ADVANCED TECHNOLOGIES IN HOUSING CONSTRUCTION

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BACKGROUND

Advanced technologies in housing construction are not used as frequently as the more standard construction technologies described in earlier chapters, which involve the use of masonry, timber, and concrete. However, as with other innovations, it is expected that over time these newer technologies will gain wider acceptance. For purposes of the World Housing Encyclopedia, advanced technologies include seismic isolation and passive-energy dissipation devices. As of this writing, the WHE database contains three reports describing the applications of advanced technologies: two of them describe base-isolation systems from China (WHE Report 9) and Kyrgyzstan (WHE Report 76), and the third report describes the use of a seismic protection system developed in the former Soviet Union, called "disengaging reserve elements" (WHE Report 77, Russian Federation).

The first application of advanced technologies in housing construction dates back to the 1970s. For example, the sliding-belt isolation scheme was developed in Russia around 1975, with its first application in Kyrgyzstan in 1982. The disengaging reserve elements (DRE) were developed in Russia in 1970 and first applied in 1972. The first code addressing this type of construction was issued in 1981. In China, the widespread use of base isolation for housing has only been employed since 1990, with the first code addressing this technology published in 2000.

Figure 1: Base-isolated brick masonry building with RC concrete floors and roof in China (WHE Report 9)

Figure 2: Load-bearing wall buildings protected with a sliding-belt isolation system in Kyrgyzstan (WHE Report 76)

SEISMIC ISOLATION (adapted from Mayes and Naeim 2001[1])

Seismic isolation is a relatively new concept in earthquake engineering, having been introduced in the early 1980s in the USA and New Zealand, and as early as 1975 in the former Soviet Union. Quite simply, the idea underlying the technology is to detach the building from the ground in such a way that the earthquake motions are not transmitted up through the building, or are at least greatly reduced. Seismic isolation is most often installed at the base level of a building and is called *base isolation*. This new concept meets all the criteria for a classic modern technological innovation: the necessary imaginative advances in conceptual thinking, new materials available to the industry, and as can be seen in the WHE reports using isolators, simultaneous development of the ideas worldwide.

The principle of seismic isolation is to introduce flexibility at the base of a structure in the horizontal plane, while at the same time introducing damping elements to restrict the amplitude of the motion caused by the earthquake. The concept of seismic isolation became more feasible with the successful development of mechanical energy dissipators and elastomers with high damping properties. Seismic isolation can significantly reduce both floor accelerations and interstory drift and provide a viable economic solution to the difficult problem of reducing nonstructural earthquake damage, as illustrated in Figure 3.

There are three basic elements in any practical seismic isolation system. These are as follows:

- A flexible mounting so that the period of vibration of the total system is lengthened sufficiently to reduce the force response
- A damper or energy dissipator so that the relative deflections between building and ground can be controlled to a practical design level
- A means of providing rigidity under low (service) load levels, such as wind and minor earthquakes

Seismic isolation achieves a reduction in earthquake forces by lengthening the period of vibration in which the structure responds to the earthquake motions. The most significant benefits obtained from isolation are thus in structures for which the fundamental period of the building without isolation is short—less than one second. Therefore, seismic isolation

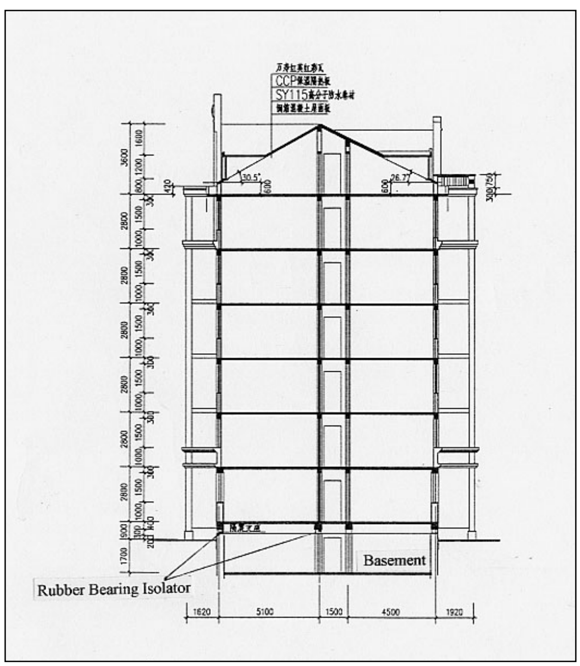

Figure 3: Vertical section through a base-isolated building in China (WHE Report 9)

is most applicable for low-rise and medium-rise buildings and becomes less effective for high-rise structures.

