Seismic Evaluation of Existing Reinforced Concrete Building

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ABSTRACT: The recent earthquakes have exposed the vulnerability of the existing reinforced concrete buildings in India. The Bhuj earthquake (2001) saw a great deal of damage to multi-storey buildings in the urban area of Gujarat. This has posed a serious threat to the many existing Indian RC buildings which are designed mainly for gravity loads. The need for evaluating the seismic adequacy of the existing structures has come into focus following the damage and collapse of numerous concrete structures during recent earthquakes. In order to carry out seismic evaluation, a simplified procedure for evaluation is highly in need for a country like India which is prone to earthquakes. It is important to estimate the response of buildings under earthquakes from the viewpoint of life reservation and risk management. The Response Spectrum analysis procedure is applied for the evaluation of existing design of a reinforced concrete bare frame, frame with infill and frame with infill and soil effect. In order to examine the performance of these models, the Response Spectrum analysis for seismic evaluation of existing buildings is performed. After performing the analysis reinforcement required in each format is determined and retrofitting is suggested accordingly. Different retrofitting method are studied in this work. Also it is concluded that the effect of infill plays very crucial role in seismic evaluation of existing RC buildings.

Keywords— Masonary infill wall, equivalent diagonal strut, reinforced concrete, retrofitting,

1. INTRODUCTION

Amongst the natural hazards, earthquakes have the potential for causing the greatest damages to engineered structures. Since earthquake forces are random in nature & unpredictable, the engineering tools needs to be sharpened for analyzing structures under the action of these forces. India has a number of the world's greatest earthquakes in the last century. In fact, more than fifty percent area in the country is considered prone to damaging earthquakes. The northeastern region of the country as well as the entire Himalayan belt is susceptible to great earthquakes of magnitude
more than 8.0.

Fig 1: Area expose to seismic risk in Indian Classification

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During the last century, 4 great earthquakes struck different parts of the country: (1) Great Assam earthquake (1897), (2) Kangra earthquake (1905), (3) Bihar Nepal earthquake (1934) and (4) Assam earthquake (1950). In recent times, damaging earthquakes experienced in our country include (1) Bihar Nepal earthquake (1988), (2) Uttarkashi earthquake (1991), (3) Killari earthquake (1993), (4) Jabalpur earthquake (1997), (5) Chamoli earthquake (1999) and (6) Bhuj earthquake (2001) and recently occurred (7) West Bengal earthquake (2011). In all of these earthquakes there is huge loss of life and very large destruction of existing reinforced concrete (RC) buildings. Most recent constructions in the urban areas consist of poorly designed and constructed buildings. The older buildings, even if constructed in compliance with prevailing standards, may not comply with the more stringent specifications of the latest standards of IS 1893(Part 1):2002, IS 4326:1993 and IS 13920: 1993. The existing buildings can become seismically deficient since design code requirements are constantly upgraded due to advancement in engineering knowledge.

Investigations of past and recent earthquake damage have illustrated that the building structures are vulnerable to severe damage and/or collapse during moderate to strong ground motion. An earthquake with a moderate magnitude is capable of causing severe damages of engineered buildings, bridges, industrial and port facilities as well as giving rise to great economic losses.

After the Bhuj earthquake (2001) considerable interest in this country has been directed towards the damaging effect of earthquakes and has increased the awareness of the threat of seismic events. Most of the mega cities in India are in seismically active zones and are designed for gravity loads only. The magnitudes of the design seismic forces have been considerably enhanced in general, and the seismic zonation of some regions has also been upgraded. Thus a large number of existing buildings in India needs seismic evaluation due to various above mentioned reasons. Hence evaluation of existing RC buildings in India is a growing concern.

