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EFFECT OF TRANSFER GIRDER ON SOFT STOREY CONDITION OF FRAME FLOATING FROM IT

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Abstract* - I.S. 1893 : 2016 (Part 1) (Sixth Revision) was adopted by Bureau Of Indian Standards in December 2016. The definition of Soft Storey condition has been altered and equal or higher lateral stiffness of lower storey as compared to immediate upper storey is proposed than that were allowed in I.S. 1893 Part 1 : 2002. Due to scarcity of land, development rules regarding open spaces and parking, multi-storey and high-rise structures are constructed with transfer girders to create column free spaces to provide clear drive way and parking movability. The present analytical study concentrates on effect of variation in stiffness of transfer girder on the lateral stiffness of the frame floated from it under lateral load. This Analytical study of R.C. frame on R.C. transfer girder is done using Staad Pro Software. The results show that, the soft storey condition of a floating frame remains unaltered, irrespective of the change in stiffness or end support conditions of the transfer girders or its placement on transfer girder.

***Key Words* -** I.S. 1893 : 2016, I.S. 1893 : 2002, Lateral Stiffness, Soft Storey, Transfer Girder, Floating Columns.

I. INTRODUCTION

I.S. 1893 : 2016 [1] defines, a soft storey is one in which the lateral stiffness is less than that in the storey above.

I.S. 1893 Part 1 : 2002 [2] defined,

(a) Soft Storey – 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. &

(b) Extreme Soft Storey - 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 stiffness of the three storeys above.

Thus, the revised code provisions have become more stringent and requires equal or higher lateral stiffness of lower storey as compared to immediate upper storey to avoid soft storey condition.

For economic viability of redevelopment projects, it has become necessary to load Transfer of Development Rights (T.D.R.) and increase occupancy to almost double or more on the original size of plots. Due to stringent parking requirements it has become necessary to provide stack parking in parking pits / basement with large depths and column free space for unobstructed vehicular movement. Most of the time, the foot print of building is smaller than parking pit / basement. This creates a problem of placing the columns supporting the main building. Therefore, generally transfer girders are proposed to float the columns of the main building.

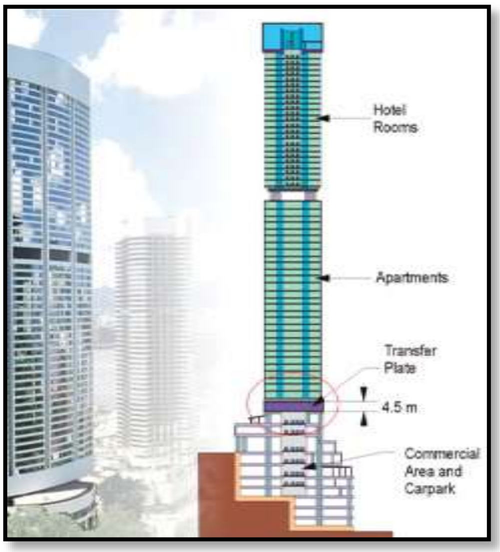

Fig. 1. Transfer Floor System (Image Source: www. Google.com)

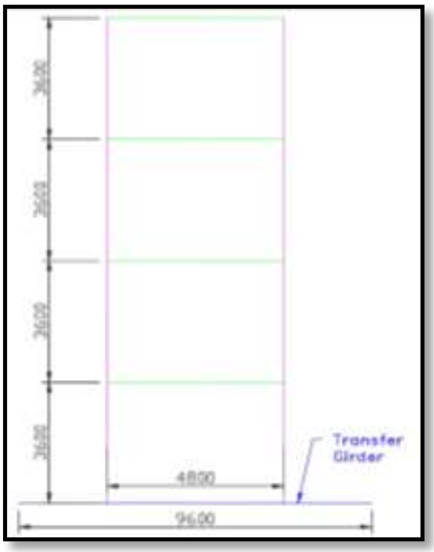

Fig. 2. Model 1 & Model 3
Bare Frame Centrally Placed On Transfer Girder

Depending upon the planning requirements, the columns may be floated from anywhere from the span of the transfer girder. **Fig. 1**, is classic example of multi-storey structure with transfer girder and multi-level car park. Transfer floors are increasingly applied in design of high-rise buildings in recent years due to the complex shapes and multi-functions of the buildings[3][4]. Four distinct types of transfer floors systems can be defined using either of girder, plate, truss and box. The girder transfer floors are widely used in multi-storey buildings.

