Earthquake Resistant Structures

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I.

In light of recent tragedy in Haiti and Chile, the design of earthquake resistant structures has grown increasingly relevant all over the world. Intended to withstand various types of earthquake exposure, earthquake resistant structures are an integral part of surviving an earthquake because they offer a place of refuge during earthquakes and can support a society after an earthquake has occurred (Harris, 1). Had Haiti and Chile been more prepared for the earthquakes that occurred in 2010 and had perhaps constructed earthquake resistant structures, the impacts of those devastating forces would surely have been less severe.

To that end, this report intends to determine which design for an earthquake resistant structure is the best in terms of its structural and economic efficiency. To assess structural efficiency, the design’s ability to minimize vibrations and structural damage was evaluated, a crucial indicator of how the design would reinforce the structure of the building in the event of an earthquake. Economic efficiency, perhaps a more important indicator of the usefulness of the design given that a majority of the countries most susceptible to earthquakes are incredibly poor, assessed the cost of construction of the structure as well as the feasibility of accessing the materials necessary for construction. Overall, this report could be used as a recommendation of which design is the most cost-effective and structurally effective to third world governments considering investing in the construction of an earthquake resistant structure.

II.

Earthquake resistant structures are by no means a modern invention. Since ancient times, earthquake resistant structures have been constructed to protect important buildings of early civilizations. In Mexico, Mayans constructed the El Castillo temple at Chichen Itza to be earthquake proof as a result of their fear that a series of earthquakes would end the world. They built the temple to be incredibly strong and stiff, using layers and layers of tightly packed stone blocks in the hopes that this would prevent the structure from collapsing in the event of an earthquake (Harris, 2).

Another well-known earthquake proof monument is the Hagia Sofia in Istanbul, Turkey. After an earthquake destroyed the main dome of the Church in 557 AD, architects reinforced the structure by adding layers of stone to the outer walls. This, like the architectural designs of the El Castillo temple, was part of a general belief that a sturdier and stronger structure would be the best force to combat an earthquake. Today, this thinking has changed (Harris, 2).

Modern earthquake engineering focuses on the idea that absorbing the earthquake is better than standing up to it. Base columns of modern earthquake resistant structures contain various devices to take in the shock of the earthquake and minimize vibrations in the structure of the building. These devices are generally made up of springs or hydraulics and can move independently to reduce structural damage in the event of an earthquake (Kishor, 2). The three main types of devices placed in the bases of modern structures are Negative Stiffness Vibration Isolators, known to be the most efficient form of earthquake resistance, Horizontal Vibration Isolators, known to be the least expensive form, and Base Isolators, the most popular kind of vibration isolation technique used.

III.

Used primarily for small structures, such as Rodin’s sculptures at the Rodin Sculpture Garden at Stanford University, Negative Stiffness Vibration Isolators are considered to be the most effective manner of minimizing structural damage because of their versatility of movement. Because they are made up of a Vertical Vibration Isolator, a Horizontal Vibration Isolator, and a Tilt Motion Isolator, a Negative Stiffness Vibration Isolator can move in six directions, allowing it to tilt in almost every possible way against the force of an earthquake and keep the structure it is holding up still. The main body of a Negative Stiffness Vibration Isolator is comprised of a spring, two beam columns, multiple negative stiffness mechanisms, and six electro-mechanical auto-adjust mechanisms. When the weight of the structure is placed on the Negative Stiffness Vibration Isolator, the negative stiffness mechanisms adjust the spring constant of the main spring to make it approach zero stiffness. Meanwhile, as the earthquake shakes the ground the structure is resting on, the six electro-mechanical auto-adjust mechanisms shift the Vertical Vibration Isolator, Horizontal Vibration Isolator, and Tilt Motion Isolator to be exactly opposite the force of the earthquake. This makes the building stay flat as if the ground was still (Minus K Technology, 1).