1.2 NEED FOR SEISMIC EVALUATION

It is known that damaging earthquakes are very often followed by a series of aftershocks and sometimes by other main shocks. Past earthquakes have shown that when urban areas are hit by damaging earthquakes, a significant percentage of structures attain light to moderate damage. Moreover, it is known that structures that sustained some damages prior to seismic event may collapse during a succeeding event. Such unfortunate events have claimed many lives. Therefore, these structures impose a potential risk to human life, economic assets and the environment. Thus, making decisions regarding the post-earthquake functionality and repair of the damaged structures is a critical part of the post-earthquake recovery process. Also, from the effects of significant earthquakes that has struck the different parts of country, it is concluded that the seismic risks in urban areas are increasing and are far from socio-economically acceptable levels. Therefore there is an urgent need to reverse this situation and it is believed that one of the most effective ways of doing this is through:

(1) The seismic evaluation of existing stuck off structures.

(2) The development of more reliable seismic standards and codal provisions than those currently available with their stringent implementation for the complete engineering of new engineering facilities.

Therefore, an accurate estimation of the performance of structure during an earthquake is crucial for estimating the actual effects of that earthquake on the existing RC structures.

The vulnerability of the structure can be assessed with a higher accuracy and better informed decisions can be made on the possible improvement of the seismic resistance of existing RC structures. For example, the critical components of the structure that are likely to sustain significant damages during future earthquake ground motions may be identified. Accordingly, the required immediate structural interventions may be designed to reduce the deformation demands on these components. Subsequently, the overall behavior of the structure may be improved to achieve a satisfactory overall seismic performance during a future earthquake.

2. METHODS OF SEISMIC ANALYSIS AND RETROFITTING

2.1 METHODS OF ANALYSIS

For seismic performance evaluation, a structural analysis of the mathematical model of the structure is required to determine force and displacement demands in various components of the structure. Several analysis methods, both elastic and inelastic, are available to predict the seismic performance of the structures. Following are some of the seismic analysis methods used for seismic evaluation;

1. Elastic methods of analysis
   A. Linear static analysis
   B. Linear dynamic analysis
2. Inelastic methods of analysis
   A. Nonlinear static analysis
   B. Nonlinear dynamic analysis.

2.1. Single equivalent diagonal strut models

In this method the analysis is carried out by simulating the action of infills similar to that of diagonal struts bracing the frame. The infills are replaced by an equivalent strut of length D, and width W, and the analysis of the frame-strut system is carried out using usual frame analysis methods. The relationships proposed by Mainstone Walls have to resist the shear forces that try to push the walls over.

for computing the width of the equivalent diagonal strut, is widely used in the literature and is given by.

$$W = 0.175\,(\lambda H)^{-0.4}\,D$$

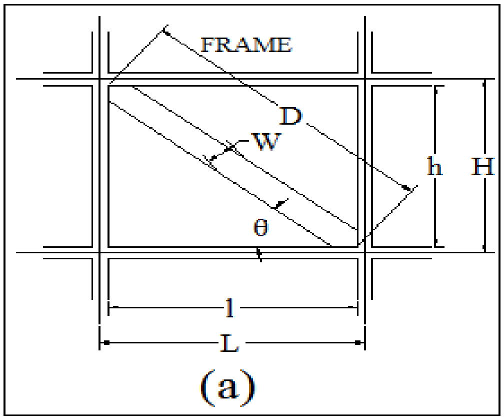

Fig 2.1 shows equivalent diagonal strut model

$$\lambda = \sqrt[4]{\frac{E_i\ t\ \sin(2\theta)}{4\ E_f I_c h}}$$

where

λ =Stiffness reduction factor

E_i = the modules of elasticity of the infill material, N/mm^2

E_f= the modules of elasticity of the frame material, N/mm^2

I_c= the moment of inertia of column, mm^4

t = the thickness of infill, mm

H =the centre line height of frames

h = the height of infill

L =the centre line width of frames

l = the width of infill

D = the diagonal length of infill panel

θ = the slope of infill diagonal to the horizontal.

Width of strut without opening (W)

$$W = 0.175\ (\lambda\ H)^{-0.4}\ D$$

Putting the value of stiffness reduction factor in above equation, width of strut has been calculated for estimation of width of strut without opening,

2.2 RETROFITTING

What is Seismic Retrofitting?
A Seismic Retrofit provides existing structures with more resistance to seismic activity due to earthquakes. In buildings, this process typically includes strengthening weak connections found in roof to wall connections, continuity ties, shear walls and the roof diaphragm. In the past, building codes were less stringent compared to today's standards, thus it is a good idea to inspect buildings constructed prior to 1998, as they were built prior to current structural codes/requirements (1997 UBC).