II. LITERATURE REVIEW

Li et al.[4] concluded that for low-rise buildings with edge columns supporting the long transfer beam gravity loads are the guiding load case for the design of the buildings. They noted that, column frame structure are strong and stiff enough to resist the seismic load even if the structural walls do not extend below the transfer structure. But, for the transfer girders supported by setback columns, less unbalanced end moment due to gravity load is induced in the columns supporting the transfer girder. Thus, the columns designed to resist gravity load are not strong enough to resist the additional seismic load. A soft storey mechanism could occur below the transfer storey under seismic conditions. Special attention must be paid to design low-rise buildings with this type of transfer structure.

J. S. Kuang and Zhijun Zhang[7], studied the structural behavior of the interaction between the transfer plate and the supported shear walls. Within an interactive zone, the interaction effect causes significant stress redistributions both in the transfer plate and in the shear walls. The influence of the span–depth ratio of the transfer plate, the stiffness and locations of the shear walls, and the stiffness of supporting columns on force transfer and structural behavior was noted. The study provided a better understanding of the interactive characteristic of transfer plate–shear wall systems along with reference for the design of transfer plates supporting in-plane loaded shear walls in tall buildings.

R. K. L. Su[8], summarized and discussed the Chinese National Standard (2001) requirements for transfer structure design under seismic conditions with an aim to improve the general understanding of the seismic response of concrete buildings with transfer structures in low-to-moderate seismicity regions. Based on the previous shaking table test results and numerical findings, the seismic effects on the inelastic behaviors of transfer structures were investigated. The mechanisms for the formation of a soft storey below transfer floors, the abrupt change in inter-storey drift near transfer storeys and shear concentration due to local deformation of transfer structures were studied and developed. Design principles were established for controlling soft-storey type failure and minimizing shear concentration in exterior walls supported by transfer structures. The influence of the vertical positioning of transfer floors on the seismic response of buildings was also studied and noted that the neighboring floors of a transfer storey is highly affected by the transfer floor location especially in the drift, drift demands and high mode effects are generally higher as the transfer floor is positioned at a higher level. More vibration modes must be considered in any response spectrum analysis in order to improve the analysis results.

Sayed-Ahmed et al[9], carried out comparative analytical study for the seismic response of high-rise buildings with transfer floors. Three-dimensional finite element models having two different transfer floor systems namely, transfer slabs and transfer girders were analyzed using elastic linear response spectrum and inelastic nonlinear time history techniques. The vertical position of the transfer system was varied with respect to the building height. Storey shear and bending moment distribution and inter-storey drift were numerically evaluated. The results showed the localization of damage in the vicinity of the transfer floor in addition to the first floor; the location of the transfer floor influenced the global seismic response of the structure. The analysis suggested that the transfer girders system can be a competitive alternative to the slab system in terms of reducing the seismic weights as well as the material cost with a slight change in the global seismic behavior of the structure. Transfer girders system is more flexible compared to slab system and generate lower straining actions on the structural vertical elements.

Tim On Tang and Ray Kai Leung Su[10], investigated the gravity loads in reinforced concrete shear walls supported on transfer structures. Importance was placed on the shear-stress concentration effects on the supported shear walls owing to the distortion of the transfer structure. To illustrate the fundamental physical interactions, a simplified model was proposed. The influences of the symmetric and asymmetric shear-wall arrangements, positioning of supporting columns and span-to-depth ratio of the transfer structure was studied using finite element analysis. Non-linear behaviors encompassing the use of yielded stiffness at ultimate limit state, sequential construction and the creep of reinforced concrete under gravity loads were addressed. Effects of modelling and simplification on stress redistribution of the transfer girder were studied. Increasing the depth of the transfer girders using late-cast slabs, use of segmented upper shear walls and provision of high grade concrete mix in critical regions was suggested as remedial measures.

