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"SEISMIC PERFORMANCE OF SOFT STOREY COMPOSITE COLUMN"

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ABSTRACT

"Soft storey" mechanism is the most frequent failure mode of reinforced concrete (R.C.) structures. The present work focused on an effect of soft storey. Severe structural damage suffered by several modern buildings during recent earthquakes illustrates the importance of avoiding sudden changes in lateral stiffness and ductility. Effective stiffness assumption in the modeling of reinforced concrete (RC) frame members is important for seismic design because it directly affects the building periods and dynamic response, particularly deflection and internal force distribution.

The soft storey effect will not only increase the total seismic horizontal load, which will induce huge moments in the columns, but also could increase the axial force in some columns. This situation will create very serious problems for columns.

1] Introduction

Earthquake produces waves which vibrate the base of structure in various manners and directions, because of which lateral force is developed on structure which shears the column or sometimes even it buckles the whole column resulting in failure of structure. Many urban multistory buildings in India today have open first storey as an unavoidable feature. Storey. The upper storeys have brick in filled wall panels. The draft Indian seismic code classifies a soft storey as one whose lateral stiffness is less than 50% of the storey above or below. Interestingly, this classification renders most Indian buildings, with no masonry infill walls in the first storey, to be "buildings with soft first storey." Whereas the total seismic base shear as experienced by a building during an earthquake is dependent on its natural period, the seismic force distribution is dependent on the distribution of stiffness and mass along the height. In buildings with first soft storey, the upper storey being stiff, undergo smaller inter-storey drifts.

However, the inter-storey drift in the soft first storey is large. The strength demands on the columns in the first storey for third buildings are also large, as the shear in the first storey is maximum. For the upper storeys, however, the forces in the columns are effectively reduced due to the presence of the Building with abrupt changes in storey stiffness have uneven lateral force distribution along the height, which is likely to locally induce stress concentration. This has adverse effect on the performance of buildings during ground shaking. Such buildings are required to be analyzed by the dynamic analysis and designed carefully.

A soft storey known as weak storey is defined as a storey in a building that has substantially less resistance or stiffness or inadequate ductility (energy absorption capacity) to resist the earthquake induced building stresses. Soft storey buildings are characterized by having a storey which has a lot of open space due to functional utility like parking garages, for example, are often soft storey, as are large retail spaces or floors with a lot of windows.

Composite Action between steel & concrete

Steel & concrete have almost the same coefficient of thermal expansion. Steel concrete composite construction utilizes the compressive strength of concrete with the tensile strength of steel so as to evolve an effective & economic structural system .hence; these essentially different materials are completely compatible to each other. Stress distribution diagram is shown in Fig 1

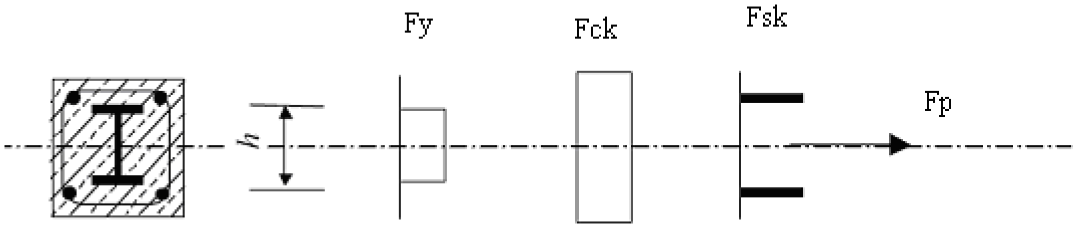

Fig 1 Stress distribution of plastic resistance to compression of an encased I section

2] Study of Soft Storey Mechanism

1) Factor which affect the soft storey mechanism

An earthquake ground motion will search for every structural weakness. These weaknesses are usually created by sharp changes in stiffness, strength and/or ductility, and the effects of these weaknesses are accentuated by poor distribution of reactive masses. Severe structural damage suffered by several modern buildings during recent earthquakes illustrates the importance of avoiding sudden changes in lateral stiffness and strength.

a) Stiffness

A building is made up of both rigid and flexible elements. For example, beams and columns may be more flexible than stiff concrete walls or panels. Less rigid building elements have a greater capacity to absorb several cycles of ground motion before failure, in contrast to stiff elements, which may fail abruptly and shatter suddenly during an earthquake. Earthquake forces automatically focus on the stiffer, rigid elements of a building. For this reason, buildings must be constructed of parts that have the same level of flexibility, so that one element does not bend too much and transfer the energy of the earthquake to less ductile elements of the building.