It is the method of strengthening of the already built damaged/ undamaged old/new structures those are found to be weak in earthquake loadings that may occur in future. Generally, structures vulnerable to earthquakes are retrofitted by means of steel jacketing, Concrete jacketing, Gaivanized steel mesh reinforcement, inclusion of new supporting walls/ concrete shear walls, Steel bracings, Fiber Reinforced polymer (FRP) Sheets or by any other suitable means.

Retrofitting works may also be necessary in a well built building if extra storeys are to be added .Also old-weak buildings can be extended after properly strengthening the older part so as to bear the increased safety demand due to the extended part.

Selection of the Proper Retrofitting Measure

Proper study of the existing structure using various analytical tools need to be carried out to identify the weak zones within the structure prior to carrying out retrofitting works. It also helps in the selection of proper retrofitting measure that should be adopted in terms of economic and safety aspects.

Building structures lying in acceleration sensitive region and velocity sensitive region of the spectrum may require different retrofitting measures. Retrofitting option suitable for one structure may prove to be inefficient for another structure with different dynamic behavior.

Also, after retrofitting, stiffness of a building structure may increased significantly, thereby increasing a load demand on the structure than before retrofitting. Increase in stiffness also depends on the type of the retrofitting measure carried out.

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Increase in stiffness also depends on the type of the retrofitting measure carried out. Conventional retrofitting measures as steel/ concrete Jacketing and inclusion of new walls are likely to increase the stiffness of the structure significantly. Thereby, altering its dynamic behavior in such re-analysis of the retrofitted structure shall be carried out Modern jacketing technique such as Fiber Reinforced Polymer(FRP) wrapping could be the best way to strengthen the capacity of structures without altering stiffness.

Besides the increment in stiffness of the structure, major repercussion in the conventional method of retrofitting could be the development of new load paths that may lead to concentration of loads at the foundation level. This happens in reinforced concrete (RC) frame structures, where inclusion of concrete shear walls in between the columns is carried out as a retrofitting measure. In such, existing foundation of the adjoining columns is likely to get overstressed.

Selection of the proper retrofitting technique shall be done by carrying out the detail analysis of the existing structure. Re-Analysis including Re-Design of the structure may be required after the introduction of retrofitting measures. So that the objective of Seismic Retrofitting is met.

Retrofitting Design Principles

Design principles, even in case of retrofitting as in case of new construction shall follow several factors.

For instance in order to have a full advantage of the potential ductility of retrofitted RC members. It is desirable to ensure that flexure rather than shear govern ultimate strength. Shear failure is catastrophic and occurs with no advance warning of distress. Many of existing RC columns and Beams have been found deficient in shear strength and in need of strengthening.

Shear Deficiencies occur due to several reasons such as insufficient shear reinforcement or reduction in steel area due to corrosion, increased service load, design principles in older codes and construction defects. As far as possible design principle in case of retrofitting shall be to improve shear. Bending, Axial & Ductile capacity of structural members & the structure as a whole. Most of the existing practices seem to provide increased confinement of the structural members-mainly increasing axial, Shear and ductile behavior. Increase in bending capacity could also be achieved if proper detailing and design principle is followed.

2.2.1 Concrete Jacketing

Concrete jacketing involves addition of a layer of concrete, longitudinal bars and closely spaced ties. The jacket increases both the flexural strength and shear strength of the column. Increase in ductility has been observed (Rodriguez and Park,1994). If the thickness of the jacket is small there is no appreciable increase in stiffness. Circular jackets of ferro-cement have been found to be effective in enhancing the ductility. The disadvantage of concrete jacketing is the increase in the size of the column. The placement of ties at the beam column joints is difficult, if not impossible. Drilling holes in the existing beams damages the concrete, especially if the concrete is of poor quality. Although there are disadvantages, the use of concrete jacket is relatively cheap. It is important to note that with the increase in flexural capacity, the shear demand (based on flexural capacity) also increases. The additional ties are providing to meet the shear demand.

