

Assessment, Analysis and Retrofit Methods of an Existing Building against Earthquake Forces

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ABSTRACT: Important structures like historical, school, hospital and other tall buildings, that were built earlier 1980^s, are probably now unsafe if checked by present seismic standards. Some of such buildings exhibit significant deficiencies in their global form or in individual members for not providing an adequate lateral resisting capacity to meet the seismic demand. Before retrofitting measures are taken, it is necessary to carryout assessment and evaluation on these buildings and identify the locations of deficiencies and distress that are found vulnerable. In the present study, an existing six storey R.C building situated in seismic zone III is chosen and analysis is carried out using existing codal provisions to calculate the additional seismic resistance required in the members or in the structure. Accordingly necessary retrofitting measures are suggested.

Recommendations are presented based on the provisions mentioned in IS 13920, IS15988 and IS 1893 codes.

KEYWORDS: Existing building, assessment, retrofit, shear and ductility.

I. INTRODUCTION

An earthquake is the vibration of the earth's ground surface caused due to movement of tectonic plates beneath the grounds surface, follows with a sudden release of energy in the crust. During an earthquake, the ground surface moves in all directions. The most damaging effects of buildings are caused by lateral movement which cause damage to the stability of the structure and ultimately leads to collapse sideways or severe damage to the structure. In India earthquake resistant design was not given its rightful significance. Generally the majority of the buildings are usually constructed to resist gravity loads, which are not ready to resist the horizontal loading. However, a successive earthquakes, beginning with the Latur earthquake in 1993, the Jabalpur earthquake in 1997 and the Gujarat earthquake in 2001, underlines the need to design and construct the structures to resist against earthquake loadings. India is a rapid developing country in its economy and also a consequent prompt development is also seen in building stock as well as stakes in business have led to greater awareness about the need to verify the safety of existing building stock and retrofit them if necessary.

Structural retrofitting of existing reinforced concrete (RC) structures is a persistently growing need due to their deterioration (environmental induced degradation, lack of maintenance, ageing and to gratify the current design requirements). Seismic retrofitting is the amendment of existing structures to make them more resistant to seismic activity during earthquakes ^[1]. The principle of seismic retrofit gradually refers to the assessment, design and then retrofit. Assessment of damage is essential in selecting appropriate retrofit method. To evaluate the damage, it is necessary to determine the extent, cause of damage and whether or not the cause is still active. Selection of a repair material must be based on the assessment of the damage, characteristics of material used and local circumstances. The design of buildings is primarily concerned with ensuring the components of the building, i.e. lateral force-resisting system. The problems in design can be condensed simply by providing adequate force and deformation capacity to

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resist the seismic demands. In this paper retrofitting of an existing building using different retrofitting techniques is presented.

II. DESCRIPTION AND MODELLING

One flat of a six storey apartment building situated in seismic zone III is chosen for evaluation, assessment and if found necessary, for appropriate retrofit methods. Assessment methods are followed according to the International codes FEMA-356 and ATC-40. Seismic analysis is carried out using IS 1893(2002) code provisions. Fig. 1 shows the beam – column layout of the building. The dimensions and specifications of the building elements are given in table 1.

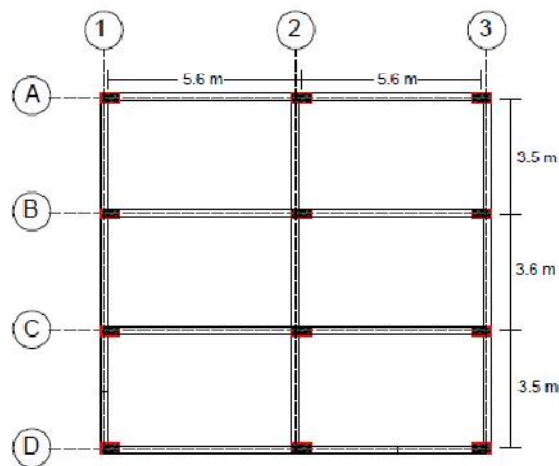


Fig. 1. Beam-column layout of building

Table 1 Dimensions and specifications of building elements

Name of the element/ property		Description
Characteristic compressive strength of concrete for	(a.) Column	25 N/mm ²
	(b.) Beam and slabs	20 N/mm ²
Yield stress of steel bars		415 N/mm ²
Unit weight of R.C.C		25 kN/m ³
Unit weight of masonry		19 kN/m ³
Cross section of Column		(0.3 X 0.6)m
Cross section of Beam		(0.3 X 0.45)m
Slab thickness		0.125 m
Exterior wall thickness		0.23 m
Interior wall thickness		0.115 m

Initially, analysis is carried out for gravity considering the following dead and live loads:

- Live load on floor = 4.00 KN/ m²
- Live load on terrace=1.50 KN/ m²

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- Floor finish = 1.0 KN/ m²
- Terrace finish = 1.5 KN/ m²

The axial loads and bending moment values under gravity load analysis are presented in table 2. Seismic load analysis is also carried out using seismic coefficient method mentioned in IS 1983 (2002) code and the values are presented in table 2.

