SEISMIC RETROFITTING OF STRUCTURES

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ABSTRACT

Many existing reinforced concrete structures in present world are inadequate for earthquakes. Recent earthquakes which occurred during last decade have indicated that major damage occurred was not directly due to actions of earthquakes but due to poor performance of structures during earthquakes. It is recognized that the most effective method of reducing the risk of damaging structure is seismic retrofitting. In recent years, there is a significant improvement of retrofitting techniques. This study highlights the principals of assessing and retrofitting of structures against seismic events. Some of these methods were practically implemented and procedures are illustrated using a case study of four storey RC building retrofitted for a moderate earthquake. Finite Element Method was used to investigate the performance of the building during the earthquake and to check the behaviour of the structure after applying retrofitting techniques. The methods such as steel and concrete jacketing and application of fibre reinforced polymer (FRP) composites which were used to improve the load bearing capacity of individual structural elements are highlighted and methods such as shear walls and shear cores which can be used to improve overall stability are discussed.

Keywords**:** Earthquake, Hazards, Retrofitting, Assessment, Finite element model

1. INTRODUCTION

An earthquake is a vibration of the earth surface that follows a sudden release of energy in the earth crust. This huge energy generated during an earthquake can be transmitted from its origin through seismic waves. These seismic waves cause vibration of the ground even far away from its epicentre. During an earthquake the ground surface moves in all directions. The most critical factor for damaging buildings is horizontal movements which cause lateral inertia forces on the structures. Generally most structures are designed and constructed to carry gravity loads. Most buildings do not have good lateral load resisting systems. It is understood that most of the buildings are not designed or constructed to face earthquake.

Concrete has been the most preferred construction material of the twentieth century and unless a new material with spectacular characteristics is invented, it appears to remain this way for another century. The existing low-rise and medium-rise buildings in the world consist of large number of reinforced concrete (RC) frame buildings designed only for gravity loads (Lakshmanan 2007). Among various methods of retrofitting, the most suitable method for a particular building can be identified after performing a structural assessment. The decision about the method of retrofitting is governed by the cost of retrofitting and the required level of performance.

2. ASSESSMENT CRITERIA

Based on current information of the building condition, an assessment procedure was developed to assess the building which is shown in figure 1.

Condition assessment procedure consists of preliminary investigation and planning, condition surveys, material testing (destructive and non-destructive testing) and field load testing. The preliminary investigation involves study of available data, discussions with relevant people, visual inspections, identification of failure modes and necessary testing. Condition survey of all the structural members must be carried out in order to identify the current condition of the structure. In the condition survey, the surveyor must record present dimensions, deterioration level of each and every member and the connections. Material testing must be carried out in order to obtain correct material properties for the analysis. For this, samples need to be taken from appropriate locations for laboratory testing and based on requirements non-destructive tests can be performed on site. The field load testing is decided depending on the measurement required and it could be either dynamic or static load testing or both. Based on the results of above investigations, the structural analysis is performed.

FEMA 356 (Federal Emergency Management Agency, 1997a, Federal Emergency Management Agency, 1997b) outlines four different procedures for analysis of the seismic evaluation of a structure: the linear static procedure, the linear dynamic procedure, the nonlinear static procedure (push-over analysis), and the nonlinear dynamic procedure (Bai, JW, year unknown, Core, B. &

Long, M., 2004). Here, the non-linear dynamic analysis was carried out. The method of retrofitting was decided based on the outcome of the analysis.

3. RETROFITTING OF STRUCTURE

There are many seismic retrofitting techniques available, depending upon the various types and conditions of structures. Some methods are additions of RC structural walls, use of steel bracings, seismic isolation, use of FRP and supplemental energy dissipation devices (dampers). Selection of the most appropriate method(s) and material(s) are based on results of structural assessment and detailed structural analysis. The structural analysis of a proposed retrofitting scheme is usually based on loads specified by the client. In the detailed analysis the best performing method should be selected according to the behaviour of the structure and the elements that need to be retrofitted must be identified. With proposed methods the structure must be reanalyzed. If the performance is up to a satisfactory level the above mentioned methods can be implemented. Otherwise the structure is reanalysed using different retrofitting improvement method(s) or material(s) until it satisfies the required improvement of the structure. The flow chart for structural retrofitting is given in figure 2.

