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ANALYTICAL STUDY ON PERFORMANCE OF BRICK INFILLED RC FRAME SEISMIC RETROFITTED WITH FIBRE REINFORCED POLYMER

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ABSTRACT

In India, brick masonry infill is widely used in RC frame for partitions. They are good in carrying vertical loads but the lateral load carrying capacity of brick masonry infill is very low. This results in out-of-plane failure of masonry wall under seismic loads which in turn results in maximum loss of life and structure during earthquakes. Therefore, increasing the lateral load carrying capacity masonry infill not only increases the stability of structure but also the loss of life in earthquake phenomena gets decreased. In this study, a 3-storey 2-bay RC frame is considered and an attempt is made to increase the lateral stiffness by using CFRP sheet. Three different strategies of wrapping the structure are considered. (i) CFRP sheet wrapped around structure with fiber oriented in vertical direction, (ii) CFRP sheet wrapped around structure with fiber oriented in Horizontal direction, (iii) CFRP sheet applied on structure in cross pattern. The main objective of this study is to increase the lateral stiffness of the RC structure under seismic loads and prevent the out-of-plane failure of brick infill by using above three retrofitting schemes. The nonlinear response history behaviour of the masonry infilled RC frames under the 1979 El Centro earthquake was simulated using discrete finite element analysis with the damage based cohesive crack modelling technique in ABAQUS. The analysis indicated that the retrofitting strategies increase the stability of structure under lateral loads. Furthermore, the analysis revealed that among the three retrofitting strategies CFRP sheet wrapped around structure with fiber oriented in vertical direction is best suited. While considering the economy, the CFRP sheet applied on structure in cross pattern is effective solution to the problem.

KEYWORDS: *Seismic Retrofitting, FRP, URM, Brick Infilled RC Frame, ABAQUS etc*.

I. INTRODUCTION

The topic of seismic retrofitting of existing reinforced concrete building with unreinforced masonry (URM) has gained attention in recent years to increase the strength, stability and stiffness of building. Furthermore the widespread damage of older buildings in Gujarat during Bhuj earthquake lead to increased focus on this topic in India. Seismic retrofit is the upgradation of existing structure to enhance the performance level so that it fulfills the requirement of current seismic design codes. Unreinforced Masonry is strong in carrying gravity load but weak in resisting lateral loads which lowers the seismic performance of the building. The reason behind this is mortar joint are strong in compression while weak in carrying tension. This out of plane failure is one of the major disadvantages of URM building which leads to maximum degradation of structure and has huge loss of life during earthquakes. That is why, to increase the seismic performance of the building lateral load carrying capacity of structural members specially, URM should be increased. To increase the overall performance of reinforced concrete building infill wall plays an important role if properly tied to surrounding frame. Most reinforced concrete (RC) frame buildings in developing countries are infilled with masonry walls. Masonry infills in reinforced concrete buildings cause several undesirable effects under seismic loads because of which seismic codes tend to discourage such constructions in high seismic regions. However, in several moderate earthquakes, such buildings have shown excellent performance even though many such buildings were not designed and detailed for earthquake forces.[1]It is obvious from experience that structures which had not been designed and constructed according to standard codes, and therefore do not have enough lateral stiffness, will undergo severe damages during intense earthquakes. One of the most important factors contributing in structural destruction is insufficient lateral stiffness. As an effective rehabilitation technique, strengthening unreinforced masonry (URM) infills with fiber reinforced polymer (FRP) can improve their contribution in load-bearing action and in doing so, they can be considered as a structural element.[2]There are many seismic retrofitting options for enhancing the seismic performance of existing structure, designed and constructed prior to 2002, which enable the building to meet present day seismic design requirements in accordance with IS 1893 (Part 1) : 2002. The seismic upgradation of building can be carried out by two methods namely local retrofit or member level retrofit and global retrofit or structural level retrofit.

1.1 Global method

This technique enhances the lateral resistance of structure as a whole. Generally structural level retrofit include the addition of shear walls, Steel braces, base isolators and Energy Dissipators which results in seismic upgradation of structure as a whole.

