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Seismic Performance Evaluation of a Multistorey Building with Soft Storey

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Abstract— Soft storey is a storey in which the stiffness is less than 70% of the storey above or less than 80% of the combined stiffness of the storeys above. In a multi-storied building, soft storey is adopted to accommodate parking which is an unavoidable feature. This open ground storey is vulnerable to collapse during earthquake. Soft storey in a building causes stiffness irregularity in a structure. In high rise building or multi storey building, soft storey construction is a typical feature because of urbanization and the space occupancy considerations. These provisions reduce the stiffness of the lateral load resisting system and a progressive collapse becomes unavoidable in a severe earthquake for such buildings due to soft storey. This storey level containing the concrete columns which were unable to provide adequate shear resistance, hence damage and collapse are most often observed in soft story buildings during the earthquake. Infill wall plays an important role in providing lateral stiffness to the building. In this paper an industrial building is selected for the study, to study the seismic performance of soft storey buildings, there are 6 3D mathematical models have been developed using ETABS. The following parameters have been studied, storey drift, storey displacement, time period, storey shear and modes shapes. Subsequently adopting the control measures to reduce the effect of soft storey in terms..

Keywords: Soft Storey, Masonry infill, shear resistance, storey drift, storey displacement, and modes shapes

I. INTRODUCTION

Reinforced-concrete framed structure in recent time has a special feature i.e. the ground storey is left open for the purpose of social and functional needs like vehicle parking, shops, reception lobbies, a large space for meeting room or a banking hall etc. Such buildings are often called open ground storey buildings or soft story buildings. Again when a sudden change in stiffness takes place along the building height, the story at which this drastic change of stiffness occurs is called a soft story. The Indian code (clause no. 4.20) classifies a soft storey as, it is one in which 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 (IS 1893:2002). Soft storey can form at any level of a multi storeyed building to fulfil required functional necessity and moreover, typical multi storeyed construction in India comprises RC frames with brick masonry infill. Unreinforced masonry panels may not contribute towards resisting gravity loads, but contribute significantly, in terms of enhancement in stiffness and strength in case of earthquake (or wind) induced lateral loading. The effect of infill may be positive or negative depending on large number of influential factors. Also infill has energy dissipation characteristic that contribute to improve seismic resistance but its self-weight increases the earthquake inertia forces. Generally designer used to treat infill as a “non-structural element” and treat the frame as bare frame which is far away from its true behaviour.

A. *Soft storey and its failures:*

Fig. 1: Typical Soft Storey in India

Fig. 2: Typical Soft Storey in Australia

Fig. 3: Typical Soft Storey Failure in Bhuj Earthquke.

Fig. 4: Typical Soft Storey Failure in Bhuj Earthquake.

This characteristic of building construction creates “weak” or “soft” storey problems in multi-storey buildings. Increased flexibility of first storey results in extreme deflections, which in turn, leads to concentration of forces at second storey connections accompanied by large plastic deformations. In addition, most of the energy developed during earthquake is dissipated by columns of the soft stories. In this process the plastic hinges are formed at the ends of columns, which transform the soft storey into a mechanism. In such case the collapse is unavoidable. Therefore, the soft stories deserve a special consideration in analysis and design. It has been observed from the survey that the damage is due to collapse and buckling of columns especially where parking places are not covered properly. On the contrary, the damage is reduced considerably where the parking spaces are covered adequately. It is recognized that this type of failure results from the combination of several other unfavourable reasons, such as torsion, excessive mass on upper floors, p-Δ effects and lack of ductility in the bottom storey.

The main Objectives of the present study is

1) To know the soft storey failure, how it causes the stiffness degradations.
2) To check the performance of masonry during seismic loading.
3) To check how the shear wall enhance the overall performance of the building.
4) To know what shape of shear wall is best suited to overcome the weak storey failures.