4. CASE STUDY

4.1 Building Description

This case study is based on a four-storey library building. The structure is a reinforced concrete structure designed for carrying only gravity loads. This is a doubly symmetric building with a floor height of 3.5m each level. The general view of the building is shown in figure 3.

4.2 Numerical Investigation

A non-linear finite element model (see figure 5) was developed to study the behaviour of the structure during prescribed earthquake loading (CSI Analysis Reference Manual, 1995). Geometric non linearity was introduced to the model by using RESPONCE 2000 package and moment curvature curve which was used in the analysis is shown in figure 4. Analysis was done for expected earthquake loading based on details gathered during the initial condition assessment process. The outcome of the analysis was compared with limitations given in relevant standards. Deformed shape for peak ground acceleration is shown in figure 6. Secondly one or more retrofitting techniques were introduced to the model at once and performance was compared with allowable limits. Based on this analysis the most suitable retrofitting technique(s) was selected for the construction. The final proposal was drawn in such a way that it improves the strength, ductility and stiffness of the structure and it was taken in to account in terms of the inter-storey drift ratio, storey shear force and fundamental period of the structure.

5. RETROFITTING METHODS OF STRUCTURES

Among various methods of retrofitting techniques available, for this case three types were selected: Introducing a shear core in a suitable location, applying FRP at selected structural elements and constructing bracing dampers across the selected places. Analysis was done by introducing one method at first and introducing the next in cumulative manner. Maximum and minimum values of displacement of these techniques are tabulated in table 1. Based on the results of the numerical analysis the final retrofitting proposal was developed. Other than that concrete and steel jacketing was done in columns in order to increase the load carrying capacity. The load bearing capacity of RC slabs were increased by introducing steel girders.

5.1 Shear Core

The overall stability of the structure was increased by introducing shear cores at well identified locations. Introduction of shear walls for low-rise buildings can improve its lateral load bearing capacity due to the increase of lateral stiffness. The construction of the shear core is shown in figure 7.

5.2 Fibre Reinforced Polymer

This is an innovative retrofitting method currently used all around the world in various retrofitting activities. It has properties such as high specific stiffness, low weight compared to some other materials (concrete) and superior environmental durability. In this case fibre reinforced polymer is applied at columns, beams, slabs and beam column joints. Application of these, results in improving structural performances such as stiffness, load carrying capacity and ductility. Application of FRP at beam column joint and slabs is shown in figure 8 and 9.

6. CONCLUSION

Laterial variable load carrying capacity is important for structures in order to resist earthquake loading. It is the responcibility of designers to analyse structures applying the effect of lateral loads in a proper manner during the design stage.

Structures that are not designed for lateral variable loads are vulnerable for earthquake loading and unsafe. Therefore, such structures must be subjected to appropriate retrofitting. Determining the most suitable (with respect to structural integrity, possibility of applying on the structure and cost) retrofitting technique, material and method could be done after analysing a finite element model of the structure using computer based softwares.

The case study shows that the lateral load carrying capacity of existing structures that are not originaly designed for variable lateral loads could be improved applying retrofitting techniques.

7. DISCUSSION

This paper presented a case study of retrofitting of a four storey library building. In the original design (existing structure) there was no provision for later load resistance except the primary walls. Therefore the client insisted on getting a detailed analysis and proposal for retrofitting the structure to enhance its lateral load carrying capacity. The prior assessment helped optimizing the cost as well as the project duration.