1.2 Local method

This technique enhances the ductility of structural element which thereby increases the lateral stability of the structure. This can be done by jacketing either Steel plates or fibre reinforced polymer (FRP).

In India, unreinforced masonry is a common practice. The effective bonding of masonry wall with surrounding frame governs the behaviour of structure as a whole. Sometimes dowel bars are used as connecting member between column and unreinforced masonry walls which increases the stiffness and stability of structure during seismic hazard. Basically, there are 2 failure modes.

1. Corner crushing failure mode of masonry infill - Crushing of infill at one of its corner is known as corner crushing mode. This type of failure generally occurs where the masonry infill is less strong than mortar joint. Hence, this type of failure is also known as strong joint weak member failure.

2. Sliding shear failure mode of masonry infill- Horizontal sliding shear failure occur through the bed joints of masonry infill and is known as sliding shear failure. This type of failure generally occurs where the mortar joint is less strong than masonry infill. Hence, this type of Failure is also known as strong member weak joint failure.

Un-reinforced masonry buildings are designed and constructed to withstand gravity loads which results in challenging engineering problem seismic disaster mitigation. Earthquake resistance of the structure depends on energy dissipation potential such that it can undergo large but controlled inelastic deformation in the event of design earthquakes. In case of URM, a grid of horizontal, vertical or diagonal elements, break a large wall into smaller wall area and confine them. These structures respond to the stress of the earthquake by working along the joints between infill and confinement elements. The straining and sliding of confining elements dissipates a significant amount of energy during earthquake.[3]Retrofitting techniques using FRP sheets results in increase of stiffness as well as ultimate load carrying capacity of structure by avoiding the undesired failure modes. In our study, FRP sheets are used for seismic enhancement of the structure.The common failure which are seen in RC buildings are due to inadequate share capacity, Core confinement, rebar splicing of columns, rebar Anchorage, inadequate confinement of beam to column joints and plastic hinge rotation capability of beams. The presence of soft story, in plane discontinuity, out of plane offset of ground floor columns and eccentric mass are commonly observedirregularities in RC buildings. [4]The failure of FRP sheet wrapped on surface is by bond i.e. the interface between substrate and FRP is very important as the failure of bond makes the FRP sheet useless[5].ABAQUS, finite element based software, is well suited for Linear as well as nonlinear analysis of structures. It is widely used in Automotive and Aerospace applications. Moreover, it has importance in academics and Research Institutes due to the material modelling capability of the software. ABAQUS offers library of cohesive elements to model the behaviour of adhesive joints, interfaces in composites, Rock fractures and many other situations where the strength and integrity of interface may be of interest.Moreover, mortar joint influence the behaviour of masonary infill. Hence, it should be accurately modeled using FE based software ABAQUS by Traction-separation law.

II. SYSTEM DEVELOPMENT

The reinforced concrete frame of 2-bay 3-storey as considered in the study is assume to be fixed at the bottom. The column and beams of the frame are modelled using eight nodes 3D solid element (C3D8) element while the reinforcement is modelled using two-noded 3D truss element (T3D2) embedded in the concrete surface. This means that the Steel nodes follow deformation of the concrete nodes. Meshing of the model is applied with maximum mesh size for frame members and steel reinforcement not greater than 100 mm. Similarly, masonary infill is modelled using eight-noded, 3D solid elements (C3D8) as micro modelling.Strength of mortar joint is often comparatively lower than masonary unit in masonry infill walls. Hence the step down cracking pattern is often developed along the joints when infilled frame is subjected to in-plane lateral loads. Cracking of mortar joint leads to stiffness degradation of the infill wall and has the significant effect on the contact forces of the infill to frame interface. Hence, the accuracy of modelling the pre- and post-fracture behaviour of mortar joints determines the reliability of the simulation. To model the crack propagation in the infill wall, the discrete modelling approach is adopted with the enforcement of damage based cohesive interaction on the contact surface of masonary units. A distinct approach for modelling the mortar joint is used in the analysis, where no mortar element is inserted between the masonary units, whereas the cohesive interactions with the finite sliding formulation are enforced on the contact surface of masonary units. The model is implemented in ABAQUS through the user subordinate for traction separation behaviour in general contact simulation. The post fracture behaviour of contact surface for brick units follows the coulomb friction law. Interaction of masonry infill and bonding frame is incorporated using contact interaction enforced between contact surfaces. The contact properties follow coulomb friction law with the friction angle of 28° and are enforced by the penalty method. The concrete material is modelled as concrete damaged plasticity model (CDP). This model takes into account the degradation of the elastic stiffness induced by the plastic strain in both in tension and compression. It also account for stiffness recovery effects under cyclic loading. The compressive behaviour is elastic until initial yield and then is characterized by strain hardening followed by strain softening after the ultimate. After the onset of micro cracking the response is softened inducing strain localisation in the concrete structure. In tension behaviour the stress strain relationship is assumed to be linear until the failure stress, which corresponds to the onset of macro cracking. This is very often followed by softening which induces strain localisation.

