Earthquake Resistant Design of Low-Rise Open Ground Storey Framed Building

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Abstract: **Presence of infill walls in the frames alters the behaviour of the building under lateral loads. However, it is common industry practice to ignore the stiffness of infill wall for analysis of framed building. Engineers believe that analysis without considering infill stiffness leads to a conservative design. But this may not be always true, especially for vertically irregular buildings with discontinuous infill walls. Hence, the modelling of infill walls in the seismic analysis of framed buildings is imperative. Indian Standard IS 1893: 2002 allows analysis of open ground storey buildings without considering infill stiffness but with a multiplication factor 2.5 in compensation for the stiffness discontinuity. As per the code the columns and beams of the open ground storey are to be designed for 2.5 times the storey shears and moments calculated under seismic loads of bare frames (i.e., without considering the infill stiffness). However, as experienced by the engineers at design offices, the multiplication factor of 2.5 is not realistic for low rise buildings. This calls for an assessment and review of the code recommended multiplication factor for low rise open ground storey buildings. Therefore, the objective of this thesis is defined as to check the applicability of the multiplication factor of 2.5 and to study the effect of infill strength and stiffness in the seismic analysis of low rise open ground storey building. Infill walls can be modelled in commercial software using two-dimensional area element with appropriate material properties for linear elastic analysis. But this type of modelling may not work for non-linear analysis since the non-linear material properties for a two-dimensional orthotropic element is not very well understood. Seismic evaluation of an existing reinforced concrete (RC) framed building would invariably require a non-linear analysis. Published literature in this area recommends a linear diagonal strut approach to model infill wall for both linear (Equivalent Static Analysis and Response Spectrum Analysis) and nonlinear analyses (Pushover Analysis and Time History Analysis). An existing RC framed building (G+3) with open ground storey located in Seismic Zone-V is considered for this study. This building is analyzed for two different cases: (a) considering both infill mass and infill stiffness and (b) considering infill mass but without considering infill stiffness. Two separate models were generated using commercial software SAP2000. Infill weights were modelled through applying static dead load and corresponding masses considered from this dead load for dynamic analyses. Infill stiffness was modelled using a diagonal strut approach. Two different support conditions, namely fixed end support condition and pinned end support condition, are considered to check the effect of support conditions in the multiplication factors. Linear and non-linear analyses were carried out for the models and the results were compared. The analysis results show that a factor of 2.5 is too high to be multiplied to the beam and column forces of the ground storey of low-rise open ground storey buildings. This study conclude that the problem of open ground storey buildings cannot be identified properly through elastic analysis as the stiffness of open ground storey building and a similar bare-frame building are almost same. Nonlinear analysis reveals that open ground storey building fails through a ground storey mechanism at a comparatively low base shear and displacement and the mode of failure is found to be brittle. Linear and nonlinear analyses show that support condition influences the response considerably and can be an important parameter to decide the force amplification factor.**

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

I Introduction

Due to increasing population since the past few years car parking space for residential apartments in populated cities is a matter of major concern. Hence the trend has been to utilize the ground storey of the building itself for parking. These types of buildings (Fig. 1.1) 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 significant advantage of these category of buildings functionally but from a seismic performance point of view such buildings are considered to have increased vulnerability. From the past earthquakes it was evident that the major type of failure that 2 occurred in OGS buildings included snapping of lateral ties, crushing of core concrete, buckling of longitudinal reinforcement bars etc. Due to the presence of 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 (Fig. 1.2) 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.

Fig. 1.2: Behaviour of OGS buildings like as inverted pendulum

The OGS framed building behaves differently as compared to a bare framed building (without any infill) or a fully infilled framed building under lateral load. A bare frame is much less stiff than a fully infilled frame; it resists the applied lateral load through frame action and shows well-distributed plastic hinges at failure. When this frame is fully infilled, truss action is introduced. A fully infilled frame shows less inter-storey drift, although it attracts higher base shear (due to increased stiffness). A fully infilled frame.

II SEISMIC BEHAVIOUR OF OPEN GROUND STOREY BUILDING

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 behaviour of infill wall, they can be modelled 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).