The paper described the application of numerical methods to evaluate the performance of the existing structure and retrofitted structure. It also discuss about various materials and several techniques in the retrofitting field. From the study it was understood that rather than introducing one technique at once it is efficient go for different techniques in the same structure where applicable.

Retrofitting of structures is not an easy task. It requires testing, structural analysis and cost analysis for deciding on a proper retrofitting scheme.

8. REFERENCES

Applied Technology Council. Report ATC-40:1996. *Seismic Evaluation and Retrofit of Concrete Buildings*. Redwood City, U.S.A.

Bai JW. Seismic Retrofit for Reinforced Concrete Building Structures: Final Report. Texas: A&M University Consequence-Based Engineering (CBE) Institute; xxxx.

Core B, Long M. *Analysis of Rotational Column with Plastic Hinge*. Rice University and Bates College. 2004.

CSI Analysis Reference Manual for SAP2000®: ETABS. Computers and Structures, Inc. California, USA. 1995.

Federal Emergency Management Agency. FEMA 273:1997a. *NEHRP guidelines for the seismic rehabilitation of buildings*. Washington, D.C.

Federal Emergency Management Agency. FEMA 274:1997b. *NEHRP Commentary on the guidelines for the seismic rehabilitation of buildings.* Washington, D.C.

Lakshmanan N. *Seismic Evaluation and Retrofitting of Buildings and Structures: [the annual lecture 26th ISET]*. Structural Engineering Research Centre; Texas A&M University. 2007.

National Research Council of Canada. NRC/IRC:1993. *Guidelines for Seismic Evaluation of Existing Buildings*. Ottawa, Ontario.Institute for Research in Construction.

Seismic Safety Commission. Report SSC 96-01:1996. *Seismic Evaluation and Retrofit of Concrete Buildings*. Sacramento, U.S.A.

