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Proposing Suitable Methods for Seismic Rehabilitation of Concrete Structures

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ABSTRACT: Seismic assessment projects in Iran have been started considerably since publishing the first edition of "Seismic Rehabilitation Criteria" in 2000. This criterion is mainly based on FEMA criteria and ATC40 publication. Nowadays, after publishing new editions of this criteria, a great developing in such projects has been arisen.

In this paper, process of seismic assessment studies of a concrete structure with the age of 10 is exhibiting; and, seismic rehabilitation plan is proposed. The desired structure is a hospital, which is located in Esfahan province, Iran. In strengthening concrete structures, the best condition is when minimum harms are caused to the structure, especially to the columns. In the present study, noting to the above general instruction, rehabilitation of mentioned structure is designed with three approaches: adding shear wall, performing steel jacket around columns and twisting FRP tapes around some columns and girders. With implementing these methods, for the structure, life safety of habitants will be provided in Basic Safety Earthquake-1(475 year return period; and, the structure will be protected from destruction in Basic Safety Earthquake-2(2475 year return period).

1. INTRODUCTION

In many structures the seismic principles are not observed at all. In many others that the design is assessable, a proper implementation or supervision has not been enforced or even if had, they were subjects of the older code and regulations. The necessity to observe the specifics of the new regulations should be considered, while the regulatory draft for seismic evaluation that contains new and effective procedures is being introduction.

-Whatever was addressed in the initial (first generation) versions of the regulations 'drafts for the buildings was defined for a specific earthquake and the structure strength and the low life loss were determined as two needs or conditions influencing the requirements .The common aspect among these regulations was that they did not distinguish different structures according to their efficiencies .

-The next (second generation) of the regulations, like the first, emphasized on the prediction of the seismic force, according to which the structure –movement –rate was to be minimized. In these regulations the focus was on the stability of the buildings during intense earthquake in order to minimize life loss. The only innovation here was the concern about the buildings that have specific utility/efficiency and had to be protected during intense earthquake with the least of damages and continued functionality. This pattern continued and lead introduction of new parameters and importance coefficient based on which the related regulations tend to concentrate on the efficiency and the functionality of the structure.

- The new generation of these regulations cover a much bigger scope of this subject in order to attain designing procedures that will fit the individual buildings resistance against earthquake at all risk levels. In otherworld, the buildings must be of enough strength, durability and the necessary ductility to justify the selected functionality level.

The emphasis on the strength of the building is to prevent damage or deformation of non-structural elements. Now, the application of the regulations FEMA 356, ATC-40, FEMA-273, and FEMA 351 are accounted for in designing.

The regulations regarding the rehabilitation of the existing buildings with respect to seismic activities, composed by the planning &budget organization of Iran , that is mostly extracted from FEMA -356,are being observed and implemented in existing buildings' evaluation procedures in order to estimate the different risk levels . In this study we will discuss the manner by which the concrete structures are being evaluated against seismic activities in general, and the buildings with three different concrete blocks in two stories, with hospital application in specific, based on the seismic rehabilitation regulations and the FEMA -356 publication (the new generation) .This will follow a discussion on the concrete structure's rehabilitation procedures.

2. THE PROJECT

The 96 bed hospital of Khomeini shahr, located at the eastern side of Manzarie township, on a 3% N-E radiate on a 300 X 195 m site on graded land is 35 Km from the city of Esfahan. The general information of the hospital building is presented in table 1.

Table 1- The general information of the subjected building

Khomeini Shahr-Esfahan	Site	3blocks	Khomeini Shahr hospital
Hospital	Efficiency	Moment frame	Structure frame
Concrete beam-block	Ceiling	2.5 story	Number of story
Individual	Foundation type	12.22 m	Building height from base level

3. THE STUDY METHOD

The seismic evaluation study usually is divided into the qualitative, quantitative and rehabilitation design stages.

