SEISMIC LINEAR ANALYSIS OF LOW RISE OPEN GROUND STOREY BUILDINGS

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Abstract: *In a framed structure, the presence of Infill Walls differ the behaviour of a building under the effect of Lateral loads and Engineers ignore the Stiffness of these Infill Walls during the analysis of a framed building. And this way of analyzing a building is believed to provide a conservative design. However this may not always work especially in case of discontinuous infill walls in the building.*

For some of the experienced engineers, the multiplication factor of 2.5 recommended by the IS-1893 to compensate discontinuity of stiffness doesn't seem realistic for low rise buildings. Therefore this nature of assessment calls for the review of code recommended multiplication factor.

Hence the aim and the objective of this thesis will remain confined to check the nature and Applicability of multiplication factor 2.5 and moreover it relies onto the study of infill strength effect and stiffness in the seismic analysis of Open Ground Storey Buildings with two different support conditions by using the commercial software SAP2000.

As per the resulted analysis which showed that the multiplication factor 2.5 was too high for the Beam and Column forces of the low rise Open Ground Storey Buildings. Hence it was concluded that through the elastic analysis, the stiffness in both Open Ground Storey Buildings with Infill and in the similar framed building remains the same. Although the linear analysis shows that the influence in the response is considerably shown by the support conditions and therefore can be an essential parameter to decide the force strengthening factor.

Key words: infill walls, diagonal strut, open ground storey, equivalent static analysis, response spectrum analysis, pushover analysis, low rise building.

1. Introduction:

Due to growing population since the past few years car parking space for housing apartments in populated cities is a matter of major concern. Hence the development has been to make use of the ground storey of the building itself for parking. These types of buildings having no infill masonry walls in ground storey, but infilled in all upper storeys, are called Open Ground Storey (OGS) buildings. They are also known as 'open first storey building' (when the storey numbering starts with one from the ground storey itself), 'pilotis', or 'stilted buildings'.

There is considerable advantage of these category of buildings functionally but from a seismic performance point of inspection such buildings are considered to have enlarged vulnerability. From the past earthquakes it was apparent that the major type of failure that occurred in OGS buildings included snapping of lateral ties, crushing of core concrete, buckling of longitudinal reinforcement bars etc. Infill walls in the entire upper storey except for the ground storey makes the upper storeys much stiffer than the open ground storey. Thus, the upper storeys move almost together as a single block, and most of the horizontal displacement of the building occurs in the soft ground storey itself. In other words, this type of buildings sway back and forth like inverted pendulum during earthquake shaking, and hence the columns in the ground storey columns and beams are heavily stressed. Therefore it is required that the ground storey columns must have sufficient strength and adequate ductility. The vulnerability of this type of building is attributed to the sudden lowering of lateral stiffness and strength in ground storey, compared to upper storeys with infill walls. The Open Ground storey buildings varies drastically as compared to similar bare framed or completely infillled framed buildings under the effect of lateral loads. It has been observed tht bare framed buildings are less stiff than the infilled frames. Moreover it is seen tht the fully infilled framed buildings is introduced to truss action and also shows feeble inter-storey drifty which although pulls higher base shear. Infilled frames yield least force to the frame elements to which the energy is dissipated through infill walls. More commonly the stiffness value of infill walls has been put to side by the experienced engineers to whom they feel it generally provides a conservative design. But when it comes to Open Ground Storey buildings, the stiffness needs not to n illuminated because of the larger drift which may lead to the failure of the soft storey.

This paper thus explains as in the need to model the OGS buildings with and without infills for two different support conditions. The applicability of factor 2.5 recommended by the IS-CODE 1893-2000 is also validated as in to which extent it compensates the stiffness offered by infills.

2. Literature review:

Under lateral loading the frame and the infill wall stay intact initially. As the lateral load increases the infill wall get separated from the surrounding frame at the unloaded (tension) corner, but at the compression corners the infill walls are still intact. The length over which the infill wall and the frame are intact is called the length of contact. Load transfer occurs through an imaginary diagonal which acts like a compression strut. Due to this behavior of infill wall, they can be modeled as an equivalent diagonal strut connecting the two compressive corners diagonally. The stiffness property should be such that the strut is active only when subjected to compression. Thus, under lateral loading only one diagonal will be operational at a time. This concept was first put forward by Holmes (1961).

