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Determining the Damping Effect on Seismic Force Analysis during Earthquake-Resistant Base-Isolated Structures through Hybrid Spherical Rollers (HSR)

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ABSTRACT: Movement of Tectonic plate in earth produce the earthquakes. This movement causes catastrophic shocks and impulses on the earth's surface. Isolating load-bearing structures from the transmission channel is the most sensible and efficient earthquake protection. A structure's basic time is prolonged when a base isolation system is utilized instead of a permanent basis. Using this method, isolation efficacy increases as earthquake size increases. Foundation isolation protects the structure against earthquakes. It differentiates between a ground-supported superstructure and substructure. Isolators drop a system's inherent frequency below the excitation frequency, whereas dampers remove mechanical energy. In most earthquakes, the structure's acceleration is magnified beyond the grounds. The relative displacement will be smaller than the peak ground displacement in most cases. In soft soil near a fault, this isn't always true. Extensive experimentation is being done to determine which of four models is best. Every model feature three single-bay frames, each with three functions. Braced frame has best peak acceleration response, whereas bare frame has biggest peak displacement response. The braced frame provides the most robust acceleration response because of its higher excitation frequency and frame rigidity. Due to increased acceleration. The hybrid spherical roller base isolated frame with infill walls offers the lowest peak displacement response. This is due to the frame's increased energy dissipation. Despite this, this frame's peak acceleration response is the biggest among those with an infill wall; but, due to the damping effect, it's lower than that of an unfilled frame. Increased frame stiffness and excitation frequency cause this. Infill walls increase peak displacement response in frames. A wall opening reduces the wall's rigidity. The single brace frame has stronger peak acceleration and peak displacement than the base-isolated frame. The base isolated frame's dampening effect is less severe than another frames. Since bracing were added to the braced frame, the in-filled frame loses rigidity. The brace system's acceleration response is better than the in-filled systems. The prior point led to this. A braced system's peak displacement response is substantially less. In-filled frames losing more energy than braced ones may be a factor.

KEYWORDS: Seismic Force, Tectonic Plate, Earthquakes, Hybrid Spherical Rollers

I. INTRODUCTION

An earthquake is a natural occurrence that is brought on by the movement of tectonic plates. This movement results in shocks and impulses that are catastrophic in scale and are transmitted through the surface of the earth. The most logical and efficient method for protection against the high degree of acceleration generated by an earthquake is to isolate load-bearing structures from the transmission medium. The basic period of the structure is increased when a correct base isolation system is utilized rather than a permanent base structure. In addition, the isolation efficiency increases as the magnitude of the earthquake increases when using this kind of system.

Because of the foundation isolation, the building is shielded from the impacts of seismic activity. It delineates the boundary between an earth-supported superstructure and an earth-supported substructure. The primary distinction between an isolator and a damper is that the former brings the system's natural frequency down to a level that is lower than the excitation frequency, whilst the latter takes away mechanical energy from the system. In the vast majority of earthquakes, there is a window of time during which the acceleration of the structure is amplified beyond the maximum acceleration of the ground. In most cases, the relative displacement will not be more than the peak ground displacement, also known as the finite period displacement. However, there are certain instances in which this is not the case, especially in areas with soft soil that are close to the fault. The implementation of base isolation in codes is

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predicated on the concept that the energy input remains constant throughout the mid-frequency range of around 0.5 sec to 4 sec; that is, the velocity is constant. This is because the mid-frequency band is where base isolation is most usefully used.

After reaching a peak, damping reduces in contrast to the minor displacement that occurs, and unfortunately, the more powerful the earthquake, the less damping there is. The damping system works by reducing the yield level, which is expressed as a percentage of the total weight of the structure. However, the higher the yielding level, the less effective the isolation system will be in terms of minimizing the effects of mild to moderate earthquakes. This is due to the fact that the isolation system does not begin functioning until the yield threshold is exceeded, and if a high threshold is set, the system will not function if there is a greater frequency of earthquakes. The effectiveness of base isolation systems is determined not only by the parameters of the isolation devices and the superstructure, but also by the properties of the input excitations. As a consequence of this, comprehensive preliminary research must be conducted in order to ascertain whether or not a particular base isolation system for a building is effective in relation to the seismic map of the region and the characteristics of the earthquakes that are most likely to occur there.

