DL + LL) + 1.8EQY
1.2(DL + LL - EQY)	1.2(DL + LL) - 3 EQY	1.2(DL + LL) - 1.8EQY
1.5(DL + EQX)	1.5 DL + 3.75 EQX	1.5 DL + 2.25 EQX
1.5(DL - EQX)	1.5 DL - 3.75 EQX	1.5 DL - 2.25 EQX
1.5(DL + EQY)	1.5 DL + 3.75 EQY	1.5 DL + 2.25 EQY
1.5(DL - EQY)	1.5 DL - 3.75 EQY	1.5 DL - 2.25 EQY
0.9 DL + 1.5 EQX	0.9 DL + 3.75 EQX	0.9 DL + 2.25 EQX
0.9 DL – 1.5 EQX	0.9 DL – 3.75 EQX	0.9 DL – 2.25 EQX
0.9 DL + 1.5 EQY	0.9 DL + 3.75 EQY	0.9 DL + 2.25 EQY
0.9 DL – 1.5 EQY	0.9 DL – 3.75 EQY	0.9 DL – 2.25 EQY
1.2(DL + LL + SPECX)	1.2(DL + LL) + 3 SPECX	1.2(DL + LL) + 1.8SPECX
1.2(DL + LL + SPECY)	1.2(DL + LL) + 3 SPECY	1.2(DL + LL) + 1.8SPECY
1.5(DL + SPECX)	1.5 DL + 3.75 SPECX	1.5 DL + 2.25 SPECX
1.5(DL + SPECY)	1.5 DL + 3.75 SPECY	1.5 DL + 2.25 SPECY
0.9 DL + 1.5 SPECX	0.9 DL + 3.75 SPECX	0.9 DL + 2.25 SPECX
0.9 DL + 1.5 SPECY	0.9 DL + 3.75 SPECY	0.9 DL + 2.25 SPECY

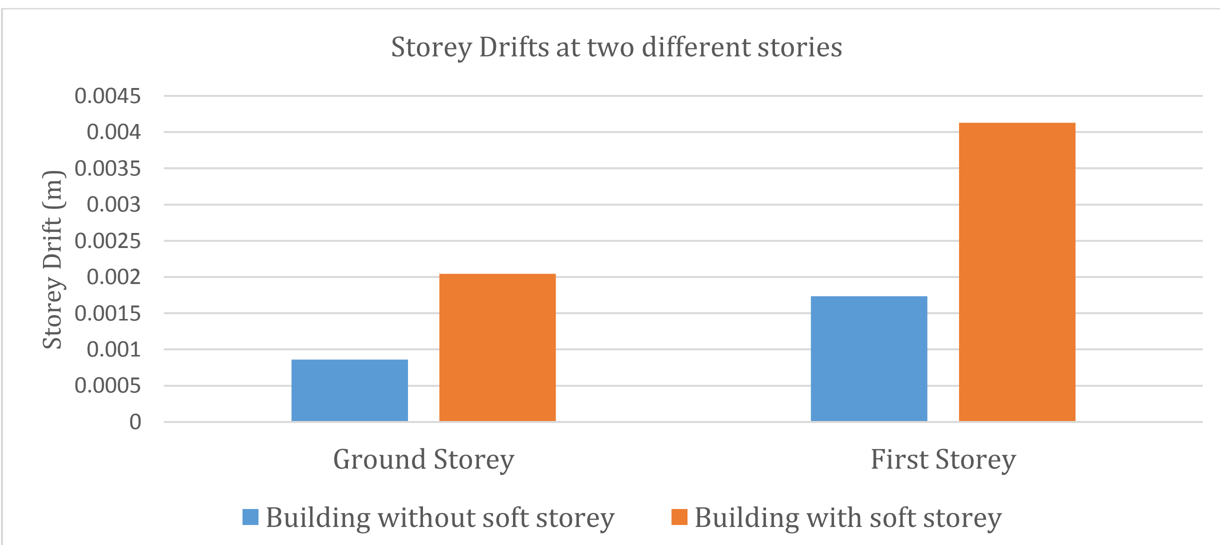
VII. MODEL ANALYSIS

Graph 1: Diaphragm displacement at Stilt and first storey for building with and without soft storey



