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HIGH PERFORMANCE WOODEN BUILDING SUBJECTED TO SEISMIC ACTION

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ABSTRACT

The paper is focusing the attention on the important aspects related not only to the acceptable safety level avoiding catastrophic failures and loss of life, but even to higher performance level requested for some important buildings, like hospital, police station, communication centers. Such buildings need to be designed to remain functional after the earthquake event.

The paper, moving from the current philosophy for seismic engineering, aims to recall and underline how the different levels of Performance Based Design of such buildings are still requesting investigation concerning the design and realization of technical devices. It is known that a building is able to respond with a predictable performance level if designed with ductility capacity, developed as response mostly by the structure. An alternative is to modify externally the building to reduce the demand or

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the response. This can be achieved either isolating the building from the ground, or dissipating the incoming energy. The paper introduce the work done by the authors, mostly developed at the University of Canterbury, by following the second design technique, describing and testing dissipating devices for wood structures.

Key words: wooden building; seismic action; high performance level; dissipation device; plastic deformation.

Introduction

The main principle of earthquake resistant design is to ensure an acceptable safety level avoiding catastrophic failures and loss of life. There are then important buildings such as hospitals, police stations, communication centres, that need to be designed for higher performance level because must remain functional after an earthquake event. Indeed the basic performance objective of conventional seismic design is the life safety but this objective is not sufficient for important structures. In the last 30 years important improvement in innovative earthquake system have been carried out in order to raise the performance level of structures but always trying to keep the costs at a reasonable level.

Performance Based Design

The current philosophy for seismic engineering is the Performance Based Design that was first formulated in the Vision 2000 document. In the document has been given a definition of the Performance Based Earthquake Engineering consisting of: ‘a set of engineering procedures for design and construction of structures to achieve predictable levels of performance in response to specified levels of earthquake, within definable levels of reliability’. Performance levels correspond to the maximum acceptable extent of damage under a given level of seismic ground motion.

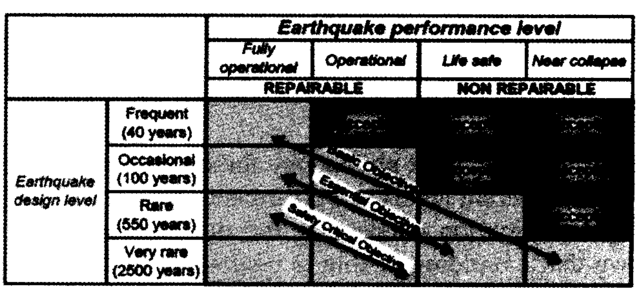

Figure 1 : Current performance Objective Matrix (modified from SEAOC, 1995) [1].

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Building Performance Subjected to Seismic Action

Buildings respond to an earthquake shaking in different ways. If a building is designed to respond elastically it may fail when it is subjected to a force that is higher than the building strength. On the other hand when a building is designed to respond with ductility it will be damaged but it is able to resist without an unexpected failure.

Therefore there are different ways and so different design possibilities to resist to the same earthquake:

- To provide the building with high strength so that it will respond elastically.
- To design the building to have normal strength following some design guidelines.
- To modify the building characteristics with the use of damping devices.

Considering the first option the structure will have no damage but this approach is not completely safe (the maximum level of ground shaking is never known for certain) and the construction cost will be too high.

On the other hand considering an elasto-plastic response, ductility is developed and the structure can reach the collapse for an exceptional earthquake.

The other possibility is to modify externally the building to reduce the demand or the response. There are two different alternatives: isolate the building from the ground shaking or dissipate the incoming energy.

There are two different ways to modify the answer of the building:

- To reduce the demand: damper devices.
- To reduce the response: isolators.

Most of the damping systems are design to dissipate the seismic energy introduced into a structure and they work as supplemental damping mechanism designed to limit the transmission of seismic energy to the primary system of isolation. The different kinds of primary isolation system and of the supplemental ones are explained in the following paragraphs.