Transfer structures are usually idealized as deep beams or thick plates. Normally, the flexural stiffness and strength of the transfer structure are much higher than those of the column supports or shear walls of the superstructure above. Many engineers and researchers, Zhang et al.[5] [6] ignore the deformations of transfer structures and adopt rigid plate and rigid diaphragm assumptions in routine structural analyses of buildings with transfer structures. However, local flexural rotations of transfer structures do exist and in many cases cannot be ignored.

The combined effect of the stiffness of transfer girder and the support conditions of the transfer girder, can affect the analysis and behavior of upper building frame with infill or without infill or combination. This can create effect of differential settlement in the frame, depending upon the deflections of the transfer girder under gravity loads as well as lateral loads. This phenomenon is not specifically explained by the code although it may increase strength and ductility demands in the frames of such structure. To understand this aspect a systematic analytical study of effect of stiffness of transfer girder on stiffness of frame supported by it is made.

III. ANALYTICAL MODELS & METHODOLOGY

Using Staad Pro software for finite element analysis, following four models were prepared.

Model 1 - A Single Bay of 4800 mm Span, Stilt + 3 Upper Floor (4 Storey) Bare Frame with all storey height = 3600 mm is considered with all columns as 300 x 600 mm throughout in all storeys and beam sizes as 300 x 600 mm at all floor levels. The frame is placed centrally on transfer girder of size 300 x 1000 mm having span of 9600 mm. Refer **Fig. 2**. Modulus of elasticity of concrete is considered same for all the members.

Model 2 - Same as Model 1, with introduction of 230 mm thick concrete block wall in upper 3 storeys, keeping first sotrey as open storey. Refer **Fig. 3**.

For both models Model 1 & Model 2, the transfer girder depths were varied as 1000 mm, 1500 mm & 2000 mm. For all three variations of depth, for both models the support conditions for transfer girders were considered as pinned and fixed. The connections between the frame columns and transfer girders were taken as rigid connections. For all combinations the stiffness calculations were made and are shown in **Table 1**.

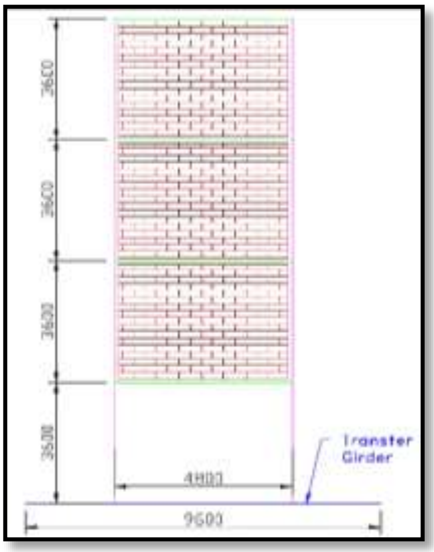

Figure 3. Model 2
Infilled Frame With Open First Storey Centrally Placed On Transfer Girder

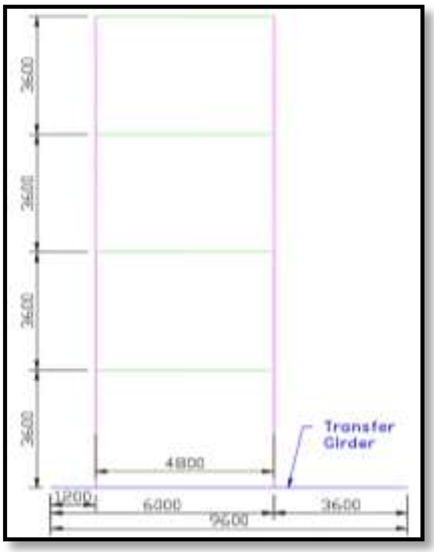

Fig 4. Model 4
Bare Frame Eccentrically Placed On Transfer Girder

Model 3 - Same as Model 1. Refer **Fig. 2**.

Model 4 - Same as Model 1, except the frame is now placed eccentrically on transfer girder having span of 9600 mm with legs spaced from left end of transfer girder at 1200 mm & 6000 mm respectively. Refer **Fig. 4**.

