

Seismic evaluation, upgrading and retrofitting of structures: Recent experiences in Iran

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ABSTRACT: Iran which is located in the Alpide Belt is one of the most famous earthquake-Hazardous countries in the world and has suffered from major seismic disasters many times in history. The June 20, 1990 earthquake of northern Iran was the latest to cause significant amount of damage to buildings and building owners. As a result, building owners and government officials have become aware of the potential risk associated with the seismically hazardous buildings in the country. Disaster experiences in Iran have urged the development of aseismic engineering for the new construction and development of the upgrading schemes for the existing buildings.

This paper offers several seismic upgrade techniques for the non-engineered Un-reinforced masonry buildings which are widely used in Iran and also presents a project successfully completed as a case study for retrofitting of engineered structures.

1 INTRODUCTION

The importance and the necessity of aseismic strengthening for rehabilitation of existing hazardous buildings have been recognized year after year in the engineering society and now in the country as a whole. Practicing structural engineers and constructors including academics innovate new repair and strengthening techniques for each job, for each building almost daily. Yamaguchi (1979) summarizes the aseismic strengthening methods and discusses advantages and disadvantages of each technique in details. A point worth noting in development of this techniques is the fact that each country practices a certain way of construction using material most available for the local constructors. Therefore, upgrading techniques should also address the needs of the local construction practices.

Another important factor before selection of the upgrade technique is the understanding of the true behavior of the building under consideration to seismic forces. After detailed investigations, the choose of upgrade design criteria becomes very important. The primary concern governing the design criteria for strengthening the buildings are either the life safety with sufficient resistance to prevent collapse, or damage control in which limited and repairable damage or no structural damage is allowed in order to ensure the continuous operation of the facility. Therefore, methods of upgrade design is established on a case-by-case basis and is based on achieving an optimum performance

concerning the desire to minimize damage while meeting limited financial resources of the owner. The final upgrade solution should always meet the above requirements, be architecturally acceptable and often needs to have minimum impact on the on-going use of the building during construction.

Traditionally in Iran, residential buildings are built using unreinforced masonry with a Jack-arch type roofing (tagh-zarbi), while new construction utilizes a combination of steel braced frames using masonry infills and concrete joist (tircheh-blook) for flooring system. In this paper number of schemes which have been proposed for traditional masonry construction and a case study which was successfully completed for the new type of the construction will be presented.

2 NON-ENGINEERED JACK-ARCHED TYPE MASONRY BUILDINGS

Majority of existing residential buildings in Iran are built as unreinforced masonry construction. These buildings use 20-35 cm unreinforced masonry brick walls as their main vertical load carrying components with little or no lateral resistance. Roofs and floors are built using steel I-beams spaced at 80-105 cm spanning in one direction between walls with arch type brick work between the steel beams as shown in Figure 1.

In order to minimize the damage to these buildings three upgrading details are recommended which are shown in Figures 2 and

3. Tension anchor in Figure 2(a), proposed by Ravaei (1991), provides sufficient connection between walls and the floor. Wall brace in Figure 2(b) limits the wall height therefore eliminating the potential for wall to buckle out-of-plane causing total collapse. Figure 3 illustrates a secondary defense system proposed by Nateghi (1992) which holds the roof and floor diaphragm in place after losing end walls to seismic forces giving enough time for evacuation of the building.

