RESPONSE OF BASE ISOLATED BUILDING DURING THE GREAT EAST JAPAN EARTHQUAKE AND THE APPLICATION OF BASE ISOLATION IN TURKMENISTAN

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ABSTRACT

To check performance of the Hachinohe government offices, in use at the time of the Great East Japan Earthquake of 2011, observation data was analyzed in this study. Numerical simulations using Modified Bi-Linear Modeling were created of the building, which took into consideration the degradation of the secondary stiffness and yielding shear force.

From the results of this analysis, it was proved that the base isolation system has non-linear behavior and the upper-structure behaves in the elastic range. This is because base isolation decouples movement from ground motion, the displacement concentrates at the isolation level and the upper-structure behaves as a rigid body.

A comparison of isolated and non-isolated building responses was performed in this study, and a design procedure for base isolated buildings in Turkmenistan is proposed. This procedure is based on the recommendations of the CIB (International Council for Research and Innovation in Building and Construction), using the preliminary design procedure for seismically isolated buildings (CW2012) and taking into consideration the Building Seismic code of Turkmenistan.

Keywords: Seismic Isolation, Observation record, Design Procedure.

1. INTRODUCTION

Earthquakes are one of the most dangerous and destructive natural disaster. Usually the earthquake lasts no more than a few minutes, but despite this it cause massive destruction and human fatalities. Over a million earthquakes occur each year around the world. Many of occurred earthquakes are too small and cannot be noticed, but some of them can be really strong and may cause huge damage and destruction of the buildings and structures, and death of the people.

In this sense, Japan is extremely vulnerable to disasters such as earthquakes. Earthquakes are more common in Japan than in any other country. Because of this Japanese engineers and researchers have made a lot of studies and researches to make buildings more strong and resistance in case of earthquakes.

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The territory of Turkmenistan is also characterized by high seismicity. More than 90% of the area of Turkmenistan is affected by earthquakes from 6 to 9 points on the MSK-64 scale. The most powerful and destructive earthquakes have occurred in the seismically active zones of Ashgabat and Turkmenbashy, where major cities and industrial areas are located, and large scale construction projects are being implemented.

2. DYNAMIC BEHAVIOR OF SEISMICALLY ISOLATED BUILDINGS

2.1 Types of base isolation devices

This research focused on Lead Rubber Bearings (LRB) the most common elastomeric bearing type of seismic isolation devices.

2.1.1 Lead Rubber Bearings

Lead Rubber Bearings (LRB), is a widely used form of isolation device for buildings and bridges. They are composed of thin rubber layers with steel plates and a lead plug core in the middle. The rubber material provides flexibility, and devices can move in a horizontal direction, while the steel plates provide stiffness vertically, the lead plug works as energy dissipation under all types of load, and it increases the stiffness of devices under low loads, such as wind, traffic and minor earthquake loads. The main advantage of LRB is that they are flexible under earthquake load, rigid for service loads (e.g. bridges) and have a damping effect for different types of load. There are also some types of LRB devices with more than one lead core, this kind of LRB are usually used for bridges.

2.1.2 Bi-linear model of LRB

As mentioned above, LRB are a combination of rubber material with a lead plug core, hence bi-linear hysteresis of LRB will also be a combination of an elastic linear model for rubber and a plastic bi-linear model for lead Figure 1.

$K_r = G_r \frac{A_r}{H_r};$

$$K_p = G_p \frac{A_p}{H_p}$$

initial stiffness $K_1 = K_2 \beta$

secondary stiffness $K_2 = K_r + K_p$

where $\beta = 10 \sim 15$.

Elasto-plastic (combination)

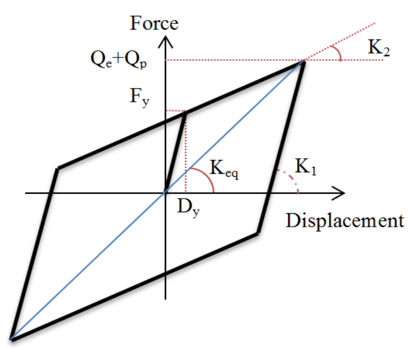


Figure 1. Bi-linear model of LRB.