For both models Model 3 & Model 4, the transfer girder depths were varied as 600 mm, 800 mm, 1600 mm, 2400 mm, 3200 mm, 4000 mm & 4800 mm. For all variations of depth, for both models, the support conditions for transfer girders were considered as pinned. The connections between the frame columns and transfer girders were taken as rigid connections. For all combinations the stiffness calculations were made and are shown in **Table 2**.

IV. RESULTS AND OBSERVATIONS

From Table 1, following observations were made.

- For both Model 1 & Model 2, the deflections were found to increase when floated from transfer girder in comparison with those placed on independent foundations.
- For both Model 1 & Model 2, it was found that as support condition of the transfer girder was changed from pinned to fixed, the deflections in the frame reduced. However, they were not less than that of frames founded on independent foundations.
- For both Model 1 & Model 2, as the stiffness of transfer girder increased, the deflections at all levels reduced, thereby increasing the stiffness of all the storeys in the frame. However, they were not less than that of frames founded on independent foundations.
- For both Model 1 & Model 2, the soft storey condition remains unaltered irrespective of the change in stiffness or end support conditions of the transfer girders.

Table 1.
Lateral Stiffness Of Bare Frame And Infilled Frame With Open First Storey

	Floor Level / Storey	Bare Frame		Infilled Frame		
		Floor Level Deflection (mm)	Storey Stiffness (KN/mm)	Floor Level Deflection (mm)	Storey Stiffness (KN/mm)	
Frame With Fixed Base (On Foundation)	4	5.233	19.109	0.538	185.874	
	3	4.688	21.331	0.338	295.858	
	2	4.152	24.085	0.181	552.486	
	1	2.269	44.072	1.752	57.078	
Frame On Transfer Girder 300 x 1000	4	6.726	14.868	2.103	47.551	Transfer Girder Pinned
	3	5.724	17.470	1.455	68.729	
	2	4.729	21.146	0.851	117.509	
	1	2.507	39.888	1.985	50.378	
	4	5.962	16.773	1.313	76.161	Transfer Girder Fixed
	3	5.183	19.294	0.883	113.250	
	2	4.421	22.619	0.497	201.207	
	1	2.434	41.085	1.900	52.632	
Frame On Transfer Girder 300 x 1500	4	5.740	17.422	1.071	93.371	Transfer Girder Pinned
	3	5.039	19.845	0.718	139.276	
	2	4.347	23.004	0.408	245.098	
	1	2.349	42.571	1.830	54.645	
	4	5.523	18.106	0.845	118.343	Transfer Girder Fixed
	3	4.888	20.458	0.555	180.180	
	2	4.263	23.458	0.309	323.625	
	1	2.332	42.882	1.810	55.249	
Frame On Transfer Girder 300 x 2000	4	5.483	18.238	0.801	124.844	Transfer Girder Pinned
	3	4.861	20.572	0.525	190.476	
	2	4.248	23.540	0.293	341.297	
	1	2.308	43.328	1.79	55.866	
	4	5.398	18.525	0.712	140.449	Transfer Girder Fixed
	3	4.803	20.820	0.462	216.450	
	2	4.217	23.714	0.255	392.157	
	1	2.303	43.422	1.784	56.054	

From Table 2, following observations were made.

- For Model 3, it was found that, as the frame was placed centrally on the transfer girder, the difference in the deflections of the transfer girder at column positions was zero but the values of the deflections kept on reducing with increase in stiffness of the transfer girder.
- For Model 3, it was found that, the change in stiffness of the frame as a whole was attributed to change in stiffness of transfer girder only.
- For Model 4, it was found that, as the frame was placed eccentrically on the transfer girder, the difference in the deflections of the transfer girder at column positions was reducing with increase in stiffness of the transfer girder.
- For Model 4, it was found that, the change in stiffness of the frame as a whole was attributed to both, the change in stiffness of transfer girder and also the difference in deflection in the transfer girder at the point under columns of the frame.

