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The Effect of Steel Bracing With Damper in Seismic Reduction of Soft Storey Effect in a Building

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Abstract—*Soft storey is a typical feature in the modern high rise building constructions in urban India. Such features are highly unacceptable in buildings built in seismically active areas. Soft storey at gf has consistently shown poor performance during past earthquakes across the world a large number of them have collapsed. Most buildings having parking in the ground storey have no masonry walls built in between any columns. This lack of infill effect in gf and leaving the columns bare is the difficulty of the matter. Such buildings are abruptly flexible and weak in the ground storey and perform poorly during earthquakes. After the Bhuj earthquake, the Bureau of Indian standards has recently revised the provision for the earthquake resistant structures in the IS 1893:2002 criteria is All Columns and beams of the soft storey by 2.5 times the storey shears and moments calculated under seismic loads.*
Apart from designing All Columns and beams of the soft storey by 2.5 times the storey shears and moments calculated under seismic loads as per IS 1893, provision of steel bracing with damper is most effective and economical in seismic reduction of soft storey effect in a building

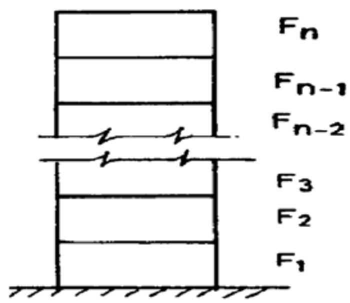
Keywords*: soft storey, steel bracing, damper.*

1. INTRODUCTION [1]

Buildings are classified as having a "soft storey", if that level is less than 70% as stiff as the floor immediately above it, or less than 80% as stiff as the average stiffness of the three floors above it. Often, open-ground-storey buildings are called soft-storey buildings, even though their ground storey may be soft and weak. Generally, the soft or weak storey usually exists at the ground storey level, but it could be at any other storey level. Soft storey buildings, having first storeys much less rigid than the storeys above are particularly susceptible to earthquake damage because of large, unreinforced openings on their ground floors. Behaviour of soft storey building to seismic forces has to be critically examined considering various geometrical and seismic parameters.

According to IS 1893 "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."

Expressing numerically, Soft Storey when Fi < .7Fi+1



$$OR\ F_i < \left(\frac{Fi+1+Fi+2+Fi+3}{3}\right)$$

Where ,

Fi's are the stiffness of the respective storeys

1.1 The Soft Storey Problem [6]

Buildings containing soft stories are extremely vulnerable to earthquake collapses. Since one floor is flexible compared to others, other storeys which are stiffened by infill walls of bracing act as a whole unit, most deformation occurs in soft storey which is less capable of taking earthquakes loads than others. Such building act as an *Inverted Pendulum* which swing back and forth producing high stresses in columns and if columns are incapable of taking these stresses or do not posses enough ductility, they could get severely damaged and which can also lead to collapse of the building. This is also known as inverted pendulum. The main problem is that in current design practice upper stiff masonry walls are not considered in design calculation hence the inverted pendulum problem is not rectified.

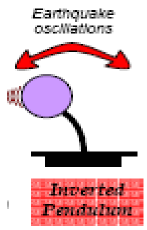


Fig. 1: 1inverted Pendulum Action

1.2 Soft Storey Failure Mechanisms

If we consider the bending moment and shear force diagram of a typical building, we know that the bending moment and shear force increases as we go down.

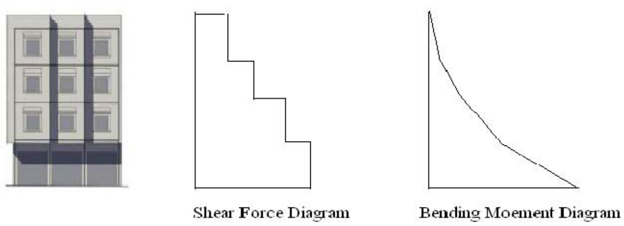


Fig. 1.4: Soft Storey Failure Mechanisms

Now as shown in the shear force and bending moment diagram of the building, ground storey experiences maximum shear force and bending moment. But ground storey has minimum stiffness compared to other storeys. Hence the ground storey experiences maximum deflection on account of its max shear force and bending moment and less stiffness. The Fig. shows typical state of building with soft ground storey after earthquake.

2. ETABS PROCEDURE FOR MODELING

The ETABS Nonlinear software is utilized to create 3D model and run all analysis. The software is able to predict the geometric nonlinear behavior of space frames under static or dynamic loadings, taking into account both geometric nonlinearity and material inelasticity. The software accepts static loads (either forces or displacements) as well as dynamic (accelerations) actions and has the ability to perform Eigen values, nonlinear static pushover and nonlinear dynamic analyses. The analysis and design of the building is carried out using ETABS computer program.

