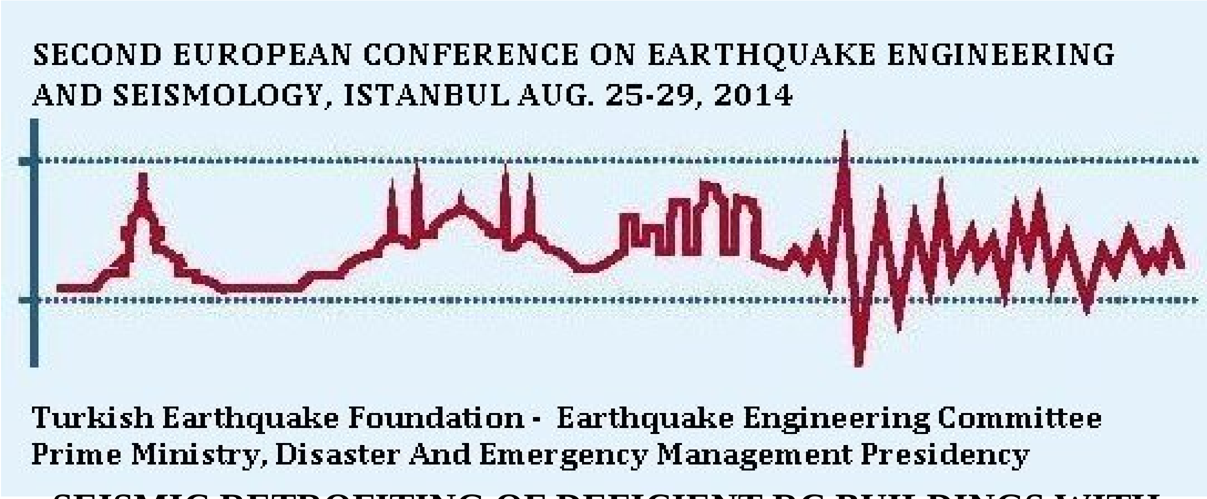

SEISMIC RETROFITING OF DEFICIENT RC BUILDINGS WITH POST-TENSIONED METAL STRIPS: FULL-SCALE SHAKE-TABLE TESTS

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The high seismic vulnerability of the existing building stock has led to catastrophic collapses during recent strong earthquakes around the world. This is more evident in developing countries (e.g. Kashmir, 2005; China, 2008; Indonesia, 2009; Haiti, 2010), where many RC buildings were built using inadequate construction practices that result in insufficient lateral load resistance and poor energy dissipation capacity. Many structural failures in these structures have been attributed to the inadequate behaviour of beam-column joints. Joints of RC frame buildings are subjected to a combination of high flexural moments and shear forces during strong earthquakes. Moreover, in comparison to interior joints, exterior joints of substandard RC buildings are more likely to experience damage because fewer beams frame around the joint core, resulting in lower levels of confinement. Since the demolition and replacement of such buildings is uneconomic, the local strengthening of deficient joints is necessary to reduce the high seismic vulnerability of existing substandard structures and the associated societal risk.

Different techniques have been used over the past to retrofit beam-column joints, such as:
a) Crack injection and/or epoxy mortar repair.
b) Concrete and shotcrete jacketing.
c) Steel jackets or steel plates, and
d) Externally bonded Fibre Reinforced Polymer (EB FRP) reinforcement.

Crack injection and/or epoxy mortar repair are typically effective only at low levels of structural damage. Steel plates and steel jacketing require trained staff and equipment to ensure welding quality and handle/lift heavy steel components. Concrete/shotcrete jacketing is usually highly invasive, labour intensive and increases the mass of the building. Moreover, these strengthening solutions are normally time-consuming and the functionality of the building can be considerably disrupted, leading to further economic losses. More recently, EB FRP reinforcement emerged as an alternative to address the above issues. Nonetheless, the relatively high initial cost of the FRP materials may hinder its use in low-income developing countries. Therefore, it is necessary to find effective low-cost retrofitting solutions suitable for developing countries.

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An economical, faster and less intrusive retrofitting technique using Post-Tensioned Metal Strips (PTMS) was developed at the University of Sheffield (Frangou et al., 1995; Frangou, 1996. The PTMS technique involves the post-tensioning of high-strength high-ductility steel strips ("banding") around concrete members using hydraulically-powered standard strapping tensioning tools as those used in the packaging industry. To maintain the post-tensioning force, the strips are mechanically-fastened with push type metal clips clamped using a pneumatic sealer (jaws). As a result, active confinement is provided to the strengthened component even before applying load. Recent research (Helal, 2012) demonstrated the effectiveness of the PTMS technique at enhancing the shear capacity of deficient joints by up to 95%. The technique can be also used to strengthen beams and columns of joint specimens (see Figure 1 taken from Garcia 2013). However, to date the effectiveness of the PTMS technique at enhancing the behaviour of a real full-scale RC structure has not been verified.

Figure 1. Retrofitting of beam and column of RC joint using the PTMS technique (column shown horizontally)

This paper examines the effectiveness of the PTMS technique at improving the performance of a full-scale RC building with poorly detailed beam-column joints. The structure was tested on the AZALEE shake table of the CEA/EMSI laboratory in Saclay, France, as part of the multi-phase EU-funded BANDIT project within the FP7 SERIES programme (Seismic Engineering Research Infrastructures for European Synergies). Figure 2 shows a general view of the BANDIT building.

Figure 2. View of BANDIT building prior to tests and PTMS retrofitting

Initial shake table tests were carried out to produce a desired level of damage in the building. The tests were halted at a PGA=0.15g to avoid excessive damage at the beam-column joints and a possible collapse of the 2nd floor. After the initial tests, columns and joints were repaired and retrofitted using the PTMS technique. The building was retested to compare the performance of this retrofitting solution under low and medium-intensity shaking. The PTMS-retrofitted building sustained a PGA of up to 0.35g and an inter-storey drift ratio δ=2.80%, equivalent to the Collapse Prevention performance level according to ASCE/SEI 41-06 (ASCE, 2007). No signs of collapse were observed during the latter tests. The building was heavily instrumented with accelerometers, displacement transducers and a series of 59 strain gauges at locations where large seismic demands were expected. This article presents results of the shake table tests performed during the initial three testing Phases of the project. The results of are examined at the local level (columns and joints) to assess quantitatively the effectiveness of the technique. It is shown that the PTMS retrofitting enhanced the capacity of the retrofitted joints and columns, thus reducing the seismic demands at the local element level and enhancing the capacity of the retrofitted structure. The PTMS retrofitting technique was shown to be easy to apply and was done without the use of adhesives, materials or sophisticated equipment. The results show that the low-cost and simple method is very effective for fast post-earthquake retrofitting of substandard RC structures, and it is especially suitable for applications in developing countries.

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