Though they are extremely effective, a downside of the Negative Stiffness Vibration Isolator is its cost. Because the structural design of the mechanism is much more complex than others it could be compared to, the Negative Stiffness Vibration Isolator is incredibly time-consuming to construct. For this reason, it is almost always used on the small scale as is seen in its use to support sculptures at Stanford University. The high cost of the device also derives from the costly materials incorporated in the design of the mechanism. Within each of the Negative Stiffness Vibration Isolators used to hold up Rodin’s sculptures at Stanford is around $120,000 of equipment. For this reason it is evident why Negative Stiffness Vibration Isolators are almost never seen on the large scale (Platus, 1).

IV.

The most cost-effective of the three designs evaluated, the Horizontal Vibration Isolator is essentially the foundation of all modern designs for earthquake resistant structures. Having originated in Japan to protect large buildings in the event of an earthquake during the 1960s, the design is rarely used today but can be found in buildings such as the National Museum of Western Art in Tokyo (TEARA, 4).

Made up of two beam columns, which are constructed from, incredibly stiff springs and multiple negative stiffness mechanisms, Horizontal Vibration Isolators rest in the base of every column in the structure, which they support. When the weight of the building is put on the columns, the beam columns straighten to support the weight of the building. In the event of an earthquake, the negative stiffness mechanisms reduce the spring constant of the very taught beam columns by centering the payload in the middle of the tilt plate held up by the beam columns. This allows the building to softly ride through the sudden and rough motions of an earthquake. As the earth beneath the structure tilts, so do the beam columns but in the opposite direction of the earth so that the drastic movements are countered and building is largely unaffected (Harris, 3).

Though they are largely unused today because they have been replaced by devices such as Negative Stiffness Vibration Isolators that can move in more than two directions, Horizontal Vibration Isolators have their benefits in terms of their cost efficiency and simplicity to construct. Constructing the Museum of Western Art in Tokyo cost around $30 million, a reasonable price considering building that same building with Negative Stiffness Vibration Isolators would have been almost double the price. Also, because they utilize almost one third of the machinery used in a Negative Stiffness Vibration Isolator, they take much less time to construct and are less temperamental during installation (Harris,2).

V.  
 By far the most commonly utilized method of earthquake resistant construction, the Base Isolation Technique can be seen in numerous important buildings such as the City Hall buildings of both San Francisco and Los Angeles. The basic idea of the Base Isolation Technique is that the superstructure of the building is separated from the substructure of the building so that the superstructure does not experience any of the vibrations and structural damage it would if it felt the impact of the earthquake directly (MSNBC, 1).

Structurally, the Base Isolation Technique works differently than the other techniques evaluated in that its function is not passive. Each floor in an Earthquake Resistant Structure that utilizes the Base Isolation Technique is supported by hydraulics that physically elevate the superstructure of the building so that it is essentially separated from the substructure. It works as a collection of isolation units that unlock from one another vertically during an earthquake to protect the upper levels of the building from being damaged.

Because of its relatively simplistic design, the Base Isolation Technique is more affordable than the Negative Stiffness Vibration Isolator. It is made from multiple sets of hydraulic systems, which are easily installed and maintained. To construct the L.A City Hall it cost $57 million, which is not unreasonable considering it is almost twenty two times as large as the Museum of Western Art in Tokyo (TEARA, 4).

VI.

Ultimately, the base isolation technique is the overall best technique because of its affordability and efficiency. Though it does not minimize vibrations and structural damage as effectively as the Negative Stiffness Vibration Isolator, and it does not cost as little as the Horizontal Vibration Isolator, it is the most sensible of the three because it is very effective and affordable. For taller buildings it is definitely the best choice in terms of performance because the unlocking floors minimizes vibrations that the other methods evaluated cannot protect as well against. For third world countries such as Indonesia, Haiti, Myanmar, and others, investing in Earthquake Resistant Structures that utilize the Base Isolation Technique would be worthwhile. Keeping an important structure, such as a government building or a hospital, standing after an earthquake is a key to recovering after a disaster as devastating as an earthquake.

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