The expense of isolation will always be a major factor to consider, and one of the primary concerns of innovators in any project. A newly separated structure, on average, costs more than a non-isolated structure. In addition, more technical effort is required to study and design the structure and its isolation system in detail. The flexibility of the superstructure in a base isolated building, on the other hand, is often less than in a non-isolated building, which may result in lower construction costs. There is another concern when choosing a heavily damped system for a possible construction: heavier dampers may cause greater floor acceleration. It is critical to pick the proper isolation type for the particular location and mass of the building.

The most major benefit of employing the base isolation system, however, is that the structure will function better during an earthquake, perhaps saving many lives. This might be classified as a long-term cost-cutting investment. This thesis demonstrates the feasibility of constructing an effective hybrid base isolation technique based on the newest technology and state-of-the-art isolation methods.

SEISMIC ISOLATION

The base isolation method was developed in response to the pressing need for earthquake-resistant constructions. The notion has matured since its inception in 1909 B. C. by a doctor called Calantarients, who advised using the talc layer between the foundation and superstructure. Numerous other types of isolators have since been developed and effectively utilized in many nations. The basic principle of an isolator is to isolate the superstructure from the foundation in order to mitigate the damaging impacts of an earthquake.

SEISMIC ISOLATION PRINCIPLE

It is possible to install seismic isolation devices in buildings in such a way that the structure's base is isolated from its superstructure or particular elements of the structure, installed so that particular elements of the structure are isolated from one another. Buildings often use energy dissipation technologies as their primary method of seismic isolation when designing new structures. The devices may be categorized in one of two ways: either according to their location in the structure or according to the principles that govern how they function. On the basis of where in the structure they are located, isolators may be divided into two distinct categories. There are two different kinds of isolators: internal and external isolators. Devices that are external to the structure are often installed in the foundations and are located outside the building. Internal mechanics are what make up what are known as energy dissipation devices. Torunbalci asserts that all response control systems may be classified as either active, passive, or hybrid depending on the operational principles that guide how they perform their functions.

Control Methods That Are Not Active

The operation of passive control systems does not need the introduction of any additional energy. As a consequence of this, the cost of establishing these systems is cheaper when compared to the cost of establishing active systems. These kinds of systems are capable of regulating the displacement up to a particular extent. The protective mechanisms that are used in passive control systems are designed with the intention of providing the required degree of protection against earthquakes of a certain size. These systems are comprised of various devices like as dampers, isolators, and

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others that may easily be bought and used. There are several distinct varieties of passive control systems, many of which have shown to be more effective in actual use. According to Torunbalci, each of these systems is dependent on the presence of components that are capable of absorbing energy at a certain level, either on their own or in combination. In irreversible displacement systems, balls or rollers are utilized as the moving components.

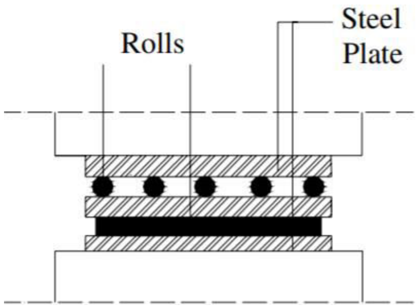

Figure 1: Irreversible displacement system

Because of these rolls, there is a possibility that the structure may move laterally during an earthquake. They are constructed with a suitable number of rolls or spherical steel balls that are positioned perpendicular to the steel plates, and they sit in between the steel plates. Plastic systems that enable superior energy absorption for seismic isolation and other vibrations have been established thanks to the malleability of lead, which has been used in these systems. (Fig. 2).