II. DESCRIPTION OF STRUCTURAL MODEL TAKEN FOR STUDY.

For the study 6 different models of ten (10) storey building are considered the building has six bays in X direction and four bays in Y direction with the plan dimension 25 m × 29 m and a storey height of 3 m each in all the floors except 1st storey, height of 1st storey is 3.5m. The building is kept symmetric in both orthogonal directions in plan to avoid torsional response. The orientation and size of column is kept same throughout the height of the structure. The building is considered to be located in seismic zone II. The building is founded on medium strength soil through isolated footing under the columns. Poisons ratio as 0.20 and 0.15 respectively Response reduction factor for the special moment resisting frame has taken as 5.0 (assuming ductile detailing). The unit weights of concrete and masonry are taken as 25.0 KN/m^3 and 20.0 KN/m^3 respectively the floor finish on the floors is 1.5 KN/m^2. The live load on floor is taken as 4 KN/m^2. In seismic weight calculations, 50 % of the floor live loads are considered. Thickness of slab, shear wall and masonry infill wall as 0.150m, 0.23 m and 0.23m respectively.

III. MATHEMATICAL MODELS GENERATED FOR ANALYSIS.

Following six (6) models are analyzed in ETABS as special moment resisting frame using equivalent static, response spectrum analysis.

Model I - Bare frame model (Including weight of Brick wall).

Model II –Infill frame model (with Bottom Soft Storey).

Model III–Model same as model II with Planar shear walls at the corners.

Model IV–Model same as model II but L-shaped shear walls provided at the corners

Model V-Model same as model II with center core walls and planar shear walls

Model VI-Model same as model II with central core walls and corner shear walls.

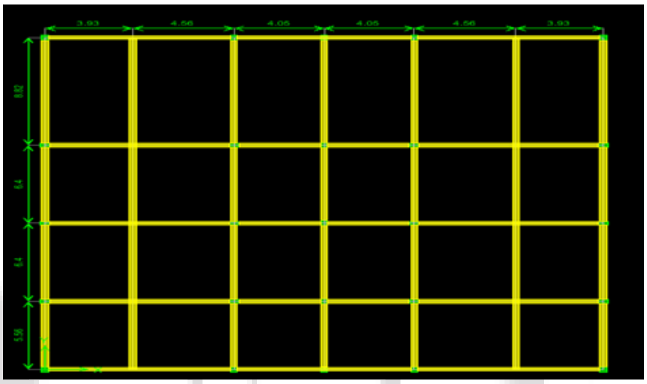
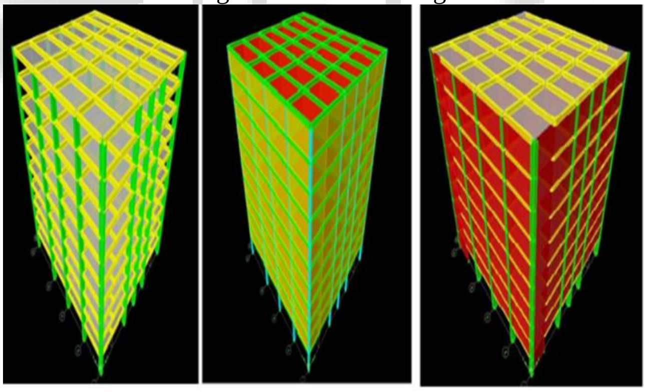
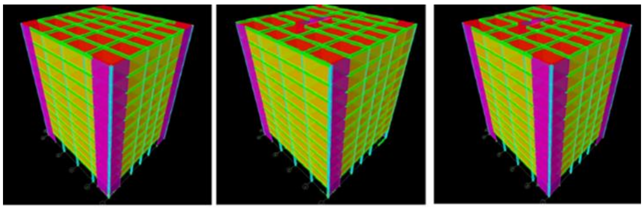


Fig. 5: Plan of Building.



Model-I Model-II Model-III

Fig. 5: Shows the isometric view of the Model-I, Model-II and Model-III



Model-IV Model-V Model-VI

Fig. 6: Shows the isometric view of the Model-IV, Model-V and Model-VI.

IV. MODELING OF FRAME MEMBERS, AND SHEAR WALL

The frame elements are modelled as beam elements, slab is modelled as rigid (in-plane) diaphragm and shear wall is modelled with Mid-Pier frame and Masonry infill Panel as Four Noded quadrilateral shell Element.

V. TYPES ANALYSIS PERFORMED ON BUILDING

Equivalent static and response spectrum analyses have been performed as per IS 1893 (part-1) 2002 for each model using ETABS 9.7 software. Lateral load calculation and its distribution along the height is done.

