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The effect of Stiffness on Behavior of Isolated Tall Buildings

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ABSTRACT: The basis of seismic isolation in reducing the acceleration applied to structures is based on an increase in the natural period. In high-rise structures, the natural period itself is high. In this case the flexibility of superstructure may be in conflict with its elastic behavior. In the present study, 240 structures were modeled and analyzed in the first step to the question of whether the addition or reduction of the stiffness of the substructure and superstructure (1-100 times and 0.001 to 1 times respectively) affected the floors acceleration distribution or not? The results of the analysis of structures that were of five types of plans and at elevations 10, 15, 20, 24 and 28 floors showed that adding the stiffness of the superstructure can lead to a decrease of about 30 and 55 percent of the maximum roof acceleration and average acceleration of floors respectively (relative to the isolated structure without increasing the stiffness of the superstructure); However, the use of base isolation in the structures decreased about 50% of roof acceleration. The significant decrease in roof acceleration was related to structures with a 10 times increase in the stiffness of the superstructure compared to normal structure. In the next step, with the push-over analysis of 15 structures of this set, it was determined that in all isolated structures (with varying stiffness), the superstructure will remain in elastic state. The number of plastic hinges in the elastic region (before IO performance level) increased by 50% in isolated structures compare to fixed base and none of the plastic hinges formed in the members, exceeded from IO region.

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1. INTRODUCTION

The use of seismic isolators in the last few decades has been considered by engineers as a very effective way of reducing the acceleration applied to the structures. Due to this fact that the main reason of acceleration decrease in base isolated structures is increase in natural period of structures, for many years, it was believed that the use of this system is beneficial for buildings up to 12 floors and it is not useful for taller buildings due to the high natural structure period. Over time this belief has been changed and the researches showed that the acceleration of isolated tall buildings decreased and also became uniform in height [1, 2].

In countries like Japan and the United States, seismic isolators were used in buildings with different heights, and in earthquakes in these countries, these buildings had a very good performance compared to the fixed base buildings. In this way, the accelerations recorded by accelerators were sharply reduced during an earthquake, and the frequency of structures also decreased [3-6].

The available technical documents for the isolated structures states that the superstructure section in these structures should remain elastic during an earthquake [1]. Regarding the importance of current research, it can be said that the drift control criteria is satisfied by adding hardness, on the other hand, the boundary of relative displacement control is based on the existing codes for the isolated structures is (0.01/R). This value is usually high (R is between 1 and 2). Accordingly, in tall isolated structures, it is very likely that there will be a relatively soft superstructure, which this will add to the flexibility of it. Now the basic question is whether with any stiffness of substructure and superstructure will the structure main elastic or not?

2. METHODOLOGY

In order to achieve the goals of this research, structures with 5 different plans and with the number of floors 10, 15, 20, 24 and 28 were defined. Initially the floor acceleration changes considered in two cases of with and without isolators. Then it is investigated that how the stiffness of substructures and superstructure effects on the floor accelerations. At each stage, the stiffness of each part (substructure and superstructures) of these structures in the two broad ranges was increased from 1 to 100 times and decreased to 0.001-0.1 times. Each structure under three time histories which are shown in Table 1, analyzed [7]. Finally, for 3 models of each structure, (fixed base and isolated base of normal stiffness and 10 times stiffness) pushover analysis were done.

To isolate each of the structures, 30 LRB isolators with the specifications given in Table 2 were used under structural columns (on the ±0.00 level, top of basement).

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Table 1. Earthquake records used for time history analysis

Name	Station	Magnitude	DT
Kobe	Takarazu	6.9	0.01sec
Northridge	Arleta	6.69	0.02sec
Tabas	Tabas	7.35	0.02sec

Table 2. Base isolators properties used for each sample

No. of stories	Lead core diameter (mm)	Lateral Stiffness (ton/mm)	Damping (%)
10	120	0.170	20.43
15	140	0.182	15.2
20	150	0.212	21.81
24	170	0.234	21.74
28	180	0.320	17.452

The structures were designed in such a way that, in addition to pass all criteria's of fixed based structures, they were resist to the minimum shear force of (V_s) [1, 8].

$$Vs = \frac{k_{D\max} D}{R_I} \tag{1}$$

The coefficient R_1 is determined according to the type of lateral load bearing system, which was considered R_1=2 in this research.

3. RESULTS AND DISCUSSION

The results showed that the isolation in selected structures reduces the floor accelerations and the acceleration decrease values, increased with increasing height of the structures. Also, by isolation of to the structures, because a large part of the structural flexibility is transmitted to the isolation level, the acceleration distribution from that level becomes uniform along the height. The optimal condition for the isolated structures is that the superstructure behave completely rigid on the isolation level. However, as the height of these structures increases, this stiffness toward softness. For this reason, when the stiffness floors in these structures increases, their acceleration becomes more uniform and decreasing compared to the structure with natural stiffness. Also because of flexibility of isolation level compared to superstructure stories, reduction of superstructure stiffness has no effects on acceleration of floors. The lateral shear-displacement curves of pushover analyzed models were linear.

4. Conclusions

1. In all of tall building studied in current research and under all earthquake records, the roof and the first floor over the isolator acceleration decreased 50 and 30% respectively compared to fixed base structures.
2. Increasing the substructure stiffness from 1 to 50 times, didn't effect on the floors acceleration.
3. By decreasing the stiffness of substructure floors, their acceleration was increased 30% average. But this decrease, didn't effect on the superstructure floors acceleration.
4. Increasing in superstructure stiffness leads to uniform acceleration distribution along the height of structure.
5. Increasing in superstructure stiffness (about 1 to 100 times) decrease the last floors acceleration about 40% but didn't effect on the substructure floors acceleration. And also it did not affect the story shears.
6. Decreasing the superstructure stiffness from 1 to 0.001 times, have no effects on the substructure and superstructure floors acceleration.
7. Increasing the average stiffness of the stories up to 10 times, significantly reduces the roof acceleration, but with a further increase in the average stiffness of stories, its effect on acceleration stiffness was reduced.
8. In all cases (all stiffness of substructure and superstructure), the behavior of the superstructure was quite linear and it mains elastic. Also all of plastic hinges in the beams, columns and walls have been in IO region.

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