Seismic Rubber Bearings for Effective Protection of Structures and their Contents

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The use of seismic rubber bearings, or commonly known as base isolation, is being increasingly employed as a means of protecting structures from earthquake damage. Today, more than 7000 structures all over the world have used this technology. The worldwide successful application of the technology has been stimulated by the good performance of isolated structures in several earthquakes such as in Northridge, California (1994) and Kobe, Japan (1995) and the introduction of Codes for constructing base-isolated buildings in Japan, China, Italy and other countries.

Base isolation offers important advantages over conventional protection methods because it reduces the earthquake forces transmitted into a structure. Thus, it protects not only the structure itself but also the contents and secondary structural features. Such a capability is particularly important for buildings such as hospitals and emergency facilities that need to maintain full serviceability after a major earthquake. The paper briefly describes the principles of base isolation and the work carried out by the Malaysian Rubber Board (MRB) in promoting the technology.

INTRODUCTION

To many structural engineers, the conventional approach to protect buildings from the destructive forces of earthquakes is to increase the strength of the buildings so that they do not collapse during such events. This approach is not entirely effective in terms of protection afforded to the contents and occupants as a result of the amplification of the forces transmitted into the building. Since the motion of earthquakes is vibrational in nature, the principle of vibration isolation can be utilised to protect the structure.

In base isolation, a building is decoupled from the horizontal components of the earthquake ground motion by mounting rubber bearings between the building and its foundation. The natural period of the building on the base isolation is typically two to three seconds. This period is long compared with both the dominant period of the earthquake and the period of a conventionally designed building (fixed-base).

Damping is normally added to the rubber bearings to reduce the response to input excitations at the isolation period. It is important to realise that despite the need for some damping, the rubber bearings are not principally acting to absorb the energy of the earthquake, but are providing an interface that reflects the earthquake energy back into the ground, thus reducing its transmission into the structure.

The main advantage of using base isolation is that it can provide effective protection both to the building and to its contents and occupants [1]. The capability to protect the contents is crucial for buildings such as hospitals and emergency centres where maintenance of function during and after an earthquake is necessary, and in places such as museums and advanced technology factories where the value of the contents is high. The technique is also applicable to bridges and industrial structures such as LNG tanks. In addition, existing buildings could also be retrofitted with rubber bearings.

At present, more than 7000 structures (buildings and bridges) in the world's seismically-prone areas (US, Japan, Italy, China, Taiwan and New Zealand) have been installed with seismic rubber bearings. The introduction of guidelines, codes and straightforward procedures for the approval of base-isolated structures has increased the exploitation of this technology. Codes have been introduced in the US, Japan, China, Italy and Armenia. A revised version of Eurocode 8, Part 1 includes a new chapter on seismic isolation [2]. Eurocode 8 – Part 2: Bridges has included a chapter on seismic isolation for some years [3].

Though the introduction of a Code has generally assisted in the uptake of the technology, the conservative approach to base isolation adopted in the Uniform Building Code and International Building Code has limited its adoption in the US. On the other hand, a more realistic Chinese Code resulted in a rapid application of the technology in China. At present, more than 800 structures in China have used the technology and, in addition, the Chinese Code on base isolation enables a reduction in construction cost by up to 20%. The reduction would be higher for buildings with more storeys compared with low rise buildings.

PERFORMANCE OF RUBBER BEARINGS IN REAL EARTHQUAKES

The effectiveness of seismic rubber bearings was clearly demonstrated during the 1994 Northridge and 1995 Kobe devastating earthquakes where base-isolated buildings performed very well compared with conventionally-built structures which were either destroyed or suffered serious damage. For example, a base-isolated University of Southern California Hospital, showed a reduction in acceleration on the seventh floor by a factor of 5 when compared to the ground acceleration. In Kobe, the sixth floor of a base-isolated West Japan Postal Service Computer Centre showed a reduction in acceleration by a factor of 10 when compared to an equivalent conventionally-built building nearby.

Figure 1: (Left) San Bernardino County Law and Justice Centre. (Right) Rubber bearings installed on foundations

After the Kobe temblor, the demand for the base isolation system skyrocketed in Japan, especially for bridges, where 99% of the newly-built bridges are now using base isolation as compared to 5% before the Kobe earthquake. The widespread use of rubber bearings for bridges in Japan was mainly due to the fact that, during the Kobe earthquake, all the bridges that collapsed were on steel mechanical bearings and none of the bridges on rubber bearings collapsed.