VI. ANALYSIS OF VARIOUS RESULTS

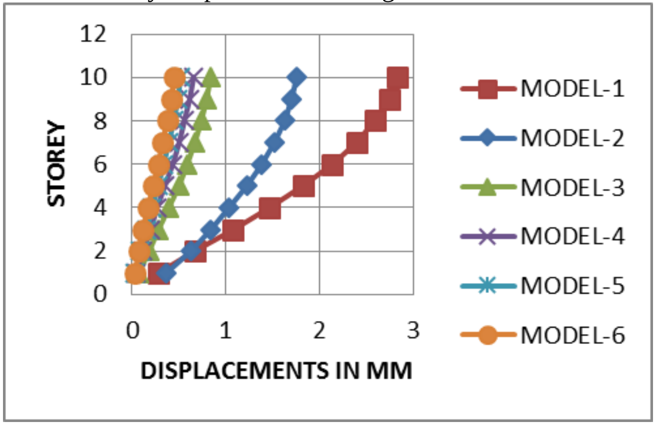
A. *Storey Displacement:*

Storey displacement is the lateral movement of the structure caused by lateral force. The deflected shape of a structure is most important and most clearly visible point of comparison for any structure. No other parameter of comparison can give a better idea of behaviour of the structure than comparison of storey displacement. The Displacement should be very less in a structure otherwise the structure may collapse and the total strength will be reduced and there will be no human comfort.

Storey Displacements in (mm)						
STOREY LVL	MODEL-1	MODEL-2	MODEL-3	MODEL-4	MODEL-5	MODEL-6
10	16.16	7.71	4.62	3.61	4.05	3.43
9	15.70	7.60	4.41	3.45	3.82	3.25
8	14.94	7.49	4.19	3.27	3.57	3.04
7	13.92	7.38	3.96	3.09	3.31	2.83
6	12.68	7.27	3.73	2.89	3.04	2.59
5	11.23	7.15	3.49	2.68	2.77	2.35
4	9.61	7.02	3.24	2.47	2.49	2.10
3	7.83	6.90	2.99	2.26	2.21	1.86
2	5.89	6.78	2.74	2.04	1.93	1.61
1	3.71	6.64	2.49	1.83	1.65	1.36

Table 1: Storey Displacement in Longitudinal Direction

Chart-1 Storey Displacement in longitudinal direction



Storey Displacements in (mm)						
STOREY LVL	MODEL-1	MODEL-2	MODEL-3	MODEL-4	MODEL-5	MODEL-6
10.00	20.36	7.63	4.16	3.06	3.73	2.84
9.00	19.79	7.54	4.03	2.88	3.52	2.66
8.00	18.89	7.46	3.89	2.68	3.31	2.46
7.00	17.64	7.37	3.75	2.48	3.08	2.25
6.00	16.09	7.27	3.60	2.26	2.85	2.04
5.00	14.28	7.18	3.44	2.05	2.62	1.81
4.00	12.21	7.08	3.29	1.82	2.38	1.59
3.00	9.94	6.98	3.13	1.60	2.14	1.36
2.00	7.45	6.89	2.97	1.39	1.91	1.14
1.00	4.64	6.78	2.81	1.17	1.68	0.93