The effect of slip and interface friction between the frame and infill wall was investigated by Mallick and Severn (1967) using finite element analysis. The infill panels were simulated by means of linear elastic rectangular finite elements, with two degrees of freedom at each of the four corner nodes. Interface between frame and infill was modeled and contact length was calculated. The slip between frame and infill was taken into account by considering frictional shear forces in the contact region using link element. Each node of this element has two translational degrees of freedom. The element is able to transfer compressive and bond forces, but incapable of resisting tensile forces.

Rao *et. al*. (1982) conducted theoretical and experimental studies on infilled frames with opening strengthened by lintel beams. It was concluded that the lintel over the opening does not have any influence on the lateral stiffness of an infilled frame. Karisiddappa (1986) and Rahman (1988) examined the effect of openings and their location on the behavior of single storey RC frames with brick infill walls.

Choubey and Sinha (1994) investigated the effect of various parameters such as separation of infill wall from frame, plastic deformation, stiffness and energy dissipation of infilled frames under cyclic loading.

The behaviour of RC framed OGS building when subjected to seismic loads was reported by Arlekar *et.al* (1997). A four storeyed OGS building was analysed using Equivalent Static Analysis and Response Spectrum Analysis to find the resultant forces and displacements. This paper shows that the behaviour of OGS frame is quite different from that of the bare frame.

The effect of different parameters such as plan aspect ratio, relative stiffness, and number of bays on the behavior of infilled frame was studied by Riddington and Smith (1997).

Scarlet (1997) studied the qualification of seismic forces in OGS buildings. A multiplication factor for base shear for OGS building was proposed. This procedure requires modeling the stiffness of the infill walls in the analysis. The study proposed a multiplication factor ranging from 1.86 to 3.28 as the number of storey increases from six to twenty.

Deodhar and Patel (1998) pointed out that even though the brick masonry in infilled frame are intended to be non-structural, they can have considerable influence on the lateral response of the building.

Davis and Menon (2004) concluded that the presence of masonry infill panels modifies the structural force distribution significantly in an OGS building. The total storey shear force increases as the stiffness of the building increases in the presence of masonry infill at the upper floor of the building. Also, the bending moments in the ground floor columns increase (more than two fold), and the mode of failure is by soft storey mechanism (formation of hinges in ground floor columns).

Das and Murthy (2004) concluded that infill walls, when present in a structure, generally bring down the damage suffered by the RC framed members of a fully infilled frame during earthquake shaking. The columns, beams and infill walls of lower stories are more vulnerable to damage than those in upper stories.

3. Structural modeling:

An existing OGS framed building located at Dharamsali Srinagar j&k (Seismic Zone V) is selected for the present study. The building is fairly symmetric in plan and in elevation. This building is a G+3 storey building (12m high) and is made of Reinforced Concrete (RC) Ordinary Moment Resisting Frames (OMRF). The concrete slab is 150mm thick at each floor level. The brick wall thicknesses are 230 mm for external walls and 120 mm for internal walls. Imposed load is taken as 2 kN/ m^2 for all floors. The cross sections of the structural members (columns and beams 300 mm×600 mm) are equal in all frames and all stories. Storey masses to 295 and 237 tonnes in the bottom storeys and at the roof level, respectively. The design base shear was equal to 0.15 times the total weight. Modeling a building involves the modeling and assemblage of its various load-carrying elements. The model must ideally represent the mass distribution, strength, stiffness and deformability.

3.1.Material Properties

M-20 grade of concrete and Fe-415 grade of reinforcing steel are used for all the frame models used in this study. Elastic material properties of these materials are taken as per Indian Standard IS 456: 2000. The short-term modulus of elasticity (*Ec*) of concrete is taken as:

$$E_c = 5000\sqrt{f_{ck}}\,MPa$$

fck is the characteristic compressive strength of concrete cube in MPa at 28-day (20 MPa in this case). For the steel rebar, yield stress (*fy*) and modulus of elasticity (*Es*) is taken as per IS 456:2000. The material chosen for the infill walls was masonry whose compressive strength (*fm'*) from the literature was found out to be 1.5 MPa and the modulus of elasticity was stated as:

Em =350 to 800 MPa for table moulded brick.
=2500 to 5000 MPa for wire cut brick.