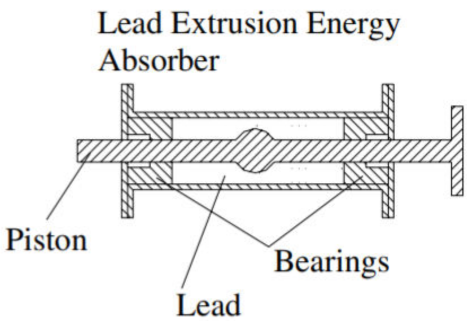

Figure 2: Plastic system

In these systems, there is normally a lead-filled cylinder and a difficult-to-move piston within that cylinder. The lead in the cylinder restricts the piston's motion, allowing the energy to be absorbed. The largest displacements are usually controlled by lead extrusion dampers.

II. RESEARCH METHODOLOGY

HYBRID SPHERICAL ROLLER SYSTEM PRINCIPLES

The principle of hybrid spherical roller system is, If the structure is allowed to displace freely in a controlled manner during the earthquake, then there will not be any major loss of strain energy (elastic energy) in the structure. The only frictional force between the isolator and the structure will be transmitted to the superstructure. Since the frictional force is small, the structure can resist within elastic limit and there will be no structural damage or non-structural damage to the buildings. This new Hybrid roller bearing isolator is designed with an objective to reduce the demand rather than increase the capacity of structures. An attempt is being made to eliminate more than 90% of earthquake force by configuration approach (arrangement of isolating components).

If the structure is properly configured (i.e., required shape, size, and arrangement of isolator) to seismic wave then the structure will be able to float in that wave. If not, the structure would collapse due to the high intensity of seismic wave. e.g.,

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- A car or bus will not get damaged structurally or non-structurally when it is parked on open ground during an earthquake.
- A steel or aluminum plate cannot float on water, but if the configuration is changed to boat-like shape and designed accordingly, it can float.

Similarly, if the structure is properly configured for the seismic wave, the structure can float in that wave and it can withstand earthquake forces. (George c. Lee 2010) carried out a shake table study on a certain version of such bearing which does not have hybrid spherical rollers. It consists of a cylindrical roller for zero post stiffness and self-certain capability. However, the vertical loading, loading history and loading rate were not considered. But, in this research, these effects are considered and the costly shear wall and costly base isolator are eliminated. The hybrid spherical roller (HSR) allows the structure to displace vertically in the near-field earthquake to reduce the vertical stress, whereas the elastomeric bearing fails to do so. According to (MotiPerets 2014), the friction pendulum bearing suffers due to the highly concentrated stress produced by the rolling ball or cylindrical rod due to the small contact surface area between rolling ball and the concave surface which results in scratches and damages to concave surface caused by the motion of ball or cylindrical rod during earthquakes.

HSR: STRUCTURAL DESIGN REQUIREMENT

Primarily the horizontal force that causes the structure to deform is eliminated by allowing it to displace within the allowable limit. The isolator is designed for the requirement of the seismic zone and the level of risk. They are allowed freely to displace in a controlled manner within the isolator and during the earthquake, the destructive rotational Rayleigh wave can be dissipated by rotating the roller on its own axis thus keeping the structure safe. The configuration curve in the isolator allows for self-centering the structure when it is displaced. If the allowable displacement of the structure exceeds in extreme cases, the roller strikes the partition wall of the isolator. The rubber pads are provided on the inner surface of the partition wall to increase damping in the structure. According to The United States Geological Survey (USGS) data, strong motion data from past 100 years were analyzed. The displacement of the ground has been studied and the isolator is designed for the worst condition of seismic force. Basically, this pattern of lateral displacement of an isolated structure will be accommodated by displacement of the isolation system rather than a distortion of the structure. The response of a pure isolator system is generated by frictional force at the sliding interface. For increased displacement, the effective period lengthens and the load on the superstructure remains constant. The isolation system governed solely by frictional forces the displacement due to the earthquake.

The main features of the hybrid spherical roller (HSR) isolator are,

- The sliding friction mechanism is integrated to bearing to provide supplemental energy dissipation to reduce the displacement response.
- The sandwich elastomeric material surrounded by the rollers will be able to eliminate the rocking effect and increase dampness to the structure.
- It will be able to come back to its initial position after the earthquake automatically.

The following are the components of the HSR isolator.

