SEISMIC RESPONSE OF A FIVE STORY BUILDING WITH ISOLATION SYSTEM AND SUPPLEMENTAL VISCOUS DAMPERS FOR PERUVIAN SEISMICITY

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ABSTRACT

Projects with seismic isolation are increasing at Peru, even the Peruvian Seismic Standard establishes that seismic isolators must be used in hospitals located in seismic zone 4 and 3 of Peruvian seismic map. Is also accepted that there may be isolated buildings on soils S0, S1, S2 and S3.

In isolated buildings that are on soil type S3 and in seismic zone 4, maximum displacement values are obtained. This implies the use of flexible connections; in addition in some cases these displacements cause that there is a smaller usable area of the building. One alternative to reduce these displacements is the use of Supplementary Viscous Dampers in the base of isolated building which adds damping to isolation system. In this research, a mathematical model of a 5-story building with elastomeric isolators, located in seismic zone 4 and soil type S3 was evaluated. This model was then analyzed with Supplementary Viscous Dampers, considering 5 different conditions of critical damping ratio: 15%, 30%, 45%, 60% and 75%. For all analyzes, 7 time-history records compatible with Peruvian seismicity were used. Displacement reductions of isolated base were obtained up to 30% of its initial value. The variation of responses (Accelerations, Drifts, Shear Forces, and Dissipated Energy) was analyzed as a function of the damping increasing. It was verified that the Peruvian seismicity combination of isolators and dampers tends to increase the responses of the superstructure.

Keywords: Seismic Isolation, Viscous Damping, Peruvian Seismicity.

1. INTRODUCTION

Severe earthquakes cause different levels of damage to structures, therefore the codes strive to minimize their effects through procedures or earthquake-resistant design techniques [1]

One of the techniques used to protect buildings is the Seismic Isolation [2], which consists of supporting the structure (super-structure) on a system composed of horizontally flexible elements (isolators) causing the building to move laterally almost like a rigid block, with this system is possible reduce the drifts and accelerations in a substantial way. The main types of isolators are elastomeric and friction pendulum [3]. The excellent performance of isolated buildings in earthquakes such as Northridge 1994 (6.7 MW), Kobe 1995 (6.9 MW), Tohoku 2011 (9.0 MW) and Chile 2010 (8.8 MW) have demonstrated the validity of this technique.

In Peru there are currently around 39 buildings with isolators: 56% correspond to hospital buildings [1] required by the Peruvian Seismic Standard (E-030) "... hospital buildings (state and private) of the second and third level, (...) will have seismic isolation in the base when they are in seismic zones 4 and 3." [4], the remaining 44% corresponds to universities buildings, offices and housing buildings.

Is also accepted that the isolated projects can be built on soils type S0, S1, S2 and S3 defined in the Peruvian Seismic Standard. In projects that are located in seismic zone 4 and on soil S3, the highest values of lateral displacement in the base are obtained; for example, for a critical damping ratio value $\beta = 10\%$ the lateral displacement in the base is 60 cm for a maximum credible earthquake (MCE), Fig. 1 shows this value in the displacement spectrum. This displacement is related to the lateral displacement that isolation system will have and involves using flexible connections (joints, pipes, etc.) that fit properly. Additionally, these lateral displacements cause the reduction of the usable area of the property.

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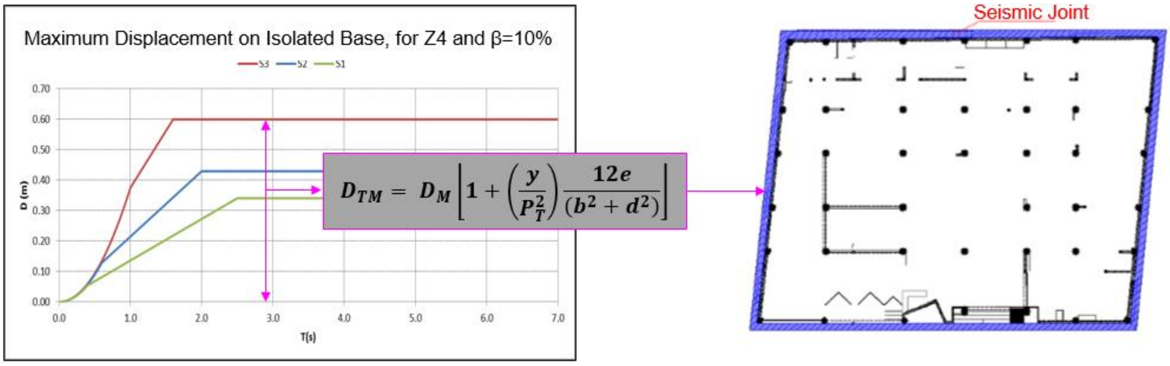

Figure 1. Lateral displacement of base isolated system as function of soil type.