3-1. The quantitative studies

Here, first information like the elements need, technical and executive documentation gathering of the subject building (drawing, laboratory test results, computation book etc.) as well as, its regional documents (city plan, urban status etc.), the technical specifications , the neighboring buildings' specifications, the site soil specifications with respect to seismic studies , the importance of the building as of its determined indexes(efficiency , dimensions, characteristics, whether it belongs to the national heritage association , inner facilities etc,) must be obtained. Then the economics, cultural, aspects, estimations for the need to probe (physical identification) and other required tests should be considered with respect to the limitation of possible rehabilitation plans and observed design regulations. And finally, based on the above obtained information and respected consideration the initial evaluation of the structure could begin. The initial evaluation is usually based on defect index that is defined as follows:

DI=V x F1 x F2 x F3 (1)

That;

V indicate vulnerability index, F1 indicate vulnerability coefficient soil type, F2 indicate topography resonance coefficients, F3 indicate resonance coefficient.

Accordingly, this building has medium vulnerability and should go through a quantitative study.

DI=0.215 x 1 x 1.2 x 1= 0.258

3-2. The quantitative study

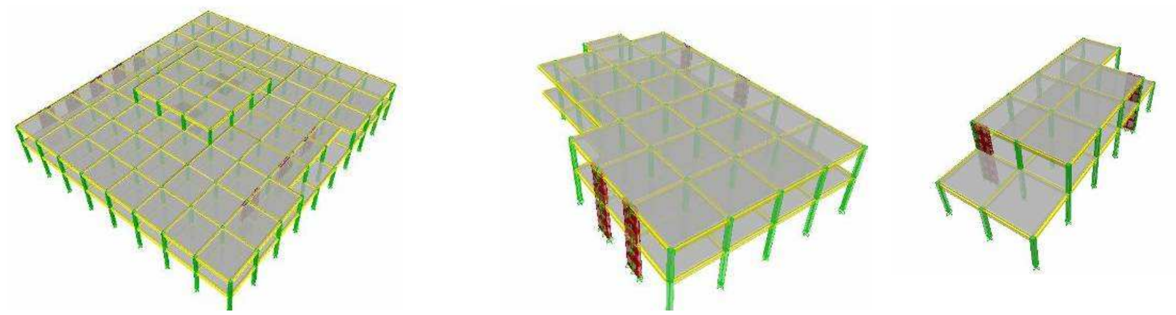
After the qualitative evaluation is conducted, the subject goes through an analytic study. At this point due to the client's request the seismic studies begin based on the selected functional level (life safety at level-1 risk and the collapse threshold at level-2 risk) that is the desired objective of optimization in accordance with the existing "optimization regulations on the buildings." The risk levels in the seismic regulation are determined as follows:

- Level 1 risk indicates that the seismic acceleration spectrum based on 10% possibility in 50 years equals a return cycle of 475 years.
- Level 2 risk indicates that the seismic acceleration spectrum based on 2% possibility in 50 years equals a return cycle of 2475 years.

In this project in order to determine the intense earth movement at the ground for risk levels 1&2, the risk analysis studies have been conducted.

3-3. Modeling and analytical method selection

In accordance with the existing seismic optimization regulations the modeling was developed in 3D, specifically in the linear analysis. Even in nonlinear analysis when modeled in 2D, for strength and resistance computation of the elements/members of the structure. The 3D properties are involved. Here, the subject is modeled in 3D in a structure analysis Etabs (Ver.9.1) s/w.



Block1 Block2 Block3

Fig 1. 3D modelling of sturctres in Etabs

The intended method of analysis of this structure is the linear dynamic method that is more accurate method compared to static linear method.

3-3-1. The results of quantitative evaluation

The weakness resulted from quantitative evaluation as below:

- Vulnerability in many columns;
- Vulnerability in some beams;
- Possible vulnerability of the bending capacity of the foundation.

Regarding the considerable difference between seismic force upon which the structure has been designed (the first version of 2800 standard of Iran) and the same in the new regulations, the existing status of the subject building is very vulnerable against lateral load .

-The columns

Based on the regulation, two-way axial bending in the columns is controllable by deformation, and the axial force and shear are determined by force control. For the controllable members by deformation the predicted strength must be used. For the controllable members by the force control the predicted low boundary strength must be used.

It should be mentioned that after compiling the existing information on the subject building and observation of the limitations and parameters expressed in previous equations based on ETABS the 3D modeling is allowable. The linear dynamic analysis was conducted by using the planning &budget organization of Iran on the model according to the building rehabilitation regulations. We should evaluate the enhanced rehabilitation objectives through which we must control basic safety objectives of the building at risk level 1; in addition we must consider obtaining risk level 2 in order to prevent collapse.