2.1.3 Modified Bi-linear model of LRB

The idea behind the modified bi-linear model is that calculations of secondary stiffness and yielding shear force of LRB devices can be made by using modification

$$K_d(\gamma) = C_{kd}(\gamma)(K_r + K_p)$$

$$Q_d(\gamma) = C_{Qd}(\gamma)\sigma_p A_p$$

factors $C_{kd}(\gamma)$ and $C_{Qd}(\gamma)$, which depend on strain level (γ). The equations show the calculation of modified secondary stiffness and yielding shear force respectively: where $C_{kd}(\gamma)$, the modification factor, depends on strain level, σ_p and A_p are the yielding shear stress of the lead plug and the cross sectional area of the lead plug respectively. Two parameters are used for the stiffness modification factor and one modification factor for yielding shear force.

$$C_{Kd(\gamma)} = \begin{cases} 0.744\gamma^{-0.427} & \rightarrow \ \gamma < 0.5 \\ 0.921\gamma^{-0.25} & \rightarrow \ 0.5 \leq \gamma \end{cases}$$

$$C_{Kd(\gamma)} = \begin{cases} 0.779\gamma^{-0.43} & \rightarrow \gamma < 0.25 \\ \gamma^{-0.25} & \rightarrow 0.25 \leq \gamma < 1.0 \\ \gamma^{-0.12} & \rightarrow 1.0 \leq \gamma < 2.5 \end{cases}$$

$$C_{Qd(\gamma)} = \begin{cases} 2.036\gamma^{0.41} & \rightarrow \gamma < 0.1 \\ 1.106\gamma^{0.145} & \rightarrow 0.1 \leq \gamma < 0.5 \\ 1 & \rightarrow 0.5 < \gamma \end{cases}$$

The initial stiffness in the modified bi-linear model can be obtained in the same way as the simple bi-linear model.

Using the parameters of the modified bi-linear model for LRB isolators, a comparison between the observed data and a numerical simulation was performed in this study.

A skeleton curve shown in Figure 2 was produced using the two parameters of modification factor for secondary stiffness. This skeleton curve based on parameters of Lead Rubber Bearings.

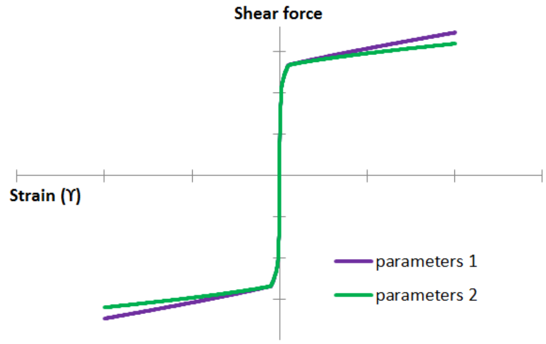


Figure 2. Skeleton curve of the Modified Bi-Linear model.

3. RESULTS OF THE ANALYSIS

3.1 Overview of the target building

A ten story steel reinforcement concrete (SRC) type building in Hachinohe, Aomori Prefecture was chosen as the target building (hereinafter H-building), see Figure 3. The building is located 292km from the epicenter of the March 2011 Great East Japan Earthquake.

A seismic isolation system was installed during construction which used LRB devices with diameters of 1200mm and 1300mm. 12 LRB with a diameter of 1200mm and 2 with a diameter of 1300mm were used.

To record large amplitude ground motion and the response of the structure to these motions on the basement, 1st and 10th floors of H-building strong motion record sensors installed. Three more ground motion sensors installed at ground level. These three sensors located on the surface, at 30 and 105m deep.

Figure 3. The H-Building.

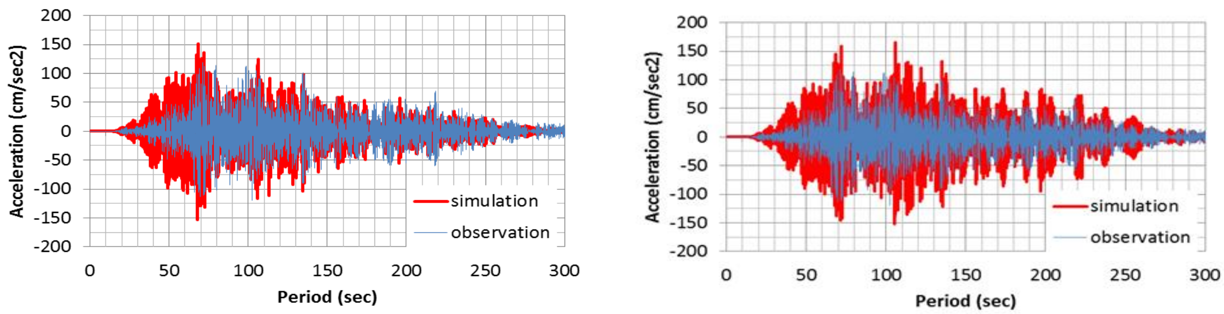
Table 1. Obtained results by using Modified Bi-Linear model.