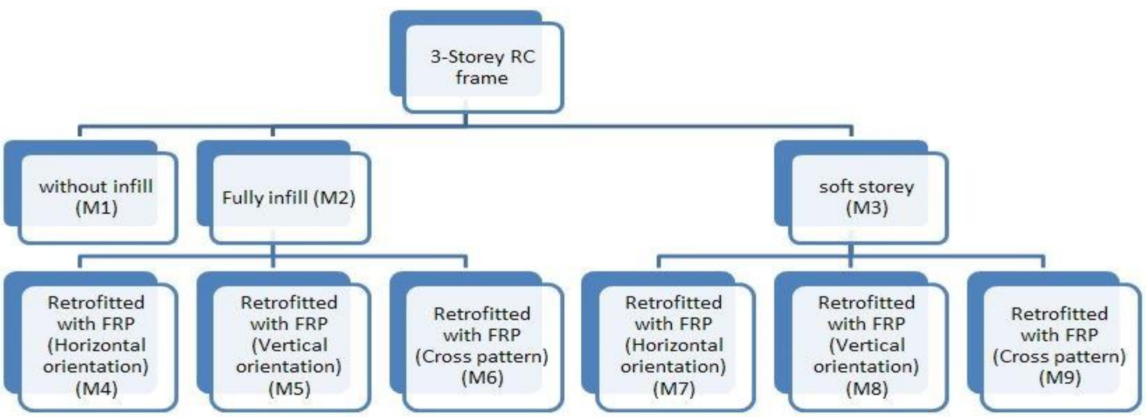


Fig. 1: Flowchart of Proposed Work

The damaged elasticity is Defined by scalar parameter that describe the recover damage that occurs during tensile cracking and compressive crushing under cyclic loading as-

$$\mathbf{E= (1\text{-}d)\, E_o}$$

Where, E_o is the initial modulus of elasticity and E is the damaged modulus of elasticity. The Steel reinforcing bars are considered as elastic perfectly plastic materials in both tension and compression. Furthermore, the bond between CFRP and RC frame with masonary infill walls is of great importance. ABAQUS offers the library of cohesive elements to model the behaviour of adhesive joints. The element used for cohesive Bond is two dimensional 4 noded (COH2D4). The model was analysed under earthquake excitation, Subjected to ground motions, the resulting hysteresis loops (showing base-shear against top drift) of the structures are plotted. The nonlinear response histories of the infilled frames are analysed in the context of realistic earthquake. The earthquake record adopted in this analysis is 1979 El Centro 1140-component at USGS-station 5056 (PGA = 0.14 g). The nonlinear time history results of the frame with infill are regarded as the baseline data for investigating the effect of different retrofitting strategies on the structural behaviour of RC frames.

The following procedure was adopted for modelling of RC frame structure with brick infill retrofitted with FRP[6]-

Step 1: Create parts. For example, to create concrete beam use solid 3D element and specify its appropriate size. Similarly, create reinforcement using wire elements of 2 noded truss type, brick masonary using solid 3D elements and FRP sheet using planer 2D element.