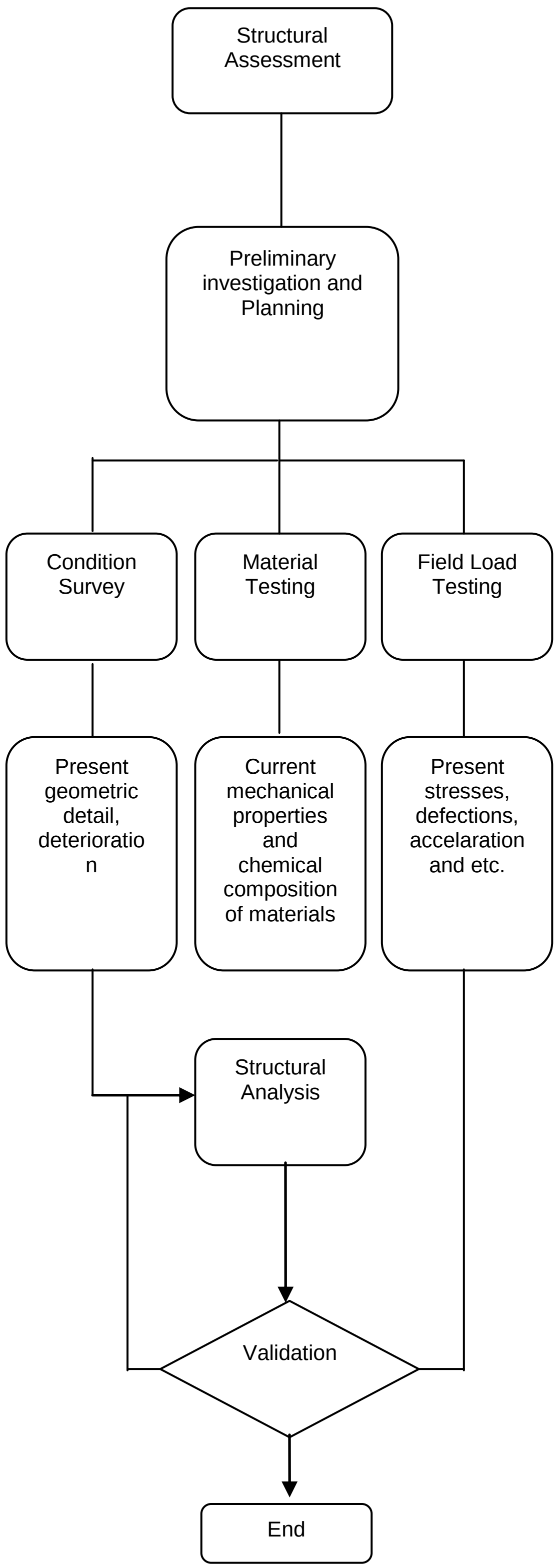

Fig 1. Assessment Procedure

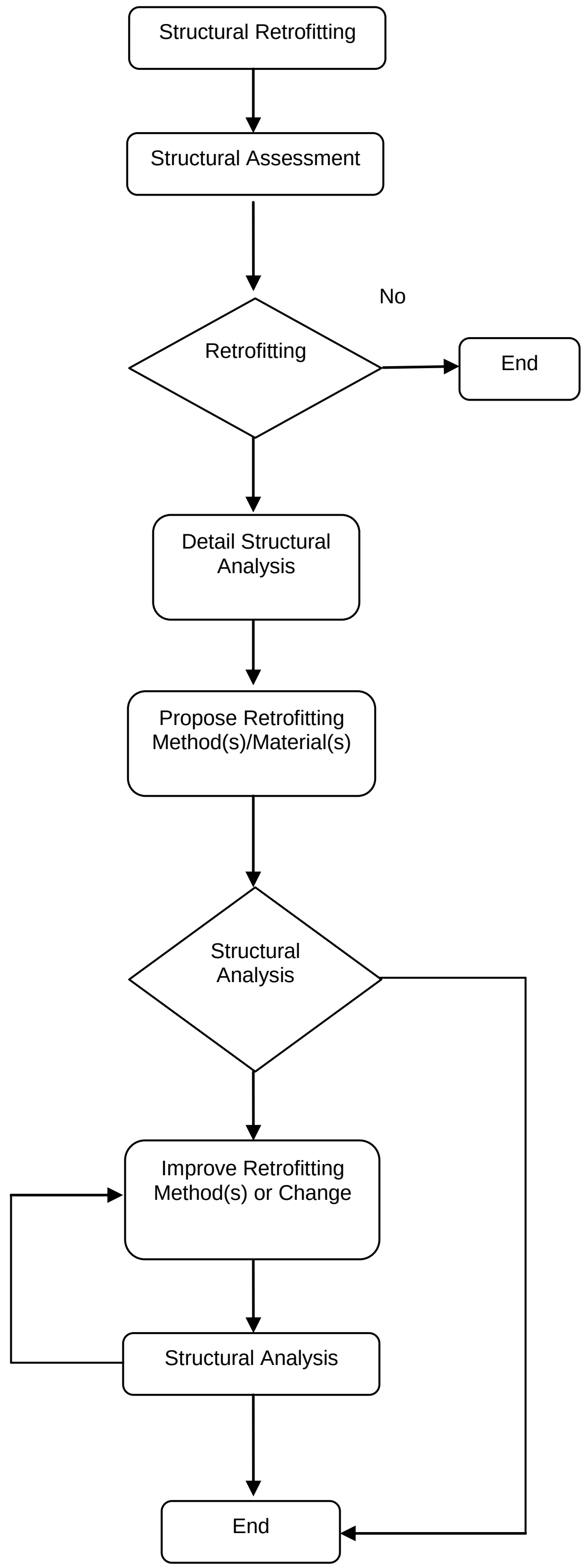

Fig 2. Retrofitting Procedure

Fig 3. General View of the Building

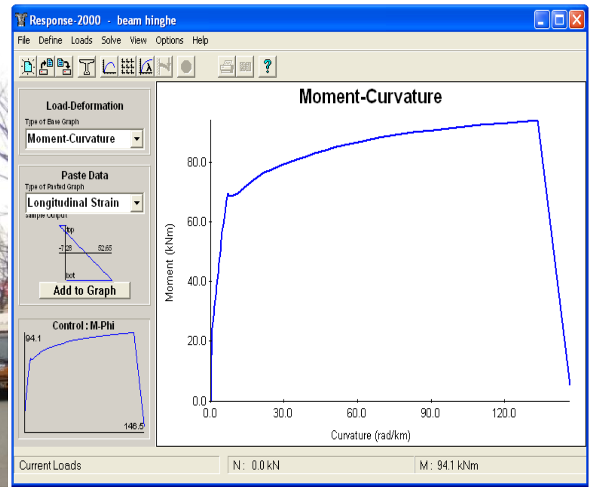

Fig 4. Moment Curvature Curve

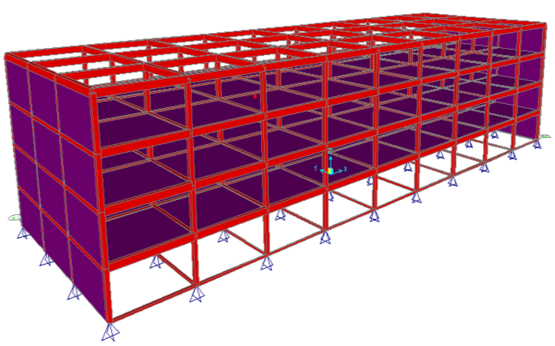

Fig 5. Finite element model

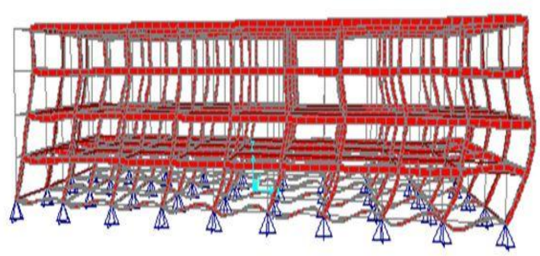

Fig 6. Deformed shape at peak accelaration

Fig 7. Construction of a shear core

Fig 8. FRP at a beam-column joint

Fig 9. FRP at a slab

