Raquel Escatel
1.054 Term Project Final Report
May 11, 2004

Developing Countries' Alternative to Seismic Design

Background

The purpose of seismic design is to proportion structures so that they can withstand the displacements and forces induced by ground motion [3]. The design of buildings must satisfy the following criteria:

- Under frequently occurring low to moderate earthquakes or sever wind storm, the structure should have sufficient strength and stiffness to control deflection and prevent any structural damage
- Under rare and sever earthquakes, the structure must have sufficient ductility to prevent collapse [1]

It is important to keep in mind that the response of structures depends on their height. In general, multiple story buildings have a stronger response to low-frequency ground motion, while shorter buildings are more responsive to high-frequency ground motion. Designers of earthquake prone structures are therefore faced with two options. One of the options is to provide adequate stiffness and strength to limit the response of the structure to stay in the elastic range. Alternatively, they can design a lower-strength structure with the ability to withstand large inelastic deformations while maintaining their load-carrying capability [2].

Although the above conventional techniques have proven to keep structures from completely collapsing during earthquakes, in recent years, there has been research in seeking alternative techniques to seismic design. In particular, countries that have experienced historic catastrophes due to earthquakes, have taken initiative in creating and analyzing different economical and feasible approaches to seismic design. Several of the reasons that seismic design is in the process of fundamental change are due to the level of damage to structures, economic loss due to loss of use of the structure, and high costs of reparations to the structure [1]. The countries I have researched are Turkey, Mexico, and Chile, which have all experienced the harsh results of inadequate seismic design. This paper gives brief descriptions of the unique situation of these countries, building code changes taking place in these countries, and ends with an in depth analysis of the innovations taking place in Chile .

Changes in Turkey's Design Code

In 1999 Turkey experienced a 7.4 earthquake, Kocaeli, which resulted in a death toll of over 17,200 and an economic loss of 20 billion US dollars. Following the earthquake, the Pacific Earthquake Engineering Research Center sent a team to evaluate the performance of the buildings. It was concluded that the majority of the failures and collapses of engineered commercial construction can be attributed to the use of non-ductile details of structural members as well as poor quality construction. For example, common use of 90-degree hooks for transverse reinforcement rather than the specified 135-degree hooks reduced the lateral strength and confinement of columns. Refer to [5] to find a table of typical failures that took place and their inconsistency with ACI and Turkish Codes.

It's interesting to note that the first seismic code in Turkey wasn't established and practiced until 1940. Since 1940, their have been numerous changes to the code. As a result of the changes in the code, many buildings built within the past three decades do not meet code standards, but their simply isn't the available funds to accommodate every building in need of improvement. There is currently a lot of research taking place to establish a building code that would be suitable for the conditions of the country as well as a method of going back and fixing those buildings that would definitely fail if another earthquake takes place.

Mexico City

Mexico City lies on what is known as a lake bed, where the soil conditions cause buildings to sink anywhere from ten to twenty centimeters a year. Ever since the 1985 earthquake, there has been hesitation to rebuild the buildings that once occupied the earthquake prone city. But in 1999, the construction of what would be the tallest and safest building in Latin America began.

The structural consultants, New York based Cantor Seinuk Inc., and local engineer Enrique Martinez Romero used an innovative technique consisting of fluid viscous dampers and diagonal bracing. The dampers and bracing resulted in a 55-story building that is able to resist earthquake forces nearly four times as efficiently as a conventionally damped building. This building has already resisted a 7.3 magnitude earthquake and the amount of money that was spent on all 93 dampers, was well made up for in the drastic insurance premium reductions due to the overall security ensured by the damping and bracing technique [5].

Torre Mayor marks the first use of dampers for seismic resistance in a perimeter frame. When compared to a conventionally designed building, the top of Torre Mayor moves 0.6 meters less.

Innovations in Chile

Chile is one specific country that is coming up with an innovative technique of preventing deformations that jeopardize the safety and serviceability of buildings. For the past six years, an isolation system has been evaluated to determine how different parameters affect its yield level. The basic concept in this type of system is the use of bearings that serve as beam-column joints. Each bearing, either rubber bearing or lead-rubber bearing allows for a specific displacement determined by its location in the building. The bearings allow for members in the building to deflect without causing deformation of the structural members.

