SIMPLE STRENGTHENING TECHNIQUES AND NEW TECHNOLOGIES FOR SEISMIC SAFETY OF EXISTING BUILDINGS: RECENT RESEARCH AND APPLICATIONS IN TURKEY

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ABSTRACT

Experiences show that many older reinforced concrete and masonry buildings suffered heavy damages during earthquakes due to their poor construction materials and non-ductile structural systems. Hence a need of new materials and technologies to be used to at least save lives; especially in crowded buildings such as hospitals and schools. In this paper, simple, fast and economical safety measures and strengthening techniques are proposed. The proposed safety measures is to install lightweight steel panels in specified locations in the structure to reduce inter-story drifts and prevent structural collapse. Furthermore specially manufactured technical textile and polyurethane glue, is proposed to save life and prevent collapse of non-structural masonry walls during a seismic event with a minimum cost. Shake table tests on full scale specimens were conducted to verify these techniques. Also parallel braced steel frame strengthening technique is proposed to strength low or middle raise buildings. In this technique all the construction works are applied from outside of the building and do not affect the building function. The idea is to reduce the earthquake displacement demand on the structure by attaching steel frames to the building floors. These frames are parallel to the structural system of the building and their foundations are connected to the existing building’s foundation. Two study cases in Istanbul were strengthened using this technique. The first one is a factory building and the other is a historical masonry building. Analysis and strengthening projects details are presented. Finally seismic retrofit of Tarabya Hotel in Istanbul is presented to shows the benefits from using new technologies such seismic isolation in improving the seismic performance of existing buildings. Tests and analysis results confirm the effectiveness of the proposed techniques.

Keywords: Earthquake, Strengthening, Textile, Steel panel, Shake table

1. INTRODUCTION

Recent earthquakes in Turkey (Van 2011, Izmit 1999) and worldwide demonstrated the power of nature and the catastrophic impact of such power upon urban cities. Surveys carried out in the aftermath of several destructive earthquakes shows that many low-rise reinforced concrete buildings have suffered heavy damages due to inadequate lateral stiffness and unsuitable design and construction. Under a major earthquake, the columns in some old reinforced concrete buildings lose their gravity-load carrying capacity due to inadequate amount of confining hoops or shear reinforcement causing collapse such as the so-called pancake. To avoid such unpleasant incident, retrofit of weak members would be necessary. However, the seismic retrofit of an old building is still so expensive that the progress of retrofit is too slow-paced worldwide. In research, there are two main concepts for seismic retrofit of existing RC buildings. The first concept depend on enhancing the seismic resistance (i.e., increasing the strength or ductility or both strength and ductility) of the structure by adding new structural members or by strengthen some of the existing structural members. Some of the most widely used techniques based on this concept are construction of new RC shear walls and jacketing existing beams, columns, or joints with new reinforced concrete, steel, or (FRP or CF) fiber wrap overlays. However, constructing a new RC shear wall in an existing building needs to evacuate the occupants, which makes the rehabilitation technique complicated and not very practical; and the use of FRP or CF in column or beam wrapping need special anchor details and skilled labors, which increase the retrofit costs. The second seismic performance enhancement concept depends on reducing the earthquake effects on the structure by changing the dynamic characteristics of
the structure using seismic isolation and damping device. One of the most widely used techniques based on the second concept is base isolation technique. This technique is most effective for relatively stiff low-rise buildings with large mass compared to light, flexible structures. In this paper, simple, fast and economical safety measures and strengthening techniques are proposed. The proposed safety measures is to install lightweight steel panels in specified locations in the structure to reduce inter-story drifts and prevent structural collapse. Furthermore specially manufactured technical textile and polyurethane glue, is proposed to save life and prevent collapse of non-structural masonry walls during a seismic event with a minimum cost. Also parallel braced steel frame strengthening technique is proposed to strength low or middle raise buildings. Two study cases in Istanbul were strengthened using this technique. The first one is a factory building and the other is a historical masonry building. Finally seismic retrofit of Tarabya Hotel in Istanbul is presented to shows the benefits from using new technologies such seismic isolation in improving the seismic performance of existing buildings. The paper documents the details of the proposed techniques; shake table performance verification tests and the details of the study cases projects.

