ASEISMIC PERFORMANCE OF REINFORCED CONCRETE INFILL FRAME

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ABSTRACT: Moderate and severe earthquakes have struck different places in the world, causing severe damage to reinforced concrete structures. Earthquake often effect the bond between the structural elements and masonry in-fills of the building. Masonry in-fills are often used to fill the void between horizontal and vertical resisting elements of the building frame. An infill wall enhances considerably the strength and rigidity of the structure. It has recognized that frames with in-fills have more strength and rigidity in conditions. Hence the studies about the behaviour of 3D-frames with or without masonry in-fills are necessary.

KEY WORDS*: dynamic analysis, response reduction factor, ductility factor, infill wall, stiffness*

I. INTRODUCTION

The buildings, which had already been constructed is susceptible to face more seismic risk, due to the increased seismic vulnerability, hence proper evaluation of the building against seismic hazards is absolutely necessary. The rapid industrialization and increase in population have called for optimum use of scale land due to which multi-storey building have become inevitable. Apart from dead and live loads, the structures have to withstand lateral foes. Under the action of natural wind and earthquake a tall building will be continually buffeted by gusts and other dynamic foes.

From the review of literature carried out, it has been found that no experimental work on single-bay, multi-storey R.C.C frame subjected to lateral loading has been done so far. In the project work an analytical study using ETABS is carried out and that is compared to experimental work which was carried out on a two bay, three storey R.C frame subjected to lateral loading. The load points were located at first storey level.

Masonry infill walls are frequently used as interior partitions and exterior walls in low or middle rise buildings. In the design and assessment of buildings, the infill walls are usually treated as non-structural elements and they are ignored in analytical models because they are assumed to be beneficial to the structural responses. Therefore their influences on the structural response are generally ignored. However, their stiffness and strength are not negligible, and they will interact with the boundary frame when the structure is subjected to ground motions. This interaction may or may not be beneficial to the performance of the structure.

Most Reinforced Concrete frame buildings in developing countries are in-filled with masonry walls. Experience during the past earthquakes has demonstrated the beneficial effects as well as the ill-effects of the presence of infill masonry walls. In at least two moderate earthquake (magnitude 6.0 to 6.5 and maximum intensity VIII on MM scale) in India, frame buildings with brick masonry infills have shown excellent performance even though most such buildings were not designed and detailed for seismic response.

2. EARTHQUAKE RESISITANT STRUCTURES

Earthquake resistant structures are structures designed to withstand earthquakes. While no structure can be entirely immune to damage from earthquakes, the goal of earthquake-resistant construction is to erect structures that fare better during seismic activity than their conventional counterparts.

According to building codes, earthquake-resistant structures are intended to withstand the largest earthquake of a certain probability that is likely to occur at their location. This means the loss of life should be minimized by preventing collapse of the buildings for rare earthquakes while the loss of functionality should be limited for more frequent ones. To combat earthquake destruction, the only method available to ancient architects was to build their landmark structures to last, often by making them excessively stiff and strong.

There are several design philosophies in earthquake engineering, making use of experimental results, computer simulations and observations from past earthquakes to offer the required performance for the seismic threat at the site of interest. These range from appropriately sizing the structure to be strong and ductile enough to survive the shaking with an acceptable damage, to equipping it with base isolation or using structural vibration control technologies to minimize any forces and deformations. While the former is the method typically applied in most earthquake-resistant structures, important facilities, landmarks and cultural heritage buildings use the more advanced (and expensive) techniques of isolation or control to survive strong shaking with minimal damage.

3. SEISMIC DESIGN FACTORS

The following factors affect the design of the building. It is important to understand these factors and deal with them prudently in the design.

Torsion: Objects and buildings have a centre of mass, a point by which the object (building) can be balanced without rotation occurring. If the mass is uniformly distributed then the geometric centre of the floor and the centre of mass may coincide. Uneven mass distribution will position the centre of mass outside of the geometric centre causing "torsion" generating stress concentrations. A certain amount of torsion is unavoidable in every building design. Symmetrical arrangement of masses, however, will result in balanced stiffness against either direction and keep torsion within a manageable range.