The WHE reports describe the applications of two different isolation systems:

- Rubber-based isolation system
- Sliding-belt isolation system

The *rubber-based isolation system* has been widely used in China (WHE Report 9). The system consists of laminated rubber bearings, with a diameter of 350 mm to 600 mm and a thickness of 160 mm to 200 mm. The isolators are reinforced by thin steel sheets. The isolators are installed on top of the basement walls or the columns, or at the plinth level in buildings without a basement. The most common application in China is for those buildings where the superstructure consists of common multistory, brick-masonry walls

Figure 4: Rubber isolators used in China (WHE Report 9*)*

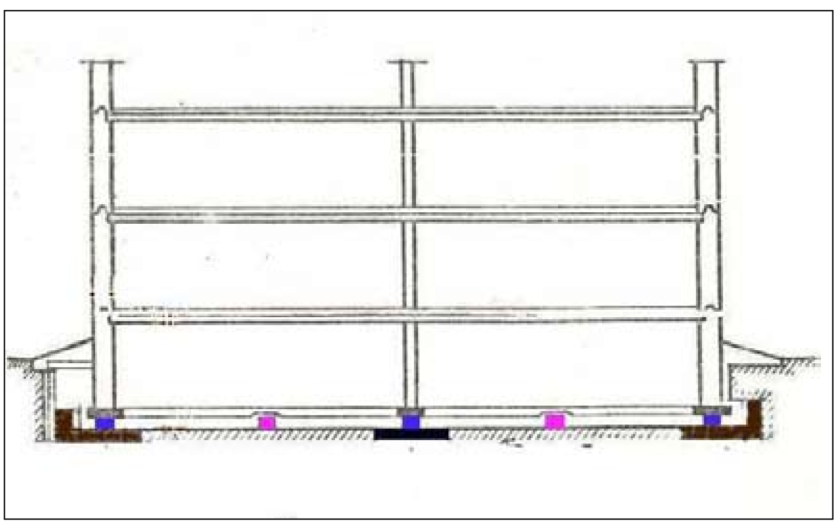

Figure 5: Building elevation showing the locations of sliding bearings (undercolumns) and vertical stops (center of spans) (WHE Report 76, Kyrgyzstan)

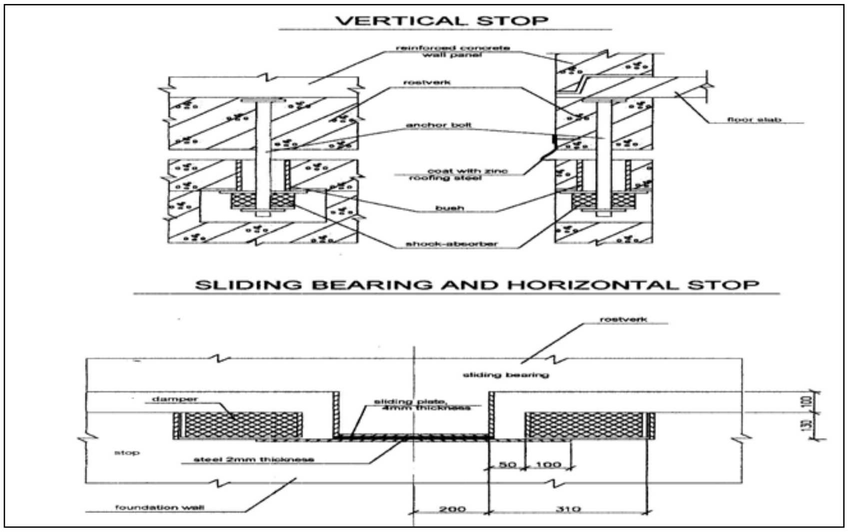

Figure 6: Components of the sliding-belt system (WHE Report 76, Kyrgyzstan)

with reinforced concrete floors/roof. The cost of this system is US$145/$m^2$. By the end of 2003, the system had been used in over 460 residential buildings in China. Sliding-belt isolation systems are installed at the base of the building between the foundation and the superstructure. The sliding belt consists of the following elements: (a) sliding supports, including the 2-mm-thick stainless steel plates attached to the foundation and 4-mm Teflon (PTFE) plates attached to the superstructure, (b) reinforced rubber restraints for horizontal displacements (horizontal stop), and (c) restraints for vertical displacements (uplift)–vertical stops. Once the earthquake base shear force exceeds the level of the friction force developed in the sliding belt, the building (superstructure) starts to slide relative to the foundation. A typical large-panel building with plan dimensions 39.6 m x 10.8 m has 63 sliding supports and 70 horizontal and vertical restraints. The sliding-belt scheme was developed in CNIISK, Kucherenko (Moscow) around 1975. The first design application in Kyrgyzstan was made in 1982. To date, the system has been applied in over 30 buildings in Bishkek, Kyrgyzstan. The applications include 9-story, large, concrete panel buildings and 3-story brick masonry wall buildings.