- For very high stiffness of transfer girder, the difference between the deflections of supporting points in eccentrically placed frame on transfer girder tends to be zero. Therefore, the stiffness of the eccentrically placed frame is almost same to stiffness of centrally placed frames.

Table 2.
Lateral Stiffness Of Bare Frame Placed Centrally & Eccentrically On Transfer Girder

Transfer Girder	Floor Level / Storey	Centrally Placed Bare Frame					Eccentrically Placed Bare Frame				
		Floor Level Deflection (mm)	Storey Stiffness (KN/mm)	Deflection Of Transfer Girder Under Bare Frame Column (mm)			Floor Level Deflection (mm)	Storey Stiffness (KN/mm)	Deflection Of Transfer Girder Under Bare Frame Column (mm)		
				Left	Right	Difference Of Deflection			Left	Right	Difference Of Deflection
300 x 600	4	11.370	8.795	7.998	7.998	0.000	15.141	6.605	3.834	11.392	7.558
	3	8.976	11.141				11.801	8.474			
	2	6.583	15.191				8.48	11.792			
	1	3.293	30.367				4.234	23.618			
300 x 800	4	7.998	12.503	4.716	4.716	0.000	9.839	10.164	2.347	6.275	3.928
	3	6.611	15.126				7.989	12.517			
	2	5.229	19.124				6.157	16.242			
	1	2.716	36.819				3.175	31.496			
300 x 1600	4	5.663	17.658	1.070	1.070	0.000	5.951	16.804	0.56	1.328	0.768
	3	4.986	20.056				5.202	19.223			
	2	4.317	23.164				4.463	22.406			
	1	2.336	42.808				2.407	41.545			
300 x 2400	4	5.398	18.525	0.421	0.421	0.000	5.487	18.225	0.225	0.52	0.295
	3	4.803	20.820				4.869	20.538			
	2	4.215	23.725				4.26	23.474			
	1	2.295	43.573				2.316	43.178			
300 x 3200	4	5.325	18.779	0.227	0.227	0.000	5.363	18.646	0.123	0.28	0.157
	3	4.752	21.044				4.78	20.921			
	2	4.187	23.883				4.206	23.776			
	1	2.283	43.802				2.291	43.649			
300 x 4000	4	5.295	18.886	0.147	0.147	0.000	5.314	18.818	0.081	0.181	0.1
	3	4.731	21.137				4.745	21.075			
	2	4.175	23.952				4.185	23.895			
	1	2.278	43.898				2.282	43.821			
300 x 4800	4	5.279	18.943	0.107	0.107	0.000	5.29	18.904	0.059	0.131	0.072
	3	4.72	21.186				4.728	21.151			
	2	4.169	23.987				4.175	23.952			
	1	2.276	43.937				2.278	43.898			
Note - For All Above Cases Transfer Girder Ends Are Pinned											

V. CONCLUSIONS

1. A frame, bare / infilled, floated from transfer girder shall have lesser lateral stiffness than the frames supported on independent foundations. In this case, it may attract condition of soft story, and hence, the revised I.S. 1893 : 2016 rightly prohibits structural designers to take floating columns as integral part of lateral load resisting system.
2. The soft storey condition of a frame, remains unaltered irrespective of the change in stiffness or end support conditions of the transfer girders as, the change in stiffness of transfer girder affects the stiffness of frame as a whole and not to any individual storey. So, although the stiffness of the frame reduces, soft storey condition of a frame placed on transfer girder remains same as that of frame placed on independent foundations.
3. When the frames are placed centrally on the transfer girder, the stiffness variation in the frame as a whole is directly proportional to variation in stiffness of transfer girder.

4. When the frames are placed eccentrically on the transfer girder, the stiffness variation in the frame as a whole is directly proportional to both the variation in stiffness of transfer girder & the differential deflections of the supports of the frame.
5. In case of very stiff transfer girders, the stiffness of frame remains unaltered irrespective of its placement position on the transfer girder.
6. Looking at above facts, it is advisable to model the frame along with transfer girder to take advantage of reduction of stiffness of the frame as a whole, resulting in increase of natural period of vibration, which will attract lesser forces under seismic episode.

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