Dissipator Devices

Base Isolation Devices

The system of base isolation that has been adopted most widely in recent years is typified by the use of elastomeric bearings (rubber or neoprene). In this approach, the building is decoupled from the horizontal components of the earthquake ground

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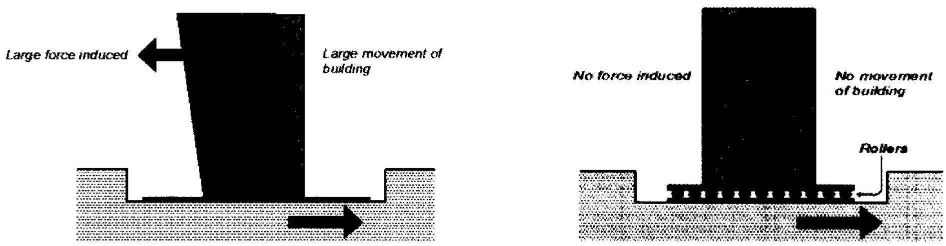
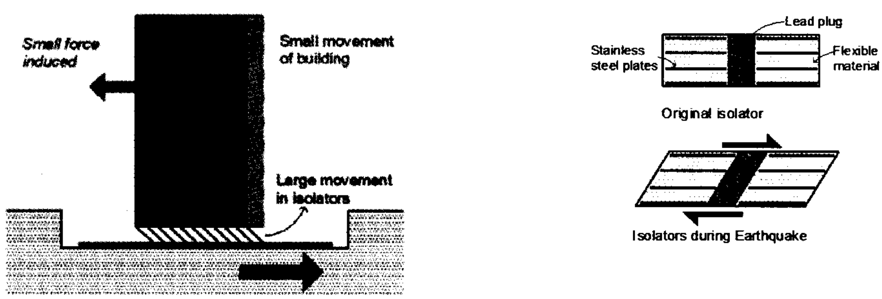
motion by interposing a layer with low horizontal stiffness between the structure and the foundation. Due to the presence of this layer the frequency of the building is much lower than the one that he should have if it is fixed on the ground. The earthquake involves a deformation in the isolation system while the building moves rigidly.



(a) (b)

Figure 2 : (a) Building resting directly on ground; (b) Building on rollers without any friction [2].



(a) (b)

Figure 3 : (a) Building on Base Isolators; (b) Details of the Base Isolator [2].

Figure 2a represents the case of the building fixed on the ground. The building is subjected to large movements and to large forces. The concept of building isolated is explained in the Figure 2b where is shown a building resting on frictionless rollers. When there is an earthquake the rollers freely roll and the building above don't move. This is an ideal representation because if the building is located on the isolators it's subjected to a small movement and small forces are induced. Due to the resistance of the system to lateral displacements some effects are transferred to the building.

There are two basic kinds of isolation system: elastomeric bearings and sliding system. In the first case the building is decoupled from the ground with the interposition of a layer of rubber that is characterized by a low horizontal stiffness.

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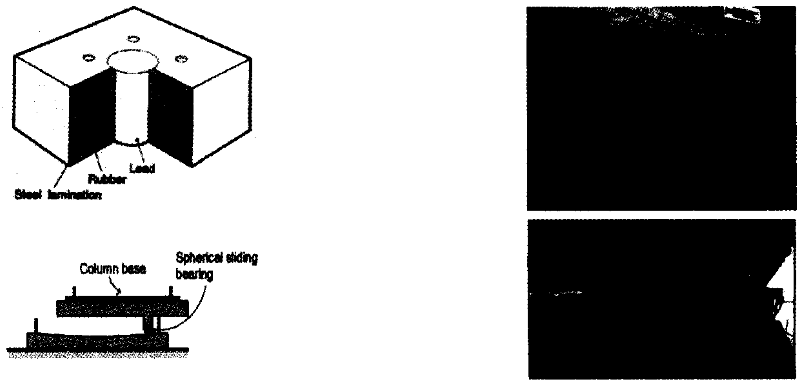

Figure 4 : Building base isolated with lead rubber bearing system (top) [2, 3]; Spherical Sliding Isolation Bearing of Mississippi Rr. Bridge (down).

The Hysteretic Dampers

The hysteretic dampers are made of metal parts and the energy is absorbed by yielding deformation of critical metallic components. In this group there are the metallic dampers that take advantage of the hysteretic behavior of metal in the post elastic range to dissipate energy and the friction dampers that dissipate the energy by friction that develops at interface between two sliding solid bodies.

The metallic dampers are designed to yield in bending or in tension or compression. For this reason they are made of different shapes whose plasticization determines their mechanical characteristics.

