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.*

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 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 thatoccurred 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 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.

II. REVIEW OF LITERATURE:

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).

III. BUILDING DESCRIPTION

An existing OGS framed building located at Guwahati, India (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/ m2 for all floors. Fig. 3.1 presents typical floor plans showing different column and beam locations. 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 storyes and at the roof level, respectively. The design base shear was equal to 0.15 times the total weight.

IV. LINEAR ANALYSIS

4.1 Equivalent Static Analysis

This is a linear static analysis. This approach defines a way to represent the effect of earthquake ground motion when series of forces are act on a building, through a seismic design response spectrum. This method assumes that the building responds in its fundamental mode. The applicability of this method is extended in many building codes by applying factors to account for higher buildings with some higher modes, and for low levels of twisting. To account for effects due to "yielding" of the structure, many codes apply modification factors that reduce the design forces. In the equivalent static method, the lateral force equivalent to the design basis earthquake is applied statically. The equivalent lateral forces at each storey level are applied at the design ‘centre of mass’ locations.

4.2 Response Spectrum Analysis

The equations of motion associated with the response of a structure to ground

Where the Mode Participation Factor are defined by modal participation factor of mode I of vibration is the amount by which mode k contributes to the overall vibration of the structure under horizontal and vertical earthquake ground motions.

For a specified ground motion ̈( ) , damping value and assuming . It is possible to solve above equation at various values of ω and plot a curve of maximum peak response ( ) . For this acceleration input, the curve is defined as Displacement

A plot of ω ( ) is defined as the pseudo-velocity spectrum and plot of ω2 ( ) is defined as the pseudo-acceleration spectrum. These pseudo values have minimum significance and are not essentially a part of a response spectrum analysis. The true values for maximum velocity and acceleration must be calculated from the solution of above equation. There is a mathematical relationship, however, between the pseudo-acceleration spectrum and the total acceleration spectrum. The total acceleration of the unit mass, single degree-of-freedom system ,response spectrum curves represent the properties of the earthquake at specific site and are not a function of the properties of the structural system. After estimation is made of linear viscous damping properties of the structure, a specific response spectrum curve is selected.

4.3. RESULTS OF LINEAR ANALYSIS

As mentioned earlier the selected OGS building is analyzed for following two different cases and two end support conditions (fixed and pinned end support)

(a) Considering infill strength and stiffness (with infill/infilled frame)

(b) Without considering infill strength and stiffness (without infill/bare frame). Equivalent static and response spectrum analyses of these four building models are carried out to evaluate the effect of infill on the seismic behaviour of OGS building for two different support conditions.

V. NON-LINEAR ANALYSIS

5.1 PUSHOVER ANALYSIS

The pushover analysis is a nonlinear static method which is used in a performance based analysis. The method is relatively simple to be implemented, and provides information on strength, deformation and ductility of the structure and distribution of demands which help in identifying the critical members likely to reach limit states during the earthquake and hence proper attention can be given while designing and detailing. This method assumes a set of incremental lateral load over the height of the structure. Local nonlinear effects are modelled and the structure is pushed until a collapse mechanism is developed. With the increase in the magnitude of loads, weak links and failure modes of the buildings are found. At each step, the base shear and the roof displacement can be plotted to generate the pushover curve . This method is relatively simple and provides information on the strength, deformation and ductility of the structure and distribution of demands. This permits to identify the critical members likely to reach limit states during the earthquake by the formation of plastic hinges. On the building frame load/displacement is applied incrementally, the formation of plastic hinges, stiffness degradation, and lateral inelastic force versus displacement response for the structure is analytically computed. But some limitations of this method is that it neglects the variation of loading pattern, influence of higher modes and effect of resonance. In spite of the above deficiencies still this method has gained a wide acceptance as it provides reasonable estimation of global deformation capacity. And also the decision to retrofit can be taken on the basis of such studies.

It gives an idea of the maximum base shear that the structure is capable of resisting and the corresponding inelastic drift. For regular buildings, it also gives an estimate of the global stiffness of the building.

In pushover analysis, it is necessary to model the nonlinear load versus deformation behaviour of every element. The beams and columns are modelled as frame elements and the infill walls are modelled as equivalent struts by truss elements. Since the deformations are expected to go beyond the elastic range in a pushover analysis, it is necessary to model the nonlinear load versus deformation behaviour of the members. The nonlinear behaviour is incorporated in the load versus deformation property of a concentrated hinge attached to the member.

5.2. RESULTS FROM PUSHOVER ANALYSIS

Pushover analysis is carried out for both of the two building models. First pushover analysis is done for the gravity loads (DL+0.25LL) incrementally under load control. The lateral pushover analysis (PUSH-X and PUSH-Y) is followed after the gravity pushover, under displacement control. The building is pushed in lateral directions until the formation of collapse mechanism. The capacity curve (base shear versus roof displacement) is obtained in X- and Y- directions .These figures clearly show that global stiffness of an open ground storey building hardly changes even if the stiffness of the infill walls is ignored. If there is no considerable change in the stiffness elastic base shear demand for the building will also not change considerably if the stiffness of the infill walls is ignored. The variation of pushover curves in X- and Y- directions is in agreement with the linear analysis results presented in the previous section with regard to the variation of elastic base shear demand for different building models.

VI. SUMMARY

Linear static and dynamic analyses of the two building models are carried out to compare the force demand in the open ground storey frames. The code specified multiplication factor is compared with the ratio of their force demands. Two different support conditions are considered for the analysis to check the effect of the support conditions on the relative frame force demand. The support conditions considered are: pinned-end and fixed-end conditions.

Nonlinear static (pushover) analysis is carried out for all the building models considered. First pushover analysis is done for the gravity loads incrementally under load control. The lateral pushover analysis is followed after the gravity pushover, under displacement control.

VII. 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.

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