There can be several schemes of providing a concrete jacket. A scheme is selected based on the dimensions and required increase in the strength of the existing column, available space of placing the longitudinal bars. To increase the flexural strength, the additional longitudinal bars need to be anchored to the foundation and should be continuous through the floor slab. Usually the required bars are placed at the corners so as to avoid intercepting the beams which are framing in to the column. In addition, longitudinal bars may be placed along the sides of the column which are not continuous through the floor. These bars provide lateral restraint to the new ties. A fie cannot be made of a single bar due to the obstruction in placement. It can be constructed of two bars properly anchored to the new longitudinal bars. It is preferred to have 135 hooks with adequate extension at the ends of the bars.

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_Fig: **Concrete Jackting**

The minimum specifications for the concrete jacket are as follows (Draft Code)

a) The strengths of the new materials must be equal to or greater than those of the existing column. The compressive strength of concrete in the jacket should be at least 5MPa greater than that of the existing concrete.

b) For columns where extra longitudinal bars are not required for additional flexural capacity, a minimum of 12mm, diameter bars in the four corners and ties of 8 mm diameter should be provided.

c) The minimum thickness of the jacket should be 100 mm.

d) The minimum diameter of the ties should be 8 mm and should not be less than ? of the diameter of the longitudinal bars. The angle of bent of the end of the ties should be 135.

e) The centre-to-centre spacing of the ties should not exceed 200mm. preferably, the spacing should not exceed the thickness of the jacket. Close to the beam-column joints, for a height of ¼ the clear height of the column. The spacing should not exceed 100mm.

3 ANALYSIS PROBLEM

3.1 STRUCTURAL DETAILS:

RC Frame Details	
1] Grade of concrete	20 N/mm^2
2] Grade of steel	415 N/mm^2
3] modulus of elasticity of concrete	22.36 kN/m^2
4] modulus of elasticity of steel	2x10^5 kN/m^2
5] unit weight of concrete	25 kN/m^3
6] Poisson's ratio	0.2
7] Sizes of beams	230x300mm,230x380mm, 230 x 450mm
8] Sizes of columns	230x300mm,230x380mm, 230 x 450mm

Brick masonry Infill Details	
1] strength of brick masonry	4 N/mm^2
2] unit weight of masonry	20 kN/m^3
3] modulus of elasticity of brick masonry(550f_m)	2035 N/mm^2
4] Thickness of peripheral wall	230mm
5] Poisson's ratio	0.15
6] Single strut model width a) along X-direction b) along Y-direction	 380,390,420,440,370,350mm 480,450,400,380,530mm
Soil Properties	
Type	Gravel
E (Modulus of Elasticity)	120 N/mm^2
Poisson's Ratio	0.15

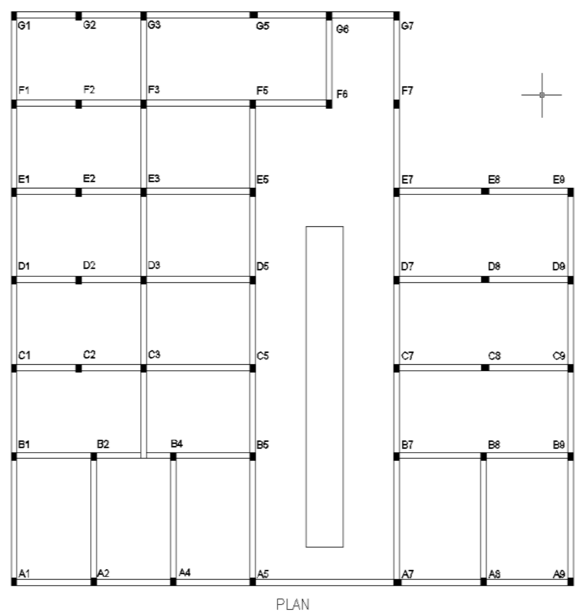

Fig 3.1: view of building.

