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SEISMIC RETROFIT AND STABILITY EVALUATION OF RC FRAMES WITH LINKED COLUMN FRAME

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Abstract – Due to the recent earthquake, the need for retrofitting and renovation is essential for existing structures. Nowadays, various methods have been applied to the local and general retrofitting of RC frames. In this paper Finite element analysis of RC frame retrofitted with the LCF system were done using ANSYS workbench 2021 R2. In this, analysis of various models of LCF link beam and comparison of external and internal retrofitting and replacement of steel link column with CFST link column is also performed. In this project, the design of LC frame members for retrofitting of RC frame using proposed simplified equations are investigated.

***Key Words*:** LCF, Retrofitting, CFST link column

1. INTRODUCTION

Due to the recent earthquakes, the need for retrofitting and renovation is essential for existing structures. After the 1994 Northridge Earthquake and the 1995 Kobe, the observations of significant damage to structures in these earthquakes, the seismic design of the structures were changed fundamentally. Codes divide the possible damages based on the importance of the building and its efficacy after the earthquake. Nowadays, various methods have been applied to the local and general retrofitting of RC frames. Several methods are used to retrofit the RC structure, such as the concrete jacket or steel jacket, Fiber Reinforced Polymers (FRP),adding steel bracing, adding concrete shear wall or Steel Plate Shear Wall, adding dampening and the new method retrofitting using the LCF system.

This structural system consists of a steel frame (LC) with replaceable link beams which acts as a fuse element to increase the seismic performance. Recently, some researchers have developed application of the structure with replaceable components. The replaceable components called "Replaceable Fuse" or "Replaceable Link". The fuse acted as a "weak link" where the inelastic deformation concentrated, whereas the remaining the main structural system remained elastic phase. The fuse acted as a "weak link" where the inelastic deformation concentrated, whereas the remaining the main structural system remained elastic phase. The using of replaceable fuse members is easily replaceable due to their ductile behavior and able to protect the main structural members and restrain their damage in them. The LCF structural system consists of the main lateral load bearing systemof the structure called the Linked Column (LC) frame and the secondary structure system is Moment Resisting (MF) frame which in addition to resisting lateral loads, also acts as gravity load bearing system. Fig.1 shows a general view of the LCF system. This structural system consists of a steel frame (LC) with replaceable link beams which acts as a fuse element to increase the seismic performance.

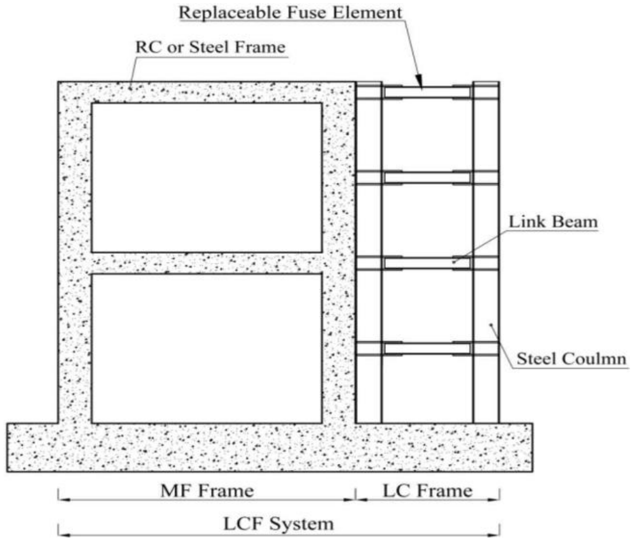

Fig1

The LC frame is made up of two closely spaced columns interconnected by replaceable link beams interconnected. The replaceable link beams of LC frame first provide the initial stiffness of the system, and then energy dissipation due to yielding and cause the displacement and ductility in the building to be increased.

In this project, the design of LC frame members for retrofitting of RC frame using proposed simplified equations are investigated. For this purpose, an experimental study is performed to investigate the behavior of the LCF system for retrofitting RC frame. The test specimen sections of the LC frame are designed based on the proposed simplified equations and interaction of the RC and LC frames. Then two large-scale numerical models of 3- and 6- story, 3-bays RC frame retrofitted with the LCF system are used to investigate the proposed equations. The purpose of this experimental and numerical study is to investigate the proposed simple equations for designing LC frame sections for RC frame retrofit. Thus, the plastic hinges are first formed in the link beam and then in the columns of the LC frame. The formation progress of these plastic hinges must form at the Rapid Repair (RR) performance level so that during strong earthquakes most of the dissipated the seismic energy occurs on beams. As a result, all members of the main structure remain elastic phase to have more potential to return to service at the hazard levels of Design Basis Earthquake (DBE) and Maximum Credible Earthquake (MCE).