In the USA, New Zealand, Japan, and Italy, base-isolation technology has been used primarily to protect critical facilities, such as bridges, hospitals, city halls, courthouses, and heritage buildings. The most popular devices for seismic isolation of buildings in the USA are lead-rubber bearings, high-damping rubber bearings, and the friction pendulum system (FPS). In Japan, as of 1999, over 300 residential buildings were protected with base-isolation devices[2] (note that there were 700 base-isolated buildings in Japan at that time). Typical residential buildings are reinforced concrete frame or wall construction, more than 5 stories, perhaps containing hundreds of apartments. The majority of base-isolated residential buildings in Japan were built after the 1995 Kobe earthquake (M7.3), which caused over 6,000 deaths, mainly as a result of vulnerable older wood housing[3].

PASSIVE ENERGY DISSIPATION DEVICES

Passive energy dissipation systems represent an alternative to seismic isolation as a means of protecting building structures against the effects of damaging earthquakes. The basic function of passive energy dissipation devices in a building is to absorb or consume a portion of the earthquake input energy, thereby reducing energy dissipation demand on primary structural members and minimizing structural damage. The means by which the energy is dissipated is either through the yielding of mild steel, sliding friction, motion of a piston or a plate within a viscous fluid, motion of an orificed viscous fluid device, or viscoelastic action of polymeric materials. The most common types of passive devices used-to-date include viscous fluid dampers, friction dampers, metallic dampers, and tuned mass dampers. These devices can be effective against wind motions as well as against earthquakes[4].

Research and development of passive devices has a 30-year history. Most often, this technology has been used to retrofit existing public buildings that do not meet the seismic code requirements or were damaged by an earthquake. There are very few examples of the application of this technology to housing construction. In Canada, friction dampers were used in 1988 to retrofit a two-story wood house in Montreal. In the former Soviet Union, a unique passive seismic protection system called "disengaging reserve elements" (DRE) has been used to protect over 140 residential apartment buildings in the last 30 years, and it is the only application of passive-energy dissipation devices currently included in the WHE.

The DRE system was developed around 1970 in the former Soviet Union (WHE report 77, Russian Federation). A building with the DRE system must be made with a flexible

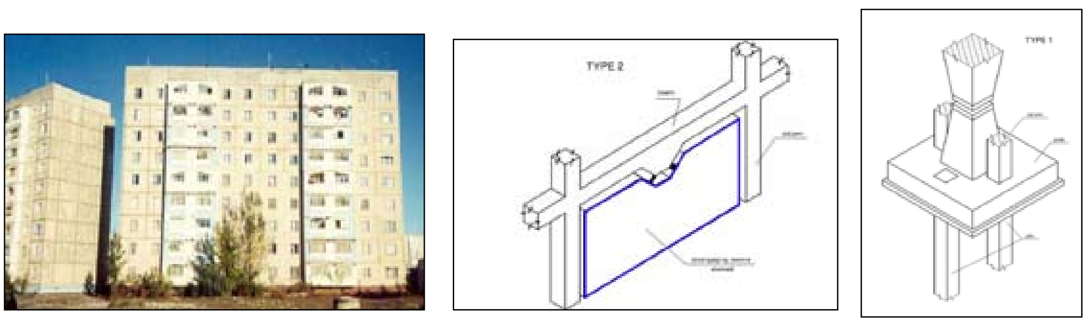

Figure 7: Typical building with DRE system in Ukraine (left); critical structural details of the system (WHE Report 77, Russian Federation), (center and right)