3.2 Analytical Models

For the analysis and design purpose four model has been considered namely as

1. Bare frame (S.M.R.F infill frame with masonary effect not considered)

2.Fully infilled frame (S.M.R.F infill frame with masonary effect considered)

3. Infilled frame with centre opening (15%)

4. Infilled frame with corner opening (15%)

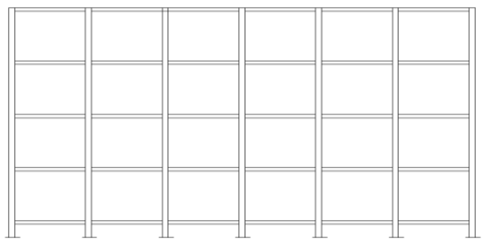

Fig 3.2: bare frame model

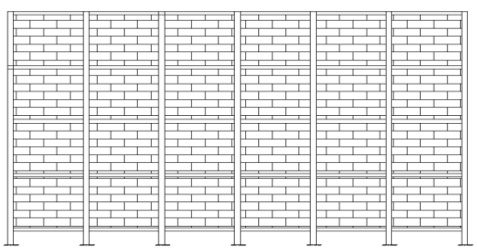

Fig 3.3: Fulley infilled frame model

The above mentioned all frame has been designed by using STAAD-Pro software.For getting results some column has been selected for getting results and they are as column no..C1,C2,C3 & C5. The results found to be are shown with the help of graph for the parameter.

1. Ast

4. COMPARISON OF RESULTS

Data of reinforcement provided to the actual building is obtained, and compared with the reinforcement required in brick infill effect model and brick infill + soil interaction effect model under seismic design. From the compression if actual reinforcement is more than the reinforcement required in the brick infill and soil interaction effect than there is no need to retrofit the actual section, it is sufficient to carry the seismic forces. But if actual reinforcement is less than the reinforcement required in brick infill or soil interaction model effect than there is need of retrofitting to the particular member. The main parameter are to be considered in the study are reinforcement of members and maximum displacement of the building.

Table:- 4.1. Reinforcement Comparison of building.

Column ID	Size (mm x mm)	Ast Pro. (mm^2)	Ast Required(mm^2)			Retrofitting Required Yes/No
			Bare Frame	Infill Wall	Soil Effect	
G.F C1	230 x 300	678	847	783	730	NO
F.F.C1	230 x 300	678	374	530	530	NO
S.F.C1	230 x 300	678	121	616	616	NO
T.F.C1	230 x 300	678	412	674	673	NO
G.F C2	230 x 380	904	No Design	903	869	NO
F.F.C2	230 x 380	904	No Design	704	704	NO
S.F.C2	230 x 380	904	No Design	477	477	NO
T.F.C2	230 x 380	904	No Design	182	182	NO
G.F C3	230 x 300	678	1145	1029	970	Yes
F.F.C3	230 x 300	678	No Design	No Design	No Design	Yes
S.F.C3	230 x 300	678	No Design	No Design	No Design	Yes
T.F.C3	230 x 300	678	No Design	No Design	No Design	Yes
G.F C5	230 x 300	678	No Design	678	660	NO
F.F.C5	230 x 300	678	No Design	670	670	NO
S.F.C5	230 x 300	678	679	440	440	NO
T.F.C5	230 x 300	678	453	179	179	NO