OBJECTIVE:

- To analyze the RC frame retrofitted with LCF system with and without initial cracking.
- To compare LCF retrofitted RC frame system with horizontal and braced link beam.
- To compare external and internal LCF system.
- To compare CFST LCF system with normal steel LCF.

2. Methodology

Literature review: Various studies had been conducted related to seismic retrofit and stability evaluation of RC frame with linked frame column systems. It deals with the previous research related to LCF link frames.

Validation: In the study conducted by **Alireza Ezoddin et al. (2021)** represents the results of an experimental and numerical investigation of the RC frame retrofitted with the LCF system which the sections of the LC frame are designed using proposed simplified equations. The design of the LC frame is based on the proposed equations in a way that the plastic hinges are first formed in the link beam and then in the columns of the LC frame. The results indicated that the tested specimen and numerical models that the RC frames retrofitted with the LCF system using the proposed equations had good stiffness, high ductility, and significant energy dissipation. The results showed that the ductility factor, the average elastic stiffness and the system bearing capacity of the RC frames retrofitted with the LCF system using the proposed equations are increased about 1.5, 7.6 and 3.7 times, respectively. Also, using the proposed equations for the design of the sections of LC frame, the formation progress of plastic hingesis formed at the Rapid Repair (RR) performance level. In addition, the ratio of the first plastic hinge formation in the beam of RC frame (Δp LCF) to the first plastic hinge formation in the beam of LC frame (Δy LCF) for the RC frames retrofitted is close to 3. In other words, the RC frames retrofitted with the LCF system based on the proposed equations are more capable of withstanding earthquake forces without damaging the members of the main frame (RC frame).
The retrofitting of single-story single bay RC frame have been evaluated using the LCF systemas numerical models. Table 1 presents geometric parameters and material properties for numerical models. The lateral load bearing systems in all structures is based on minimumdesign loads for all buildings. After creating the model and applying loads in the ANSYS in accordance with table 2, the structural design of models was performed based on ACI 318–99, the sections and reinforcements of the beams and columns were obtained using linear static analysis. Because of the similarity of the structural system in the two directions X and Y axis, the frame axis 2 is selected.

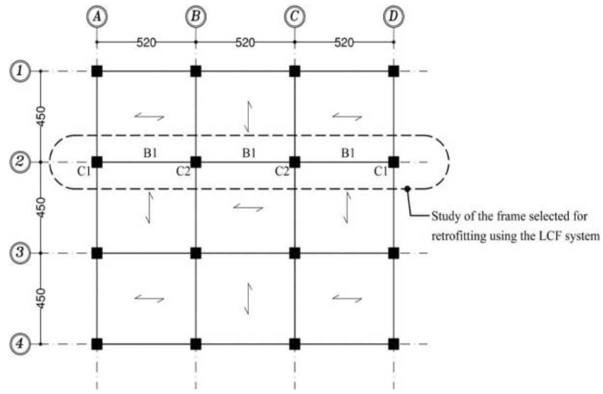

Fig2

Figure 2 shows the structural configuration and numbering of beams and columns for study of the frame. From the plan view it is clear that on which portion the retrofitting using the LCF is provided. The dimensions and reinforcement details of numerical model for transverse reinforcement of beam of the frame, 4,12mm diameter bars and stirrups of 8mm diameter at 100mm centre to centre is provided. Longitudinal reinforcement of beam having 4,14mmdiameter bars and stirrups of 8mm diameter at 100mm centre to centre is provided.
Finite element modelling of specimens is developed in ANSYS software to predict their cyclic behaviour.
From validation we concluded that the FE model developed in the present study is reliable and accurate in predicting the behaviour of the frame.