A typical application of the yielding dampers and the hysteresis loop are shown in Figure 5.

(a) (b)

Figure 5 : (a) Typical application of yielding dampers; (b) Hysteresis Loop of Hysteretic Dampers [2].

Some examples of dampers are shown in Figure 6 (images from FIP Industriale SpA).

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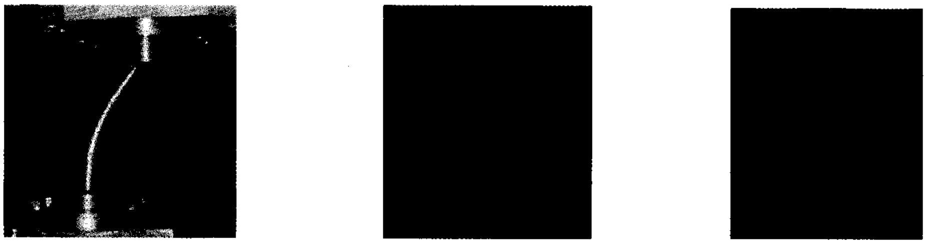
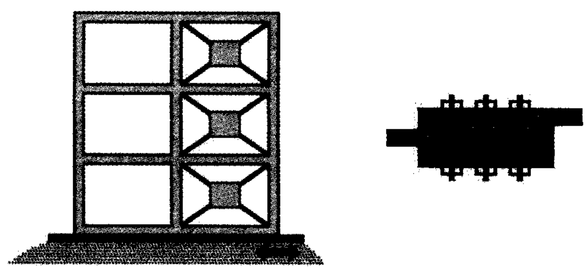


(a) (b) (c)

Figure 6 : (a) Pin shaped damper; (b) Crescent moon shaped damper; (c) Butterfly shaped damper.

To dissipate this kind of dissipaters have to go over the activation mark so they start working only after that a certain displacement has been reached. For this reason they are called 'displacement activated dampers'.



(a) (b)

Figure 7 : (a) Typical application of friction dampers [2]; (b) Possible arrangements of steel plates in friction dampers [4].

When the hysteretic dampers are used it is important to protect to the low cycle fatigue in order to prevent the crisis of the material after a low number of cycles. For this reason the mild steel is commonly used because of its property to resist to big deformations and also for its low price.

The buckling restrained braces (BRB) are hysteretic dampers that dissipate energy when subjected to compression-tension cycles in such a way that the damper can yield in both axial tension and compression under reverse cyclic load. The BRB are formed of a steel core restrained by steel casing filled with mortar and then a steel casing. The steel core carries the axial load while the outer tube provides lateral support to the core and prevents global buckling.

Between the confining material and the tube there may be a separation material in order to avoid the transfer of tangential strains between the two materials. The components of the BRB are shown in the drawing below.

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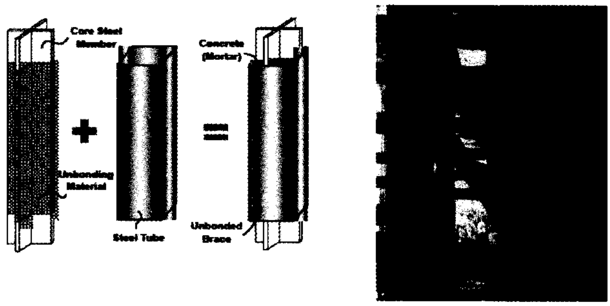

(a) (b)

Figure 8 : (a) Components of BRB; (b) Example of BRB of the Tzu-Chi Culture Building (Taipei, Taiwan) [5].

The Hybrid System

The increasing levels of expectations of buildings concerning their behaviour during an earthquake have led to a major effort toward the development of damage control design approaches and technologies. The current approach supposes that the structure remains elastic or develop a mechanism involving ductile inelastic deformations while maintaining a stable global response and avoiding loss of life.

The aims of the new target are to provide low cost, more affordable, high seismic performance structures capable to sustain a design level earthquake with limited or negligible damage. Generally the cost of repairing damages and considering also the cost of the loss of business operation during a moderately strong earthquake is comparable to the cost of the structure itself.