When the earthquake struck, the longer, more flexible columns at the front of the building passed the earthquake forces on to the short, stiffer columns in the back instead of distributing the forces equally among all of the columns. Deflection, the extent to which a structural element moves or bends under pressure played a major role.

The longer columns simply deflected or bent without cracking. The short columns, therefore, were overwhelmed and cracked. The rate of deflection is used as a measure of the stiffness of a structure.

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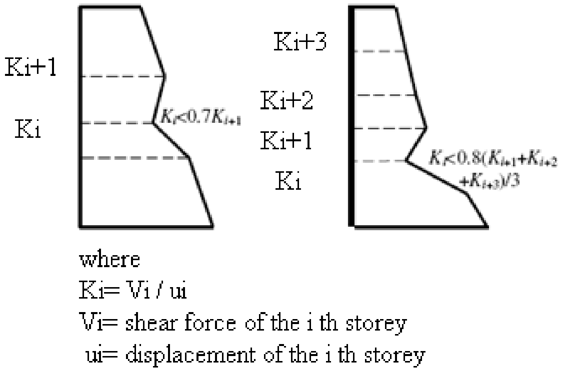


Fig 1.1 a Irregularity of lateral stiffness

According to the National Specification, a soft storey (irregularity in lateral stiffness) is defined as a storey in which the lateral stiffness is less than 70% of that of the storey above or less than 80% of the average stiffness of the three storeys above Fig.1.1.a.

Moreover, a discontinuity in vertical elements in a lateral load resisting system and the requirements of transfer of internal forces in these elements through horizontal structural elements (like a transfer truss/plate) as well as the case of abrupt change in shear capacity (Qy) of a lateral load resisting system between two adjacent storeys (that is $Qy,i<0.8Qy,i+1$) see Fig 1.2 a. are also classified as vertical irregularities.

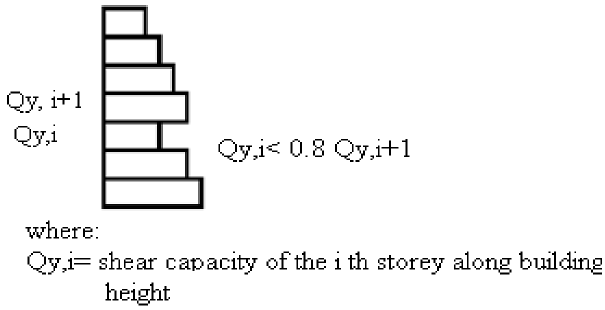


Fig 1.2. a Irregularity of shear capacity along building height

Failure Models

Fig 1.3.a and Fig 1.4.a. shows failure models

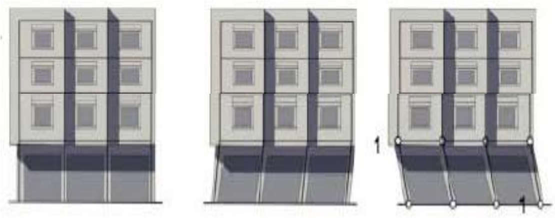
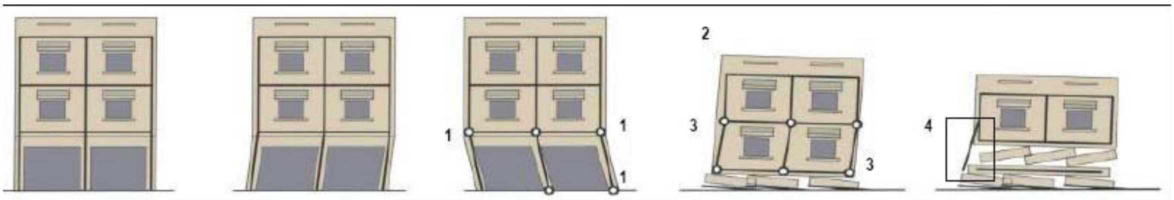


Fig 1.3 a. Failure model 1

Very stiff upper floors drifts over an open plan ground floor with insufficient resistance to moment in column to slab connections resulting in plastic hinges (1) permanent drift. Open plan shows and densely compartmented flats above result in a soft storey situation. Beyond



the limited elastic range of the column to slab connections, plastic hinges are formed. (1) With reduced stiffness, plasticized connections fail, throwing the building to the ground left side first. (2) Impact with ground probably causes the failure to left tower and its roof falls to the road. (3)The last column to detach is number (4) settling the building on its own screen.