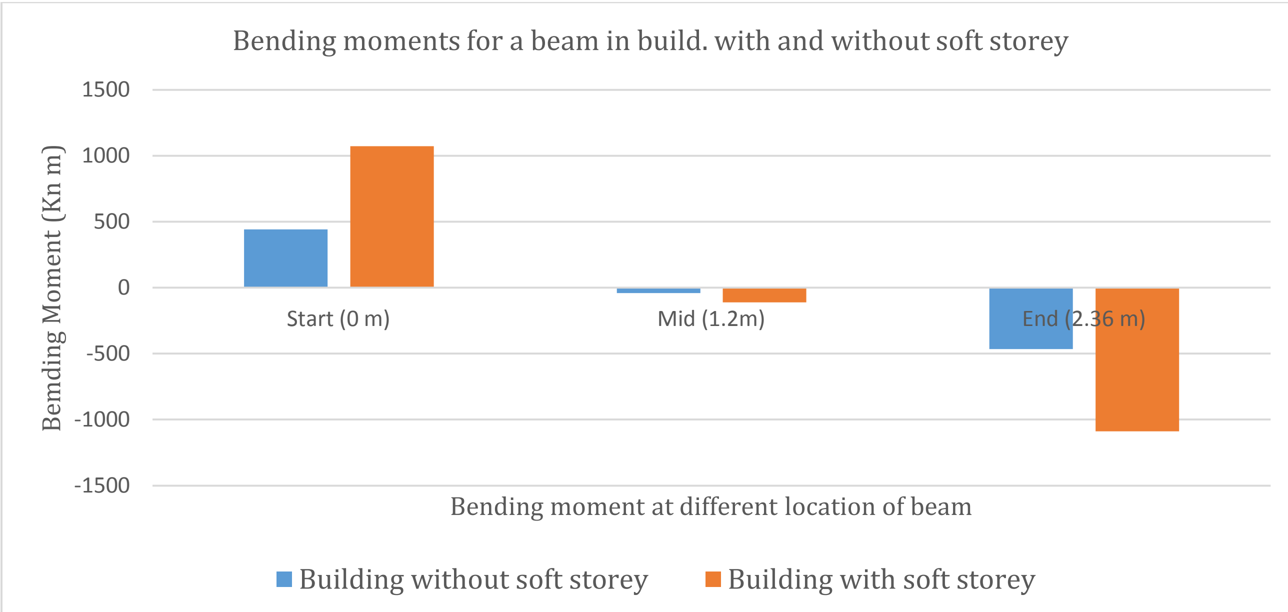
It is observed from Graph 1 that diaphragm displacements for building with soft storey is more than building without soft storey at both ground and first storey level. This is partially because of 2.5 times magnification factor for soft storey building.

Graph 2: Storey Drift at ground and first storey for building with and without soft storey



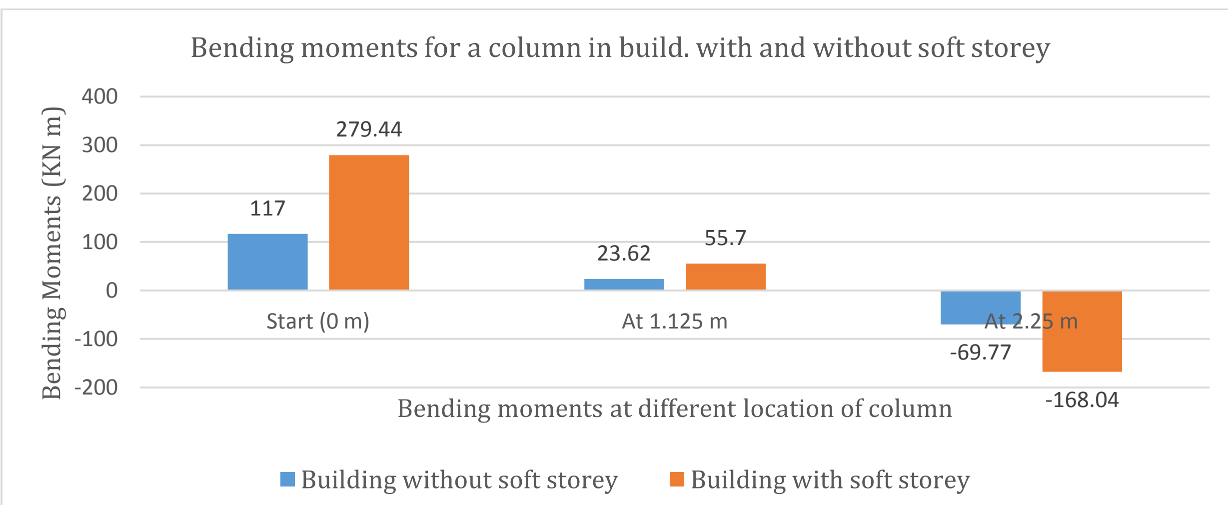
Storey drift is higher for building with soft storey at ground and first storey when compared to building without soft storey which can be seen from graph 2. This is partially because of magnification factor of 2.5 applied in building with soft storey.