Modified Bi-Linear model analysis	**X direction** [observed]	**Y direction** [observed]
Peak acceleration on 1st floor (cm/sec^2)	117.5 [122.3]	91.8 [91.4]
Peak acceleration on 10th floor (cm/sec^2)	190.7 [122.7]	151.2 [119.6]
Max. displacement on 1st floor (cm)	4.7 [4.7]	6.4 [5.4]
Max. displacement on 10th floor (cm)	5.2 [5.7]	6.8 [6.0]

3.1.1 Comparison of analysis

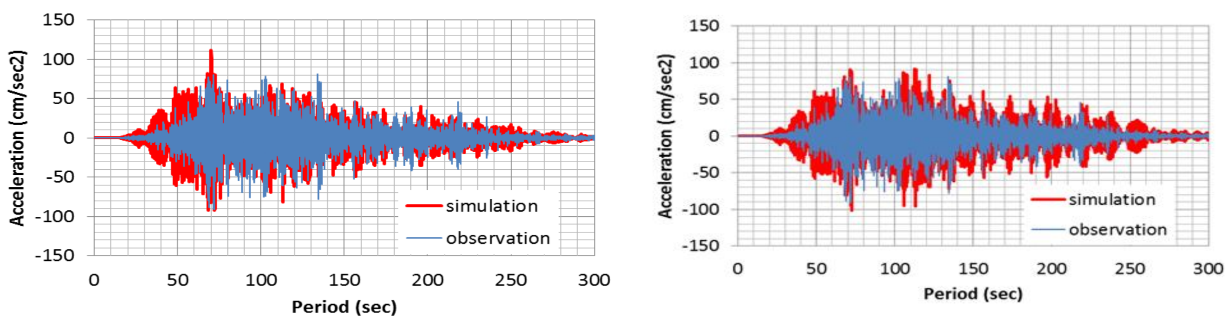
Modified Bi-Linear model gives more close result to observation data in both case (2 shear springs and 6 shear springs) than results obtained using Simple Bi-Linear model. Because of this a comparison between two types of Modified Bi-linear models was done in this sub-chapter.

A comparison of the acceleration response between two shear springs model and observation data, and also between six shear springs model and observation data shown on figures 4, 5, 6 and 7.



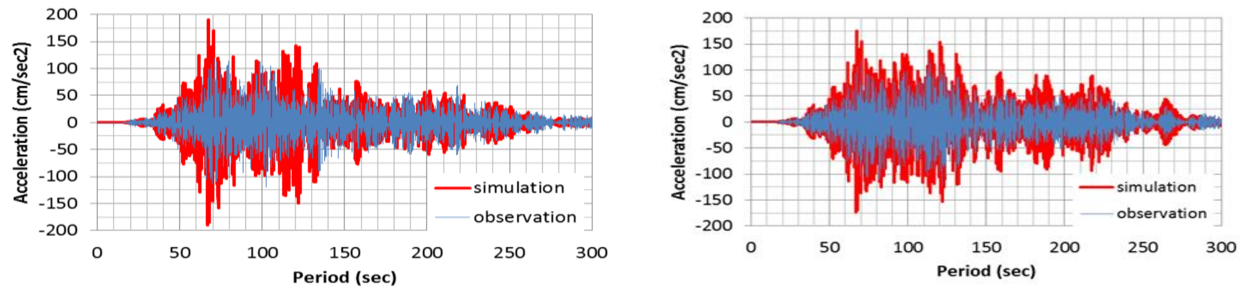
a) 2 shear springs model. b) 6 shear springs model.