2.1 Assigning the steel barcing As Equivalent Diagonal Struts [4]

Most of the studies shown that the infill wall panels fail [Pankaj Agarwal] due to the increasing intensity of lateral loads by corner crushing in the infill at least one of its loaded corners associated with strong infill surrounded by a strong frame in which the diagonal compression strut mechanism is fully developed that converts the frame system into the truss, increasing the lateral stiffness of the frame manifold. Now a day the diagonal strut model is widely acceptable as a simple and rational way to describe the influence of the frame panel interaction.

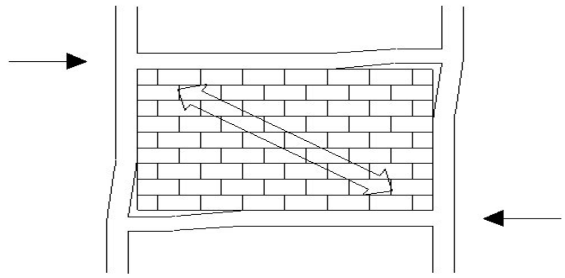


Fig. 4: Equivalent diagonal strut formation

2.2Assigning the Damper

These are the properties of the damper from the manufactured companies

element	Weight (KN)	Effective stiffness (KN/cm)	Effective damping (KN-s/m)
damper	19.24	2500	15

3. MODELLING OF BUILDING FRAMES

The properties of the considered building configurations in the present study are summarized below;

Assumptions made are;

- The structural material is assumed to be isotropic and homogenous

Table 3: Design data for all the buildings:

Structure		OMRF
No. of storey		G+11
Storey height	Ground storey	4.80 m
	Upper storey	3.60 m
Type of building use		Official
Material Properties		
Young's modulus of M25 concrete, E		25.0 x 106 kN/m2
Grade of concrete		M25
Density of reinforced concrete		25 kN/m3
Modulus of elasticity of brick masonry		2100 x 103 kN/m2
Density of brick masonry		20 kN/m3
Member Properties		
Thickness of slab		0.125 m
Thickness of wall		0.25 m
Beam size (3-storeyed)		0.25 x 0.75 m
Column size (3-storeyed)		0.25 x 0.750 m
Properties of steel bracing		
Bracing size		0.25 x 1.025 m
Grade of steel		Fe 415
Modulus of elasticity of steel		2 x 105 kN/m2

Assumed Dead Load Intensities	
Roof finishes	2.5 kN/m2
Floor finishes	1.0 kN/m2
Live Load Intensities	
Roof	2 kN/m2
Floor	2.0 kN/m2
Earthquake LL on slab as per clause 7.3.1 and 7.3.2 of IS:1893 - 2002	
Roof	0 kN/m2
Floor	0.25 x 3.0 = 0.75kN/m2

IS: 1893-2002 Equivalent Static method

Zone	V
Zone factor, Z (Table 2)	0.36
Importance factor, I (Table 6)	1.00
Response reduction factor, R (Table 7)	3.0
Damping ratio	5% (for RC framed building)
Soil type	II

4. EXAMPLE BUILDINGS STUDIED

Model 1 : Bare Frame

Model 2: soft story at GF without diagonal steel bracing with viscoelastic damper

Model 3: soft story at GF with diagonal steel bracing with viscoelastic damper

Model 4: soft story at Fourth Floor without diagonal steel bracing with viscoelastic damper

Model 5: soft story at Fourth Floor with diagonal steel bracing with viscoelastic damper

Model 6: soft story at Seventh Floor without diagonal steel bracing with viscoelastic damper

Model 7: soft story at Seventh Floor with diagonal steel bracing with viscoelastic damper

5. ANALYSIS AND LOAD COMBINATIONS

5.1 Equivalent Static Method

Load Combination	Load Factors
Gravity analysis	1.5 (DL+LL)
Equivalent static analysis	1.2(DL+LL±EQY) 1.2 (DL+ LL ± EQX)

Where DL= Dead load

LL= Live load

EQ_X, EQ_Y= Earthquake load in the X- and Y- directions, respectively

5.2 Response Spectrum Method

Load Combination	Load Factors
Gravity analysis	1.5 (DL+LL)
Response spectrum analysis	1.2 (DL+ LL ± SPY) 1.2 (DL+ LL ± SPX)

Where,

SP_X, SP_Y = Earthquake Spectrum in the X- and Y-directions, respectively

6. RESULTS AND DISCUSSION

6.1 Storey Drift

The storey drifts in any storey due to the minimum specified design lateral force, with partial load factor. of 1, shall not exceed 0.004 times the storey height.