Graph 3: Comparison of moments in a beam for building with and without soft storey



Bending moments for a beam in building with soft storey is higher than building without soft storey as soft storey is designed for 2.5 times magnification factor. Modification of load combinations caused by this factor induces more forces and moments in beams, columns and shear walls.

Graph 4: Comparison of moments in a beam for building with and without soft storey



Bending moments for a column in building with soft storey is higher than building without soft storey as soft storey is designed for 2.5 times magnification factor. Modification of load combinations caused by this factor induces more forces and moments in beams, columns and shear walls.

VIII. QUANTITY OF CONCRETE CONSUMED

Table 8: Total quantity of concrete consumed in single building

Size	**Volume (m^3)**
Beams	
0.115 x 0.45 m	7.2
0.23 x 0.45 m	135.68
0.3 x 0.45 m	55.2
0.35 x 0.45 m	13.12
Total concrete consumed in beams in single building =	211.2
Columns	
0.3 x 0.75 m	83.775
0.35 x 0.75 m	13.225
Total concrete consumed in columns in single building =	97
Shear Walls	
0.23 m thick wall	201.84
Total concrete consumed in shear walls in single building =	201.84
Total quantity of concrete consumed in one building =	**510.04**

The total quantity of concrete consumed in beams, columns and shear walls in single building is 510.04 m^3. Since both the buildings are same in terms of member sizes so the quantity of concrete is same for both the buildings.

IX. QUANTITY OF STEEL CONSUMED

Since the member sizes and grade of concrete used is same for both the buildings, the difference is in the quantity of reinforcement used. The quantity of longitudinal reinforcement for both buildings is calculated with the help of ETABS model. Both the buildings were modelled, analyzed, designed and then the quantity of longitudinal reinforcement required was obtained for all members. Detailing was carried out as per the codal provisions IS:13920 (1993). After the detailing, length of bars was obtained with help of AutoCad software. The length of the bars then multiplied by their weight per unit length gave the weight of steel used in the building. Table 9 and 10 summarizes the weight of steel used in building with soft storey and building without soft storey respectively.

Shear stirrups for beams are calculated on the basis of average weight of 1 set of stirrup per unit length. Different beam cross-sections are considered for 10 m length. Closer shear stirrups as per codal provisions IS:13920 (1993) are considered near the support as compared to center. Spacing of 125 mm near the supports upto a distance of twice the effective depth and a spacing of 175 mm in rest of the beam. Weight of one stirrup of 8 mm diameter bar is calculated when then multiplied by total number of stirrups gives the total weight of stirrup in a beam of 10 m length. Once this is done then weight per meter length is determined. Similarly, this is done for beams of different cross-sections and the average weight if stirrups per m length is found.

A similar procedure is adopted for columns also. In this building, columns are predominantly of same size, their weight per unit length is multiplied by total length to give the weight of stirrups (8 mm diameter) used in columns. For finding the weight per unit length a column in a typical storey is selected. A spacing of 100 mm is provided for L/4 distance near the supports and for rest of the length in between a spacing of 200 mm is provided. L is the length of column between restraints. Now number of stirrups in a typical storey is calculated based on spacing, these number of stirrups is multiplied by weight of 1 stirrup which gives the total weight of stirrup in a typical storey. This total weight divided by the typical storey height gives the weight per unit length. The results are summarized in Table 9 and 10.

There are 3 kind of shear walls. Weight density per meter length of each type of shear walls is calculated in the same way as it is done for columns. Here the spacing is uniform along the height of shear wall. For shear wall 1 and 2 spacing is 200 mm and for shear wall 3 the spacing is 230 mm. Rest of the procedure is same. The weight densities per meter length and weight of stirrups are mentioned in Table 9 and 10.