Damping: Buildings in general are poor resonators to dynamic shock and dissipate vibration by absorbing it. Damping is a rate at which natural vibration is absorbed.

Ductility: Ductility is the characteristic of a material (such as steel) to bend, flex, or move, but fails only after considerable deformation has occurred. Non-ductile materials (such as poorly reinforced concrete) fail abruptly by crumbling. Good ductility can be achieved with carefully detailed joints.

Strength and Stiffness: Strength is a property of a material to resist and bear applied forces within a safe limit. Stiffness of a material is a degree of resistance to deflection or drift (drift being a horizontal story-to-story relative displacement).

Building Configuration: This term defines a building's size and shape, and structural and non-structural elements. Building configuration determines the way seismic forces are distributed within the structure, their relative magnitude, and problematic design concerns.

4. REVIEW OF LITERATURE

Cinitha et al (2015) performed Nonlinear Static analysis to assess seismic performance and vulnerability of code - conforming RC buildings. Nonlinear analysis described in National Earthquake Hazards Reduction Program (NEHRP) guidelines has been used for the seismic rehabilitation of buildings. Analysis was done using SAP2000. 4 and 6 storey buildings are designed according to the code IS456:2000 and IS1893:2002. The data used for analysis were gravity load design ground acceleration - 0.36g and seismic load design ground acceleration- 0.16g with medium soil. The buildings were designed for two cases, such as ordinary moment resisting frame (OMRF) and special moment resisting frame (SMRF). A 100% dead load + 50% live load is applied to the lateral load on the structure. Inelastic beam and column members were modelled as elastic elements with plastic hinges at their ends. The analysis results observed for displacement shows that the modern codes for framed structure are within collapse prevention level.

Amin et al (2015): In an attempt to investigate the effect of soft storey for multi-storeyed reinforced concrete building frame, four building models (3, 6, 9 and 12 storey) with identical building plan were analysed. Equivalent diagonal struts were provided, as suggested in FEMA-273, in place of masonry to generate infill effect. Earthquake load was provided at each diaphragm's mass centre as a source of lateral load as set forth by the provision BNBC (1993). Soft storey level was altered from ground floor to top floor for each model and equivalent static analysis was carried away usingETABS 9.6.0 analysis package. It shows a general changing pattern in lateral drift irrespective to building height and location of soft storey. Inter-storey drift ratio was found increasing below the mid storey level and maximum ratio was obtained where the soft storey was located. The rate of increase in drift ratio at any particular floor (kept soft) for different building height increases linearly from bottom to top floor. As the building height increases, location of soft storey goes downwards from mid storey level to produce maximum lateral drift. Detailed analysis could be performed using various percentages of infill in each floor level and different orientations considering soil-foundation-structure interaction.

Md Zibran Pawaar et al (2015) studied the performance based seismic analysis of RC building considering the effect of dual systems. In this study, the buildings have been modelled as a series of load resisting elements. The lateral loads to be applied on the buildings were based on the Indian standards. The study was performed for seismic zone V as per IS 1893:2002. The frames were assumed to be firmly fixed at the bottom and the soil structure interaction is neglected. The linear-static and non-linear static analysis with different shear wall arrangements on dual systems such as flat slabs and shear walls & moment resisting frames and shear walls for different irregular plans using 9.7.4 software. The base shear for dual system model for diaphragm discontinuity was more than that of E model making E model dual system better compared to diaphragm discontinuity model.

Mohammad H. Jinya et al (2015) studied the seismic behavior of RC frame building was analyzed by performing multi-model static and dynamic analysis. The results of bare frame, masonry infill panel with outer wall opening, and soft storey has been discussed. The conclusions made in this study was infill wall (diagonal strut) change the seismic performance of RC building. Storey drift and displacement were decreased. It was suggested that the soft storey should be provided with outer masonry infill panel to increase stiffness of soft storey.