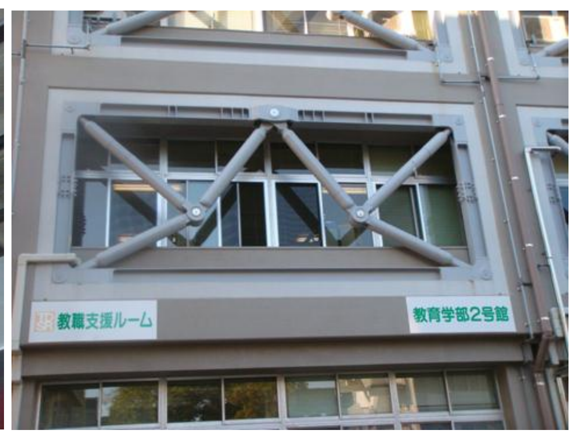

Fig 10. Steel bracing

Table 1. Comparison of peak displacements before and after applying retrofitting

joint	Direction UX	Displacement /mm			
		Original model	Shear core	Shear core, FRP	Shear core, FRP ,Brace dampers
185(top floor)	Min	63.0	42.4	38.5	33.1
	Max	67.3	43.9	36.7	28.6
184(second floor)	Min	52.0	35.2	31.1	24.9
	Max	57.4	34.9	29.9	22.9
183(first floor)	Min	38.7	27.2	21.2	11.9
	Max	50.9	28.6	23.0	22.2
182(ground floor)	Min	27.3	17.5	13.6	5.0
	Max	34.6	19.8	16.1	16.6