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NED UNIVERSITY OF ENGINEERING & TECHNOLOGY
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# Cowasjee Earthquake Study Centre NED NEWSLETTER

## Shake Table Test of BRB Strengthened RC Frame

Many existing reinforced concrete (RC) buildings do not meet the lateral strength requirements of current seismic codes and are vulnerable to significant damage or collapse in the event of future earthquakes. Various techniques have been used for seismic strengthening of RC buildings which can be classified into two main groups: the member-level techniques and the structure-level techniques. The member-level techniques rely on section enlargement of the existing structural members by jacketing to improve flexural, axial and shear strength of these members; enhancements in ductility and stiffness are also attained. However, the jacketing technique may require evacuating the whole building and is labour-intensive due to the associated heavy demolition and construction works.

The structure-level techniques are mainly intended to reduce the demand on the existing structure by introducing new elements such as shear walls or conventional steel bracings. However, there are several disadvantages to these approaches, which include the need for new foundations for the added weight to the structure. Similarly, the hysteretic behaviour of conventional steel braces (CSB) is un-symmetric in tension and compression. The yielding of the braces in tension under lateral loading provides a ductile plastic mechanism with a good source of energy dissipation. On the other hand, brace buckling in compression provides a poor source of energy dissipation because of the post-buckling behaviour of the braces which is characterised by deterioration of strength and stiffness.

The development of buckling-restrained braces (BRBs) started in Japan after the 1995 Kobe earthquake. The application of BRB in Japan was followed by their use in building retrofitting in USA. BRBs act as hysteretic dampers. The main concept of buckling restraining is to decouple stress resistance of main yielding steel member from the flexural buckling resistance. As a result, BRB reinforced frames yield in both tension and compression without buckling.

Presently, buckling-restrained braces (BRBs) have become increasingly popular which is a new and effective seismic load resisting system (SLRS) for engineers designing buildings for ductile seismic performance. BRB improves strength, stiffness and energy absorbing capacity of structures. Most of developed BRBs are proprietary although they employ similar design concepts. With little information available in regards to elemental composition it becomes necessary to verify the effectiveness of a particular design through investigational testing to ensure that a particular design meets the intent and is adequate for the seismic response of the structure.

**Figure 1: Dynamic Test Setup of BRB Strengthened RC Frame**

The existing designs of BRBs were studied by the University of Ottawa, Canada and an improved design was provided. The development of this design was carried out by Steel Canada Limited (SCL), Canada. In order to assess the dynamic performance of this design, the Department of Earthquake at NED University of Engineering and Technology was engaged by SCL to test the performance of a BRB strengthened RC frame and to compare its performance with a control frame without BRB (**Figure 1**). The shaking table testing of the frames was carried out on 13 May 2017. ***(Continued on page 2)***

## Two Powerful Earthquakes Jolt Mexico

Mexico was hit by two powerful earthquakes in two weeks. The first strong earthquake of 8.1 magnitude occurred on 9 September 2017. The earthquake was 19 km deep and occurred in the subduction zone formed by Cocos Plate which is sliding under the North American plate (**Figure 2**). More than 600 aftershocks were recorded following the main shock. At least 61 people died due to this earthquake besides, damages of hospitals and government offices in the southern part of the country that was closer to the quake's epicentre off the Pacific Coast. The earthquake was the second strongest recorded earthquake in the history of Mexico after the magnitude 8.6 earthquake that occurred in 1787. The earthquake was also was felt in Mexico City ***(Continued on page 2)***

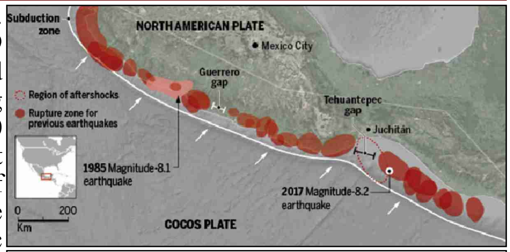


**Figure 2: The two "seismic gaps" in the subduction zone off Mexico's coast, where tectonic plates grind past one another (Source: Mexico National Seismological Service)**

### EDITORIAL

*A number of damaging earthquakes have struck different regions of the world over the last six months. The details of these earthquakes and damages caused have been covered in this issue of CESNED Newsletter. In addition, the activities of the Department of Earthquake Engineering to make the society safe against natural hazards have also been reported which are a regular feature of the Newsletter. I sincerely hope that our readers find the presented information in this newsletter informative and interesting to them — Editor*

CESNED

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## Shake Table Test of BRB Strengthened RC Frame *(Continued)*

A large audience belonging to academia, consultants, students and media witnessed the test and valued the information gained.