Lova Raju et al (2015) studied the effective location of shear wall on performance of building frame subjected to earthquake load. Four types of structures, with G+7 are considered in which one of the frame without shear wall and three frames with shear wall in various position. The Non Linear Static analysis is done using E-TABS v9.7.2 software. The structure was designed for Seismic zone II, III, IV and V. In pushover analysis the lateral force increase with increase in height of building. The behaviour of structure was determined including ultimate load and maximum deflection. The pushover curve was generated by plotting base shear and roof displacement. Frame with shear wall performs better and the base shear increased by 9.82% when compared to the frame without shear wall. Shear wall performs better to lateral displacement and it reduces by 26.7% when compared to the frame without shear wall.

Karwar et al (2014) conducted a performance of RC framed structure using pushover analysis. In this study, the G+8 and G+12 building as bare frame and these buildings with shear wall and infill and the building with shear wall and infill with soft storey has been considered in this study. The nonlinear analysis of a structure was an iterative procedure. The effective damping depends on the hysteretic energy loss due to inelastic deformations, which depends on the final displacement. The result shows the base shear is minimum for bare frame and maximum for frame with infill for G+8 building. For G+12 building, the base shear is minimum for bare frame and maximum for frame with shear wall. Capacity curve and plastic hinges gave an insight into the real behaviour of structures.

Lakshmi K.O et al (2014) determined effect of shear wall location in buildings subjected to seismic loads. Analysis software E-TABS 9.5 was used to create the 3D model and run the linear static and dynamic analysis. Pushover analysis was done in SAP2000 V.14.1. Eight different models were considered. Sixteen storey (G+15) residential building having ground storey height and floor height of 3m is analysed for the soil type medium. Loads were taken from IS:875 (Part 2). The load combinations considered for the analysis and design was as per IS:1893 -2002. The seismic weight was calculated using full DL+ 25% of LL. Fixed supports were provided at base. Medium high rise buildings with shear wall were found to be effective in improving the overall seismic capacity of the structure. Drift value was reduced when shear wall is provided at the corner. The reinforcement requirement in column was reduced by the location and orientation of adjacent shear walls and columns. Push over analysis results provides a detail about the performance of structures in post elastic range.

Bhatt et al (2013) performed a comparison between American and European codes on the Non Linear Static analysis of RC buildings. Non linear Static Procedures (NSP) was a performance based seismic design which behaves sensible in seismic force than a strength designed in force based philosophy. They evaluate deformation in Global and Component level. N2 and Capacity spectrum method in FEMA 440, ATC 40 and EURO 8 was used. Static pushover analysis was done on 5 storey RC building which survived without damage in earthquake (1997). The building is designed properly for shear and collapse. The building was modelled using Fibre element model in SeismoStruct software. Hysteric damping was predefined in the model while non hysteric damping was 5% of tangent stiffness proportional damping. The displacement is calculated using N2 method. The torsional effect was calculated using torsional correction factor by amplifying the displacement results. In pushover analysis, N2 method was performed by applying. Top displacements, lateral displacement profiles and inter storey drifts were determined using both methods. The CSM-FEMA440 was usually closer to the time-history. CSM-FEMA440 gives accurate procedure to calculate the target displacement. N2 method was the only method which gives the correct torsional motion of the building. Both American codes CSM-ATC40 and CSM-FEMA440 need improvements to estimate the torsional motion.

Md. Rashedul Kabir et al (2013) has determined response of multi-storey regular and irregular buildings of identical weight under static and dynamic loading in context of Bangladesh. 15 storeyed regular (rectangular, C shape and L-shape) shaped and irregular (combination of rectangular, C-shape and L-shape) shaped buildings have been modelled using program 9.6 for Dhaka (seismic zone 2), Bangladesh. The effect of static load, dynamic load and wind load was analysed. The mass of the each buildings were considered the same. Displacement due to wind load is maximum in all type of buildings. Static and dynamic analysis gives less variation in displacement. The displacement obtained from static analysis is more when compared to dynamic analysis. The displacement increases with storey height. C shaped and L shaped structure has higher displacement. Rectangular and irregular shaped structure show almost similar displacement against wind load as the total mass was constant.