reinforced concrete frame on the ground floor while the upper stories may be made with any of the more rigid systems: typically, large precast panel construction or brick masonry wall construction. The elements are constructed within the bays of the reinforced concrete frame on the ground floor. They consist of a "rigid structure," generally RC wall panels, connected to the adjacent RC frame members by means of disengaging restraints. The DRE do not carry any gravity load and are only installed to act as a part of the lateral load-carrying system. The disengaging restraints, which connect the DRE to the RC frame, are sacrificial reserve elements (fuses) that are designed so that they will be the first structural members damaged in a large earthquake. Typical restraints are made of steel plates joined together by means of rivets or steel bolts, steel bars, concrete prisms or cubes. Initially (at the lower ground motion levels), the DRE and RC frame system (at the ground floor level) work together as a rigid structure; at that stage, disengaging elements transfer lateral loads to the DRE (RC panels). However, once the lateral load exceeds the prescribed level (depending on the site seismicity and other factors), the disengaging elements snap and disconnect from the DRE. At that stage, due to the suddenly increased flexibility, a building changes its vibration period to a higher value of about 0.8–1.0 sec. As a result, resonance effects are avoided and seismic demand is reduced. After an earthquake, disengaging restraints need to be replaced. However, the cost is not high and the replacement is not complex.

This system was developed by Professor J. Eisenberg. The first building using the DRE system was constructed in 1972 in Sevastopol, Ukraine (the former Soviet Union). The system has been widely used in earthquake-prone areas of Russia and Kyrgyzstan. In Russia, about 140 buildings are protected with this system, primarily in North Baykal City and Siberia. There are several dozens of buildings with this system in Kyrgyzstan, Kazakhstan, Tajikistan, and Georgia. Most of the buildings are residential and currently occupied.

EARTHQUAKE PERFORMANCE

Typically, all the buildings built with these new technologies have performed or are expected to perform well in major earthquakes. In fact, unlike some of the other construction technologies described in the WHE, this technology is used to improve a building's performance in an earthquake. In China, where the use of base isolation for rigid masonry buildings is becoming more widespread, these buildings have been subjected to numerous strong earthquakes and have all performed well. No damage to this building type has been observed in any of these earthquakes: 1994 Taiwan Straits (M 7.3); 1995 Yunan Province (M 6.5); 1996 Yunan Province (M 7.0), and the 2000 Xinjian Autonomous Region (M 6.2).

RETROFIT

Again, unlike some of the other construction technologies described in the WHE, buildings built with these advanced technologies do not need to be strengthened to improve their performance in earthquakes. Rather, these technologies can be used to strengthen buildings. Some structures are inherently more suitable for retrofit using seismic isolation than others; for example, bridge superstructures lend themselves to the replacement of steel bearings with elastomeric ones. Buildings are typically more difficult to retrofit than bridges. A Marina apartment building in San Francisco, California, is one of the rare applications of base-isolation technology for seismic retrofit[5]. This four-story, wood frame building was severely damaged during the 1989 Loma Prieta earthquake. In 1990, thirty-one Friction Pendulum (FPS) bearings were installed at the base of the new garage-level steel columns. FPS bearings "isolate" the structure from the most

Figure 8: Typical earthquake damage to brick masonry buildings without base isolation (1976 Tanshan earthquake) (WHE Report 9, China)

Figure 9: Base-isolated, brick masonry buildings remain undamaged in the 1996 Yunan earthquake (M 7.0) (WHE Report 9, China)

damaging earthquake motions by using the characteristics of a pendulum to lengthen the structure's natural period. The total retrofit cost was less than the cost to structurally upgrade the building to the seismic requirements of the then current UBC code. Interestingly, this building is considered to be the first base-isolated building in Northern California.

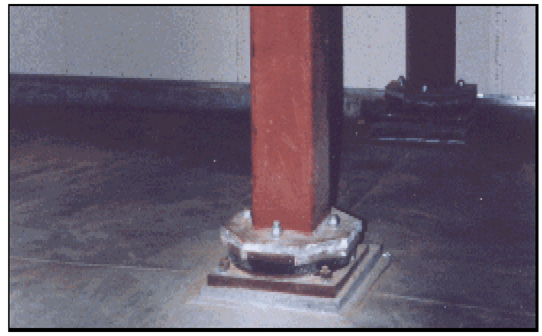

Figure 10: Marina apartment building (left); installation of FPS bearing at the column base (right)

ENDNOTES

[1] Mayes, R. L. and Naeim, F., 2001. Design of structures with seismic isolation, in *The Seismic Design Handbook , 2nd edition,* (F. Naeim, ed.), Kluwer Academic Publishers.
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[4] Constantinou, M. C., Soong, T. T., and Dargush, G. F., 1998. *Passive Energy Dissipation Systems for Structural Design and Retrofit,* Multidisciplinary Center for Earthquake Engineering Research, Buffalo, New York.
[5] Earthquake Protection Systems, Inc., http://www.earthquakeprotection.com.