Seismic Isolation of Buildings Using Passive Control Technologies

Project Progress Report

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ABSTRACT

Passive control technologies, particularly rubber bearings, will be discussed. Some of the applications in countries like China, Italy, New Zealand, Armenia, USA , Japan and others will be presented. Design codes and standards will be discussed, as well as examples from some of the mentioned countries. Finally Results from three experimental studies are presented , they include : shake table study on a mass eccentric base isolated model, shake table study on an aseismic roof isolation system , and an experimental study on seismic responses of multifunctional vibration absorption RC megaframe structures.

INTRODUCTION

Passive control technologies represent a set of innovative systems to protect construction(buildings and bridges) from earthquake attack[1].Control of the structural response to earthquakes can be effected by means of various systems, based on different concepts, such as modifying rigidities, masses, damping and producing passive or active counter-forces. This control is essentially based on two approaches: modification of the dynamic characteristics or modification of the energy absorption capacity of the structure. In the first case, the structural period is shifted away from the dominant frequencies of the seismic input, thus avoiding the risk of resonance, and usually leading to less severe dynamic actions. In the second case, the capacity of the structure to absorb energy is increased through appropriate devices, which preserve the structure from damage. Both these approaches can be implemented in passive, active or hybrid systems. For the passive systems, which do not require an external power source, the structural properties (period and/or damping capacity) do not depend on the seismic ground motion. Base isolation or damping devices serve as the first line of defence against seismic forces, leaving the structure itself and its inelastic reserve of strength as secondary defences. Thus, the structures receive only a part of the seismic forces, the rest being dissipated by the action of the devices. Passive control systems used in Europe basically adopt two approaches: seismic isolation and energy absorption, which very often act together in the same system[2].

Different building styles in different areas require different features of seismic isolation, such as different materials for the isolators, different location of the isolation layer, different design safety levels for isolation.

Five kinds of material are used for isolators : Sand layer, Graphite-lime mortar layer, Sliding friction layer, rollers and Rubber Bearings. The first three types suffer from sensitivity to foundation settlement and inability to recover displacement. The main advantage of rollers as isolation device is that it effectively isolates the ground motion. The main problem is that the device needs careful maintenance to ensure effective operation over its long working lifetime. Rubber bearings are the most widely used isolator , these are laminated steel sheet–rubber bearings with or without a lead core[3].

Four possible locations of an isolation layer with rubber bearings are employed :

_ Base isolation. The isolation layer is located at the base of the building;

_ Basement isolation. The isolation layer is located on top of the basement.

_ Storey isolation. The isolation layer is located on top of the first storey or a higher story of the superstructure.

_ Top isolation. The isolation layer is located on top of the building it is common practice to add one or two storey on top of existing buildings in seismic retrofit.

TECHNICAL CODES ON SEISMIC ISOLATION

It is known that the growth in the number of seismically isolated buildings, with the exception of some countries such as Japan, Italy[4], China[3] and currently Armenia[5], is still quite slow. One reason is the lack of provision in seismic codes for such type of buildings. To date seismic isolation systems have been designed for particular applications. This has meant that often the designs are of a prototype nature and extensive prototype testing is required. In some countries, USA for example, every device is required to be tested . This excessive testing places an unnecessary additional cost on the application of seismic isolation [6]. The following is a brief description of the codes and standards used in three of the countries studied [5].

China

There are three different sets of technical codes on seismic isolation in China [3]. The main features of all these codes on seismic isolation in China are that they :
_ Provide design methods for seismic isolation of buildings, bridges, special structures and industrial facilities
_ Provide design methods for seismic isolation of newly designed structures and to retrofit existing structures
_ Specify three design levels, depending on the importance of structures and requirements of owners in areas with different economic conditions (Table 1)
_ provide two methods of structural analysis for seismic isolation of structures
_ Allow reduction of the design seismic shear load for the superstructure, providing savings in costs
_ Allow a choice of the compression stress level for the isolators (Design Levels 1,2 3)
_ Control the maximum horizontal shear displacement of the isolation layer
_ Specify high-quality rubber bearings proved by thorough testing. Two kinds of testing are required: product characterization for quality control and product characterization for particular projects.

Italy

In Italy, the Ministry of Public Works recently issued the final version of the '*Guidelines for Design, Execution and Certification of Seismically Isolated Structures*' (1998). This is the result of almost 10 years of activity by many national organizations, which supported the Italian Ministry in producing these first guidelines [4]. They have been a pressing need for many years, as the application of innovative techniques for seismic protection in Italy has become more and more widespread. In fact, without an official code, approval of such unconventional design projects had become a very critical issue.
The guidelines are devoted to passive protection techniques are subdivided into: seismic isolation techniques; energy-dissipation techniques, and mixed techniques. The isolation systems are classified according to the type of isolators. The energy dissipation systems are classified according to the method which is used for producing the dissipating effect.