Table 2: Storey Displacement in Transverse Direction

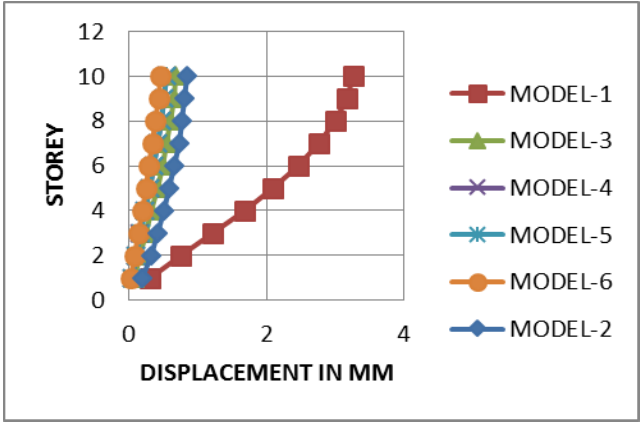


Chart 2: Storey Displacement in Transverse Direction

It Can Be Seen From Above Figures, The Displacement Of The Stories Of Structures Is Reduced By Developing MODEL- 2,3,4,5,6.The Displacement In Model-2 Has Been Reduced By 57.5 % In Comparison Of Model-1, Model-3 Has Been Reduced To75.5%.Model-4 Has Been Reduced By 81.4%, Model-5 Has Been Reduced By 78.4%, Model-6 Has Been Reduced By 82.4%.According To This Work, The Reduction Of Displacement Of Stories Is Due To Increase Of Stiffness Of Structure As Well As Decrease Of Velocity And Acceleration Of Structure. In Other Words By Creating Themodel-2, 3,4,5,6 The Response Of Structure Such As Velocity And Acceleration Can Be Reduced And It Is The Cause Of Reduction Of Displacement. On Observing, Displacements At The Entire Storey In The MODEL-1 Are More Than Those In Other Model. Here As One Can See Displacements Lowest In Bottom Stories, Very High At The Upper Stories. The Displacement Is Of Interest With Regard To Structural Stability, Strength And Human Comfort. The Displacement Of MODEL-1is More Than The Other Model.

B. *Storey Drift:*

Storey drift is the drift of one level of a multistory building relative to the level below. Inter story drift is the difference between the roof and floor displacements of any given story as the building sways during the earthquake, normalized by the story height. For example, for a 10foot high story, an inter-story drift of 0.10 indicates that the roof is displaced one foot in relation to the floor below.

Storey Drift in Longitudinal Direction						
STOREY LVL	MODEL-1	MODEL-2	MODEL-3	MODEL-4	MODEL-5	MODEL-6
10	0.00023	0.00004	0.00007	0.00005	0.00008	0.00006
9	0.00038	0.00004	0.00007	0.00006	0.00008	0.00007
8	0.00050	0.00004	0.00008	0.00006	0.00009	0.00007

7	0.00058	0.00004	0.00008	0.00007	0.00009	0.00008
6	0.00065	0.00004	0.00008	0.00007	0.00009	0.00008
5	0.00072	0.00004	0.00009	0.00007	0.00010	0.00008
4	0.00077	0.00004	0.00009	0.00007	0.00010	0.00009
3	0.00081	0.00004	0.00009	0.00007	0.00010	0.00008
2	0.00090	0.00005	0.00009	0.00008	0.00009	0.00008
1	0.00103	0.00189	0.00055	0.00041	0.00050	0.00034

Table 3: Storey Drift in Longitudinal Direction

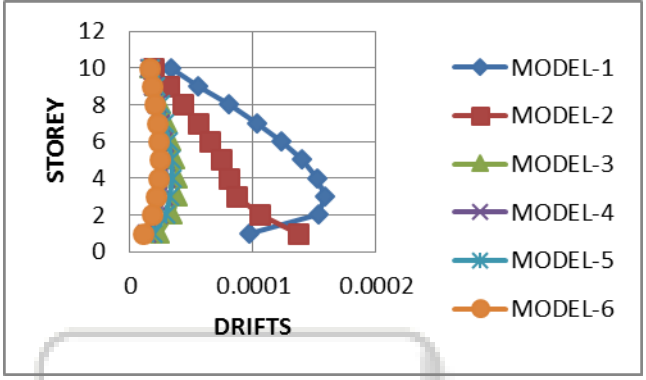


Chart 3: Drift in Longitudinal Direction

Storey Drift in transverse direction						
STOREY LVL	MODEL-1	MODEL-2	MODEL-3	MODEL-4	MODEL-5	MODEL-6
10	0.0002	0.0000	0.0000	0.0001	0.0001	0.0001
9	0.0004	0.0000	0.0000	0.0001	0.0001	0.0001
8	0.0005	0.0000	0.0000	0.0001	0.0001	0.0001
7	0.0006	0.0000	0.0001	0.0001	0.0001	0.0001
6	0.0007	0.0000	0.0001	0.0001	0.0001	0.0001
5	0.0007	0.0000	0.0001	0.0001	0.0001	0.0001
4	0.0008	0.0000	0.0001	0.0001	0.0001	0.0001
3	0.0008	0.0000	0.0001	0.0001	0.0001	0.0001
2	0.0009	0.0000	0.0001	0.0001	0.0001	0.0001
1	0.0010	0.0015	0.0006	0.0003	0.0004	0.0003