Figure 4. Comparison acceleration on the 10th floor Y-direction (Modified Bi-Linear model).



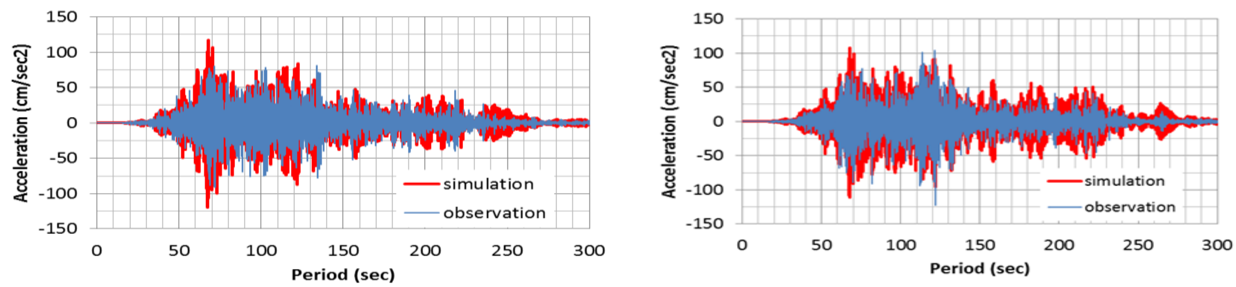
a) 2 shear springs model. b) 6 shear springs model.

Figure 5. Comparison acceleration on the 1st floor Y-direction (Modified Bi-Linear model).



a) 2 shear springs model. b) 6 shear springs model.

Figure 6. Comparison acceleration on the 10th floor X-direction (Modified Bi-Linear model).



a) 2 shear springs model. b) 6 shear springs model.

Figure 7. Comparison acceleration on the 1st floor X-direction (Modified Bi-Linear model).

4. PROPOSAL FOR TURKMENISTAN DESIGN CODE.

The design procedure for seismically isolated buildings in Turkmenistan proposed in this research is based on the recommendations of the CIB (International Council for Research and Innovation in Building and Construction) using the preliminary design procedure for seismically isolated buildings (CW2012) and Russian Federation Seismic Building Design Code (СНиП II-7-81*, updated edition. Moscow, 2011) taking into consideration the Turkmenistan Seismic Building Design Code. There are two options for the design of seismically isolated buildings; they are the Time History Analysis Method (THAM) and the Equivalent Linear Analysis Method (ELM). This research proposes design procedure using an Equivalent Linear Analysis Method.

4.1 Equivalent Linear Method

Requirements for using the Equivalent Linear Method for assessing of seismically isolated buildings are described as follows:

- Building height should not be more than 60m;
- Buildings should only be constructed in areas with soil types I or II and ground where there is no possibility of liquefaction;
- Isolation devices located only in the basement;
- Maximum mass stiffness center eccentricity is 3%;
- Tension on isolation devices shall not be permitted;
- Yield strength should be more than 0.03W;
- Period range of the isolation system should be T>2.5 sec.

5. CONCLUSIONS

An analysis of the acceleration data recorded during the Great East Japan Earthquake of 2011 and the Modified Bi-Linear Model numerical simulation were made to investigate the nonlinear behavior of the base isolation systems.

The results of the comparison between the numerical simulation of the building in Hachinohe and observation data correlated well, showing that the building behaved as should be expected. It is necessary to continue study in this field to get more accurate results.

From the results of analysis of the residential building in Turkmenistan the effectiveness of using the seismic isolation systems can possibly be assessed. The main controversy arising in the design of seismic isolation systems were seen between the reductions of acceleration and limiting relative displacements at the seismically isolated layer was manifested in the analyzed building.

The study showed that seismic isolation systems are an effective way to lessen the buildings damages from earthquakes. The primary purpose of seismic isolation systems is to reduce the acceleration response and relative displacements of structures. Proposed method of design procedure by using the Equivalent linear method allows the assessment of the effectiveness of seismic isolation systems and, to carry out the selection of parameters of the seismic isolation systems and their reliability.

Finally, base isolation systems can be applied in designing new buildings in Turkmenistan to mitigate the effects of large scale earthquakes.

This technology should be introduced to Turkmenistan, due to the country’s high seismicity and the huge amount of construction work that is underway.

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