Shinde et al (2012) have done pushover analysis of multi storey building. In this study, a building frame of G+10 floors has been considered. It has been consisting of two bays in both the directions. The spacing along X and Y directions was 5m and the story height was 3m. The frame was located in seismic zone III. The seismic response of RC building frame in terms of performance point and the effect of earthquake forces on multi storey building frame with the help of pushover analysis was carried out in this paper. In the present study a building frame has been designed as per Indian standard i.e. IS 456:2000 and IS 1893:2002. The design base shear of the building frame was found to be 720 KN as per calculation. After performing the analysis the base shear at performance point was found to be 915KN which was greater than design base shear. Since at the performance point base shear was greater than the design base shear the building frame was safe under the earthquake loading.

Praveen Rathod (2012) performed Non-Linear Static analysis of G+6 storeyed RC buildings with openings in infill walls. Two-dimensional seven storeyed reinforced concrete (RC) building models have been considered with of 5%, 25%, and 35% openings. Bare frame and soft storey buildings were modelled considering special moment resisting frame (SMRF) for medium soil profile and zone III. Pushover analysis as per FEMA 440 was done using SAP2000. The moment-curvature values for beam column and load deformation curve values for strut were substituted instead of default hinge values in SAP2000. Base force and displacement along longitudinal direction for all building models were obtained. When the percentage of openings increases, the base force at performance point decreases for both default and user defined hinges. The user-defined hinge models were more successful in capturing the hinging mechanism compared to the default hinge models. The default-hinge model was preferred due to simplicity.

Nitin Choudhary et al (2011) performed pushover analysis of RC frame building with shear wall. In this project, a four storied reinforced concrete frame building situated in Zone IV, was taken for the purpose of study. Euro codes EC2 and EC8 are also based on performance based design philosophy, but Indian codes were still silent over this method. FEMA-273, FEMA-356 and ATC-40 gives the detailed procedure of non-linear pushover analysis. The performance based seismic design obtained by above procedure satisfies the acceptance criteria for immediate occupancy and life safety limit states for various intensities of earthquakes. Performance based seismic design obtained leads to a small reduction in steel reinforcement when compared to code based seismic design (IS 1893:2002) obtained by STAAD.Pro.

Jaya Prakash Kadali et al (2011) conducted study on static analysis of multi-storeyed RC buildings by using pushover methodology. The frames with number of storeys 4,6, 8 and 10 all having 7 bays has been designed and detailed as SMRF and OMRF as per IS 1893 (2002). A total of 10 frames were selected by varying number of storeys, number of bays, infill wall configurations, and design methodology. The designs for SMRF buildings were done using IS13920 (2002). The storey height is 3.5m and bay width is 3m, which was same for all frames. The buildings are modelled and Pushover Analysis is performed in SAP2000. Pushover analysis is a static nonlinear procedure to analyse a building with the increase in the magnitude of loads, the weak links and failure modes of the building are found. Special Moment Resisting Frames (SMRF) were used as seismic force resisting systems in buildings to resist earthquakes. SMRF resist strong earthquake shaking without loss of stiffness or strength.The buildings designed as SMRF perform much better compared to the OMRF building. The ductility of SMRF buildings was almost 10 to 33% more than the OMRF buildings in all cases, the reason being the heavy confinement of concrete due to splicing and usage of more number of stirrups as ductile reinforcement. The base shear capacity of OMRF buildings was 7 to 28% more than that of SMRF buildings.

