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PERFORMANCE OF STRUCTURE WITH AND WITHOUT BASE ISOLATION

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Abstract

The primary objective of this investigation is to outline the relevant issues concerning the conceptual design performance for base isolated structures. A 90 feet high, 6 stories tall, moment steel frame structure with tension cross bracing is used to compare the response of both fixed base and base isolated structure to severe earthquake excitations. Techniques for modeling the superstructure and the isolation system are also described. Elastic time-history analyses were carried out using comprehensive finite element structural analysis software package SAP2000. Time history analysis was conducted for the 1940 El Centro earthquake. Response spectrum analysis was employed to investigate the effects of earthquake loading on the structure. In addition, the building lateral system was designed using the matrix stiffness calibration method and modal analysis was employed to compare the intended period of the structure with the results from computer simulations. Base isolation proves to be effective in reducing the induced inertia forces on a structure by increasing the effective period of oscillation.

Keywords: *Base Isolation, Time History Analysis, Response Spectrum Analysis, Matrix Stiffness Calibration Method.*

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1. INTRODUCTION

The aim of this work is to design a base isolation system for a low rise building and to evaluate its performance using various techniques including dynamic time history analysis, static pushover analysis. Characteristics of base isolation devices currently available on the market will be evaluated and compared. The main comparison criteria are cost, durability, residual displacement and ability to provide wind resistance.

A traditional "brute force" method for making earthquake resistant structures is to design a stiff and strong enough structure so that it could accommodate foreseeable lateral forces. This may not be the most cost efficient method. The problem with this method is that the building has to absorb all the lateral forces induced by the seismic ground motion. The technique of base isolation allows to go around the aforementioned problem. The method of base isolation was developed in an attempt to mitigate the effects of earthquakes on buildings during earthquake attacks and has been practically proven to be one of the very effective methods in the past several decades. Base isolation consists of the installation of the support mechanisms, which decouple the structure from earthquake induced ground motions. Base isolation allows to filter the input forcing function and to avoid the acceleration induced seismic forces on the structure. If the structure is separated from the ground during an earthquake, the ground is moving but the structure experiences little movement. This technology was first introduced in the 1900's but it only evolved into the practical strategy for seismic design in the 1970's.

The fundamental goal of base isolation is to reduce substantially the absorption of the earthquake induced forces and energy by the structure. This is accomplished by placing a structure on a support mechanism with low lateral stiffness so that in the event of an earthquake, when the ground undergoes strong motion, only moderate motion is induced in the structure itself. As the flexibility of the support bearings increases (stiffness decreases), movement of the structure relative to the ground under wind loads may become a problem. It has been indicated that a base isolator with hysteric force-displacement characteristics provides the required high flexibility, high damping and force limitation under earthquake loads, while at the same time sufficiently high stiffness under smaller loads to handle wind induced horizontal forces [Skinner and McVerry, 19751. Connor [2002] gave an introduction to the fundamentals in analyzing the response of base isolation mechanisms through a two degree of freedom linear dynamic system. Base isolation mitigates seismic response through shifting the effective fundamental frequency of the system out of the range where earthquake would produce greatest inertia forces. Increased flexibility of support bearings (or their decreased stiffness) increases the equivalent natural period of the system. Because period is increased beyond the period range of the earthquake induced ground motion, resonance is avoided and the seismic acceleration response is reduced. The success of a base isolation system in a building depends on the parameters of bearing mechanisms, which decouple the structure from the ground motions. Therefore, it is of extreme importance to have an understanding of the influence of parameters of the support systems and the structure on the seismic performance base isolated structures. Low stiffness of the support mechanisms in a base isolated structure gives a building a long effective period and therefore reduces the earthquake generated lateral inertia forces on the structure. Numerous types of base isolation devices have been developed to accomplish this function, such as laminated elastometric rubber bearings, lead rubber bearings, yielding steel devices, friction devices (PTFE sliding bearings) and lead extrusion devices.