Step 2: Define materials. For example, define concrete material by incorporating the density, elasticity, plasticity, compression behaviour and tensile behaviour. The plasticity for concrete is well defined by concrete damage plasticity model. Similarly, the material property of Steel such as mass density, elasticity and plasticity are defined. Thereafter, material property of brick masonary is defined by density, elasticity, plasticity, compressive behaviour and tensile behaviour. Finally, the material property of unidirectional fibre reinforced polymer sheet is established by orthotropic property of material. The stiffness of FRP in relative directionis specified.

Step 3: Create and assign section. The concrete element and brick masonary element defined as solid element are homogeneous in nature. Hence, homogeneous section is defined and assigned to concrete element as well as brick masonary element. The Steel element which is defined as wire element is firstly assigned a circular cross section of required diameter and then assigned the homogeneous section similar to prior assignment. The section for FRP sheet is defined as shell Homogeneous. The 2D planer element of FRP is then assigned with this section property of shell Homogeneous section.

Step 4: Create assembly. Assembly means to assemblage different structural component in one workbench i.e. the predefined instances such as concrete, steel, brick masonary and FRP sheets are selected and brought into one workbench. All the instances are linearly patterned and the required numbers of instances are produced on one workbench. By rotating and translating the instances the proper assembly of G + 2 is constructed by giving a proper concrete cover to steel reinforcement. Brick masonry infills are placed wherever required. FRP sheet is placed where out of plane failure of brick masonry infill is to be avoided.

Step 5: Define constraints. As rebar is embedded in the concrete section, constraint is applied between concrete and rebar section to be embedded. This constraint helps to behave total RCC member as a one unit while modelling in ABAQUS. Similarly, a tie constrain is adopted between column and beam joint and column to column joint to behave the joint monolithically.

Step 6: Define step. The type of analysis to be performed is based on the type of step chosen. In our study dynamic explicit step is taken into consideration.

Step 7: Apply boundary conditions. The bottom of the column is considered as fixed. As weight of masonary makes the infill wall stable, while modelling the bottom of the brick masonary is considered to be fixed.

Step 8: Apply interaction. Interaction between surrounding frame and masonary wall is not a firm contact and hence is enforced by coulomb friction law having fiction angle of 28°. The brick to bricks interaction is defined by traction separation law for cohesive cracking. A distinct approach for mortar joints is adopted where no mortar element is inserted between the brick units. Cracking of mortar joint leads to degradation of the stiffness of the brick infill wall.

The macroscopic traction-separation and fracture behaviour of mortar joints by using the contact formulation rather than cohesive elements, the element distortion can be controlled and hourglass deformation modes are not necessary. The traction-separation law for cohesive cracks considering the mixed-mode fracture behavior of mortar joints is

$$\mathbf{t = (1\text{-}D)K_e[u]}$$

Where, t and [u] is the traction and displacement jump vector between two masonry Unit surfaces, respectively, Ke is an initial isotropic elastic stiffness tensor; and D is a Scalar damage parameter of value within [0,1].

For modelling the interaction between FRP and brick infill masonary a similar approach of cohesive zone modelling is used.

Step 9: Mesh the model. The mesh at the joint and at the critical junction of stresses should be kept finer than that of other locations.

Step 10: Create field output request. The field output request considers the output or the results to be required after the analysis. Stress, strain, displacement, base shear, lateral drift, etc. as required are selected from the list.

Step 11: Create job and submit analysis. In this step, the unique job name is to be used for the model and submitted for analysis. ABAQUS uses iterative Newton-Raphson numerical method for analysis of model.

Step 12: Result and Analysis: ABAQUS is a powerful tool, as it gives directly the graph between any two entities as selected. The direct relation between any two quantities is plotted and results are obtained.

III. RESULTS AND DISCUSSION

For the frame subjected to seismic loads, the beam-sway mechanism is the most desirable failure mechanism because the earthquake induced vibration energy can be stably dissipated in designated and well confined region, i.e. beam ends and column bases. Thus, the columns, which serve as the most important structural component to support buildings, are protected from severe damage during an earthquake. The red colour indicates the location of plastic hinge in the model. The level of cracking strain developed in that region is indicated by different colours in the legend with least cracking strain indicated by grey colour as shown in figure 2.