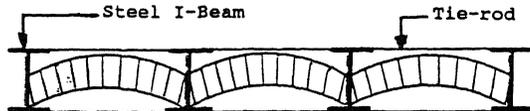


Figure 1 I-beam and jack-arched roofing

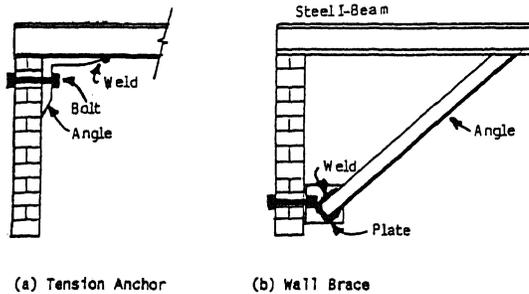


Figure 2 Strengthening method of unreinforced masonry walls

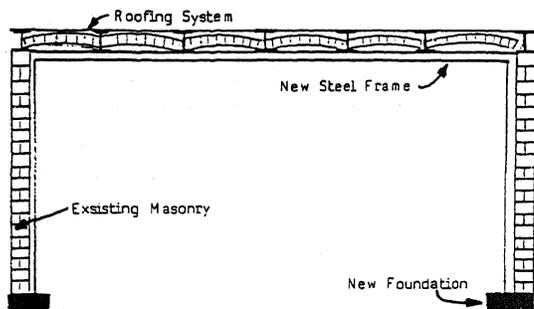


Figure 3 Secondary resisting system for masonry construction

3 ENGINEERED STEEL-BRACED FRAME BUILDINGS

Engineered buildings are usually easier to reanalyze and determine the adequacy of the structure to sustain seismic forces. However, it is very important to realize that if the structure requires strengthening, the original resisting system should be kept the same as much as possible. The strengthening scheme has to upgrade and compliment the existing system rather than change of total resisting system. Two main parameters effecting the choose of upgrade in these types of buildings are usually cost and functional usability of the building during construction.

Following case study is a representative upgrade design used after the devastating earthquake of June 1990 for this type of construction in Iran.

4 CASE STUDY

The manjil-Roudbar earthquake of June 20, 1990 occurred at 21:00 GMT in north and northwestern Iran. The body wave magnitude, M_b , of the main shock was reported at 7.3. The surface wave magnitude, M_s , of the quake was estimated at 7.6. The epicenter of the earthquake was located at near the city of Roudbar (36:49:00 N and 49:24:51 E) with a focal depth being reported between 10-20 km as stated by Nateghi and Eshghi (1991).

The isosismal map given by Nateghi and Tavakoli (1991) of the effected region is shown in Figure 4. Earthquake caused wide-spread geotechnical and structural damages covering an approximate area of 10,000 sq-km resulting in 37,000 life losses, 100,000 injuries, and 100,000 building failures leaving more than 400,000 people homeless.

Following this earthquake a new seismic code was implemented by the building officials. Therefore, the deemed-to-comply code required that every building being constructed must follow the requirements. This strengthening effort is therefore the result of the latest building requirements.

5 DESCRIPTION OF THE BUILDINGS

The buildings are steel structures with five stories above ground level, constructed of steel braced frames with concrete joist used as floors and infilled with hollow blocks. Figure 5 shows the picture of the buildings. The plan of the basic structural system is shown in Figure 6. Dimensions of the buildings are 23 m x 14.5 m, with story height of about three meters. Foundations consist of single and spread footing with soil capacity of 2 kg/sq-cm.