Andriono [1990J suggested that base isolation systems significantly reduce the super-structure lateral stiffness and ductility demands compared to unisolated structures. This allows cost savings from less materials being spent on lateral systems and sim-plification of structural detailing. In addition, base isolation enables a wider range of architectural forms and structural materials to be available to the designer. Beside the technical feasibility, a key parameter that needs' to be approached in the early phases of design is economic feasibility. The principal factors to be evaluated.

2. METHODOLOGY

In this study the performance of a six-story braced moment steel frame structure subjected to severe earthquake loads was evaluated using elastic/linear analyses. Based on the findings from the analysis, a base isolation system was designed for the structure. The parameters of base isolation system were chosen using the theory of multi degree of freedom dynamic systems. Then base isolation parameters were included into the initial model and the performance of the isolated structure subjected to the same seismic loads was evaluated. The two sets of results were compared and the structural effectiveness of base isolation system for that particular building was discussed. In addition, economic and practical aspects of base isolation systems were discussed and the conclusion with regard to feasibility of the system was drawn based on both structural and economic arguments.

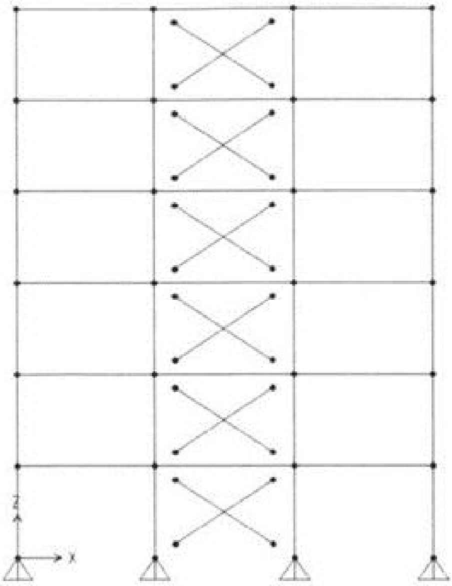


Figure 1. Building frame elevation view

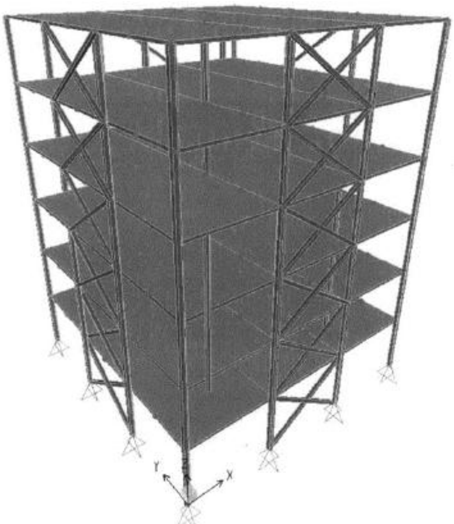


Figure 2. Building frame 3-d view

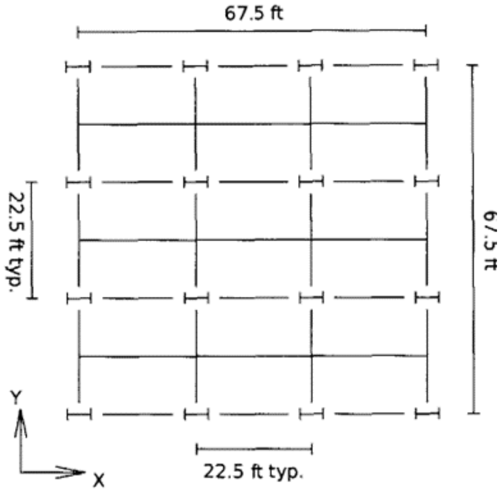


Figure 3. Floor framing plan

3. BUILDING STIFFNESS CALIBRATION

Masses mi to rn5 for the discrete model shown in Figure 4 are calculated based on floor loads and weight of structural members. The results are summarized in Table 1.