To test the use of bearings, Chile has constructed a hospital building and an engineering faculty building. Due to the use of bearings, in the hospital building, no extra slab was required and all shear walls as well as all construction joints were eliminated. In the Engineering Faculty building, "extra costs due to the isolation were counterbalanced by

(i) the elimination of the construction join in the structure (ii) a more economic design of the foundation system; and (iii) a lower density of shear walls and reinforcement "[4].

Problem Statement

As previously stated, Chile, whose location on the west coast of South America makes it prone to earthquakes with magnitudes of more than 7.8 on the Richter Scale. In the past, Chile, as well as other developing countries has been the victims of tragic and catastrophic collapses of structures due to their inappropriate design. Reparations of buildings are not always immediately possible due to the economic situation of the country. However, a research team has designed and built two buildings using lead-rubber bearings in place of joints. In the past six year, these two buildings' structural and seismic performance have been tested and analyzed. Based on these tests, it was concluded that the use of bearings is suitable for protecting the integrity of buildings. In the preceding paragraphs, I have given examples of the how an unreliable building code is the potential cause of more future damage and of alternatives to seismic design used in Mexico and Chile. The rest of my research will be focused on the hospital building with lead-rubber bearings built in Chile. The geometry of the hospital makes it possible to do a SAP analysis on the structure as if it were built using the IBC code for Seismic Design.

Research and Methodology

In order to compare how the structure would perform in response to a 2 second period earthquake, using the IBC code, several characteristics of the building are needed. Llera provides enough description of the building which can be summarized by the following:

- Building Weight : 10341 tons above the isolation level (basement)
- Plan Dimensions : 78m x 31 m
- Basement Story Height: 4 m
- Height of other Five Stories: 3.4 meters
- Beams: 80cm x 80 cm with a typical 12 m span
- Columns: 75 x 75 cm
- Basement Columns: 90cm x 90 cm

I was in contact with the chairman of the structural and geotechnical engineering department at the Universidad Catolica de Chile, Juan C. de la Llera as well as with Henry Sady, who was the engineer responsible for the construction of the isolated buildings and the following loads were provided:

- wind load: 75 [kgf/m2]
- dead load: 325 kgf/m2 for the roof and 551 kgf/m2 for the rest of the building
- live load: 100 kgf/m2 for the roof and 400 kgf/m2 for the rest of the building.

The weight of the structural elements was not included in these loads, but by entering the dimensions and the material properties of the members the self weight was calculated by SAP.

Although I have never used the SAP linking properties, I have attempted to model the behavior of the structure with the isolators in place. These isolators were used in SAP by cutting the already designed column. From [4] and further contact with the engineers, it was found that the isolators can be considered as linear elements with an effective lateral stiffness of 127.3 ton/m and 160.3 ton/m for the rubber bearings(RB) and lead rubber bearing(LRB) types respectively and an effective damping of 7.09 ton-s/m and 23.81ton-s/m for the RB and LRB type respectively. These properties were essential to the use of isolators in SAP.

Although only a linear analysis was performed, the parameters for non-linear analysis are provided below, also courtesy of Henry Sady.

1) RB type:
- Stiffness: 219 ton/m
- Yield strength: 4.38 ton
- Post yield stiffness ratio: 0.429

2) LRB type:
- Stiffness: 2500 ton/m
- Yield strength: 10.0 ton
- Post yield stiffness ratio: 0.038

Concrete with a cylindrical strength of 300 kg/cm^2 and steel with a nominal yield stress of 4200 kg/m^2 were used in the construction of this structure. In addition, we have been informed that the nominal isolation periods of the structure are Tx = 2.8 seconds and Ty = 2.64 seconds.

The hospital will first be analyzed as shown in Figure 2. Once results for this simplified structure are obtained, I will attempt to replace all the joints in the structure with the bearings to be able to compare how the deflections vary. Joints on each floor level will be replaced with bearings with the properties show in the figure below.