According to FEMA 356:2000 elasticity of modulus of brick is taken as *Em* = 750 *fm'*.

For the present study the modulus of elasticity of the masonry is taken as given in literature by Asokan (2006).

3.2 Structural Elements

Beams and columns are modeled by 3D frame elements. The beam-column joints are modeled by giving end-offsets to the frame elements, to obtain the bending moments and forces at the beam and column faces. The beam-column joints are assumed to be rigid.

Beams and columns in the present study were modeled as frame elements with the centerlines joined at nodes using commercial software SAP2000. The rigid beam-column joints were modeled by using end offsets at the joints (Fig. 3.2). The floor slabs were assumed to act as diaphragms, which ensure integral action of all the vertical lateral load-resisting elements. The weight of the slab was distributed as triangular and trapezoidal load to the surrounding beams.

The structural effect of slabs due to their in-plane stiffness is taken into account by assigning 'diaphragm' action at each floor level. The mass/weight contribution of slab is modeled separately on the supporting beams.

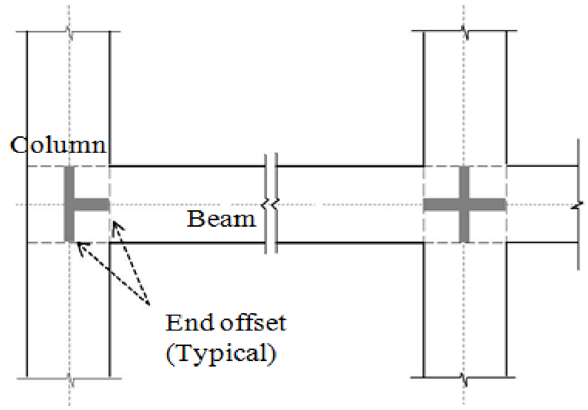

Fig.3.2 Use of end offsets at beam-column joint.

3.2 Stress-Strain Characteristics for Concrete

The stress-strain curve of concrete in compression forms the basis for analysis of any reinforced concrete section. The characteristic and design stress-strain curves specified in most of design codes (IS 456: 2000, BS 8110) do not truly reflect the actual stress-strain behavior in the post-peak region, as (for convenience in calculations) it assumes a constant stress in this region (strains between 0.002 and 0.0035). In reality, as evidenced by experimental testing, the post-peak behavior is characterized by a descending branch, which is attributed to 'softening' and micro-cracking in the concrete. Also, models as per these codes do not account for strength enhancement and ductility due to confinement.

However, the stress-strain relation specified in ACI 318M-02 consider some of the important features from actual behaviour. A previous study (Chugh, 2004) on stress-strain relation of reinforced concrete section concludes that the model proposed by Panagiotakos and Fardis (2001) represents the actual behaviour best for normal-strength concrete. Accordingly, this model has been selected in the present study for calculating the hinge properties. This model is a modified version of Mander's model (Mander*et. al.*)

- The model can be applied to any shape of concrete member section confined by any kind of transverse reinforcement (spirals, cross ties, circular or rectangular hoops).

The validation of this model is established in many literatures (*e.g.*, Pam and Ho, 2001).

Objective:

Following the literatures, the objectives of this paper are defined as:

- To examine the infill strength and stiffness offered by the infill walls present in the Open Ground Storey buildings.
- To review the code recommended multiplication factor of 2.5 for compensation of stiffness offered by the infills.
- To analyze the effect of two different support conditions for the seismic behavior of Open Ground Storey buildings.

4. Results and Conclusions:

4.1 Column Interaction Ratios

Table. A Comparison of Ground storey column interaction Ratio for pinned End case.