MODELLING AND ANALYSIS

We analysed the RC frame retrofitted with LCF system with and without initialcracking, For the analysis a two-storey single bay frame was selected. Geometry of the retrofitted frame used for the numerical analysis was made by ANSYS. The dimensions and reinforcement details are given. Retrofitting was done using steel I-section. First RC frame was analysed without providing any crack and retrofitting. This can be consideredas the normal condition of a building in service period without any damage or collapse. The force displacement graph, equivalent stress and total deformation were obtained. The maximum deformation is about 30.631mm. Maximum equivalent stress is 32.628MPa. Fig 3 shows the result from without crack and retrofit**.**

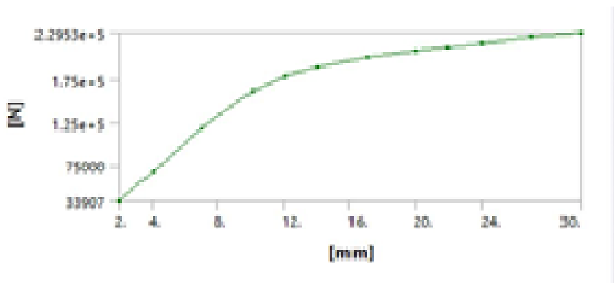

Fig 3

Then RC frame was analysed without providing any crack but by providing the retrofit. This can be considered as the condition of a building in service period without any damage or collapse but taken a precaution by providing retrofitting the force displacement graph equivalent stress and total deformation were obtained. The maximum deformation is about 30.544mm. Maximum equivalent stress is 496.59 Mpa. Fig 4 shows Result obtained from frame without crack and with retrofit

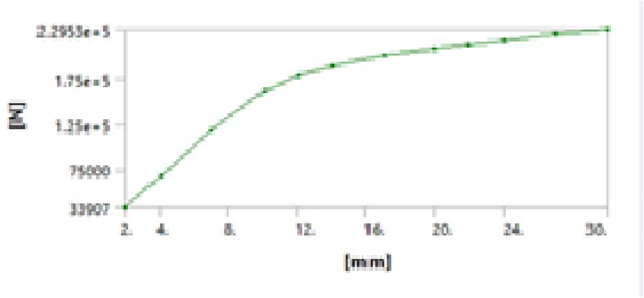

Fig 4

Finally, RC frame was analysed without providing any crack and the maximum stress concentratedpart was found out to provide an initial crack so that the situation matches with real case building affected by some damage and later retrofitted. The force displacement graph equivalent stress and total deformation were obtained. The maximum deformation is about 30.50mm. Maximum equivalent stress is 486.3 Mpa. Fig 5 is the Graph obtained from frame with crack and with retrofit

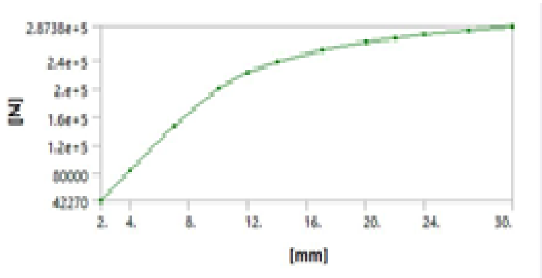

Fig5

Frame with initial crack and retrofitted with the new LCF with the new LCF system can withstand a force more than that without initial crack and without retrofit. The maximum force obtained when frame without crack and without retrofit is $2.29x10^5$ N, without crack and with retrofit is $2.8x10^5$N and RC frame with initial crack and retrofit can withstand a load of $2.87x10^5$ N. Hence percentage increase of load carrying capacity of RC frame with and without LCF retrofitting is 24%. Frame with initial crack and retrofitted with the new LCF system can withstand a forcemore than that without initial crack and without retrofit. Thus the use of LCF retrofitting is reliable.

To compare LCF retrofitted RC frame system with horizontal and bracedlink beam:

The replaceable link beams of LC frame first provide the initial stiffness of the system, and then energy dissipation due to yielding and cause the displacement and ductility in the building to be increased. These replaceable link beams act as a fuse element to increase the seismic performance. Here three different configuration of link beams are selected

a) LCF system with horizontal link beam:

This is the normal case of providing link beam for LCF retrofitting. The force displacement graph, equivalent stress and total deformation is obtained. Maximum deformation is at the top of frame and minimum at the at the bottom portion. The maximum deformation is about 30.544mm. Maximum equivalent stress is 496.54MPa. Fig 6 is the Graph obtained from LCF system with horizontal link beam