Mass (kg)	Stiffness (kN/m)	Damping (kN s/m)
$m_b = 6800$	$k_b = 232$	–
$M_1 = 5897$	$k_1 = 33732$	$c_1 = 67$
$M_2 = 5897$	$k_2 = 29093$	$c_2 = 58$
$M_3 = 5897$	$k_3 = 28621$	$c_3 = 57$
$M_4 = 5897$	$k_4 = 24954$	$c_4 = 50$
$M_5 = 5897$	$k_5 = 19059$	$c_5 = 30$

Table 1: Properties of isolators corresponding to their location (basement, first floor, second floor, etc.)
Source: Juan De la Llera

Results and Discussion

When the simplified model was analyzed under an earthquake with a 2 second period, the roof of the building deflected four inches. Once the joints were replaced with isolators, it is assumed that the joints of the building will not deflect more than the diameter of the rubber isolator. Below you can find a section of the hospital building modeled, where an isolators have replaced joints.

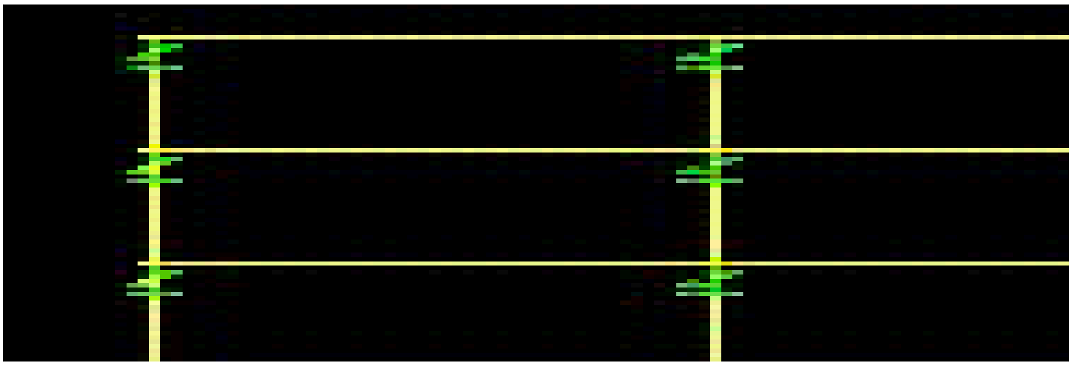

Figure 6: SAP model of isolators at every joint in hospital building.

Although the SAP model for the hospital with isolators was created, it was not able to be analyzed through the student version of SAP that I had available, results of Llera's work, however, has led the country of Chile to begin the construction of a military hospital using isolators. With the isolators in place, a specific deflection can take place without jeopardizing the safety of the building. In addition, the use of rubber and lead, allows for an plastic energy to be dissipated if necessary, which is additional safety feature.

Although the cost of this new technique is within the range of the conventional buildings, Chile is in such a location that makes it prone to earthquake of diverse magnitudes. The peak ground acceleration curves for the country demonstrate
the need of satisfactory building response to earthquakes.

Many times, the integrity of a building is traded off for a more economical design, especially in developing countries. Historic catastrophes are now inspiring the construction of safe and reliable buildings despite the intial large amount of capital needed for such a task. But it seems as if those countries are coming to the realization that building correctly and appropriately in the first place can save thousands of dollars and most importantly a number of lives.

List of Tables and Figures

References

[1] Balendar, T., "An economical structural system for wind and earthquake loads," *Engineering Structure*, Vol. 23, pp. 491-501, 2001.

[2]Ghobarah, A., "Performance0based design in earthquake engineering:state of development,"*Engineering Structures*, Vol.23, pp.878-884, 2001.

[3] Nilson, A., "Seismic Design," *Design of Concrete Structures*, McGraw-Hill, pp.700-703, 2004.

[4] Llera De La, J., "Analysis, testing, and implementation of seismic isolation of buildings in Chile," *Earthquake Engineering and Structural Dynamics Journal*, Vol.33, pp.543-574, 2004.

[5] Post, N., "Damper-Studded Diamonds in Mexico City Raises Bar on Earthquake Resistance,"http://www.construction.com/NewsCenter/Headlines/ENR/20030630eg.asp, May 2003.

[6] Sezen, H., "Performance of reinforced concrete buildings during the August 17, 1999 Kocaeli, Turkey earthquake, and seismic design and construction design in Turkey," *Engineering Structures*, Vol.25, pp.103-114, 2003.

Special thanks to Juan De la Llera and Henry Sady for providing information regarding their isolation projects in Chile, and to Oguz Gunes for help with SAP.