- Top and bottom bearing cup of the isolator with its Configuration.
- Spherical roller bearing.
- Sandwich plates (steel & rubber pads).

SPECIFICATIONS

The models of base-isolated frame along with the components are shown in fig 3. and4. The base isolated frame consists of 4 rollers, which are sandwiched between two bearing plates. The top and bottom bearing plate having a flat and concave surface are in contact with the rollers. Both the top and the bottom square cups are of dimension 45mm and 80mm. These plates are anchored to the superstructure and substructure. The four spherical rollers are separated by the partition walls inside the cup and these walls consist of steel plate and its inner surface is sandwiched between elastomeric layers. The walls are basically provided to eliminate the collision between the rollers during seismic excitation and to reduce the vibration during excitation.

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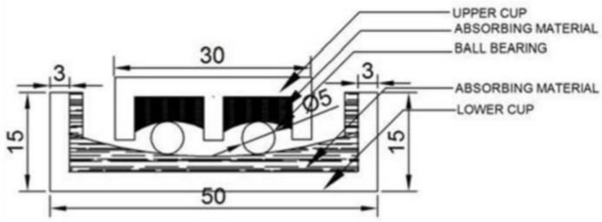

Figure 3: Analytical model of Base Isolator (Bottom and Top Cup)

Figure 4: Actual model of the Hybrid spherical roller

A rubber and steel plate of thickness 2mm laminates are used to absorb the seismic waves and improves damping. The bottom plate is made into a concave shape to create a self-centering capability after the excitation and the sloping angle is limited to 11° as indicated by (MaluGirish and Manual Pranesh 2013). Once the substructure moves, rollers will roll between the bearing plates and dissipates energy. The design displacement capacity of the bearing is 15mm on all sides. The spherical steel balls are used for making roller and the grade of bearing plate is Fe250. The diameter of the roller is 15mm. The total weight of the model used is 15 kg including its self -weight for fixed and base-isolated structure. The following are the dimensions of the components of the isolator.

- The Size of a top plate- 45 mm x 45 mm.
- The Size of a bottom plate- 80 mm x 80 mm.
- The spherical ball bearing of 15mm diameter is housed between the top and bottom plates.
- Steel and rubber sandwiched layer of 8mm at the top and bottom plate.
- Partition wall height– 40mm.

Analytical and experimental examinations were done on the developed model of the structural system (hybrid spherical roller) which satisfied the above guidelines.

ANALYSIS AND INTERPRETATIONS

BASE ISOLATED FLOOR (BIF) RESULT ANALYSIS

The maximum response for BIF is different from FF due to several reasons they are, the stiffness of the member, natural frequency, the damping ratio of the structure, lateral load transfer mechanism etc. The response of BIF is reduced by modifying these engineering these parameters. This topic will be discussed in detail in the further headings. From the illustration, the maximum response (acceleration, velocity, and displacement) of BIF at 2.8 Hz frequency are 0.89, 1.3, and 1.7 times the ground floor. For the FF it was 4.8Hz.

Table 1: Response between time period and acceleration – BIF

S. No.	Frequency	Period	Acceleration $(m/s)^2$				R. Acceleration $(m/s)^2$		
	Hz	sec	GF	I Floor	II Floor	III Floor	I Floor	II Floor	III Floor
18	10.00	0.10	0.09	0.03	0.02	0.05	0.06	0.01	0.03
17	9.65	0.10	0.10	0.03	0.02	0.05	0.07	0.01	0.02