Fig 1.4 a. Failure model 2

Building with open plan shops and two floors of densely compartmented flats above. Past the elastic range of column to beam connections of the ground floor hinge (1) and building drifts to one side and collapses. (2) Impact with ground probably causes hinging in the first floor connections and a new "soft storey" is formed. (3) Note the column piercing the slab (4) suggesting the first floor failed drifting towards the last.

b) Ductility and Strength

Ductility is the ability to undergo distortion or deformation without resulting in complete breakage or failure. The ductility of a structure is in fact one of the most important factors affecting its earthquake performance. One of the primary tasks of an engineer designing a building to be earthquake resistant is to ensure that the building will possess enough ductility to withstand the size and types of earthquakes it is likely to experience during its lifetime.

Curvature ductility

Defining the yield Φy and ultimate Φu curvatures as shown in Fig.1.1. b the curvature ductility of the cross section $\mu\Phi$ is defined as

$$\mu\Phi = \Phi u / \Phi y \qquad (1)$$

Furthermore, assuming that the curvature ductility is related to the overall structural ductility $\mu\Delta$ according to $\mu\Phi = 4\ \mu\Delta$ (Park and Paulay 1975) and that the system ductility for special moment frames $\mu\Delta=3$, members of frames designed for inelastic action in regions of high seismicity should have curvature ductility's of approximately $\mu\Phi > 12$. With this as a guide, the inelastic behavior of the composite cross sections can be evaluated based on the moment versus curvature behavior shown in Figs. 1.1.b for several design parameters. Discrete curvature ductility's determined from these plots .

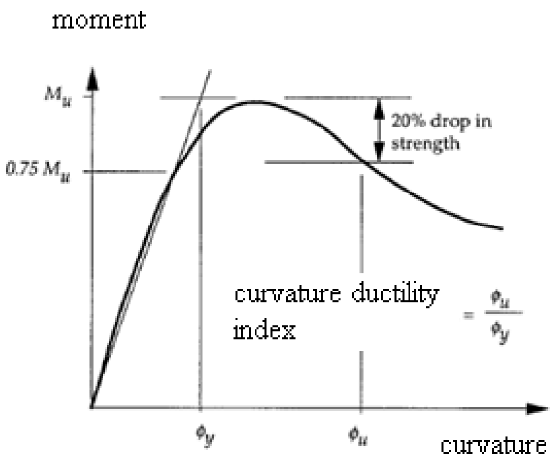


Fig 1.1 b Definition of curvature ductility ratio

c) Effect of soft storey on column

The soft storey effect will not only increase the total seismic horizontal load, which will induce huge moments in the columns, but also could increase the axial force in some columns. This situation will create very serious problems for columns. The first reason for this philosophy is that it is much easier to design a beam with high ductility, since the axial force in beams is very small and no P-Δ effect occurs in beams. The second reason is that the failures of beams would not create a catastrophic situation. However, we can conclude that the plastic hinge will occur at the column first, since the beams have been strengthened by the walls. This means the strong-column-weak-beam design breaks down and the actual structural behavior is strong-beam-weak-column. Also, another situation causing column failure by non-structural walls is the well-known short-column effect.

3] MODELING OF STRUCTURE

For any detailed structural analysis, development of computational model is a must. Modeling of a structure means modeling of all its members and its material property. The members are connected so that it will represent the actual load flow path. The model should accurately represent mass distribution, strength, stiffness and deformability. The different types of computational models are three dimensional model, two dimensional model. This chapter gives an overall idea about the three dimensional computational modeling aspects of reinforced concrete structures.

The study has been carried out for the following 4 models or variants involving changes in material & floor to floor height.