One-third scaled models of both types of frames were employed. The design of the frames was provided by University of Ottawa, Canada. The peak ground acceleration record for the 1988 Kobe earthquake was employed to simulate the earthquake ground motion for the testing. The duration of this earthquake is 40.9 sec with peak ground acceleration (PGA) 0.34g. The acceleration record was scaled for the testing of model. The model was subjected to different intensities of a seismic excitation in an incremental fashion. The intensities were varied from 25-500 percent in increment of 25 percent. These records were calibrated prior to the test so that the machine output matches closely with the input time-history record. At the end of each sequence of seismic excitation, physical inspection of the model was carried out to assess the damage pattern and photographs were taken. The videos of the tests were continuously recorded from two different angles.

## Two Powerful Earthquakes Jolt Mexico *(Continued)*

**Figure 3: (Left) Enrique Rebsamen elementary school in Mexico City before earthquake (Right); Collapsed building after earthquake (Source: Google Earth/Getty Images, Reuters)**

and Guatemala City. The Mexican interior reported that 428 homes were destroyed and 1700 were damaged in a highly seismic state Chiapas.

The second 7.1 magnitude earthquake struck Mexico City on 19 September 2017. The city is one of the most populous cities in the Western Hemisphere with a population more than 21 million. The earthquake caused a heavy and prolonged rattling in the capital for about 20 seconds. The Mexico City Mayor reported that at least 250 people died due to this earthquake and dozens of buildings in central Mexico were turned into dust and debris. The earthquake caused severe damages to more than 5,000 schools and 21 children also died under the debris of the Enrique Rebsamen School in the Coapa district (**Figure 3**). In addition, at least 22 hospitals were damaged in and around Mexico City. This Central Mexico earthquake occurred on the 32nd anniversary of the 1985 Mexico City earthquake, which killed about 10,000 people. The epicentres of both earthquakes were about 650 km apart from each other (**Figure 4**). The United States Geological Survey (USGS) reported a measurement of VIII (Severe) on the Mercalli intensity scale for the 19 September earthquake. National Seismological Service of Mexico recorded a peak ground acceleration of 112 cm/s$^2$ (0.114g) at their closest reporting station.


**Figure 4: Locations of Mexico earthquakes (Source: USGS)**

Although two major earthquakes in the same country within a short span of time are rare, these are possible in such a seismically active region as Mexico. Both earthquakes seem to be a result of the rupture of fault lines within the North American tectonic plate.

## Recent Earthquakes in China

A 7 magnitude earthquake struck southwest region of China on 8 August 2017 (**Figure 5**). The earthquake killed at least 19 people whereas 247 others were injured. The earthquake hit a sparsely populated area which is situated at 200 km northwest of the city of Guangyuan. Shaking was felt in the provincial capital Chengdu. According to an estimate more than 130,000 houses were damaged due to the earthquake.