2. PROPOSED TECHNIQUES FOR COLLAPSE PREVENTION AND LIFE SAFETY

Two strengthening technique are proposed to save lives and prevent collapse of existing buildings. A lightweight fabricated steel panels which can be fit easily inside a RC reinforced concrete frame are proposed for retrofitting low-rise RC frame structures. The panels may consists of simple steel truss or may consists of a thin steel plate of 3mm thickness welded in between two 40mm box section steel profiles as shown in Fig. 1.

![Diagram of proposed lightweight steel panels](image)

Fig 1. The concept of proposed lightweight steel panels

To reduce material costs, the 3mm thick steel plate of the panel can be perforated and shear stiffeners may be added to increase the panel shear strength. At each story of the building the panels are rigidly connected to the upper level RC beams and semi-rigidly connected to the lower level RC beams in the story. The panels will be designed to have higher lateral stiffness than the lateral stiffness of the existing RC columns. During an earthquake, it is expected that the panels will work as an electric fuse in an electric circuit by attracting more seismic forces than the existing RC columns and they may totally damage but they will prevent severe damage in the main structural system by reducing inter-story drifts. Moreover, the semi rigid connections at the bottom of the panels will help in reducing story floor accelerations and results in reducing inter-story drifts and prevent possible collapse (i.e., prevent possible pancake or story collapse). The panels are light weight, easy to handle, and can be constructed very quickly. Moreover, they are cheap, and do not need formwork or skilled workers. Shaking table tests on a 1/2 scale 3D RC frame model specimen (see Fig 2a) shows that the behavior of the specimen before and after retrofitting when they subjected to the same base excitation of maximum acceleration.
of $0.33G$ (see Fig 2b and Fig 2c), it is clear that adding the fabricated panels to the RC frame specimen results in four times reduction of story drift and an increase of the stiffness. Also, the performance of the RC columns of the test specimen was improved from CP (collapse prevention, i.e., column joint rotations 0.03 rad) in case of no retrofitted specimen to IO (immediate occupancy, column joint rotations 0.005 rad) in case of retrofitted specimen. More details about these tests can be found elsewhere (Mowrtagea, (V. karakale) 2012).

Thin wallpaper like glass fibre textile glued directly on an existing plaster in a building with a special high ductile water based polyurethane adhesive is proposed to save life and prevent collapse of non-structural masonry. The idea is to attach glass fiber textile on the brittle brick partition walls in the buildings and connect them with the peripheral structural frames. During an earthquake it is expected that the system will hold the non-structural elements in place and prevent their out of plan failures; also it will improve their in-plane stiffness making them working as structural infill walls. The practical benefits are: No plaster has to be removed, very fast and clean application like wallpaper hanging, health friendly material, and high deformable connection plaster to textile. Shake table on full scale brick wall specimens was conducted. The strengthened specimen and the non-strengthened specimens were fixed on the same shake table for a direct comparison and the amplitudes of base accelerations were increased until severe damage is reached in the non-strengthened and/or strengthened
specimen. The seismic performance of the 2 × 2 specimens (two without and two with strengthening) was compared in terms of stiffness, strength, deformability and ductility. All thought that the specimens were excited under their resonance frequencies, no damage at all occurred in the strengthened specimen and total collapse happened already in the non-strengthened panel under low amplitudes (see Fig 3). More details about these tests can be found elsewhere (Lothar et al., 2014).

3. PARALLELL STEEL FRAME STRENGTHENING TECHNIQUE

parallel braced steel frame strengthening technique is proposed to strengthen the low or middle raise structures in which all the construction works are applied from outside of the building and do not affect the building function. The main features of this technique are ensuring the view, ventilation, and sunlight from windows after the retrofitting work is done. Furthermore, using the construction steel members lead to shortening the
construction term, improve in quality, and reduce costs. The idea of this technique is to reduce the earthquake displacement demand on the nonductile existing structures by attaching steel frames to the building floors.