- MODEL 1 - G+7, RCC, with 3 m storey height.
- MODEL 2 - G+7, with a composite column of 3 m height at ground level.
- MODEL 3 - G+7, with a composite column of 3 m height at ground level & 1st storey level.
- MODEL 4 - G+7, with a composite column of 4 m height at ground level

The structural analysis – one for RCC & one for composite action has been carried out with help of a 3D computer model using software package STAAD-PRO 2007.the drawing are based on framing system including structural sections, dimensions and levels at various heights which have been considered in analysis

Salient features for design & engineering- RCC MODEL

The analysis for RCC structure has been done considering the entire structure as a 3D model framed structure using STAAD package. Beams & columns are modeled as beam elements. The slab & shear walls are modeled as slab element. There are 422 nodes & 956 beam elements in the STAAD analysis model of the structure. The main objective of modeling the structure as 3D model is to take in to account the behavior of each & every component in space structure environment.

Different loads & load combinations considered for analysis are:

1. DL (Dead load including wall load)
2. LL (Live load as given in IS:875 for residential building)
3. WLx (Wind load in X- direction as per IS:875)
4. WLz (Wind load in Z- direction as per IS:875)
5. EQLx (Earthquake load in X- direction as per zone of IS :1893)
6. EQLz (Earthquake load in Z- direction as per zone of IS :1893)
7. For load combination with DL & LL , factored load = 1.5(DL +LL)
8. For load combination with DL ,LL & WL , factored load = 1.2(DL + LL + WLx) or 1.2(DL + LL + WLz)
9. For load combination with DL ,LL & EQL , factored load = 1.2(DL + LL + EQLx) or 1.2(DL + LL + EQLz)
10. The load combination with DL &WL, factored load = 1.5 (DL + WLx) or 1.5 (DL + WLz)
11. The load combination with DL &EQL, factored load = 1.5 (DL + EQLx) or 1.5 (DL + EQLz)

b) Design of RCC columns

The forces based on 3D analysis for various column members i.e. axial forces & moments in X & Y directions are taken from the extract of computer output for design calculation. Sample calculation for design of column has been carried out. M20 grade of concrete has been used for RCC columns to satisfy the Durability aspect Of IS 456:2000.

COMPOSITE STRUCTURE MODEL

The Composite structure is modeled as 3D frame. RCC beam & composite column are modeled as beam element and shear wall &slab are modeled as slab elements. There are 427 nodes, 956 beam elements in the STAAD analysis model of the structure. The soft story column is modeled as concrete & steel composite sections. Beams, slab, column (other than soft storey column) are modeled as RCC structure.

a) Design of Composite Column

The data based on 3D analysis for various column members in frame i.e. axial forces & moments in X & Y directions are taken from the extract off the computer output. Sample calculation for design of column has been carried out on the basis of these values multiplied by factors recommended in IS 800:1984 to arrive at plastic design reaction forces, which are checked against the plastic capacities of the section. M20 grade of concrete has been used for columns to provide for adequate safeguard against the Durability problems as envisaged in IS 456:2000.

Model 1: Building with uniform storey height.

In the present study a G+7 reinforced cement concrete special moment resisting frame is considered for the analysis in accordance with IS 456:2000,IS1893:2002 provisions. The results of various methods employed to determine stiffness of column. We divide all columns in 5 group, in which group 1,2,3 having same column size 380 mm x 830 mm and group 4,5 of column size 300 mm x 1050 mm. storey height is 3 m.

Model 2 : Building with composite columns at ground storey .

Keeping all parameters unchanged, only ground storey columns are replaced with its composite column.

Model 3: Building with composite columns at ground storey & first storey .

Keeping all parameters unchanged, only ground storey & first storey columns are replaced with its composite column.

Model 4 : Building with composite columns at ground storey with 4 m height .

Keeping all parameters unchanged, only ground storey columns are replaced with its composite column of 4 m height.

4] Result & Discussion

The results of model 1, model 2, model 3, and model 4 are based on STAAD-PRO analysis

Comparative study of 4 models

Table No.6.1- Stiffness of Columns Group 1

	Model 1	Model 2	Model 3	Model 4
G. storey	181480.67	288935.79	190034.79	201298.72
1st storey	315470.06	318556.55	306707.26	264831.55

2nd storey	168661.76	168664.74	194630.13	153712.16
3rd storey	112423.17	112426.38	121300.68	94514.77
4th storey	54761.90	54762.69	35512.27	56435.17
5th storey	28514.12	28514.44	45280.15	34745.05
6th storey	14904.64	14904.79	25911.09	18976.54
7th storey	5754.07	5754.11	10710.75	6361.90