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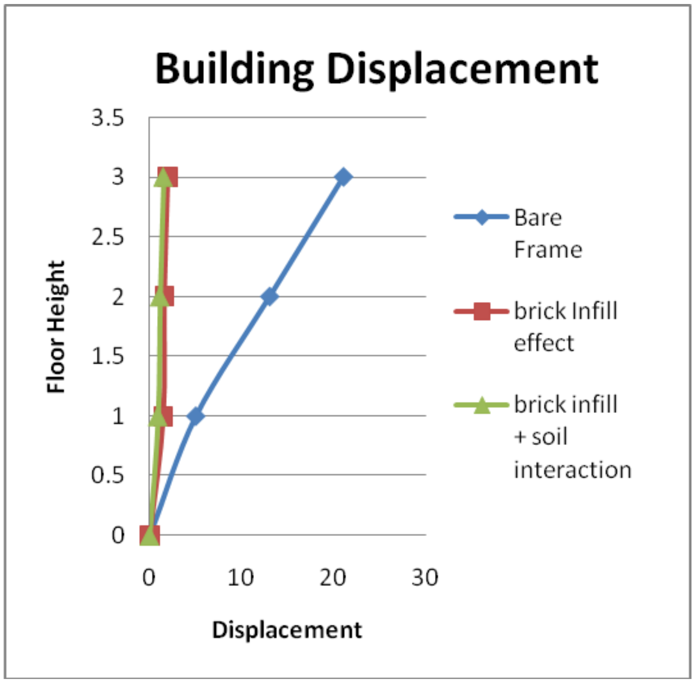

Figure No.4.1.:- Displacement comparison of building

From the above figure it is found that in Brick infill + soil interaction effect frame model deflection reduced by 90 - 92% as compared to bare frame model.

Retrofitting:

In case study building no 1 column C3 needs retrofitting. So for retrofitting, concrete jacketing method is recommended which involves additional layer of concrete of about 75 mm from all the sides, longitudinal bars and closely spaced ties.

After the retrofitting the analysis and design is done again and required reinforcement is calculated. Below table shows the reinforcement required after the retrofitting.

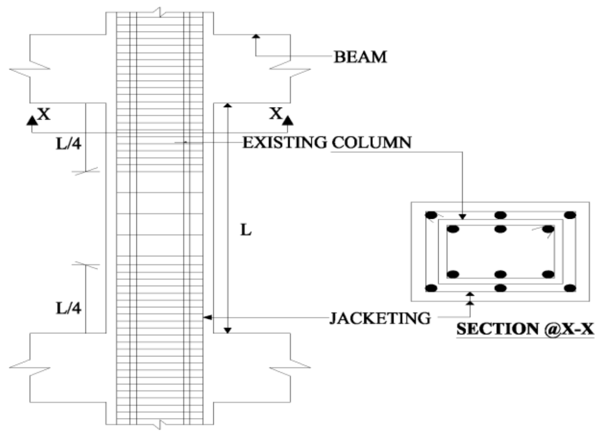

Figure No.4.2.: Column Jacketing

Table:- 4.2. Reinforcement Comparison of building After Retrofitting.

Element ID	Size (mm x mm)	Ast Provided (mm²)	Ast Required (mm²)		
			Bare Frame	Infill Wall	Soil Effect
G.F.C3	450 x 380	904+452	1041	930	870
F.F.C3	450 x 380	904+452	886	861	861
S.F.C3	450 x 380	904+452	545	345	345
T.F.C3	450 x 380	904+452	779	223	223

CONCLUSIONS:-

The whole study is concentrated on seismic evaluation and retrofitting of existing RC building. Seismic analysis is carried out for existing reinforced concrete building. The reinforcement provided in building is compared with all the three formats of modeling i. e. Bare frame modeling, brick infill frame modeling, and infill + soil effect interaction model. After all the study the following conclusions are drawn .

- It is concluded that if the strengthening is done as suggested in this thesis, the strength of the existing structure can be enhance to the required level and it will definitely improve the seismic resistance capacity of the building required for zone III.
- It is concluded that concrete jacketing method is easy, effective, and economical method for

improving the seismic resistance capacity of the member and building as well.

- Results indicate that infill panels have a large effect on the behavior of frames under earthquake excitation. In general, infill panels increase stiffness of the structure.
- From the result it is observed that due to infill effect stiffness of the frame increases and due to which comparatively less reinforcement is required as compared to reinforcement required in bare frame.
- Deflection is very large in bare frame compared to in-filled frame.
- It is concluded that about 30% to 40% less reinforcement required in building with brick infill + soil interaction effect as compare to bare frame in ground storey. And relatively less difference in reinforcement in other upper storey.
- If methodology (analyzing by considering effect of infill wall + soil effect is adopted for new constructions then it will be useful in determining the economical structural member sizes for earthquake resistance.

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