Fig 4. Factory building plan and FE model
These frames are parallel to the structural system of the building and their foundations are connected to the existing building’s foundation. Also the frames can be designed to the desired performance limit states specified in FEMA or Turkish earthquake codes and can be installed in building plane in such a way to reduce the torsional effects on the irregular structures. This technique was applied to two buildings in Turkey. The first one is a RC factory building and the second one is a historical masonry building with plan irregularities. In the factory building the frames were located in a symmetrical plan and to balance the torsion effects which may occur during an earthquake due to the existing no engineered shear wall as shown Fig. 4. TPushover analysis results shows that the lateral load carrying capacity of the factory building increases by about five times when strengthened by the proposed external parallel steel frames as shown in Fig 5.

![Pushover analysis results](image)

The same technique was applied to Sirkeci Kredi Han building in the city of Istanbul. The building was constructed in 1889 and it was used as a shopping hall. In this project the building function was changed from shopping hall to a four stars hotel. The building is approximately 3060 square meter, including five stories and basement. The structural system of the building consists of under reinforced masonry (URM) bearing walls supporting RC joist slabs. The frames were located in the building in such a way to balance the torsional affects which may occur during a future earthquake as it is shown in Fig 6. The frames are five stories and partially braced by steel arches .They were rigidly connected to the existing building foundation using epoxy anchored bolts. At each story level the frames were rigidly connected to the existing steel floor beams. The frames do not have any connections with the URM bearing walls and they are in parallel to the peripheral bearing walls from the interior side. After strengthening the natural period of Kredi Han building were dropped from 1.76 sec to 0.9 sec , which means that proposed parallel steel frames increased the building stiffness by more than three times . Furthermore analysis results shows that the global drift of the strengthened structure reduced in half compared with non-strengthened case.

4. **BASE ISOLATION CASE STUDY**

Seismic isolation of structures is a mature technology of mitigation of seismic damage for civil structures and equipment, and has proven to be reliable and cost-effective for many structures. In this paper seismic isolation retrofit schemes for the Grand Tarabya Hotel is presented. The hotel, located in a moderate seismic hazard zone
in the city of Istanbul, was built during the period 1958-1964. The 41000 square meter project site is located on the Bosphorus and comprises several high-rise and low-rise blocks separated by expansion joints. The structure consists of 13 story-high and low-rise blocks separated by expansion joints. The lateral force resisting system was essentially designed for prevailing wind forces is only of the order of about 2% of the building weight. The proposed rehabilitation schemes complied with the design code (FEMA-356) and achieve the performance criteria defined as: Immediate Occupancy at BSE-1 level earthquake and Life Safety at BSE-2 level earthquake.

Fig 6. Application on historical masonry buildings
As the isolator elements, the friction pendulum systems (FPS) were selected. The isolators were installed at the first floor of the high-rise blocks as shown in Fig 7. Two size of friction pendulum bearings were used named Type A and Type B (Figure 9). The isolation system consists of 33 pieces of Type A and 106 pieces of Type B making a total of 139 bearings. Type A is designed to carry 1500kN vertical load, its bearing size is 152mm in diameter and its interior surface diameter is 787mm. Type B is designed to carry 4600kN vertical load, its bearing size is 280mm in diameter and its interior surface diameter is 914mm. Both bearing types have a 2235mm radius of curvature, a lower bound coefficient of friction of 3% (controls displacements), upper bound coefficient of friction of 6% (controls forces) and a displacement capacity of 280mm. The nonlinear time history analysis shows that the maximum displacement of isolation system due to BSE-2 level earthquake ground motion is 150mm which is less than the 280mm displacement capacity of the bearings used. The maximum superstructure base shear due to BSE-1 level earthquake (using an upper bound friction coefficient of 6%) is about 50000kN which is about 12% of the structural weight. For a load reduction factor of 2 (R= 2) as per IBC-2000, it reduces to only 6% of the structural weight which coincides with the linear elastic lateral load capacity of the strengthened super structure. Displacement and hysteresis curves of a link element (i.e. isolator unit) located at the middle part of the isolation system under the affect of BSE-2/MCE level earthquake are shown in Fig 8 respectively.
5. CONCLUSION

Shake table tests results and analysis results confirm the effectiveness of the proposed techniques.

REFERENCES