Table No.6.2- Stiffness of Columns Group 2

	Model 1	Model 2	Model 3	Model 4
G. storey	300635.53	508900.01	301716.29	350739.72
1st storey	505744.24	552759.61	551403.43	439135.14
2nd storey	251227.55	290169.44	353589.39	254330.38
3rd storey	150100.08	191746.63	219570.78	151090.39
4th storey	66732.67	92241.65	85334.90	86883.02
5th storey	29140.01	47098.47	83430.70	51389.96
6th storey	9131.55	23751.63	48811.26	24886.46
7th storey	7980.02	7980.14	21984.26	8418.19

Table No.6.3- Stiffness of Columns Group 3

	Model 1	Model 2	Model 3	Model 4
G. storey	117593.42	186284.54	124783.72	130521.56
1st storey	204970.98	204993.01	196632.03	138287.95
2nd storey	108195.49	108193.18	103040.00	86503.37
3rd storey	71923.22	71924.16	44271.28	38798.01
4th storey	34757.64	34757.93	11686.62	40657.40
5th storey	17822.31	17822.47	17399.28	22488.25
6th storey	9078.30	9078.37	11086.32	10974.49
7th storey	3139.75	3139.79	5999.45	3293.67

Table No.6.4- Stiffness of Columns Group 4

	Model 1	Model 2	Model 3	Model 4
G. storey	210140.19	334137.18	221467.23	231537.6
1st storey	363323.86	366618.80	352679.59	301997.23
2nd storey	193483.47	193493.85	223310.71	175043.35
3rd storey	128562.22	128563.54	138474.50	106634.93
4th storey	62262.94	62263.07	43188.90	63014.27
5th storey	32100.35	32100.41	51015.28	38327.80
6th storey	16503.34	16503.36	28686.83	20270.58
7th storey	5984.46	5984.50	11159.76	5852.78

Table No.6.5- Stiffness of Columns Group 5

	Model 1	Model 2	Model 3	Model 4
G. storey	468623.50	756711.63	505442.10	519670.88
1st storey	814503.46	821465.22	789657.88	668325.73
2nd storey	430634.27	430628.08	497066.77	384879.93
3rd storey	283961.23	283952.19	305457.09	231218.32
4th storey	135916.66	135914.26	98621.05	134169.99
5th storey	68702.71	68701.54	109242.18	79327.11
6th storey	33928.63	33928.00	58968.75	39003.05
7th storey	29510.05	12218.16	19285.18	6934.92

The result obtained by using STAAD- PRO is agree with IS: 1893-2002[7] clauses 4.30 for soft or weak storey. The result obtained using IS; 456[8], IS 1893[7] for manual calculations lead us to the same calculation.

In these 4 models it is clearly seen that the stiffness of ground storey in composite column model is greater than RCC structure (model 1) .also it can be seen that the stiffness of ground storey is greater than stiffness of storey above. Model 2 & Model 4 i.e. Use of composite column in ground gives more stiffness as compare to 3rd models. In model 2 ground storey stiffness is increased up to 75% of above storey stiffness & also in model 4 ground storey stiffness is increased up to 77% of above storey stiffness.The Ductility of composite column is twice of the RCC column

5] Conclusion

In these 4 models it is clearly seen that the stiffness of ground storey in composite column model is greater than RCC structure (model 1) while model 1 gives only 54% to 58% stiffness to ground storey, .also it can be seen that the stiffness of ground storey is greater than stiffness of storey above. Model 2 & Model 4 i.e. Use of composite column in ground gives more stiffness as compare to 3^{rd} models. In model 2 ground storey stiffness is increased up to 75% of above storey stiffness & also in model 4 ground storey stiffness is increased up to 77% of above storey stiffness. Model 2 improve stiffness of ground storey only up to 60% of above storey stiffness but according to clause 4.30[7] first floor stiffness is at least 70% of above storey & It also become costly. The under-lying principle of any solution to this problem is in (a) increasing the ductility and stiffness of the first storey such that the first storey is at least *50%* as stiff as the second storey, *i.e.*, soft first storey are to be avoided, and (b) providing adequate lateral strength in the first storey. The possible schemes to achieve the above are (i) provision of stiffer columns in the first storey, and (ii) provision of a concrete service core in the building .so it has been necessary to increase stiffness and ductility of soft storey building by using “I” sec up to a parking level.

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