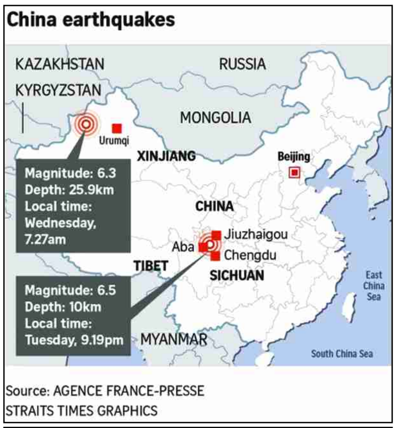


**Figure 5: China Earthquake (Source: Agence France-Presse, Straits Times Graphics)**

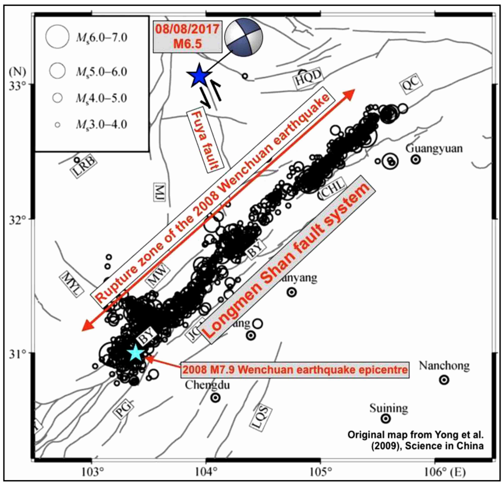


**Figure 6: Longmen Shan fault System (Source: Science in China 2009)**

Sichuan is frequently struck by earthquakes and a huge earthquake there killed almost 70,000 people in May 2008. In addition, 400,000 people were injured, over 5 million buildings were destroyed and over 45 million people were affected across western China due to this earthquake. The earthquakes in northern Sichuan are a result of shallow strike-slip faulting in the interior of the Eurasia plate. The earthquake on 8 August 2017 occurred on either a southeast striking left-lateral fault or on a southwest striking right-lateral fault (**Figure 6**).

Another earthquake of magnitude 6.6 hit China's far northwestern region of Xinjiang on 9th August 2017. The earthquake injured 32 people in the mostly rural area. Recent earthquakes in this area have also caused secondary hazards such as landslides that might have contributed to losses.

# Research for Flood Resistant Structures in Pakistan

Pakistan has been a victim of different disasters time to time. Different hazards in Pakistan include earthquakes, floods, landslides, hurricanes, etc. The country faced devastating floods for three consecutive years from 2010 to 2012 along river Indus (**Figure 7**). These caused widespread damages in different parts of the country. According to an estimate these flood affected 20% of the country and destroyed more than 2.5 million houses in across the country. In addition, almost 20 million people were made homeless. These statistics are a clear indication of limited capacity in Pakistan to dealing with flood hazard.

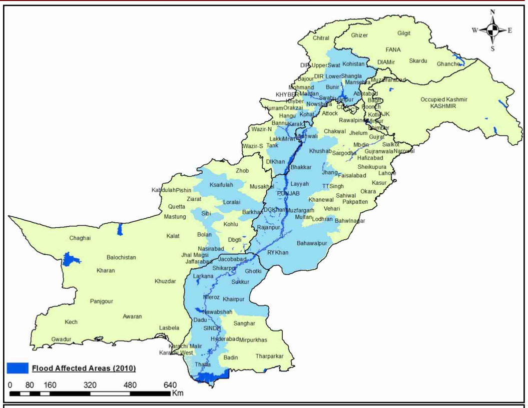


**Figure 7: Flood extent across Pakistan in 2010 (Source: Internet)**

The research on the construction of flood resistant structures is limited in the available literature. Existing guidelines on disaster risk reduction emphasizes on simply avoiding flood plains, which at times is not possible to follow for the people. In order to get livelihood communities prefer to live close to the rivers which make them vulnerable to flood hazard. Pakistan is no exception and human habitat along river Indus presents a good example of this vulnerability which was witnessed during the 2010-2012 floods.

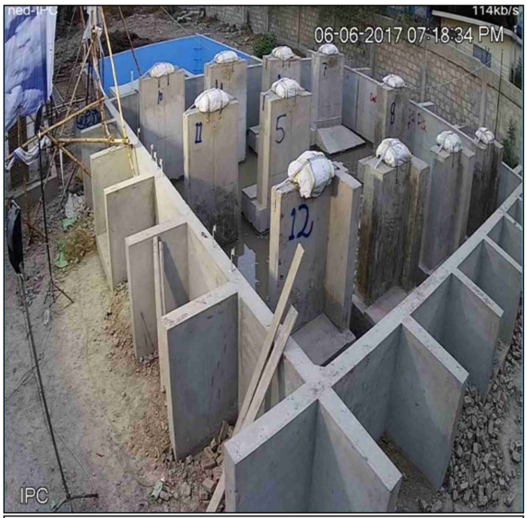


**Figure 8: View of flood testing facility with specimen walls**

A study related to observing performance of different types of walls in standing flood water was conducted by the Department of Earthquake Engineering along with Ove Arup & Partners Ltd (Arup) and International Organization for Migration (IOM). The study was supported by the Department for International Development (DFID), UK. A total of twelve walls including earthen walls with different foundations and protections were constructed and tested for standing flood condition (**Figure 8**). In addition, the walls were also tested for rain damages using a type II design storm (**Figure 9**). The testing provided important information related to the performance of earthen construction in flood situation.