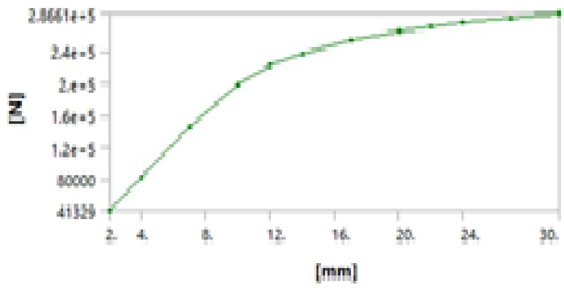

Fig 6

b) LCF system with forward link beam

The horizontal link beam in LCF system is replaced by forward link beam as shown below. The force displacement graph, equivalent stress and total deformation after analysis is obtained. The maximum deformation is about 30.433mm. Maximum equivalent stress is 486.3 Mpa. Fig 7 is the Graph obtained from LCF system with forward link beam

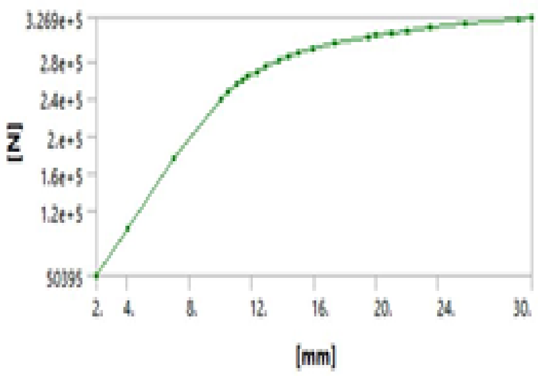

Fig 7

c)LCF system with cross link beam

The horizontal link beam in LCF system is replaced by cross link beam as shown below. The maximum deformation is about 30.50mm. Maximum equivalent stress is 486.3 Mpa. Fig 8 shows the graph obtained from LCF system with cross link beam

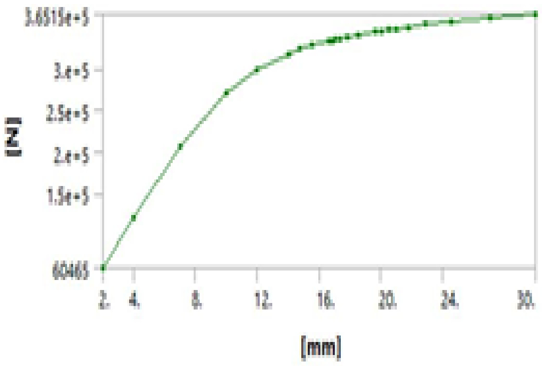

Fig 8

In LCF system, link beam is replaceable element and it's the member that yields first the column of LCF yields later only the member RC frame get affected. The load carrying capacity of horizontal link beam LCF are 2.886×10^5 N, 2.69×10^5 N, and 3.651×10^5 N. The percentage increase in in load carrying capacity of forward beam LCF than horizontal link beam LCF system is 14% and that of cross link beam LCF system is 27%. LCF system with cross link beam can withstand more than horizontal and forward link beam. But due to economic reasons forward link beam can be preferred than other two types. Thus, the use of LCF retrofitting is reliable and economic.

To compare internal and external retrofitted RC frame system.: Internal retrofitting using LCF system is another option where we cannot provide retrofitting externally such as in case of any adjacent building or any other hindrances. These two cases were analysed, and the result was compared.

a) RC frame with external retrofitting

This is the normal case of providing LCF retrofitting. Disadvantage of bracing system is that it occupies movement space and suffers from shortcomings when considering return to occupancy despite their ability to provide stiff and ductile response. But LCF is economical and occupy less space and is open structure. The maximum deformation is about 30.544mm. Maximum equivalent stress is 496.53 Mpa. Fig 9 is the Graph obtained from RC frame with external retrofitting

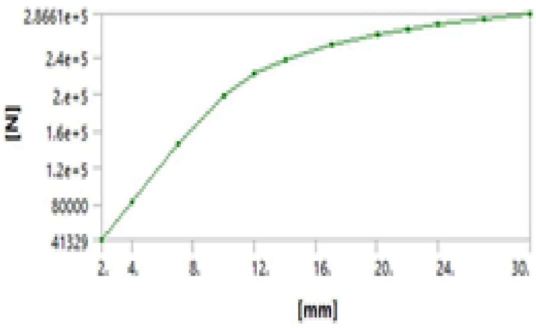

Fig9

b) RC frame with internal retrofitting

Internal retrofitting using LCF system is another option where we cannot provide retrofitting externally such as in case of any adjacent building or any other hindrances.. The maximum deformation is about 30.5284mm. Maximum equivalent stress is 486.3 Mpa.