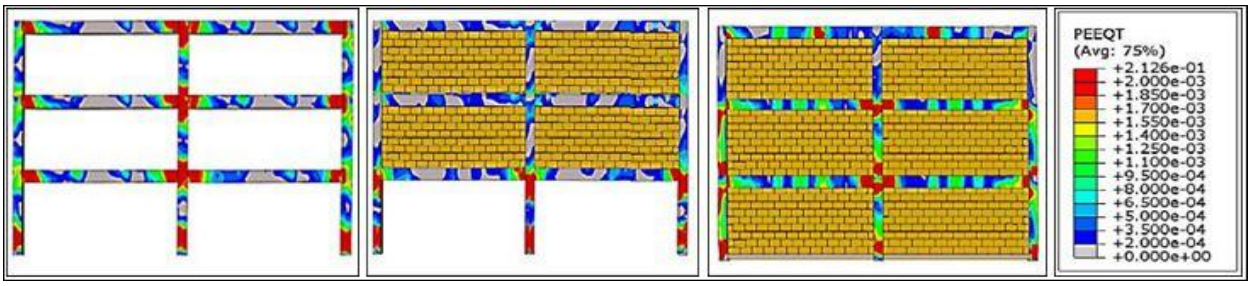


Fig. 2: Comparision ofCracking Strain at Peak Response

In contrast to the bare frame, the fully infilled frame exhibit localized damage. Although the fully infilled frame has regular and symmetrical arrangement, the first-storey columns still suffer unavoidable severe damage as shown in figure 2. This damage is due to the brittle failure of the infill panel because lower storey generally bears stronger seismic actions, the brittle infills in this storey often cracked first. Infill cracking immediately causes a decrease in the overall stiffness and strength of the corresponding storey due to the damage of the compressive struts running along the infill panels. The resulting stress redistribution and possible soft-storey effect incur larger deformation to the storey, with seriously cracked infill panels, as observed for the first storey. Undesirable localised damage and failure modes are observed in the structures with vertically discontinuous infills. Due to the abrupt change in the vertical distribution of the lateral stiffness and the strength of the structure, the non-infilled first storey becomes a soft storey. As a result, an undesirable column-sway failure mechanism occurs in the structure subjected to earthquake excitations, in which plastic hinges, with some concrete crushing, are mainly formed in the column ends in the first storey. By contrast, the infills restrain the deformation of the upper storey, and thus little damage is incurred in the upper storey. The column-sway failure mechanism is very dangerous for structural stability because the vertical bracing strength will be significantly reduced following the localised damage of the columns supporting the weight of the upper storey.