Col. ID	IR (ESA)		Ratio of IR	IR (RSA)		Ratio of IR
	WI	WOI		WI	WOI	
C1	1.12	1.52	0.736	2.04	1.77	1.152
C2a	1.93	1.92	1.005	2.44	2.23	1.094
C2b	1.83	1.81	1.011	2.48	2.08	1.192
C3	1.83	1.90	0.963	3.89	3.33	1.168

Table. B Comparison of ground storey column interaction ratio for fixed end case.

Col. ID	IR (ESA)		Ratio of IR	IR (RSA)		Ratio of IR
	WI	WOI		WI	WOI	
C1	0.88	0.92	0.95	1.23	1.18	1.042
C2a	1.03	1.12	0.91	1.25	1.22	1.025
C2b	1.01	1.06	0.95	1.23	1.20	1.025
C3	1.41	1.51	0.93	2.03	1.92	1.057

This table clearly shows that for a low rise Open ground storey building model with fixed-end support the ground storey column forces actually reduced when infill stiffness is considered in Equivalent Static Analysis. It marginally increases (less than 10%) in the case of response spectrum analysis. This is because the forces applied to building model with infill stiffness is little more compared to that applied to building model without infill stiffness in Response Spectrum Analysis. But the applied forces to these two buildings are same in case of Equivalent Static Analyses. Therefore using a multiplication factor of 2.5 for ground floor columns of low rise Open Ground storey buildings as per Indian Standard IS 1893:2002 (Part-1) is not justified.

4.2 Beam Demand-to-Capacity Ratios

Table. C comparison of Beam DCR(Pinned end)

Beam ID	DCR (ESA)		Ratio of DCR	DCR (RSA)		Ratio of DCR
	wOI	WOI		WI	WOI	
B1	1.87	2.80	0.66	1.31	1.64	0.79
B4	1.83	2.62	0.69	1.14	1.44	0.79
B5	1.02	1.52	0.67	0.61	0.80	0.76
B7	1.32	1.92	0.68	0.85	1.08	0.78
B8	1.76	2.51	0.70	1.23	1.51	0.81
average			0.68			0.79
Standard Deviation			0.01			0.02

Table. D comparison of beam DCR (fixed end)

Beam ID	DCR (ESA)		Ratio of DCR	DCR (RSA)		Ratio of DCR
	WI	WOI		WI	WOI	
B1	1.03	1.73	0.59	0.64	0.94	0.68
B4	1.15	1.77	0.64	0.59	0.87	0.67
B5	0.75	1.07	0.70	0.33	0.51	0.64
B7	0.81	1.28	0.63	0.45	0.65	0.69
B8	1.01	1.58	0.63	0.63	0.88	0.71
AVERAGE			0.64			0.68
Standard Deviation			0.04			0.03

Table above presents results from both equivalent static analyses (ESA) and response spectrum analyses (RSA). The Force demands in all first floor beams are found to be lower when infill stiffness modeled in OGS building. It can be concluded from this results that it is conservative to analyze low-rise OGS building without considering infill stiffness. Tables above shows that the average ratio of DCR values (ratio of DCR in WI model to DCR in WOI model) for first floor beams is below 0.70 for both pinned-end and fixed-end building in Equivalent Static Analyses. They also shows that the average ratio of DCR values for first floor beams is 0.79 for pinned-end building in Response Spectrum Analyses although this lies within 0.70 for fixed-end building model. A statistical analysis of the DCR ratios shows that the DCR ratios for all the beams are very consistent (standard deviation is within 0.04 for all cases). A conclusion can be drawn from these results that amplification factor of 2.5 need not be multiplied to the beam forces even when infill stiffness is not modeled in analysis. However, this statement is valid for low-rise OGS building and cannot be used for high-rise OGS buildings.

It is experiential from the results presented here that analysis of the model without taking into consideration the infill strength and stiffness gives a conservative estimation for all beam and column elements in a low-rise open ground storey building. This is right for equivalent static analysis as well as response spectrum analysis. Therefore, multiplication factor of 2.5 as recommended in Indian Standard IS 1893 (Part -1): 2002 need not be multiplied to the beam forces even when infill stiffness is not modelled in analysis.

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