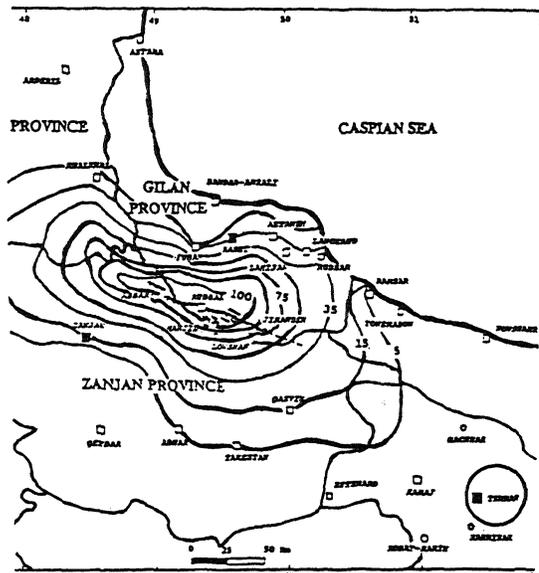


Figure 4 Isosismal map of the effected region

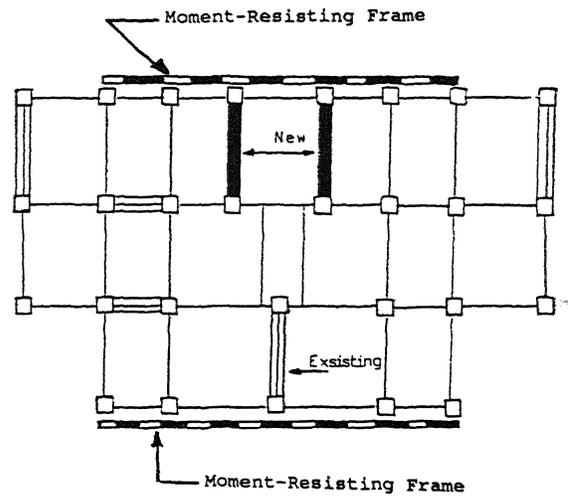


Figure 6 General plan of the buildings



Figure 5 Photo of the upgraded buildings

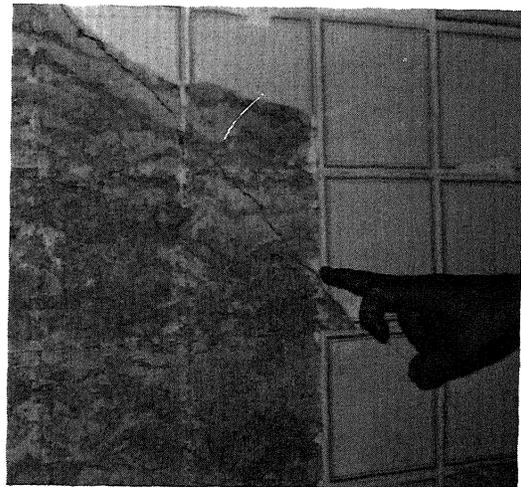


Figure 7 Damage caused by the earthquake

6 DAMAGE OF THE BUILDING

The basic structural system suffered minor damages such as some cracks. The cracks are hardly larger than 3 mm in thickness as shown in Figure 7. The main reason for development of these cracks are the out of the plane buckling of the braces. The primary reason for strengthening was the upgrade of the system to accommodate for the new building code.

7 ANALYSIS OF THE STRUCTURE

According to the seismic code of Iran, static loads were used in preliminary analysis and later on for checking purposes a Time History Analysis using Tabas earthquake with peak acceleration of 0.35g for the region was used as given by Nateghi and Shahbazian (1992). Results of the analysis before and after the strengthening are given in Table 1.

Table 1. Results obtained from the analysis.

Feature	Characteristics	
	Before	After
Stiff Direction of the Structure	Short	Equal
Predominant Period of Soil	0.5 sec	0.5 sec
Natural Fundamental Period	$T_S = 0.85$ $T_L = 0.63$	$T_S = 0.61$ $T_L = 0.51$
Average Stress on Soil	18 T/m ²	19.85 T/m ²
Weight of the Building	1382 T	1415 T
Coordinate of the Center of Gravity	$X_G = 6.51$ $Y_G = 11.5$	$X_G = 8.51$ $Y_G = 11.5$
Coordinate of the Center of Rigidity	$X_R = 6.85$ $Y_R = 11.5$	$X_R = 6.95$ $Y_R = 11.5$
Eccentricity of the Rigidity Center	$e_X = 4.3\%$ $e_Y = 0\%$	$e_X = 3.6\%$ $e_Y = 0\%$
Energy Absorption Capacity	Poor	Fair
Base Shear Coef. for Elastic Response	0.6	0.67
Base Shear Coef. for Inelastic Response	0.085	0.096

8 METHOD OF REPAIR AND STRENGTHENING

Since the damages were not structural, infilled walls containing the cracks were demolished or cut for possible strengthening of the existing braces. Repairs were ruled out due to cost considerations. Cost of demolishing a wall was much cheaper than using repair substances and techniques.

Four main upgrading methods were analyzed for determination of the best possible method considering cost, usability and workability which are as follow: a) addition of new reinforced concrete shear walls; b) use of moment-resisting frames; c) use of dual system of frames and shear walls; d) strengthening the existing braces and addition of moment-frames.

Addition of shear walls were ruled out due to the excessive amount of destruction at floor level and worry of insufficient attachment between the new walls and the existing structure. Destruction at floor levels were costly and would have resulted in functional disability of the buildings. Another problem was the overturning moments generated at foundations causing very high uplifting

forces. This phenomenon would have required extending existing foundations which was extremely difficult both in terms of workability and cost.