Armenia

In order to successfully implement seismic isolation in Armenia it was necessary to develop a code for the design of seismic isolation systems. This work was accomplished in 1995–1996 and was financed by the World Bank within the framework of the Armenia Earthquake Zone Reconstruction Project [5]. The proposed code is divided into three parts: (A) Design of Overall Isolation System; (B) Design and Type Testing of Rubber Isolators; and (C) Manufacture and Quality Control Testing of Rubber Isolators[5]. However, that code was not approved by the Ministry of Urban Development (MUD) of Armenia, as there was an opinion that the country has the National Seismic Code that allow for the design of seismic isolation, and there is no need to have separate code for seismic isolation. The MUD has opted instead for a separate code for seismic isolation with guidelines for seismic isolation of buildings and structures as an attachment to the National Seismic Code. In 2000 , The guidelines for seismic isolation of buildings and structures were developed on the basis of already proposed code[5].
The guidelines involve provisions on the types, calculation, design, and maintenance of the passive seismic isolation systems. Also, examples for design of base-isolated buildings are given in the guidelines. Seismic isolation is taken to mean isolation of buildings and structures against ground motions in the horizontal direction only. The system should display high resilience, allowing for great horizontal displacements without any damage. Under design impacts, the horizontal displacements should be within 50–400 mm. Design should allow free access to each isolator and provide the possibility to replace it without difficulty, if necessary. Normative 40–45 year lifetime of isolators should be accounted for. Seismic isolation systems are applicable both in the construction of new, and in upgrading earthquake resistance (retrofitting) of existing structures. Seismic isolation is efficient for buildings and structures displaying 0.1–1.0 s natural oscillation period with their bases fixed (without seismic isolation). For buildings and structures with 0.2–0.7 s periods, Seismic isolation is most adequate. The most important difference in the guidelines developed in Armenia is in the definition of the minimum lateral force.
At the design level earthquake, the structures of the isolation system and its connection to the superstructure and the foundation shall be designed and constructed to withstand a lateral force F_H without sustaining any damage and remaining serviceable.

APPLICATIONS OF SEISMIC ISOLATION AROUND THE WORLD

China

Over 450 civil buildings with rubber isolation bearings have been built in China up to now, including houses (about 70%), offices, schools, museums, libraries and hospitals. Their height is 3–19 storey. The commonest structural types are concrete frame or masonry structures. The rubber bearings are the most popular isolators in widely spread used in China because of their many unique features
compared with the other kinds of isolator

1. Effective isolation. They decrease the structural response to 1/2–1/8 of the traditional response.
2. Stable character of isolators. With no maintenance the specified working lifetime is'100 years [3].
3. They recover displacement perfectly after earthquakes.
4. Vertical tension capacity. They can accommodate vertical motion of building during earthquakes.
5. Insensitivity to foundation settlement. They can adjust the structural force by deformation of the rubber bearings when foundation settlement of building occurs before or after earthquakes.
6. They decrease the temperature stress in structures by free horizontal deformation of bearings during large change of temperature around the structure.
7. They have operated successfully in real earthquakes in China, USA, Japan and other countries.

Design safety level

Three design levels of isolation buildings depending on the type of building (Table –1)

Examples of seismic isolation of civil buildings (Table 2)

USA

The University of Southern California Teaching Hospital in eastern Los Angeles is an eight-story concentrically braced steel frame supported on 68 lead rubber isolators and 81 elastomeric isolators [7]. (USCTH) was 36 km (23 miles) from the epicenter of the Mw 6.8 1994 Northridge earthquake. The peak ground acceleration outside the building was 0.49 g, and the accelerations inside the building were around 0.10 to 0.13 g. In this earthquake the structure was effectively isolated from ground motions strong enough to cause significant damage to other buildings in the medical center[7]. The records obtained from the USCTH are particularly encouraging in that they represent the most severe test of an isolated building to date. To 1997 45 base-isolated buildings in the U.S. are planned, under construction, or completed—for new construction and for retrofitting. The use of base isolation applications up to this time in the U.S. has been for structures with critical or expensive contents, but there is increasing interest in applying this technology to public housing.

Japan

Although such buildings in Japan require special approval from the Ministry of Construction, as of June 30, 1998, 550 base-isolated buildings had been approved. Currently the largest base-isolated building in the world is the West Japan Postal Computer Center, located in Sanda, Kobe Prefecture. This six-story, 47,000 m square (500,000 ft square) structure is supported on 120 elastomeric isolators with a number of additional steel and lead dampers. The building, which has an isolated period of 3.9 sec, is located approximately 30 km (19 miles) from the epicenter of the 1995 Hyogoken Nanbu (Kobe) earthquake, and experienced severe ground motion. The peak ground acceleration under the isolators was 400 cm/sec square (0.41 g) but was reduced by the isolation system to 127 cm/sec square (0.13 g) at the sixth floor. The estimate of the displacement of the isolators is around 12 cm (4.8 in.). A fixed-base building adjacent to the computer center experienced some damage, but there was no damage to the isolated building. As a result of superior performance of the West Japan Postal Computer Center, there has been a rapid increase in the number of permits for base-isolated buildings, including many apartments and condominiums.

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