Table 4: Storey Drift in Transverse Direction

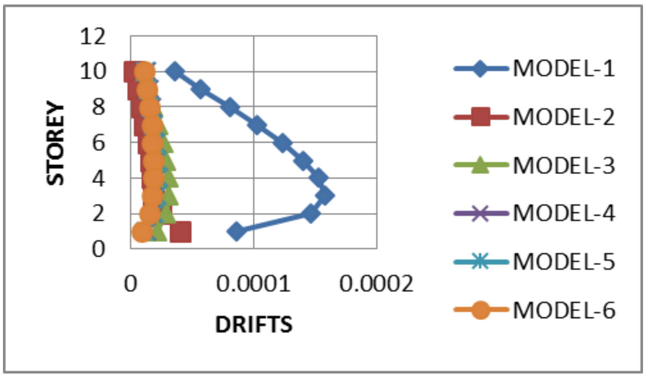


Chart 4: Storey Drift in Transverse Direction

As it can be seen from the above results that the storey drifts has been reduced in Models 1, 3,4,5,6. The storey drift has been reduced in Model-1 by 38.7% in comparison of model-2, Model-3 has been reduced by64.6%, Model-4 has been reduced by 77.8%, Model-5 has been reduced by 74.3%, and Model-6 has been reduced by 82%.

C. Base Shear:

Shear induced at the base of building during earthquake is called base shear which depends on the seismic mass and stiffness of building. The results of variation in Base Shear due to the effect of floating columns for different cases are tabulated below.

Base Shear in Longitudinal direction (KN)						
STOREY LVL	MODEL-1	MODEL-2	MODEL-3	MODEL-4	MODEL-5	MODEL-6
10	72.1	59.8	142.8	186.5	171.8	221.0
9	153.9	132.4	310.4	404.8	368.9	479.7
8	210.6	202.8	464.8	607.5	545.8	715.9
7	250.4	271.2	606.5	794.5	703.1	929.7
6	285.9	337.8	736.4	966.6	842.7	1122.0
5	319.8	402.9	856.0	1124.8	967.2	1294.6
4	348.2	466.7	966.9	1270.6	1079.4	1449.6
3	373.2	529.5	1070.7	1405.3	1182.2	1589.0
2	401.3	591.7	1169.0	1530.1	1278.3	1714.3
1	428.7	641.9	1246.2	1628.0	1352.9	1810.6

Table 5: Base shear in KN in Longitudinal Direction.

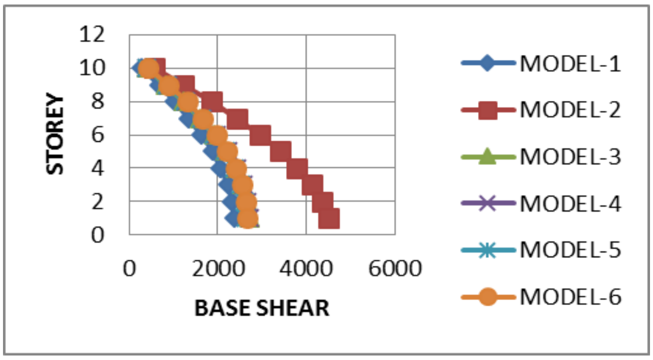


Chart 5: Base shear in Longitudinal Direction

Base Shear in Transverse direction (KN)						
STOREY LVL	MODEL-1	MODEL-2	MODEL-3	MODEL-4	MODEL-5	MODEL-6
10	69.2	59.8	136.4	242.1	181.7	252.3
9	140.7	133.2	301.1	520.3	392.8	544.7
8	189.7	205.2	457.8	773.3	585.6	808.7
7	230.9	275.8	606.5	1001.5	760.5	1044.8
6	266.5	345.2	747.8	1206.1	918.8	1254.2
5	296.7	413.5	882.0	1389.3	1062.1	1439.2
4	325.7	480.8	1010.1	1553.3	1192.3	1602.3
3	351.1	547.3	1132.5	1700.3	1311.6	1746.0
2	374.5	613.1	1249.9	1832.4	1421.8	1872.1
1	398.2	666.1	1343.1	1931.9	1506.8	1965.9

Table 6: Base shear in KN in Transverse Direction.