Table 2. Comparison of critical beam moments

Critical column		Axial load (kN) due to		Moment (kN-m) due to		Additional moment due to seismic	Additional steel required for retrofit
		Gravity load	Seismic load	Gravity load	Seismic load		
Corner	A ₂ &D ₂	962.05	958	10.54	85.26	74.72	2892mm ²
Middle/ Exterior	B ₁ , B ₃ , C ₁ & C ₃	915.65	855	40.4	574.66	534.26	

Table 3. Comparison of critical beam moments

Critical beam	Moments due to		Additional moment due to seismic load	Additional steel required for retrofit
	Gravity	Seismic		
A ₂ B ₂	27.79	149.19	121.4	2286mm ²
B ₂ C ₂	27.08	205.24	178.16	
C ₂ D ₂	19.69	149.19	129.5	

III. ASSESSMENT OF DAMAGE AND EVALUATIONS

It is important to assess the condition of the building before any retrofit methods are taken up. Evaluation determines whether a deteriorated building be demolished or retrofitted keeping in view its cost-effectiveness and overall safety. The assessment procedure involves in two stages:

1. VISUAL INSPECTION:

- Collection of information – Building data with respect to structural and constructional drawings, vulnerability, number of stories, year of construction, seismicity and codes followed earlier etc.
- Condition of the building – Identification of structural damages such as cracking, spalling, quality of construction, lateral load resisting system, load path, maintenance, corrosion, recent retrofit measures and modifications.

2. DETAILED INVESTIGATION:

In case construction drawings and structural details are not available, detailed investigations have to be conducted. Properties of materials like concrete and steel can be obtained by conducting non-destructive testing (NDT) in the field and laboratory. With the assessment analysis, safety of the building can be evaluated to recommend retrofitting/ strengthening measures.

The assessment report on visual and detailed inspection is presented table 4 as follows

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Table 4. Visual inspection assessment report

S.No	Structural component	Place / Position	Status/ Condition	Method of retrofit
1	Column	Corner	Minor cracks and spalling of small portions of concrete due to corrosion of steel bars are observed	Column jacketing on four sides of existing column in cellular floor column, jacketing on two sides of middle exterior columns in other floors
		Exterior/ middle	Minor cracks are observed at junction of beam – column joint	
		Interior	No defects are observed	
2	Slab	Terrace	Leakage problem exists during rains, minor superficial cracks at top surface of slabs	Retrofitting is not required
		Other floors	No symptoms of cracks	
3	Beams	Terrace	Minor cracks are observed at beam column joint	Beam jacketing at roof and cellar floor levels
		Other floors	In cellar floors cracks are observed in beam- column joint and at middle of the beam	
4	Walls	Interior	Shear diagonal cracks are observed	In cellar floor periphery columns may be connected with R.C shear walls
		Exterior	Tension and diagonal cracks are observed	

IV. SELECTION OF RETROFITTING TECHNIQUES

Numerous seismic retrofit techniques are available, depending upon the type and condition of structure. Therefore, the selection of the type of retrofit technique is a complex process, and is governed by technical as well as financial and sociological considerations.

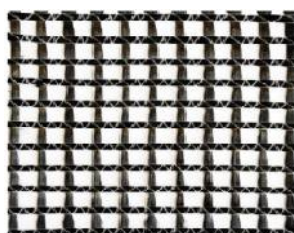


Fig. 2. Geometry of carbon textile



(a)



(b)

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Fig. 3 Process of application of FRP jacketing (a) Cracked beam (b) Beam with grid of grooves (c) Impregnation of the textile fibers with epoxy resin (d) Addition of extra layer of mortar

DESIGN OF RCC BEAM JACKETING AS PER IS 15988:2013

Width (b) = 300 mm, Depth (D) = 450 mm

f_{ck} by NDT = 20 N/mm², f_y = 415 N/mm²

Ultimate Moment (M) = 85.3 kN-m (for gravity) and 205.24 kN-m (for seismic)

The beams designed for the structure are designed to resist gravity loading and are provided with a reinforcement of 4 bars with 10mm Ø gives 316mm².

But when the beams are designed to resist lateral seismic forces, the reinforcement to be provided to resist the seismic forces is,

4 bars of 20mm Ø and 2 bars of 16mm Ø at top gives 1658mm² and

2 bars of 16mm Ø and 2 bars of 12mm Ø at bottom gives 628mm²

The total reinforcement to be provided is 2286mm².

Reinforcement deficiency = 2286-316 = 1970mm²

Provide 8 bars of 20mm Ø gives 2513mm².

Minimum thickness to be provided for jacketing is 100mm. So, provide 100mm thickness.

Therefore revised jacketed section of the beam will be (500 x 650) mm

Provide a shear reinforcement using 2 legged 8mm ϕ bars

Spacing Required:

1. $d/4 = 412/4 = 103\text{mm}$
2. $0.75 d = 0.75 \times 650 = 457.5\text{mm}$
3. 300mm
4. $S_v = \frac{0.87 \times f_y \times A_{sp} \times d}{V_d} = \frac{0.87 \times 415 \times 100.5 \times 412}{115.99 \times 10^{-3}} = 128.88\text{mm}$

Take minimum of above value

Provide 2 legged 8mm ϕ stirrups @100mm C/C.