An alternative to reduce the lateral displacements of the isolated base is the use of complementary viscous dampers in the base. The dampers apply a force as function of the seismic movement speed and in opposite to the direction of the lateral displacement of the base, which reduces significantly the displacement of the structural system. San Bernardino Hospital in USA, and the LDS Church in Concepción, Chile, are examples of their application.

However, some analyzes show that the combination of isolators and dampers can increasing the seismic response in the superstructure, depending on the level of damping provided [5], other research shows that seismic response of the structure with isolators and additional dampers varies in function of the seismicity of each region [6]. In Peru, the response in buildings with the combination of these devices has not been studied, nor has the way in which the seismic response of building varies according to different types of complementary viscous dampers that provide different levels of damping.

1.1. Previous Researches

In 1995, San Bernardino Hospital incorporated for the first time in the United States an isolation system composed of elastomeric isolators and supplementary viscous dampers [6].

Another project with similar characteristics was the Hayward City Hall, which uses friction pendulum isolators combined with viscous dampers; there is also the Kaiser Coronado Data Center building that was built in 1989 with seismic isolation and in 1998 were added viscous dampers in its base.

In a theoretical analysis by Kelly [5] it was concluded that the incorporation of dampers to an isolated building can be detrimental to the seismic response if moderate earthquakes occur, instead it is beneficial for earthquakes that have accelerations with very large amplitudes in periods of very short duration.

Saif and Satari [7] showed the efficiency of design of an isolation system with complementary viscous dampers for near-fault earthquakes applied to the L.A. Regional Transportation Manager.

A study was also made with mathematical models of two isolated 8-story buildings subjected to acceleration records of the earthquake of Kobe (1995), Northridge (1994), and Imperial Valley (1979); In this study it was established that the use of complementary viscous dampers in the isolated base represents an effective design strategy for earthquakes with nearby fault characteristics, however the introduction of additional dampers for earthquakes with faults far away is inefficient and harmful. [8]

In 2016 a temple was built in Concepción - Chile, which has an isolated base structure and uses 8 complementary viscous dampers to reduce lateral displacement.

In Peru, no research based on our seismicity has been developed by applying this combination of devices.

2. OBJECTIVE

The objective of the present study was to evaluate the seismic response of a 5-story building, located in seismic zone 4 and soil type S3, which has LRB isolators and complementary viscous dampers in its base, being demanded by seismic actions compatible with the spectrum established in the Peruvian Seismic Standard.

3. METHODOLOGY

The seismic response of a building that has isolators and dampers was evaluated, subject to seismic demands compatible with the spectrum of the E-030 standard, for which the model of a hospital-type building with dimensions in floor plan: 21.6 m × 36.0 m

(Figure 2), total height 22.5 m (5 floors), columns of 0.7 $m \times 0.7\ m$, frames of 0.35 $m \times 0.75\ m$, quality concrete $f'c = 280\ kg/cm2$.

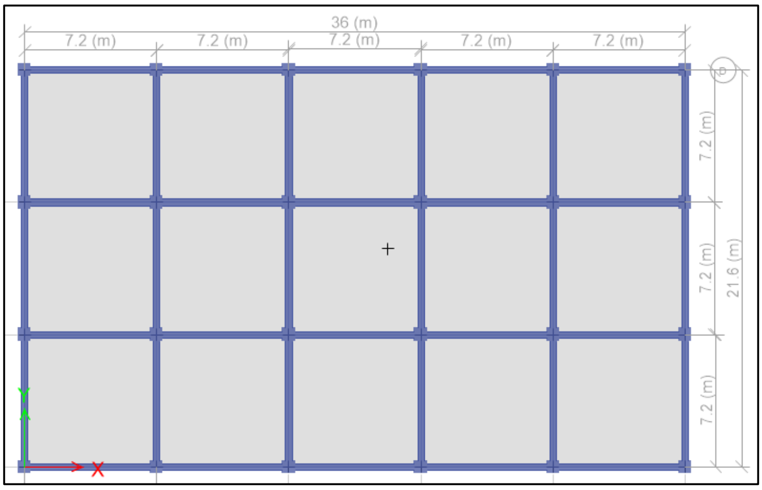

Figure 2. Plan view of the building model analyzed.