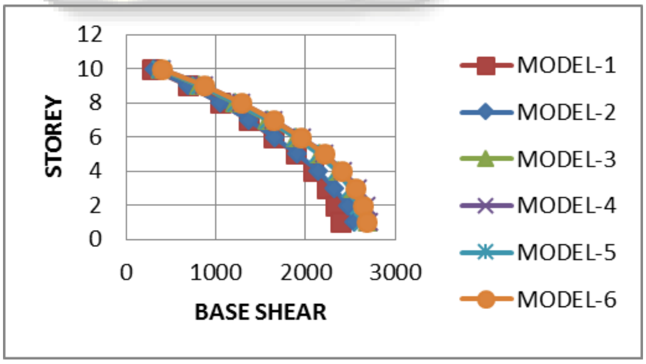


Chart 6: Base shear in Transverse Direction

As it can be seen from figure, the base shear has been reduced in Models-1, 2,3,4,5. The Base shear has been reduced by 78% in comparison of model-6,Model-2 has been reduced by 65.4%, Model-3 has been reduced by 31.5%,Model-4 has been reduced by 6%, Model-5 Has been reduced by 24.31%.Model-6 has maximum base shear where Model-1,2,3,4,5 has less Base shear.Model-1 has minimum base shear.

D. Fundamental Time Period:

Time periods in Seconds			
MODELS	MODE-1	MODE-2	MODE-3
1	0.5972	0.5731	0.5935
2	0.3471	0.3188	0.3096
3	0.2846	0.2589	0.2443
4	0.2443	0.2233	0.1667
5	0.2316	0.2233	0.1902
6	0.2012	0.1978	0.1578

Table 7: Base shear in KN in Transverse Direction.

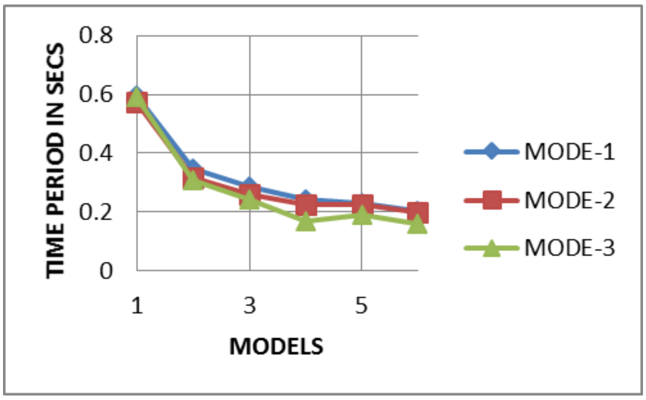


Chart 7: Time periods in Seconds

The value of T depends on the building flexibility and mass; more the flexibility and mass, the longer is the period. The maximum time period is in MODEL-1 and minimum time period is in MODEL-6. Therefore one can say that MODEL-6 has more strength and mass when compared to other models.

VII. CONCLUSIONS

1) Model-1 shows highest time period and lowest base shear, it indicates it has got least stiffness as compare to other five Models.
2) Model with bottom soft storey shows highest storey drift at ground level as compare to other models , it shows that bottom soft storey has got lesser stiffness as compare to above stories , therefore soft storey is dangerous at lower level, so that any suitable provision should be made so as to avoid the catastrophic or sudden collapse.
3) When we compare bare frame model with other models, it shows highest storey displacements at top storey, when we add planar or L- shaped shear wall, displacement got reduced considerably hence provision of shear wall reduces storey displacements and make the structure stiff
4) When we compare Model-II with other four models it shows least stiffness, therefore provision of shear walls will make the structure strong and sustainable to seismic threatening.
5) Model without core wall showing same behavior with central core wall models hence core walls should be provided in the models to nearest of centre of mass point.
6) Position of shear wall plays a very vital role in the seismic resistance, it has to be placed in such a way that the overall behavior of the structure should not be disturbed.
7) Mode shapes study shows that, Model-II shows higher torsion at ground storey as compare with other models.
8) When we don't consider the importance of masonry infill panels in modeling and designing , it considerably effect the overall behavior of the structure , it may leads to form the soft storey, as reveal by the results .

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