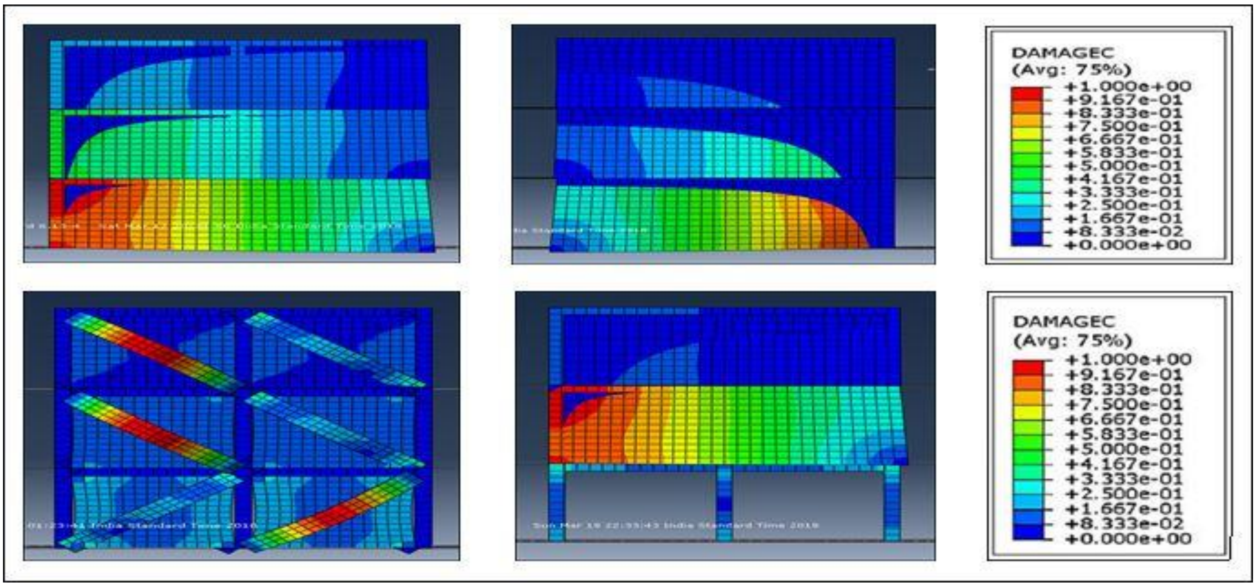
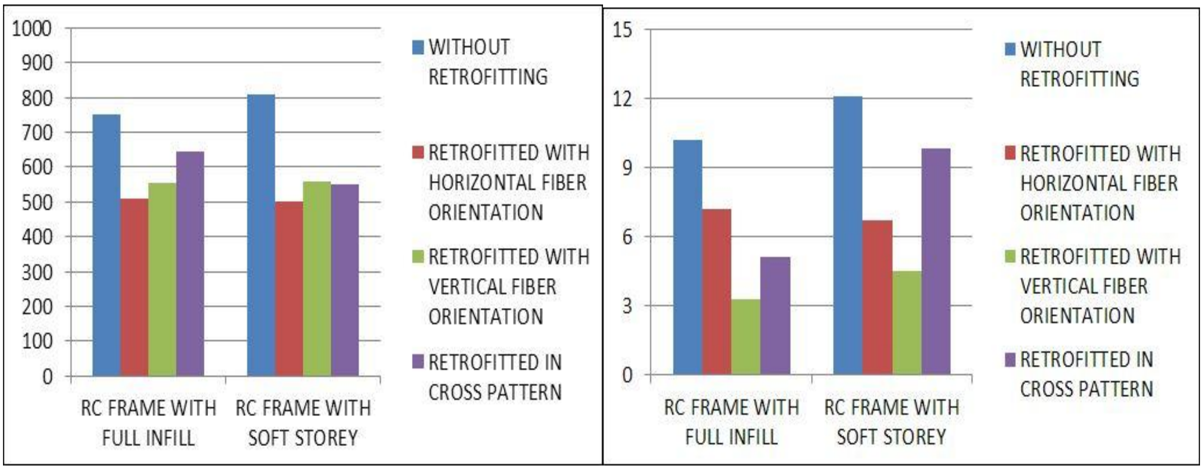


Fig. 3: Failure Patterns of Different FRP retrofitting schemes

The failure of CFRP is due to the bond failure at the interface. Figure 3 shows debonding failure of CFRP sheets.Wrapping of CFRP on structure in vertical orientation proved to be best scheme among the three strategies adopted for study. Due to wrapping of FRP on structure the lateral stability get increased highest for CFRP with vertical orientation followed by cross pattern and then by horizontal orientation. The comparative study of three is given in figure 4.



(a) BASE SHEAR (b) TOP DRIFT

Fig 4: Comparision of Base Shear and Top Drift for Different Model

IV. CONCLUSIONS

The seismic behavior of RC frame with different infill configuration and retrofitting strategies as studied lead to the following conclusions:

1. Irregular arrangements of infill walls incur serious stress and damage localisation.
2. Abrupt changes in the vertical stiffness of the infilled frame with a soft first storey lead to concentrated damage of the soft-storey columns, reducing the load carrying capacity.
3. The sudden drift due to lateral loads gets drastically reduced due to retrofitting scheme adopted thereby preventing out of plane failure of masonary blocks.

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