Therefore, both the risk levels were controlled and evaluated with respect to the most critical conditions in the related table regarding the main members of the structure.

- Axial force relation:

$$PR = \frac{P_{UF}}{KP_{CL}} \leq 1 \tag{2}$$

- Bending controlling relations:

$$PR = \left[\frac{M_{UD(X)}}{m_x k M_{CE(X)}}\right]^2 + \left[\frac{M_{UD(Y)}}{m_Y k M_{CE(Y)}}\right]^2 \leq 1 \tag{3}$$

- Shear controlling relations:

$$PR = \frac{V_{UF}}{KV_{CL}} \leq 1 \tag{4}$$

-Controlling the beams:

According to the regulation in the beams, the controllable moment is through deformation and controllable shear is through force.

-the moment relations:

$$PR = \frac{M_{UD}}{KmM_{CE}} \leq 1 \tag{5}$$

-the shear relations:

$$PR = \frac{V_{UF}}{KV_{CL}} \leq 1 \qquad (4)$$

In this relation:

P_{UF}: Axial force of the element
P_{CL}: The low stress strength boundary
M_{UDX}: Designed bending moment X direction for axial force P_{UF}
M_{UDY}: Designed bending moment Y direction for axial force P_{UF}
M_{CEX}: Predict bending strength elements surrounding X axes with axial force P_{UF}
M_{CEY}: Predict bending strength elements surrounding Y axes with axial force P_{UF}
V_{CL}: The low strength of shear
V_{UF}: Design shear force
On foundation analysis the following were investigated as well.

1- Sub base soil interaction control
2- The foundation resistance against exerted load on earth
3- Investigating the foundation rise level to exerted force

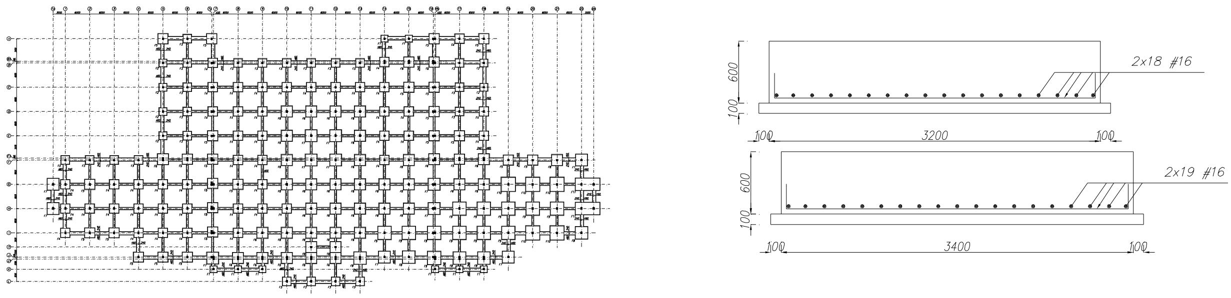


Fig 2. Existing foundation of the structure

Fig 3. General view of the subject structure

The results indicate the bending weakness of the existing foundations against exerted load. In general, regarding the graphs above it can be seen that the existing members such as beams, columns and foundations are vulnerable against moment bending.

3-4. The rehabilitation design

Based on the significant difference in the seismic force (the old version and new version of standard 2800 of Iran) according to which the structure was designed (old version), the existing situation of the structure is vulnerable against lateral loading. The new design by the selected consultant allows for concrete shear wall use in case some columns are not able to compensate for exerted loads despite the fact that the supporting wall FRP on the spot could help and have technical and economical justification in addition to time saving in implementation among other alternatives .Due to architectural limitations of this building and its function no span from the plan could be completely closed for bracing or wall erecting.

A concrete shear wall could be erected by adding a boarder element at the end. This is for sure the most proper of all other alternatives. In addition, due to the limited length of the shear walls there exists the possibility that some members may need reinforcement to reduce vulnerability. Here FRP or still brackets (jackets) could be used .the following procedures could be used for rehabilitation of the buildings.