Riza Ainul Hakim et al (2011) performed a seismic assessment of an RC building using pushover analysis. A 6-storey reinforced concrete structure located in Saudi Arabia with a story height of 4.0 m was used in the static pushover analysis. The soil type was selected as soft rock or site class C according to the Saudi Building Code 301.The FEMA 356 rule, which was built in SAP 2000 with the IO(Immediate Occupancy), LS(Life Safety) and CP(collapse prevention) limit states for hinge rotation have been used for the acceptance criteria.Pushover analysis produces a pushover curve or capacity curve that presents the relationship between the base shear (V) and roof displacement (Δ).The structural system was designed using two methods; 1. Design based only on the gravity load and 2.Design of intermediate resisting frame (IMRF) according to SBC 301.The comparison of the pushover curve shows that the stiffness of frame was larger in IMRF (SBC301) when compared with the gravity load design.SBC design has a greater capability to resist lateral load (seismic load) than the gravity load design. The performance point location is at IO (Immediate Occupancy) level which means the structure experience light damage. The design satisfies pushover analysis according to ATC 40.

Ambrisiand M. De Stefano et al (2010): deals with seismic performance of an irregular mass-eccentric 3D RC framed structure subjected to seismic actions. . The sample structure has three double-span and six-storey plane frames and it is stiffness-regular both in plan and in elevation. Seismic response of the structure has been analyzed by performing a nonlinear dynamic analysis. In the analyses they concluded that mass centre has been shifted from stiffness centre at a distance going from zero to 15% of the relevant building plan dimension.

Md Zibran Pawaar et al (2010) studied the performance based seismic analysis of RC building considering the effect of dual systems. In this study, the buildings have been modeled as a series of load resisting elements. The lateral loads to be applied on the buildings were based on the Indian standards. The study was performed for seismic zone V as per IS 1893:2002. The frames were assumed to be firmly fixed at the bottom and the soil structure interaction is neglected. The linear-static and non-linear static analysis with different shear wall arrangements on dual systems such as flat slabs and shear walls & moment resisting frames and shear walls for different irregular plans using 9.7.4 software. The base shear for dual system model for diaphragm discontinuity was more than that of E model making E model dual system better compared to diaphragm discontinuity model.

Akshay V. Raut et al (2010) has performed pushover analysis of G+3 reinforced concrete building with soft storey. They have created the basic computer model of four storey building frame structure and define properties and acceptance criteria for the pushover hinges. The program includes several built-in default hinge properties that were based on average values from ATC-40 for concrete members and average values from FEMA-356 for steel members. With the increase in the magnitude of the loads, weak links and failure modes of the building were found. The curves show the behavior of the frame in terms of its stiffness and ductility. For bare frame, maximum base shear from pushover analysis is 951.78 KN and maximum displacement of 240.65mm in X direction. The performance point was obtained by superimposing demand spectrum on capacity curve transformed into spectral coordinates. The performance point was obtained at a base shear level of 550KN and displacement of 45mm in the X direction. Hinges have developed in the beams and columns showing the three stages immediate occupancy, Life safety, Collapse prevention. The column hinges have limited the damage.

Rajesh et al (2009) performed seismic performance study on RC wall buildings from pushover analysis. In the present work, a six-storey RC wall building is modelled by using 2D idealization and analysed using SAP2000 pushover analysis capabilities. Mender model for confined and unconfined concrete and Park model for reinforcing steel which has been available in SAP2000 were used as nonlinear material models. The curve was then superimposed on the demand imposed by the earthquake forces to assess the level of performance of the structure. The vulnerable locations to be improved with boundary elements for optimum improvement in seismic performance can be located by studying the stresses developed in concrete at the performance point. It can be concluded that the presence of openings reduces the base shear capacity of the wall significantly in walls strengthened with boundary elements. While in the walls without boundary elements presence of opening not only reduces the base shear capacity of the wall but also degrades the post yield stiffness of the wall and affects its ductility.