Inter story drift maximum limits for the models analyzed are 14.40 mm for 3.6m storey height and 19.20 mm for 4.8 m ground floor height, as per clause 7.11.1 of IS 1893 (part 1): 2002. From the results mentioned above it can be observed that Model I, Model II, Model III and Model IV crosses inter storey drift limits but Model III, Model V, and Model VII doesn't crosses the inter storey drift limits. Hence the Model I, Model II, Model III and Model IV need to be retrofitted diagonal steel bracing with viscoelastic dampers to reduce Drift

Table 6.1.1: Storey Drift comparisons for model 1, 2 and 3

STORY DRIFT	MAX LIMIT	MODEL 1	MODEL 2	MODEL 3
	0.004*H	RS METHOD	RS METHOD	RS METHOD
TERRACE	14.4	3.676	1.35	2.162
10	14.4	6.116	1.615	2.661
9	14.4	8.079	1.891	3.09
8	14.4	9.568	2.116	3.427
7	14.4	10.816	2.299	3.697
6	14.4	11.936	2.439	3.901
5	14.4	12.923	2.546	4.017
4	14.4	13.807	2.665	4.149
3	14.4	15.314	3.046	4.792
2	14.4	16.109	2.366	4.035
SOFT GF	19.2	19.834	20.628	2.656

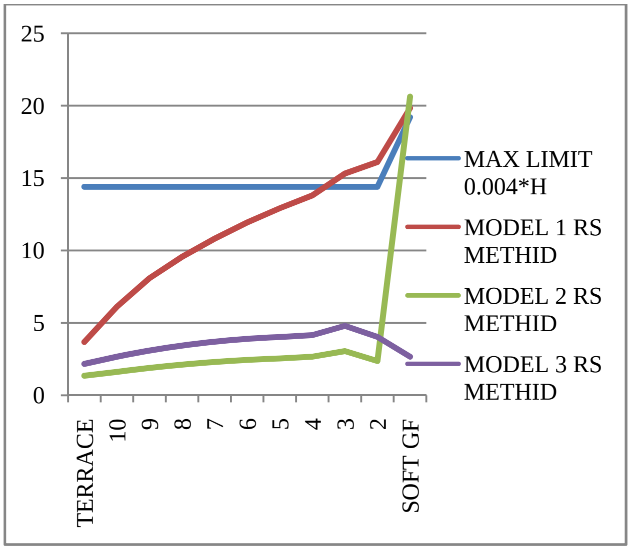


Fig. 6.1.1: storey drift in x direction for soft storey at GF

Table 6.1.2: Storey Drift comparisons for model 1, 4 and 5

STORY DRIFT	MAX LIMIT	MODEL 1	MODEL 4	MODEL 5
	0.004*H	RS METHOD	RS METHOD	RS METHOD
TERRACE	14.4	3.676	2.466	3.454
10	14.4	6.116	3.047	4.205
9	14.4	8.079	3.556	4.862
8	14.4	9.568	3.971	5.388
7	14.4	10.816	4.346	5.804
6	14.4	11.936	5.305	6.072
SOFT	14.4	12.923	21.903	4.36
4	14.4	13.807	5.723	6.638
3	14.4	15.314	5.354	7.77
2	14.4	16.109	4.992	6.875
1	19.2	19.834	5.778	7.944