Elements in the superstructure were considered with linear properties, isolators and dampers were analyzed with non-linear properties. Seven pairs of seismic records compatible with the spectrum of the E-030 standard for soil type S3 and seismic zone 4 were used, Etabs software was used for the analysis. The analysis cases are shown in Fig. 3.

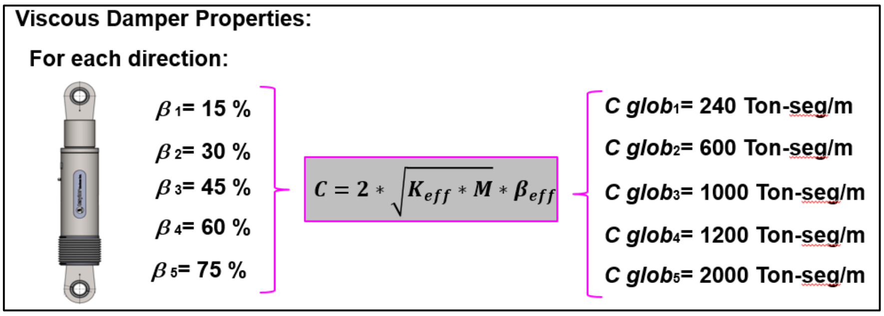

Figure 3. Analysis cases.

The damping values were verified after the analysis, based on the lateral displacement obtained and its corresponding stiffness for the system.

Seven pairs of seismic records were scaled and used in the research: Lima 1966, Lima 1970, Lima 1974, Moquegua 2001, Tarapacá 2005, Pisco 2007 and Concepcion 2010. The records were scaled so that each component is spectrum-compatible, the software used for scaling was the Seismo Match.

According to ASCE 7-16 [9], maximum and minimum properties of dampers and isolators were considered. Maximum and minimum values of each property were based on the comments of the standard ASCE7-16.

For isolators they were taken as values:

Secondary Stiffness (Kd):
Upper Bound λ_máx=1.3;
Lower Bound λ_mín=0.8
Characteristic Strench (Qd):
Upper Bound λ_máx=1.5;
Lower Bound λ_mín=0.8

For dampers, the following values were taken:
Damping coefficient (C):
Upper Bound λ_máx=1.2;
Lower Bound λ_mín=0.8

An acceptable floor drift limit of 0.0045 and an acceptable floor acceleration limit of 0.4g are established, both determined by a time-history analysis.

4. RESULTS

4.1. Lateral Displacement

Reductions in lateral displacements were obtained by increasing the level of damping in the structure. Lateral displacements decreased by up to 70%. Fig. 4 shows the different displacement values obtained.

The restoring capacity of the isolation system was verified for lower value of lateral displacements (most unfavorable condition), this value is calculated according to ASCE 7-16, as follows:

$0.5 \times K_d \times Dm \geq 0.025W$, where

Kd= Post Yielding Stiffness of Isolation System
Dm= Maximum Lateral Displacement
W= Seismic Weight of Building

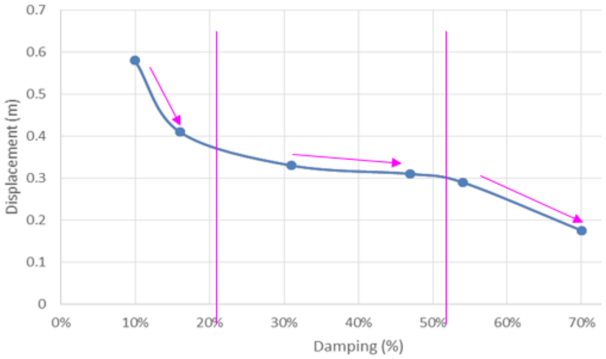

Figure 4. Lateral displacement of the base as function of damping.

4.2. Drifts

In the analysis of the structure that has only isolators, the drifts at spectral and time history analysis have similar results. For other cases, as damping increases, the drifts tend to increase and (from the second case) the drifts exceed the established limit.