**Figure 9: Rain testing of wall panels**

# Earthquake Jolts Rawalpindi and Islamabad

Earthquake shaking was felt in some parts of northern Punjab, in Pakistan including Rawalpindi, Islamabad, Wah Cantt. and Khyber Pakhtunkhwa (KP) on 27 August 2017. The shaking lasted nearly ten seconds. National Seismic Monitoring Centre (NSMC) reported magnitude of earthquake as 5 with its epicentre located at 67 km north of Mingora in KP. On the other hand, USGS reported epicentre at a depth of 30.9 km and nearly roughly 6 km to the southwest of Rawalpindi. Pakistan Metrological Department placed the epicentre in Kohistan in KP at about 67 km north of Mingora at a depth 17 km from the surface.

Although no loss of life or damage to property was reported, people were terrified and they came out of their houses in panic. Most of the Pakistan is seismically active and a number of earthquakes have been observed over the years in its different parts.

# Earthquake Rocks Greece and Turkey

A magnitude 6.7 earthquake hit Dodecanese Islands in Greece and the Aegean coast of Turkey (**Figure 10**) on 21 July 2017. The earthquake produced more than 100 aftershocks of magnitude as high as 5.1. At least two people were killed by this earthquake on the Greek island of Kos. The earthquake was also felt on the Datca peninsula and Izmir in Turkey. The maximum perceived shaking was VII on the Mercalli intensity scale. According to US Geological Survey, the epicentre of the earthquake was approximately 10.3 km (6.4 miles) south of Bodrum, Turkey, about 700 km (435 miles) from Istanbul and Ankara and 16.2 km east of the island of Kos in Greece. The earthquake is believed to be the result of normal faulting at shallow depths in the Eurasian plate. The area is known for both trans-tensional and extensional faulting and it has a complex geologic history.


**Figure 10: Map locating a 6.7-magnitude quake near the Greek island of Kos (Source: USGS, AFP Photo/Gal ROMA)**

## In-plane and Out of Plane Response of Concrete Block Infilled Frames with Openings

Masonry walls in reinforced concrete (RC) frames play a vital role to resist the lateral loads due to their high stiffness and strength. It is widely known that infill walls contribute to stiffness and strength of RC frames which are subjected to lateral seismic loads. In case of openings in the infill wall, strength and stiffness gradually reduces depending upon the opening size and location. Several studies have been conducted over the years to explore the effects of openings in infill walls. Fundamental period and damping of RC frames are also affected due to the infill walls and their openings. Use of masonry infill wall is neither beneficial nor detrimental. It depends upon the masonry infill wall arrangement used in the building frame structure.

Masonry infill panels help to decrease the interstory drift ratio which subsequently decreases the structural member forces; this shows that the infill buildings are capable of resisting large lateral forces even if they are not considered in the design of the structure. Many researchers have reported greater mechanical strength, higher ductility and lower displacements of masonry infilled frames.

In order to investigate the contribution of infill, laboratory tests were conducted on mortar cubes, masonry units, masonry prism and masonry walls in compression, shear and diagonal compression to find the mechanical properties of infill which are needed for analytical modelling studies. Finally, bare and in-filled RC frames were tested (**Figure 11**). Cyclic monotonic lateral loading were applied in three cycles. The average strength and stiffness of infill frame were found to be, respectively, 4.7 and 5.5 times higher than bare frame. The contribution of masonry infill can be increase/decrease depending up on mortar strength, masonry unit strength, thickness of masonry wall, size of column and beam, amount of reinforcement provided in columns and beam and size of reinforced concrete frame. The results from this research shall be useful for the analysis of both the old structures as well as the design of the new structures. In particular, the usefulness of this study shall be appreciated during the analysis of the existing structures which were not designed to meet the existing seismic demand. The presence of infill walls will ensure the increase in strength and stiffness of the existing structure resulting in less strengthening requiring which becomes beneficial for the facility owner.