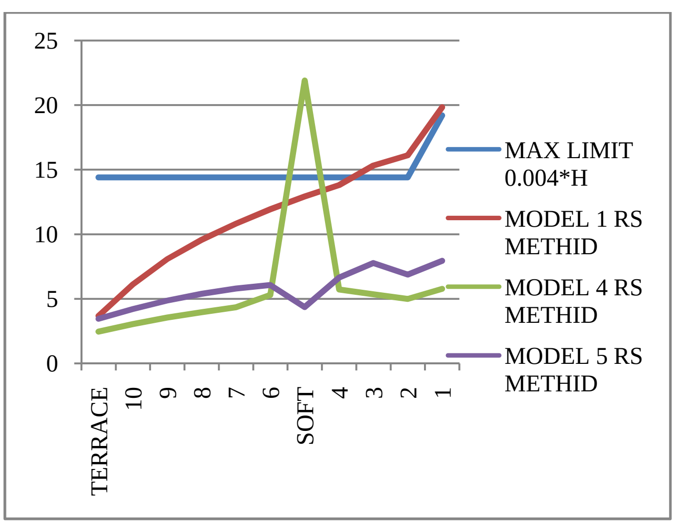


Fig. 6.1.2: storey drift in x direction for soft storey at 4th floor

Table 6.1.3: Storey Drift comparisons for model 1, 6 and 7

STORY DRIFT	MAX LIMIT	MODEL 1	MODEL 6	MODEL 7
	0.004*H	RS METHOD	RS METHOD	RS METHOD
TERRACE	14.4	3.676	2.398	2.662
10	14.4	6.116	2.964	3.291
9	14.4	8.079	3.928	3.844
SOFT	14.4	9.568	15.745	2.996
7	14.4	10.816	4.852	4.688
6	14.4	11.936	4.312	5.061
5	14.4	12.923	4.439	5.215
4	14.4	13.807	4.613	5.429
3	14.4	15.314	5.341	6.319
2	14.4	16.109	4.782	5.556
1	19.2	19.834	5.538	6.403

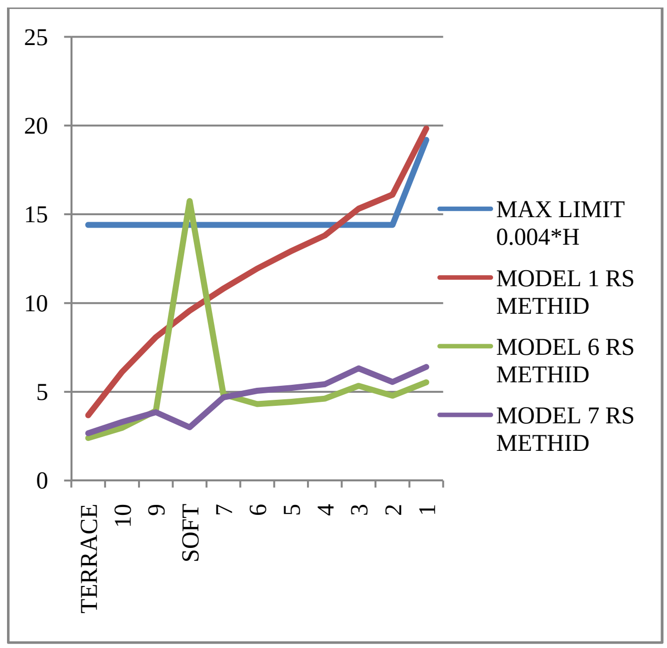
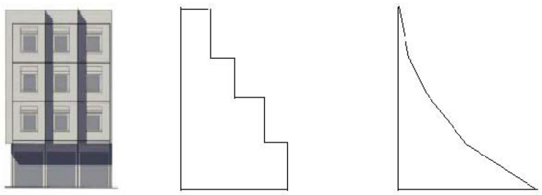


Fig. 6.1.3: storey drift in x direction for soft storey at 7th floor

6.2 Shear Force and Bending Moment of Soft Storey Columns

If we consider the bending moment and shear force diagram of a typical building, we know that the bending moment and shear force increases as we go down.

Now as shown in the shear force and bending moment diagram of the building below, ground storey experiences maximum shear force and bending moment. But ground storey has minimum stiffness compared to other storeys. Hence the ground storey experiences maximum deflection on account of its max shear force and bending moment and less stiffness. The Fig. shows typical state of building with soft ground storey after earthquake.



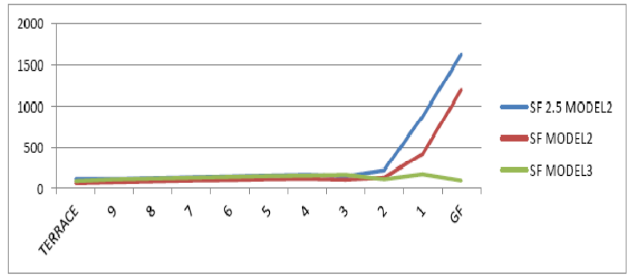
Comparative study of SF and BM of Column C1 with IS 1893 provision and providing Diagonal Steel Bracing with ViscoElastic Damper

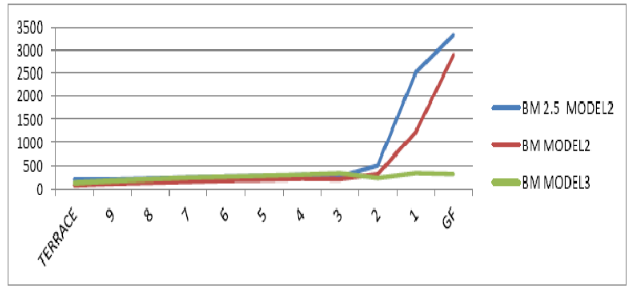
Table 6.2.1: Comparison of SF and BM of Column C1 in model 2, 3 and 2.5 factored model 2