For this reason the last target of Earthquake Engineer is to expect building to survive to a moderately strong earthquake without no disturbance to business operation. Allowing the movement of the structural elements, a self-centring system provides an amount of energy dissipation with a controlled rocking. In the ancient Greek and Roman temples that were constructed with blocks of stones, a rocking behaviour was displayed. The structural elements resist to the lateral loads thanks to their own weight (they were approximately 0.6 to 1 m height) and to the friction between the elements themselves. The self-weight of the columns provides the necessary amount of pre compression and so during an earthquake the elements separate at the junctions producing a rocking behaviour.

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Figure 9 : Earlier implementation of a self-centring limited-damage rocking system, for earthquake loading (Dionysus temple in Athens) [4].

The 'Hybrid system' is a re-centering solution that combines unbounded post-tensioned cables to dissipater devices. The structure is so allowed to have relative displacements through a rocking motion. This solution is effective to achieve the aim of having low damage.

Indeed the dissipators devices reduce the incoming energy while the post tension cable with a rocking movement re-center the structure; the result is that there isn't any localization of the efforts (no plastic hinges) and the cost of repair are kept to a reasonably level. This solution can be achieved with different structural configurations like the beam column joint, the rock to foundation joint, and segments of column rocking on each other.

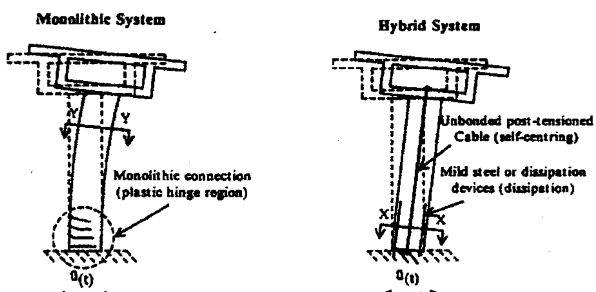

Figure 10 : Controlled Rocking concept of bridge piers [6].

<u>The Hybrid System for Timber Structures</u>

The hybrid system has been developed for concrete structures and then also timber and steel structures.

In particular the use of post tension in timber has been developed at the University of Canterbury, Christchurch (New Zealand) following the example of the US PRESSS coordinated by the University of California, San Diego which has proposed important post tension technology applied to the concrete.

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The post tension in timber is conceptually identical to the post tension in concrete. The material used is the Laminated Veneer Lumber (LVL) which is obtained peeling logs into 3 mm veneers and gluing into billets of 1.2 mm and thickness from 40 mm to 100 mm. The wood is usually stressed parallel to the grain and the pre-stressing loads are almost the same because the compressive strength of the LVL is similar to the concrete one (from 30 to 40 MPa).

The technology has been proposed by Palermo et al. (2005) and validated by experimental tests carried out at the University of Canterbury (Christchurch, NZ).

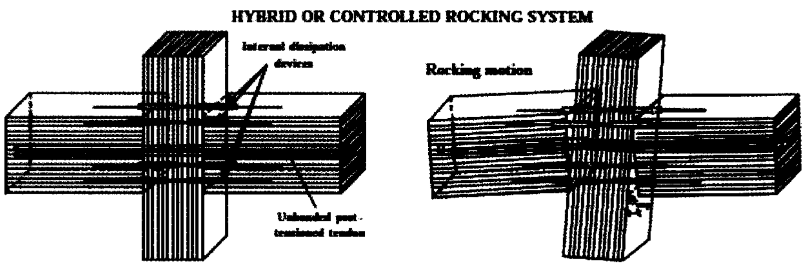

Figure 11 : Application of Hybrid Concept to LVL frame system [7].

Following the declared target of no damage structural system and considering the cost associated to the damage of non-structural components such as the sacrificial ones, the use of external dissipaters have been proposed [8]. The strong point of these devices called 'Plug and Play' dissipators is that they are easily replaceable after an earthquake if damaged.

Figure 12 : Internal versus External Replaceable Dissipators at the base of the wall [4].

Laminated Veneer Lumber walls have been tested at the University of Canterbury using U shaped dissipators, internal and external dissipators.