-Adding shear wall

With respect to the stresses and the existing vulnerability of the columns and beams the best procedure for reinforcement is the addition of lateral load bearing system. Therefore, concrete shear walls have been erected to reinforce the lateral load bearing system.

-Using FRP and steel brackets (jackets)

Although a few of the columns and beam were still a little vulnerable after adding the shear wall, instead of adding more shear wall we reinforced them with steel jackets and FRP.

-Reinforcing the existing foundation

As we found out in this study, the foundations are vulnerable against bending; there for, we performed .

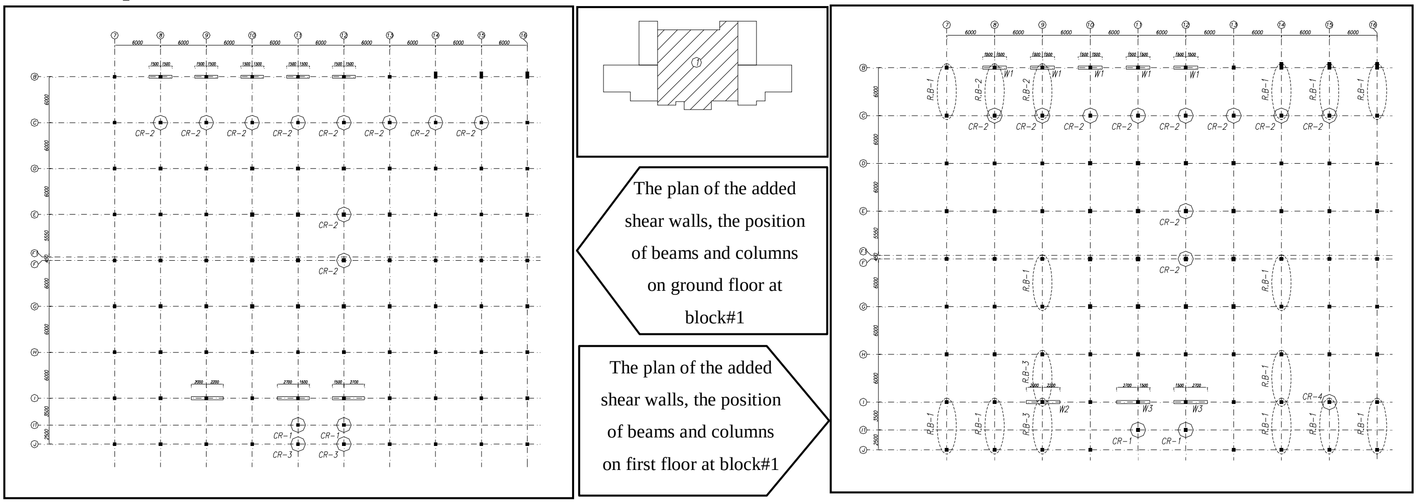


Fig 3. Locataion plan of Retrofitting shear wall,column ,beams at block1

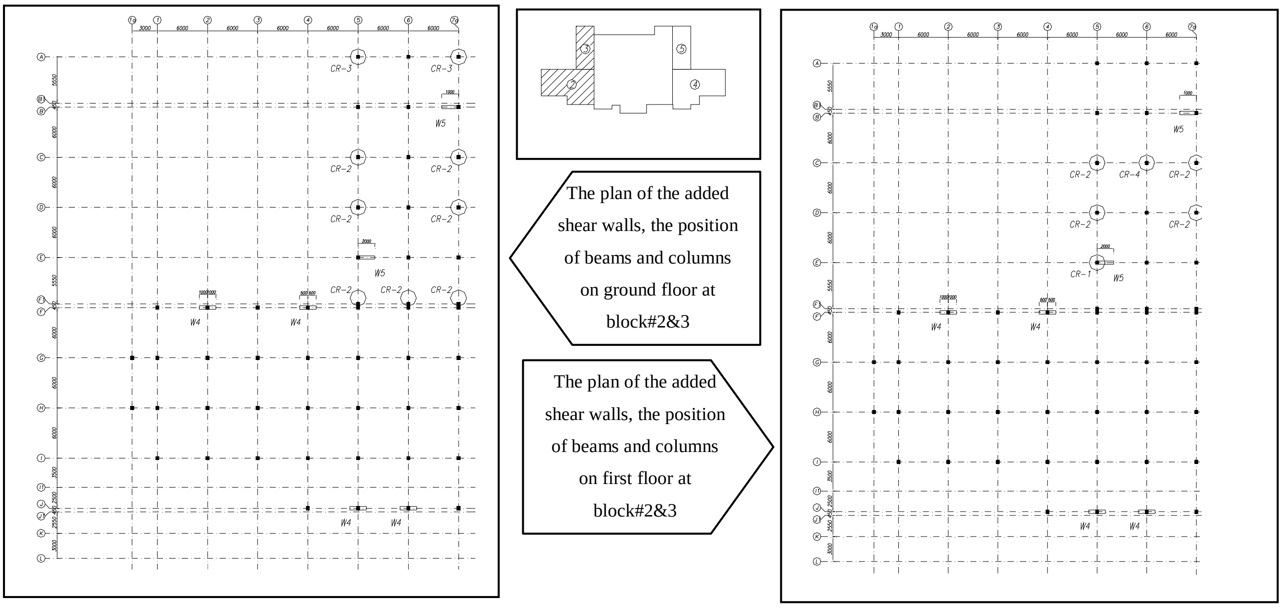


Fig 4. Locataion plan of Retrofitting shear wall,column ,beams at block 2,3

In the continuation some of the details of the rehabilitation design is being presented.

Installation of concrete jacket around column

Adding shear wall and enforcing it with FRP bands

Column-beam connection by using FRP bands

Fig 5. General view of the subject structure

3-5. The sufficiency of the design

Reinforcing the capacity of the elements under exerted load in a manner that the element PR is smaller than 1. The sufficiency of the elements in the design is presented.

-Columns

Despite the addition of shear walls in the structure a few PR ratios were more than 1; therefore, 2 approaches were selected for column reinforcement against bending.

1- Using FRP
2- Using steel jacket

For the columns with a PR ratio less than 1.1 FRP is used and for the rest with a ratio over 1.1 the steel jacket is used. At the end the efficiency of the design was controlled.