III 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 behaviour 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 behaviour is characterised 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.*, 31 1988) where a single equation can generate the stress f_c corresponding to any given strain.

IV Stress-Strain Characteristics for Reinforcing Steel

The constitutive relation for reinforcing steel given in IS 456 (2000) is well accepted in literature and hence considered for the present study. The 'characteristic' and 'design' stress-strain curves specified by the Code for Fe-415 grade of reinforcing steel (in tension or compression)

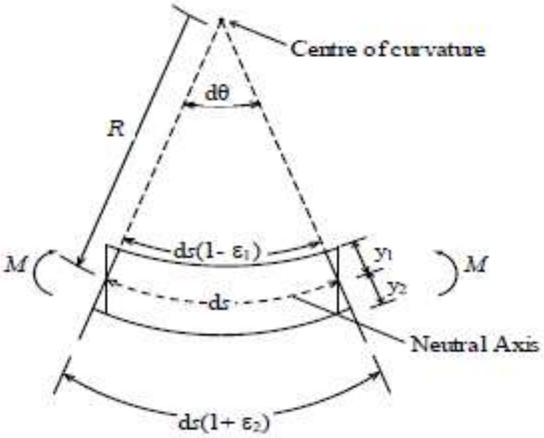

Fig Curvature in an initially straight beam section

(Pillai and Menon, 2009) If the bending produces extreme fibre strains of ε. If the beam behaviour is linear elastic, then the moment-curvature relationship is linear, and the curvature is obtained as $\varphi\varphi=MMEEEE$ (3.6)$_1$ and ε$_2$ at top and bottom at any section as shown in Fig. 3.7 (compression on top and tension at bottom assumed in this case), then, for small deformations, it can be shown that ()12ϕ=ε+εD35 The flexural rigidity (EI) of the beam is obtained as a product of the modulus of elasticity E and the second moment of area of the section I. When a RC flexural member is subjected to a gradually increasing moment, its behaviour transits through various stages, starting from the initial un-cracked state to the ultimate limit state of collapse. The stresses in the tension steel and concrete go on increasing as the moment increases. The behaviour at the ultimate limit state depends on the percentage of steel provided, i.e., on whether the section is 'under-reinforced' or 'over-reinforced'. In the case of under-reinforced sections, failure is triggered by yielding of tension steel whereas in over-reinforced section the steel does not yield at the limit state of failure. In both cases, the failure eventually occurs due to crushing of concrete at the extreme compression fiber, when the ultimate strain in concrete reaches its limit. Under-reinforced beams are characterized by 'ductile' failure, accompanied by large deflections and significant flexural cracking. On the other hand, over-reinforced beams have practically no ductility, and the failure occurs suddenly, without the warning signs of wide cracking and large deflections.

V CONCLUSIONS

Followings are the salient conclusions obtained from the present study:

i) IS code gives a value of 2.5 to be multiplied to the ground storey beam and column forces when a building has to be designed as open ground storey building or stilt building. The ratio of IR values for columns and DCR values of beams for both the support conditions and building models were found out using ESA and RSA and both the analyses supports that a factor of 2.5 is too high to be multiplied to the beam and column forces of the ground storey. This is particularly true for low-rise OGS buildings.

ii) Problem of OGS buildings cannot be identified properly through elastic analysis as the stiffness of OGS building and Bare-frame building are almost same.

iii) Nonlinear analysis reveals that OGS building fails through a ground storey mechanism at a comparatively low base shear and displacement. And the mode of failure is found to be brittle.

iv) Both elastic and inelastic analyses show that the beams forces at the ground storey reduce drastically for the presence of infill stiffness in the adjacent storey. And design force amplification factor need not be applied to ground storey beams.

v) The linear (static/dynamic) analyses show that Column forces at the ground storey increases for the presence of infill wall in the upper storeys. But design force amplification factor found to be much lesser than 2.5.

vi) From the literature available it was found that the support condition for the buildings was not given much importance. Linear and nonlinear analyses show that support condition influences the response considerably and can be an important parameter to decide the force amplification factor.

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