THE MALAYSIAN RUBBER BOARD (MRB) BASE ISOLATION PROJECTS

For effective performance, seismic rubber bearings require some level of damping. High damping rubber bearings (HDRB) are a simple, economic and maintenance-free means of providing the isolation interface. This type of rubber bearing was developed by the MRB in the late 70s [1] as part of a joint R&D effort with the University of California, Berkeley, to evaluate the use of seismic rubber bearings for structures. The performance of HDRB was evaluated in shaking-table tests carried out at the Earthquake Engineering Research Center, California [4]. The joint R&D resulted in the application of the technique in the seismic protection of the San Bernardino County Law and Justice Centre, California (Figure 1) erected in 1984 and the first such project in the world.

As part of a continuous program to promote HDRB bearings and as a service to humanitarian causes, the MRB was involved with the United Nations Industrial Development Organisation (UNIDO) in three projects [1] to demonstrate the feasibility of utilising HDRB bearings for base isolation of public dwellings in developing countries. In 1993, the MRB participated in a UNIDO program to encourage the extension of base isolation using HDRB bearings to ordinary dwellings, particularly public housing, in developing countries which are earthquake-prone.

The first project involved the construction of an 8-storey demonstration apartment building in Shantou, China which was completed in 1994. The second project was the construction of a base-isolated 4-storey demonstration building at Pelabuhan Ratu in Indonesia which was completed in 1994. The third project was retrofitting an existing 5-storey unreinforced masonry apartment block in Vanadzor, Armenia, which was completed in 1996. The apartment sits on 30 HDNR bearings.

While Malaysia may be regarded as seismically stable, nevertheless, it is at close proximity to the seismically-active Sumatran fault and subduction zone on the western part of Sumatra. The massive destruction suffered by Mexico City in 1985 was due to an earthquake of which the epicentre was some 400km away. Earthquakes have also occurred in areas traditionally regarded as safe, such as Newcastle in Australia in 1991 and Maharastra in India in 1993.

Therefore, it is felt that seismic awareness in Malaysia and the necessary precautions ought to be given some prominence by constructing a building

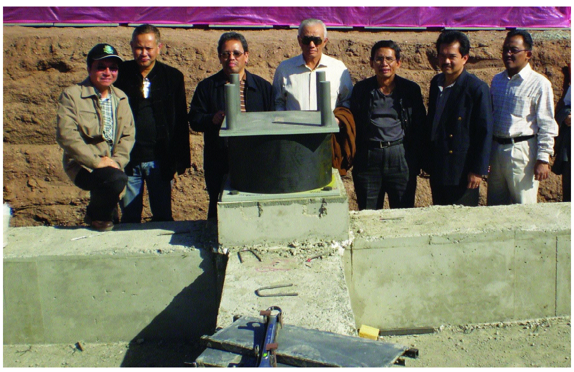

Figure 2: The first bearing for the Iranian project installed on 9 November 2007

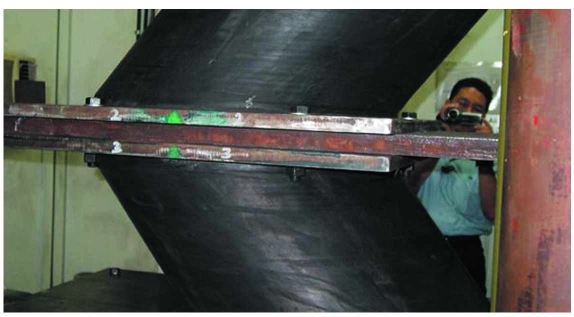

Figure 3: A pair of the Iranian bearings being simultaneously compressed and sheared at a cyclic rate of 0.004Hz