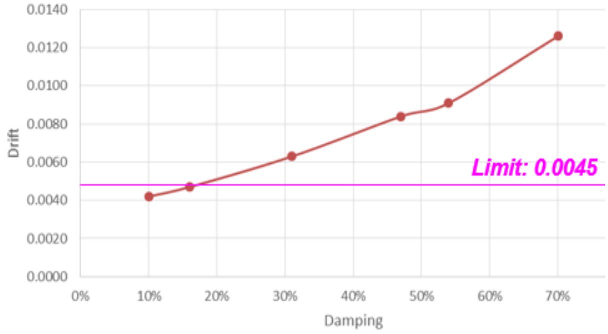

Figure 5. Variation of the Maximum Story Drift as function of damping.

4.3. Floor Accelerations

The increase of damping causes an increase of floor accelerations, even for damping of 50% there are accelerations close to 1g, only for damping below 15% the accelerations are within the acceptable limits.

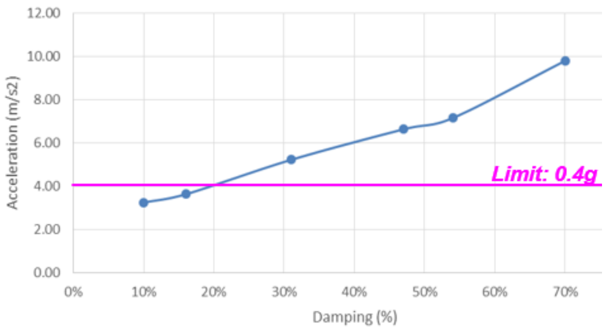

Figure 6. Variation of the Maximum floor Acceleration as function of damping.

4.4. Forces in Dampers

The force in dampers increases in function to the greater dissipation of energy. This force is transmitted to the superstructure and increases the shear force of the building (Figure 7) and is one reason for the increase in drifts and accelerations.

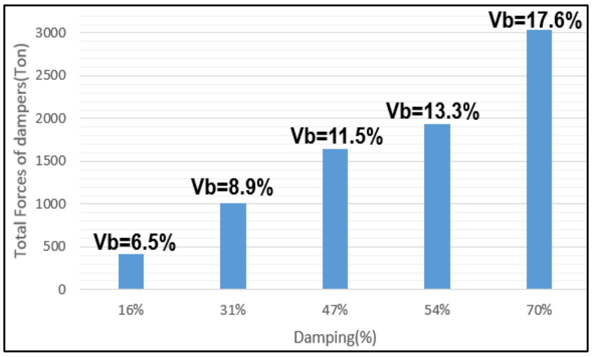

Figure 7. Variation of Forces in Damper for each analysis.

4.5. Energy Dissipation

As the damping level increases, the energy dissipation of the isolators decreases, while the energy dissipation of the dampers increases. For a force-displacement graph of the dampers like Figure 8 (where the area represents the energy dissipation), if the lateral displacement is reduced and at the same time dissipate more energy, then the force values tend to increase.

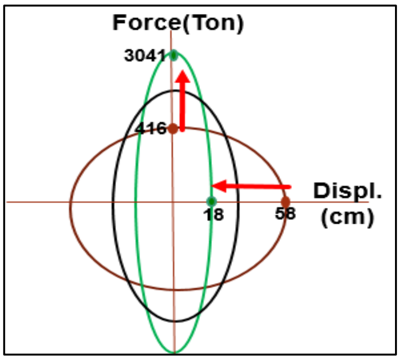

Figure 8. Variation of Force-Displacement graph of Dampers as function of the increase in damping.

CONCLUSIONS

For the case of combination of isolators and dampers with β = 70%, the lateral displacement in the base is reduced by 70% compared to the displacement of the isolated building without dampers, but the accelerations and drifts in the superstructure are increased as the damping.

In the case of the combination of isolators and dampers with β≤ 15%, the drift and acceleration values are kept below the acceptable limits of 0.0045 and 0.4g respectively, the lateral displacement is reduced by 30% with respect to the displacement of the isolated building without dampers, this being the optimal case however this level of damping can also be achieved using only isolators.

Finally, for Peruvian seismicity the use of elastomeric isolators and supplemental viscous dampers system to reduce the seismic joint is not recommended since it increases the drifts and accelerations in the superstructure.

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