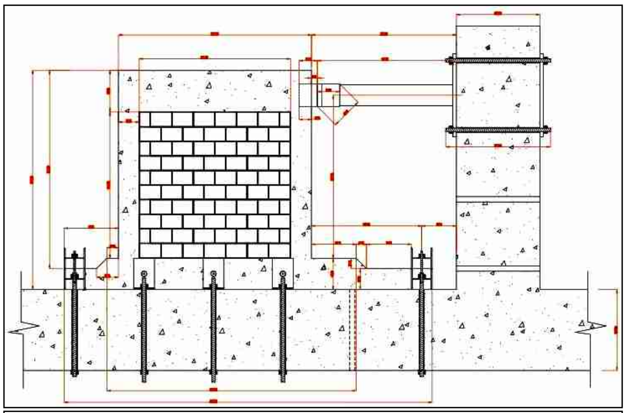

**Figure 11: View of infill frame testing**

In continuation of this study, work has been started to study the effects of openings in the in-plane and out-of-plane directions in the reinforced concrete frame. The parameters of the study include the following;

1. Dimensions of the wall (length/height ratio of wall)
2. Location of opening
3. Ratio of opening area to full infill wall area

## Earthquake Rocks Greece and Turkey *(Continued)*

Significant fault lines pass through Turkey and Greece and both these countries have regularly been hit by earthquakes in recent years. The seismicity of this region of the Mediterranean is due to the northward collision of the African plate into the Eurasian plate at 4 to 10 mm per year (**Figure 12**). This collision has caused a series of devastating earthquakes in the region in the past.

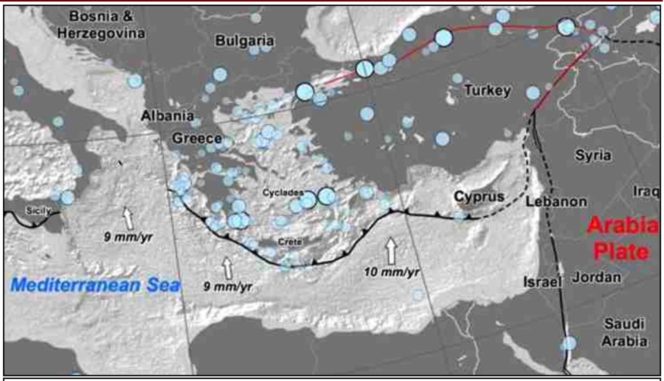


**Figure 12: Collision of the Africa and Eurasian Plate. Line with triangles pointing north denote location of major faulting. (Source: USGS)**

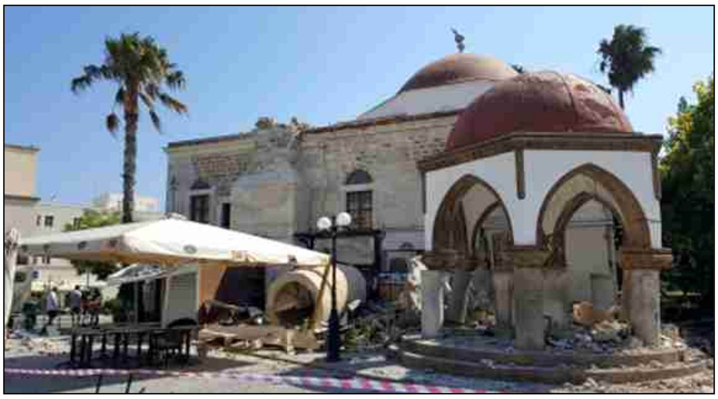

**Figure 13: The Defterdar mosque on Kos (Source: AFP Photo)**

The earthquake on 21 July 2017 triggered a small tsunami that brought two-foot tidal waves. It caused flooding in Bodrum and parts of Kos. Significant damages to the buildings and a port have been reported in Kos. A 14th-century fortress at Kos's main port and the 18th century Defterdar mosque were also damaged due to the earthquake (**Figure 13**).

**RESOURCE PERSONS:**

- Prof. Muhammad Masood Rafi
- Prof. Rashid A. Khan
- Dr. Mukesh Kumar

**Mail:**
Cowasjee Earthquake Study Centre NED,
Department of Earthquake Engineering,
NED University of Engineering and Technology,
Karachi-75270, Pakistan

**Phone:** +92-21-9926 1261- 68 Ext. 2605
**Fax:** +92-21-9926 1255
**Email:** rafi-m@neduet.edu.pk
**Web page:** www.neduet.edu.pk/EQD/