In final analysis, method d was selected due to both cost and accessibility. Infilled walls were cut above the braces and new elements were welded to the existing braces in short direction as shown in Figure 8 & 9. In long direction, due to openings a set of moment frames were designed to be attached outside the building to the existing structure as shown in Figure 10. New foundations were also enlarged accordingly. The final results in terms of displacements before and after the upgrade are show in Figure 11.

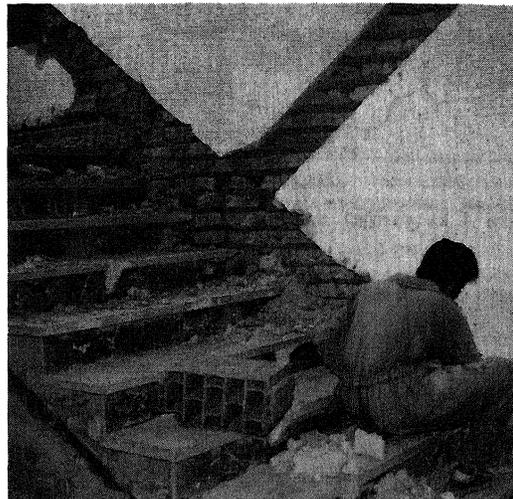


Figure 8 Cut section of the infilled walls



Figure 9 Installment of new steel braces

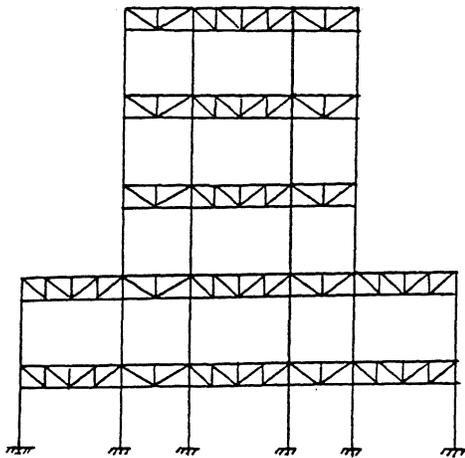
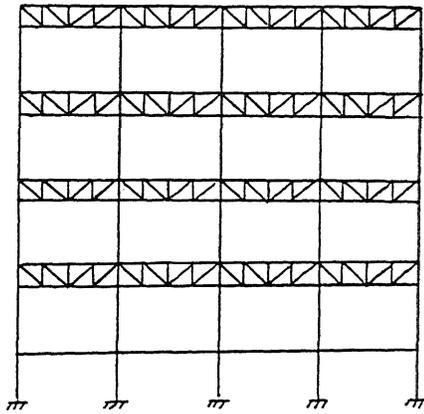


Figure 10 New moment-resisting frames installed in long direction, north and south sides respectively

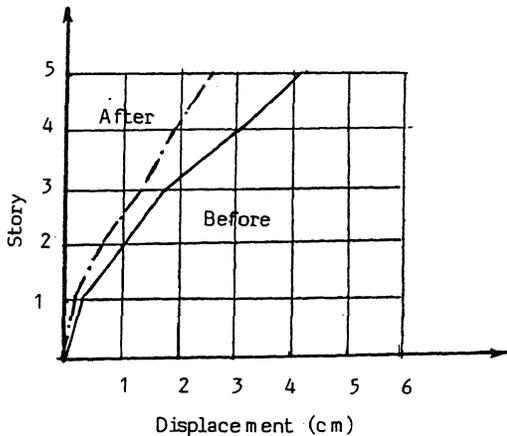


Figure 11 Displacements before and after

9 CONCLUSIONS

In general repair and strengthening is an art which must be supplied with the structural analysis for obtaining the best results. Each upgrade design is unique to itself because the structure and the degree of damages vary considerably from one building to another. However, a common denominator in all upgrading efforts, is the safety of the buildings and the people who occupy them. Of course, cost and functional use must also be considered. It is suggested that cost of repair and strengthening should always kept below the 25 percent of replacement. In this effort, 240 five story steel framed buildings were upgraded to the new standards and total cost was estimated at eight percent of the total replacement cost.

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