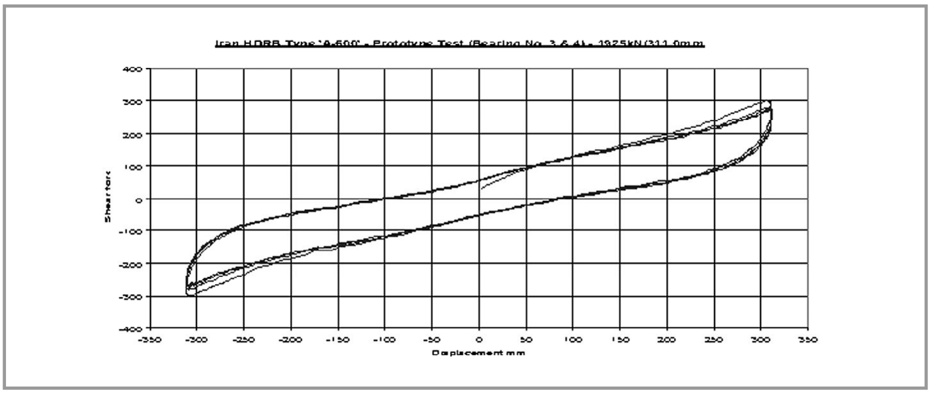

Figure 4: Typical shear force-deflection loops for the Iranian bearings. The bearings underwent cyclic shear deformation at 0.004Hz while being subjected to 2000kN vertical load

isolated with rubber bearings in Lahad Datu, Sabah, which is near to the seismic areas of southern Philippines and the Sulu Sea. A 3-storey building belonging to the Malaysian Palm Oil Board was installed with 28 rubber bearings and the construction was completed in 2001.

THE WORLD'S LARGEST BASE ISOLATION PROJECT IN IRAN

Iran is situated in an area with active seismic activity and is constantly under threat from devastating earthquakes. The recent Iranian earthquake in December 2003 which destroyed the historical city of Bam illustrates the destructive power of the earthquake. Since 2004, the MRB has been actively promoting seismic rubber bearing technology in Iran. Last year, the Iranian government had agreed to use this technology in Iran for the first time for a housing project awarded to a Malaysian developer. The project involves the construction of apartment buildings in Parand, a new township about 30km south of Tehran. It is expected that more than 8,000 rubber bearings will be used for about 150 blocks of 8- and 12-storey high buildings. This is the world's largest application of seismic rubber bearings in a single project.

The first batch of 196 rubber bearings, manufactured locally by a Malaysian manufacturer, are now being installed for the first three blocks of 12-storey buildings. Figure 2 shows the first bearing that was installed on 9 November 2007. All the bearings were tested according to the design specification before being sent to Iran. Figure 3 shows the bearings being tested under combined vertical and horizontal loads. Since the fastest test frequency is 0.004Hz and the isolation frequency is 0.5Hz, a frequency correction factor was determined using scaled-down model bearings subjected to a cyclic test at 0.5Hz. Figure 4 shows a typical shear force-deflection loop of the Iranian bearings. The important properties evaluated are the vertical and horizontal stiffness, and damping.

REQUIRED PROPERTIES OF HIGH DAMPING RUBBER BEARINGS

The pertinent properties of the rubber bearings for effective performance during a major earthquake are as follows:

- low horizontal stiffness at design displacement
- high vertical stiffness
- capability to support gravity load of structure over long term
- capacity to accommodate large horizontal displacement during an earthquake and, at the same time, support vertical load including seismic loads
- moderate level of damping (10%-15% for buildings)
- capability to re-centre structure after an earthquake
- stable stiffness and damping properties over long term
- high initial horizontal stiffness to provide wind restraint
- ability to function again after the design earthquake

A seismic rubber bearing consists of alternate layers of rubber and steel plates. The steel plates can greatly increase the vertical stiffness of the bearing; a ratio of around 1500:1 between vertical and horizontal stiffness is typical. The plates also enable the bearing to support the vertical load even under a large shear displacement. A strong bond between the rubber and steel is critically important for the correct functioning of the bearing. The natural rubber is specially formulated to give the required damping and it is normally 10% to 14% of critical. The use of high damping rubber avoids the need for auxiliary dampers such as viscous or elasto-plastic steel dampers in the isolation system.

CONCLUSION

Seismic rubber bearings are a simple, economic and maintenance-free means of providing the isolation interface and are now being used worldwide in seismically-prone areas. The technology can not only protect the structures, but also the contents and the occupants. In addition, the structures could continue operating after a major earthquake and this is advantageous for critical buildings such as hospitals. The effectiveness of the rubber bearings has been demonstrated in the recent earthquakes of Northridge and Kobe where base-isolated buildings and bridges performed very well. The MRB has been promoting the technology worldwide and is currently involved in the world's largest base isolation project in Iran. ■

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