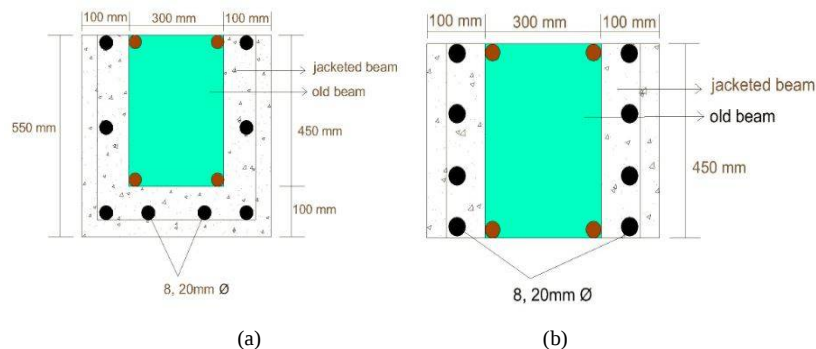


Fig. 4 Revised retrofit beam section (a) with 3 sides reinforced beam (b) with 2 sides reinforced beam

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COLUMN JACKETING

Jacketing of existing columns with new reinforced concrete, steel or fibre wrap overlays can be carried out. The new materials shall be selected and constructed to act compositely with the existing concrete. When reinforced concrete jackets are used, the design shall provide detailing to enhance ductility^[5].

When corrosion in the reinforcement steel bars was found, the following steps should be carried out:

- Remove the concrete cover.
- Clean the steel bars using a wire brush.
- Coat the steel bars with an epoxy material that would prevent corrosion.

If there was no need for the previous steps, the jacketing process could be done by the following steps:^[1]

- Adding steel connectors into the existing column in order to fasten the new stirrups of the jacket in both the vertical and horizontal directions. The connectors are added into the column by drilling holes 3-4mm larger than the diameter of the used steel connectors and 10-15cm depth.
- Filling the holes with suitable epoxy resin material then inserting the connectors into the holes.
- Adding vertical steel connectors to fasten the vertical steel bars of the jacket following the same process in above two steps.
- Installing the new vertical steel bars and stirrups of the jacket according to the designed dimensions and diameters.
- Coating the existing column with a suitable epoxy material that would assure the bond between the old and new concrete.
- Before the epoxy material dries, pouring of concrete to the jacket should be completed. The concrete used should be of low shrinkage and consists of small aggregates, sand, cement and additional materials to avoid shrinkage.

DESIGN OF RCC COLUMN JACKETING AS PER IS 15988:2013

Height of Column = 3 m, Width (b) = 300 mm, Depth (D) = 600 mm,

Ultimate Axial Load (P) = 1289.4 kN (for gravity) and 1254 kN (for seismic),

Ultimate Moment (M) = 40.4 kN-m (for gravity) and 202.53 kN-m (for seismic),

Concrete grade by NDT = 25 N/mm²

The columns in the building are designed to resist gravity loadings, reinforcement provided with 8 bars of 16mm ϕ = 1608mm².

When the same building when designed to resist lateral earthquake forces, reinforcement to be provided is 10 bars of 25mm ϕ = 4500mm².

Reinforcement deficiency = 4500 – 1608 = 2892 mm².

But as per IS 15988:2013 code,

Area of steel for jacketing = $(4/3) A_s = (4/3) \times 2892 = 3856 \text{ mm}^2$

Hence provide $A_{s1} = 3856 \text{ mm}^2$, i.e.; 8 bars of 25mm ϕ gives 3926.9mm².

Minimum thickness to be provided for jacketing is 100mm. So, provide 100mm thickness.

Therefore revised jacketed section of the column will be (500 x 800) mm

Design of lateral Ties

Dia. of bar = $\frac{1}{4}$ of ϕ of largest longitudinal bar = $\frac{1}{4} \times 25 = 6.25 \text{ mm}$ take 8mm

Spacing of bar

1. Least lateral dimension = 230mm
2. 200mm
3. $16 \times \phi$ of smallest longitudinal reinforcement = $16 \times 16 = 256 \text{ mm}$
Provide 8mm ϕ @ 200mm C/C spacing.

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VI. CONCLUSION

Since slabs are parallel to earthquake forces generally, they need not to be strengthened. However, columns and beams which were not designed for lateral loads like earthquake forces are more vulnerable against earthquake forces since shear forces will be induced in these elements for which it was not designed. Hence, generally columns and beams are to be retrofitted. R.C.C retrofitting technique enhances the axial load and moment carrying capacity in column. In addition to this, application of TRF jacket increases the performance levels against lateral loads.

In order to mitigate the seismic risk associated with the existing building, the currently developing strategies and implementation of retrofit techniques are employed to enhance performance levels. An integral part of the overall seismic risk is to evaluate and apply innovative technologies such that the building can be retrofitted in a cost effective manner. The proper use of these emerging technologies in building retrofit will be less intrusive to building occupants and cost effective.

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