RC frame with internal LCF retrofitting can withstand more force than external retrofitting.But the selection depends upon the availability of space in the building. Fig 10 is the Graph obtained from RC frame with internal retrofitting

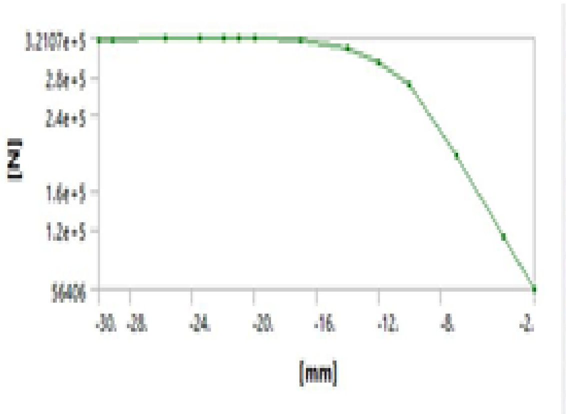

Fig10

Externally retrofitted RC frame can withstand a load of 2.86×10^5N and RC frame with internal retrofitting can withstand a load of 3.21×10^5 N. The percentage increase in load carrying capacity is about 12%. Thus, RC frame with internal LCF retrofitting can withstand more force than external retrofitting. But the selection depends upon the availability of space of building.

To compare RC frame with CFST and steel column LCF system: In this **objective, mainly used to compare the RC frame with concrete filled steel:**

tubular columns and with steel column with LCF systems. Concrete filled steel tube consist of outer steel tube and concrete in filled, which combines the merits of steel and concrete. This kind of composite member has various advantages such as high strength, high ductility, favourable cyclic behaviour and excellent constructability. The maximum deformation is about 30.497mm. Maximum equivalent stress is 486.3 Mpa. Fig11 shows the Graph obtained from RC frame with CFST and steel column LCF system

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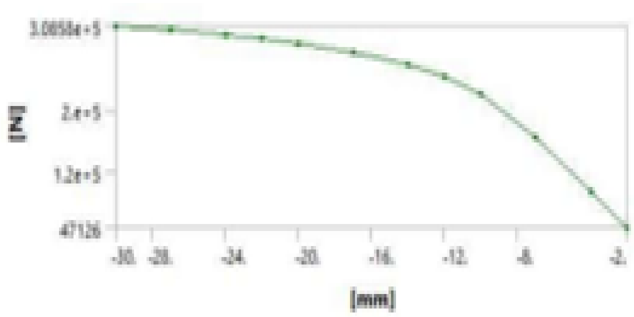

Fig 11

The LCF system is an effective brace free lateral load resisting system. The normal case of providing LCF retrofitting is where the external retrofitting members are fully made with steel sections. Whereas using CFST column as link columns, the performance of LCF system is increased about 8%.

3.CONCLUSIONS

The need for retrofitting and renovation is essential for existing structures. The replaceable components called "Replaceable Fuse" or "Replaceable Link". The fuse acted as a "weak link" where the inelastic deformation concentrated, whereas the remaining the main structural system remained elastic phase. The using of replaceable fuse members is easily replaceable due to their ductile behavior and able to protect the main structural members and restrain their damage in them. The LCF structural system consists of the main lateral load bearing systemof the structure called the Linked Column (LC) frame and the secondary structure system is Moment Resisting (MF) frame which in addition to resisting lateral loads, also acts as gravity load bearing system. The result indicates that the numerical models that the RC frames retrofitted with the LCF system, are more capable of withstand earthquake forces without damaging the members of the main frame. Frame with initial crack and retrofitted with the new LCF system can withstand a force more than that without initial crack and withstand retrofit. The use of LCF retrofitting is reliable. LCF system with cross link beam can withstand more force than horizontal and forward link beam. But due to economic reason forward link beam can be preferred than other two types. Thus, the use of LCF retrofitting is economic and reliable. RC frame with internal LCF retrofitting can withstand more force than external retrofitting, but the selection depends upon the availability of space in the building. The normal case of providing LCF where the external retrofitting members are fully made with steel sections, whereas using CFST column as link columns, the performance of LCF system is increased.

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