Table 9: Weight of steel used in building with soft storey

Members	**Weight (kg)**
Beams – Longitudinal Steel	
Ground storey and First storey	8828.8
Second storey to Terrace (6 levels)	16997.82
Total longitudinal steel in beams =	25826.62
Beams – Stirrups	
Average weight of stirrup per meter beam length =	2.94 kg/m
Total weight of stirrups used in beams =	5629.51
Total weight of steel used in beams =	31456.13
Columns – Longitudinal Steel	
Total longitudinal steel in columns =	12685.02
Column – Stirrups	
Average weight of stirrup per meter length =	13.5 kg/m
Total weight of stirrups used in columns =	5745.6
Total weight of steel used in columns =	18430.62
Shear Wall – Longitudinal Steel	
Total longitudinal steel in shear walls =	15035.68
Shear Wall – Stirrups	
Average weight of stirrup per meter length =	
Weight of stirrup per m length for SW 1 =	18.90 kg/m
Weight of stirrup per m length for SW 2 =	33.64 kg/m
Weight of stirrup per m length for SW 3 =	55.2 kg/m
Total weight of stirrups used in shear walls =	8371.8
Total weight of steel used in shear walls =	23407.48
Total weight of steel used in building with soft storey =	**73294.23**

Table 10: Weight of steel used in building without soft storey

Members	**Weight (kg)**
Beams – Longitudinal Steel	
Ground storey and First storey	5665.94
Second storey to Terrace (6 levels)	16997.82
Total longitudinal steel in beams =	22663.76

Beams – Stirrups	
Average weight of stirrup per meter beam length =	2.94 kg/m
Total weight of stirrups used in beams =	5629.51
Total weight of steel used in beams =	28293.27
Columns – Longitudinal Steel	
Total longitudinal steel in columns =	7590.68
Column – Stirrups	
Average weight of stirrup per meter length =	13.5 kg/m
Total weight of stirrups used in columns =	5745.6
Total weight of steel used in columns =	13336.28
Shear Wall – Longitudinal Steel	
Total longitudinal steel in shear walls =	12866.24
Shear Wall – Stirrups	
Average weight of stirrup per meter length =	
Weight of stirrup per m length for SW 1 =	18.90 kg/m
Weight of stirrup per m length for SW 2 =	33.64 kg/m
Weight of stirrup per m length for SW 3 =	55.2 kg/m
Total weight of stirrups used in shear walls =	8371.8
Total weight of steel used in shear walls =	21238.04
Total weight of steel used in building without soft storey =	**62867.59**

Total built up area = 2920.92 m^2

Steel required for Beams & Columns of built up area for building with soft storey = 73294.23/2920.92 = 25.09 kg/m^2

Steel required for Beams & Columns of built up area for building without soft storey = 62867.59/2920.92 = 21.52 kg/m^2

X. COSTING

Rate of twisted/deformed bars as per Delhi Analysis of Rates – 2014 is Rs 4500/quintal. Applying cost index of 104 as on 31/07/2015 issued by Central Public Works Department (CPWD). The new cost will become Rs 4680/quintal or Rs 46.8/kg.

Cost of reinforcement for building without soft storey = Rs 46.80 x 62867.59 = Rs 29,42,203.21

Cost of reinforcement for building with soft storey = Rs 46.80 x 73294.23 = Rs 34,30,169.96

Percentage difference in cost = 16.5 %

Total built up area = 2920.92 m^2

Cost of built up area excluding Foundation & slabs for building without soft storey = 2942203.21/2920.92 = Rs 1007.28/m^2

Cost of built up area excluding Foundation & slabs for building with soft storey = 3430169.96/2920.92 = Rs 1174.35/m^2

XI. RESULTS

Total volume of concrete consumed in single building for beams, columns and shear walls is 510.04 m^3. Reinforcement required for beams, column and shear walls in single building with soft storey is 73294.23 kg and for building without soft storey is 62867.59 kg. There is increase of 10426.64 kg for building with soft storey when compared to building without soft storey.

Longitudinal steel in beams for ground storey (soft storey) is 4414.4 kg and for regular ground storey it is 2832.97 kg. There is a difference of 1581.43 kg or 55.8 %.

Cost of reinforcement for beams, columns and shear walls for building without soft storey is Rs 29,42,203.21 and for building with soft storey is Rs 34,30,169.96. The difference in cost of building with soft storey and building without soft storey is about 16.5 %. Also the cost per sq. m for building without soft storey is Rs 1007.28 and for building with soft storey it is Rs 1174.35.

XII. CONCLUSION

There is increase in reinforcement of about 10426.64 kg for building with soft storey. In this case study, it has been observed that the structural cost of Columns, Beams & Shear Walls considering only steel & concrete and excluding Foundations & slabs increases by 16.5 % (app.) for building with soft storey when compared with exactly similar building without soft storey (regular building). It may be possible that for building with higher number of storeys this difference might get reduced. It can be concluded that additional 15%-20% of structural cost may be increased while designing the buildings with soft storey and the same may gets reduced for higher number of floors which can be taken as future scope of works.

XIII. REFERENCES

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