C1	SHEAR FORCE		
STORY NO	2.5 MODEL2	MODEL2	MODEL3
TERRACE	117.6	62.54	88.93
9	113.43	73.58	107.69
8	124.43	84.37	121.47
7	135.56	94.02	132.84
6	146.84	102.52	142.83
5	156.56	109.24	151.89
4	165.1	113.99	158.79
3	148.85	106.77	167.73
2	219.7	133.31	109.55
1	874.41	412.6	173.83
GF	1626.6	1200.03	95.68

C1	BENDING MOMENT		
STORY NO	2.5 MODEL2	MODEL2	MODEL3
TERRACE	186.732	90.02	127.183
9	197.086	118.595	175.099
8	215.576	141.024	206.764
7	234.368	161.242	232.544
6	253.716	179.579	255.392
5	270.717	195.015	276.545
4	290.234	208.863	294.71
3	254.093	198.224	329.117
2	505.801	304.345	219.877
1	2514.016	1223.023	333.386
GF	3329.317	2898.282	304.853

From the above results its clearly shows that if we design column C1 of MODEL 2 for 2.5 times factored load conditions the SF consideration is 5.05 times more when compared to model 3, Therefore SF consideration in model 3 is reduced due to providing Diagonal Steel Bracing with ViscoElastic Damper to the same soft storey building.





Graph6.2.1: Comparison of SF and BM of Column C1 in model 2, 3 and 2.5 factored model 2

Similarly, if we design column C1 of MODEL 2 for 2.5 times factored load conditions the BM consideration is 7.52 times more when compared to model 3, Therefore BM consideration in model 3 is reduced due to providing Diagonal Steel Bracing with ViscoElastic Damper to the same soft storey building.

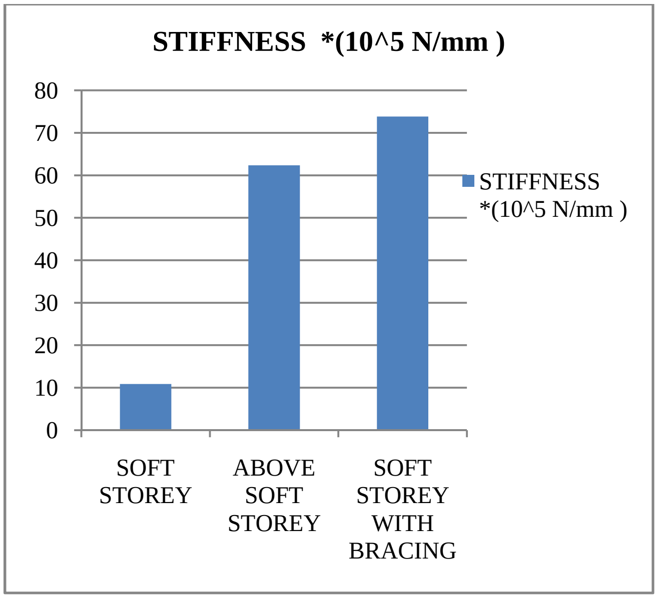
Providing Diagonal Steel Bracing with ViscoElastic Damper to the soft storey building is most economical and safe when compared to designed it for 2.5 times factored load conditions

6.3 Effect of Stiffness In Soft Storey Due To Steel Bracing With Damper

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 storey above.

Table 5.7: Lateral stiffness

	stiffness *(10^5 n/mm)
Soft Storey	10.858
Above Soft Storey	62.34
Soft Storey With Bracing	73.84



Graph 5.7: Lateral stiffnes

7. CONCLUSION

1. Building for different model and methods of analysis as compared to the stiffness of bare frame model.
2. Due to presence of open ground storey and presence of masonry infill walls in the upper storey, a sudden change in displacement profile has been observed which indicates stiffness irregularity and is most vulnerable in earthquakes
3. In all the discussed models the transverse direction is more vulnerable than longitudinal direction.
4. Performance points of building models soft storey and infill frame were observed before the collapse of the building and is concluded that the building is safe under design basis earthquake.
5. Providing Diagonal Steel Bracing with Viscoelastic Damper to the soft storey building is most economical and safe when compared to design it for 2.5 times factored load conditions.

DISCUSSIONS

Basically steel having high tensile strength and load bearing capacity, so it is used in developing bracing materials (diagonal bracing)

Due to its light weight and strengthen advantageous materialistic property of steel it is used as a diagonal bracing material in between beam and column joints of a soft storey building**.**

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