Abhijeet A. Maske et al (2008) conducted a pushover analysis of reinforced concrete frame structures. Pushover analysis was a nonlinear static analysis used mainly for seismic evaluation of framed building. Seismic demands are computed by nonlinear static analysis of the structure, which was subjected to monotonically increasing lateral forces with an invariant height-wise distribution until a target displacement was reached. It is also necessary for evaluating the seismic adequacy of existing buildings. The general finite element package SAP 2000 has been used for the analysis. A three dimensional model of each structure has been created to undertake the nonlinear analysis. Beams and columns were modeled as nonlinear frame elements with lumped plasticity at the start and the end of each element. When the buildings were pushed well into the inelastic range, the curves become linear again but with smaller slope. For a target displacement of 0.28m for the 5 storey building, the base shear of whole structure is 1946.3 KN which was equivalent to 1.2 times that of structure under elastic seismic design. For 12 storeys building, for a target displacement of 0.5m the base shear is 2646 KN which represents 1.55 times that of elastic base shear.

Dhanasekar (2008) carried out an investigation on the influence of brick masonry infill properties on the behaviour of unfilled frames by using a finite element model and verified the results by comparing with racking test on unfilledframes. From his test he concluded that, modulus of elasticity of the infill masonry significantly influences the load-deflection characteristics of the composite frame and influence of variations in poison's ratio and influence of the characteristics of the masonry are insignificant.

Diptesh Das et al (2008) performed five reinforced concrete frames with brick masonry infill, designed by equivalent braced frame method. Infill reduces the overall structure ductility, but increases the overall strength. The columns, beams and infill walls of the lower stories are more vulnerable to damage than those in the upper stories. Infill walls, when present in a structure, generally bring down the damage suffered by the RC frame members during earthquake shaking.

5. CONCLUSIONS

- The presence of infill wall can increase the strength and stiffness of the structure.
- Axial foe in column increased, story displacement and story drift are decreased and base shear is increase with higher stiffness of infill.
- Stiffness and strength of infilled frame is significantly high as compared with the bare frame.
- Base shear increases with the increase of mass and number of story of the building, also base shear obtained from pushover analysis is much more than the base shear obtained from the equivalent static analysis.
- Stiffness and strength of infilled frame is significantly high as compared with the bare frame.
- The finite element models presented here can accurately reproduce the load–displacement response, crack patterns, and failure mechanisms of the infilled frames.
- Infill Frame specimen while apply the loads in diagonally the cracks are formed (first crack) at the infill portion and the cracks are extended in diagonally`
- In infilled frame, failure of each of the walls is brittle in nature and is, therefore, associated with sudden drop in base shear.
- The study demonstrate that masonry infill highly increases the stiffness and strength of a structure as long as the seismic demand does not exceed the deformation capacity of the infills
- In order to obtain realistic results, the infills should be included in the mathematical model the superior performance of structures with continuously arranged masonry infills with respect to corresponding bare frames.
- Infill thickness has no significant effect on the response of frame with absence of infill in stories beyond the ground story.
- The inelastic behaviour of the infilled frames is not very sensitive to the lateral loading history but a monotonically increasing load could lead to higher peak strength than fully reversed load cycles.
- Infill thickness plays important role in collapse mechanism of frame under lateral load.
- As the thickness of wall increases, tendency of occurrence of soft-story mechanism increases
- The complexity and the cost of the analysis used herein, design framework may be envisaged, at least in the case of exceptional or particularly important structures, or for code calibration procedures.
- The finite element models presented here can accurately reproduce the load–displacement response, crack patterns, and failure mechanisms of the infilled frames
- By comparing all parameters with & without shear wall at all floor it is advisable to provide shear wall at X direction for a better performance of structure.
- Base shear increases with the increase of mass and number of story of the building, also base shear obtained from pushover analysis is much more than the base shear obtained from the equivalent static analysis.
- The rate of increase in drift ratio at any particular floor (kept soft) for different building height increases linearly from bottom to top floor.
- Inter-storey drift ratio was found increasing below the mid storey level and maximum ratio was obtained where the soft storey was located.

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