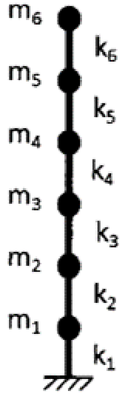


Figure 4. Discretized lumped mass model

Table 1. Nodal mass distribution for a discretized model

Floor	1	2	3	4	5	6
Weight of columns (*kips*)	9.84	19.68	19.68	19.68	19.68	9.84
Weight of beams (*kips*)	33.41	33.41	33.41	33.41	33.41	33.41
Weight of slab (*kips*)	455.63	455.63	455.63	455.63	455.63	455.63
Weight due to live loads (*kips*)	441.72	441.72	441.72	441.72	441.72	91.13
Total weight of floor (*kips*)	940.6	950.4	950.4	950.4	950.4	590.0
$m_i\ (kips\frac{s^2}{in})$	2.43	2.46	2.46	2.46	2.46	1.53

Note that in order to convert kilo-pound force units into imperial mass units, the values need to be divided by a factor g=386.4 in

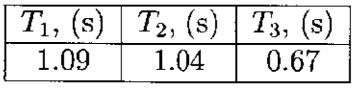
4. ANALYSES

In order to successfully design the base isolating system for the structure the dynamic response of the unisolated structure needs to be studied. A series of analyses involving fixed-base structure was performed on the building using SAP2000 nonlinear finite software. The primary objective of the analyses is to study the displacements, inter-story drifts and stresses in the structure under earthquake loads. The fundamental period found through modal analysis was compared to the target period of 1 second and reasons for discrepancy were discussed. The target period of 1 second was chosen to put the structure at the top plateau of the response spectrum curve, so that seismic forces experienced by the structure were at their maximum. This was done in order to demonstrate how effectively base isolation reduces earthquake effects.

4.1 Modal Analysis

In order to find the period of the structure, linear modal analysis was performed. Because the analysis is linear, it is possible to design tension-only bracing by using only one diagonal member working both in tension and compression. In the linear range, it produces the same effect as the tension-only cross bracing. It is possible to model tension-only bracing by assigning compression limits to frame members, but such method only works in nonlinear analysis cases and hence is not suitable for linear modal case.

Table 2. Global modal periods: Fixed base structure



T_1, (s)	T_2, (s)	T_3, (s)
1.09	1.04	0.67

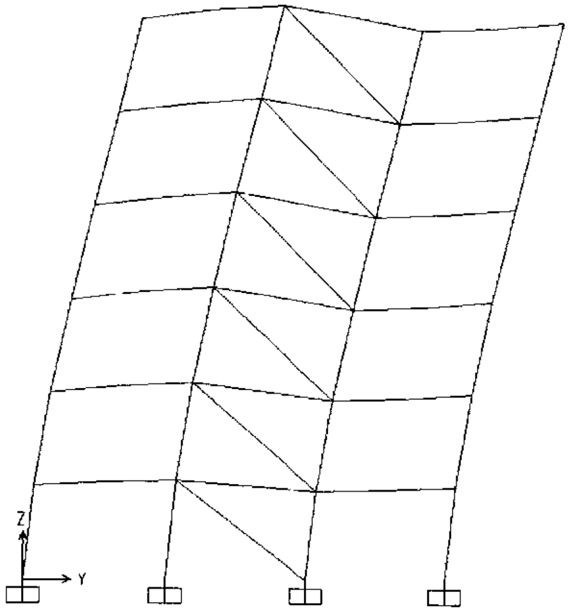
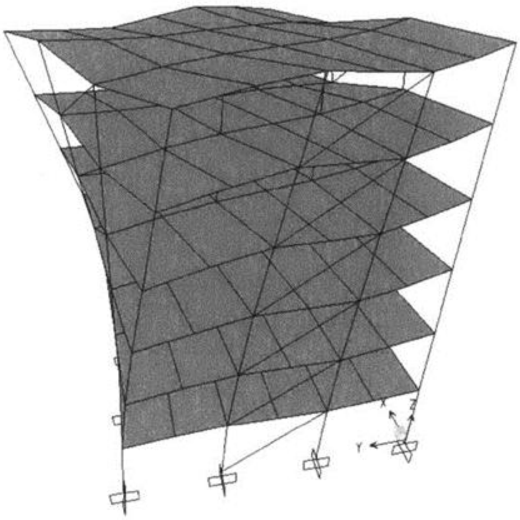