- Beams

For the beams with a PR ratio between 1-1.05 on layer and for the ratio over 1.05 two layers of FRP was used for reinforcement, at the end the efficiency of the design was controlled.

- Foundation

Due to the weakness against bending in the majority of the existing foundations , the thickness was increases from existing 60 cm to new 100 cm. On the upper layer # 20 mm rebar mesh was installed in 30 cm intervals .For new and old concrete adhesion in addition to chipping the concrete surface shearing connectors # 20 mm rebar was used in 30 cm intervals.

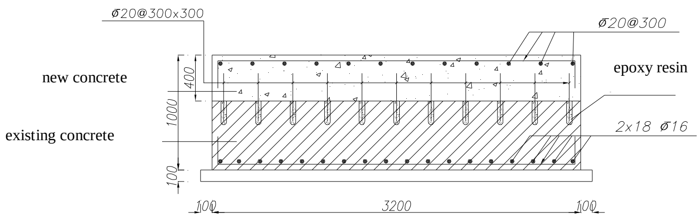


Fig 6. Detail of retrofitting foundation

4. Refrences

1. Institute of Standards and Industrial Research of Iran, Y. 2006. *Seismic Resistant Design of Buildings* – Code of Practice.

2. Office of Deputy for Technical Affairs, Y. 2004. *Design of Concrete Structures*, Iranian National Building Code of Steel Structures, Part 9.

3- Building Seismic Safety Council for the Federal Emergency Management Agency ,Y. 2000, *Prestandard & Commentary for the Seismic Rehabilitation of Buildings* ,report No .FEMA 356.

4- Management and Planning Organization Office of Deputy for Technical Affairs Technical Criteria Codification & Earthquake Risk Reduction Affairs Bureau ,Y. 2007, *Instruction for Seismic Rehabilitation of Existing Unreinforced Masonry Buildings* , NO.376.

5- Management and Planning Organization Office of Deputy for Technical Affairs Technical Criteria Codification &Earthquake Risk Reduction Affairs Bureau ,Y. 2007, Instruction for SeismicRehabilitation of Existing Buildings , NO.360.