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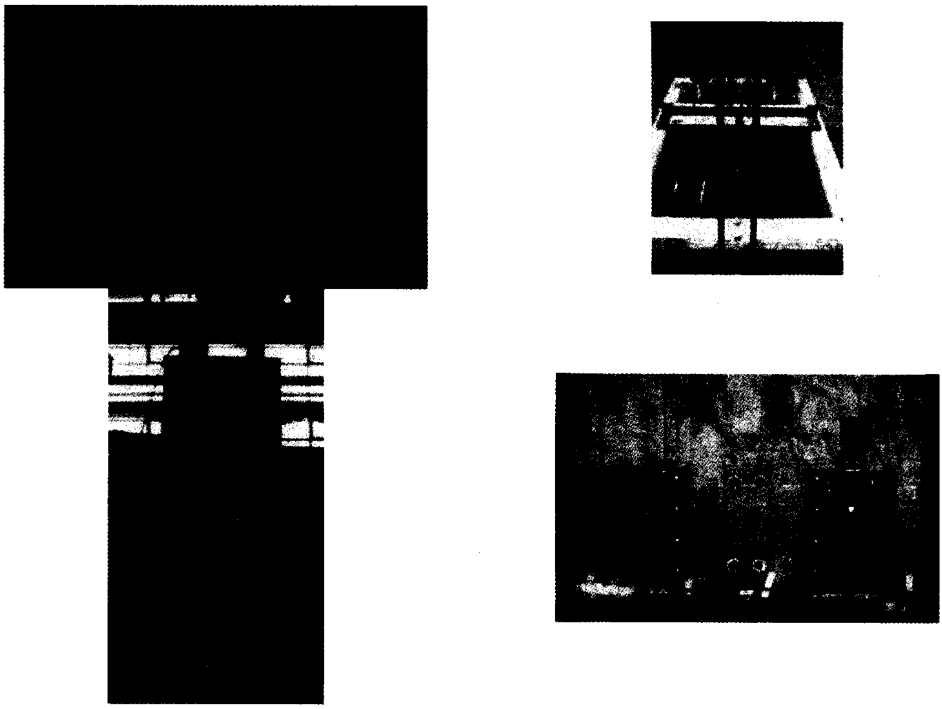
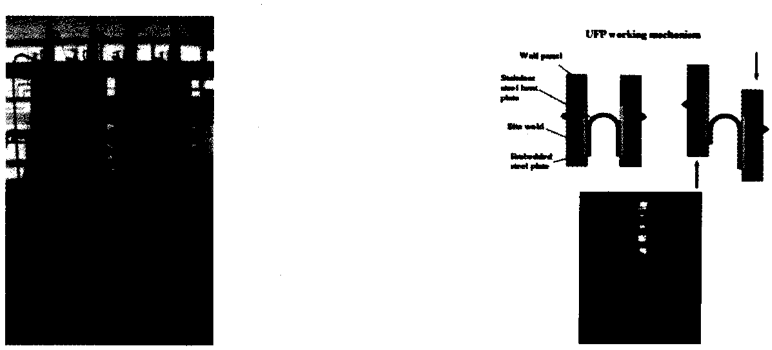


Figure 13 : Hybrid Timber Wall with Internal Dissipators (top) [9]; Wall-foundation joint using external dissipators (bottom) [10].

The U shaped have been used to couple post tensioned precast concrete walls to obtain an hybrid system where energy is dissipated through yielding of the mild steel U-shaped plates, while the post-tensioning in the walls provides the restoring force.



(a) (b)

Figure 14 : Test set up of Coupled Wall System with UFP devices (left), Particular of UFP devices (right) [11].

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This solution is independent of the mechanical properties of the adopted structural material and so the same principles have been applied to timber coupled walls [11]. The UFP is welded to a plate in the terminal sides and then a semi-circular strip is free to roll when the walls rock producing a relative displacement. Due to the relative displacement of the walls the elements yield.

Conclusion

The new target of Earthquake Engineering is to design buildings with higher performance level so they will remain functional after an earthquake event. To satisfy this need in the last 30 years has been made important progress to raise the performance of building during an earthquake, in particular studying different ways to dissipate the incoming energy. This paper proposes an overview on the main ways to modify the answer of the building and keep them safe and there is an introduction to 'hybrid system' that allow to keep it even functional. The use of the hybrid system in fact combines dissipation devices and post tension cable to guarantee both energy dissipation and re-centring capacity. In this way the building shows a controlled rocking movement that prevent for damage and high cost of repair consequently. The 'hybrid system' has been developed first for concrete structures then even for timber ones and some examples with different kind of dissipator devices tested at the University of Canterbury (Christchurch, New Zealand) are shown.

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