Figure 5. First mode shape (T_1= 1.09s)



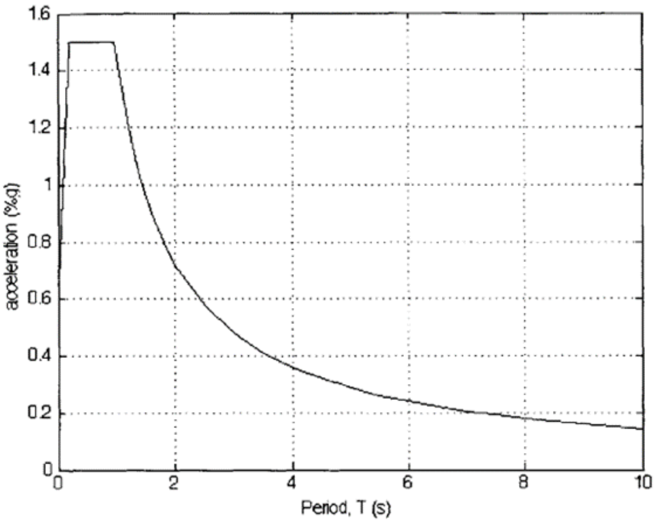


Figure 6. Torsional mode shape (T_3= 0.67s) Figure 7. Response spectrum curve

Table 2. Global modal periods: isolated structure

T_1, (s)	T_2, (s)	T_3, (s)
3.62	3.61	2.97

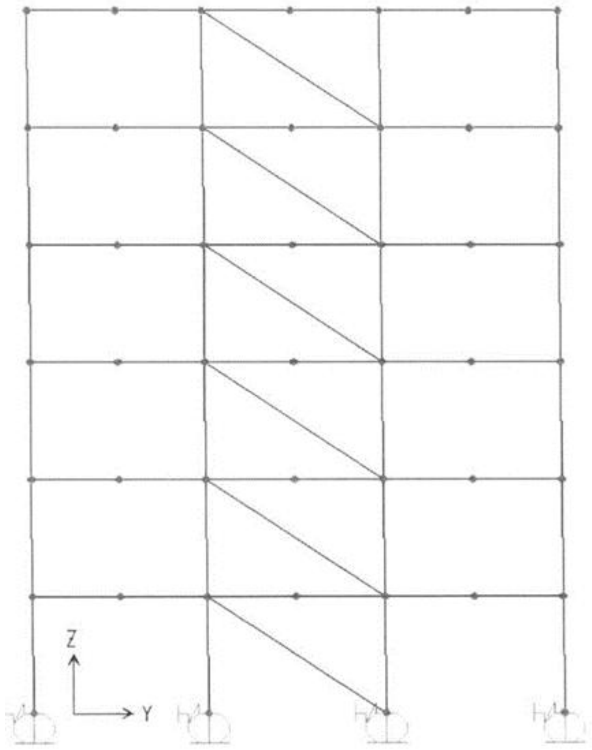


Figure 8. First mode, xy axes show origin position (T_1= 3.62s)

5. CONCLUSION

The series of analyses has proven the benefits of base isolation. The stiffness parameters of bearings were designed and analyzed to maximize the seismic performance of the structure. Base isolation has displayed significant positive effects by increasing the structure's natural period and hence reducing inertia forces on the structure. This investigation outlined the major relevant issues concerning the conceptual design of a base isolated structure. The parameters of the building and the site conditions chosen for the study were deliberately chosen in such a way that the earthquake effects were most severe. In reality, the stiffness calibration approach can be integrated together with the base isolation design in early stages of projects in order to develop structures of high seismic performance.

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