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16	9.00	0.11	0.18	0.03	0.02	0.08	0.15	0.01	0.05
15	8.65	0.12	0.23	0.04	0.02	0.10	0.19	0.02	0.06
14	8.00	0.13	0.19	0.03	0.04	0.09	0.16	0.01	0.06
13	7.70	0.13	0.18	0.03	0.05	0.09	0.15	0.02	0.06
12	7.00	0.14	0.18	0.03	0.05	0.09	0.15	0.02	0.06
11	6.70	0.15	0.18	0.02	0.05	0.10	0.16	0.03	0.07
10	6.00	0.17	0.19	0.03	0.07	0.11	0.16	0.03	0.08
9	5.75	0.17	0.19	0.04	0.07	0.11	0.16	0.04	0.08
8	5.00	0.20	0.18	0.04	0.08	0.12	0.14	0.04	0.08
7	4.80	0.21	0.18	0.04	0.08	0.12	0.13	0.04	0.08
6	4.00	0.25	0.15	0.06	0.10	0.13	0.09	0.03	0.07
5	3.80	0.26	0.14	0.07	0.10	0.14	0.08	0.03	0.07
4	3.00	0.33	0.11	0.10	0.14	0.18	0.01	0.04	0.08
3	2.80	0.36	0.10	0.11	0.15	0.20	0.01	0.04	0.08
2	2.00	0.50	0.07	0.09	0.10	0.12	0.02	0.01	0.04
1	1.85	0.54	0.06	0.08	0.09	0.11	0.02	0.01	0.03

results of the experimental response between time period vs. acceleration, time period vs. velocity, time period vs. displacement, time period vs. drift ratio, and time period vs. shear force for all individual models were analysed. These results were presented in the form of graphs. After that, each of the four models was compared to the others in a single graph for each floor in order to obtain the acceleration spectra, velocity spectra, displacement spectra, drift ratio, and shear force distribution. This was done so that a comprehensive understanding of the behaviour of the models could be gained when they were subjected to harmonic excitation. In the third and final section, the findings of peak experimental and analytical response of the FF, BIF, IF, and BF were examined, and a percentage of variance was derived for the purpose of determining the quantitative dependability of the data. By the end of this chapter, we are able to comprehend that the HSR is able to conform to the purpose of the thesis. In the next chapter, we will draw a conclusion to all of the observations made in the preceding chapters.

III. CONCLUSION

A rather exhaustive experimental investigation is carried out with the purpose of determining which of four potential models is the most effective. Every model is constructed from three single-bay frames, and each of those frames has three levels. Out of all the frames, the one with the braced frame has the largest peak acceleration response, whereas the bare frame has the biggest peak displacement reaction. This is because the greater stiffness and higher excitation frequency of this frame. The peak displacement response is greatest for the frames that include infill walls. This is because the presence of an aperture in the wall causes the wall's overall stiffness to be reduced. The peak acceleration and peak displacement responses of the frame with the single brace are higher when compared to the frame with the base isolated frame. The damping impact of the base isolated frame is less when it is compared to the influence of another frame. When compared to the in-filled frame, the braced frame possesses more rigidity. As a direct consequence of this, the acceleration response of the brace system is noticeably superior than that of the in-filled system. On the other hand, when contrasted with a system that is braced, the peak displacement response is much lower. It's possible that this has something to do with the fact that in-filled frames lose more energy than braced ones do.

SUMMARY

The following are the findings that may be drawn from the limitations of the experiment:

With a fixed frame, we were able to decrease the maximum amount of the structure's movement by up to 93.1 percent. It was discovered that the displacements on the first and second stories are considerably below the isolator limit, and that only the third level has relative displacement. There was a 93.3 percent reduction in the amount of seismic force that was delivered to the structure (g). When compared to the tale drift in BIF, it is 1.7 percent; thus, when compared to NZS 1170.5, it is within the authorized final limit state (Uma, S. R. King A. B. 2012). When compared to a structure with a fixed frame, the maximum seismic story force distribution can be reduced by up to 93.1 percent, and the base shear can be reduced by up to 92.1 percent. The velocity is decreased from 351.06N to 24.5N, which is a reduction of

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93 percent compared to the stationary frame. Other discoveries that emerged as a consequence of this experiment include the fact that the frictional force that is created by the rubber is induced to the structure, which is what led to the relative displacement.

In conclusion, the purpose of the thesis is restated for the purpose of confirmation. For the purpose of creating earthquake-resistant base-isolated structures, a novel configuration of hybrid spherical rollers (HSR) has been developed. Four distinct kinds of reduced scale models were put through a linear harmonic shaking table test: a fixed frame, a base isolated frame, an in-filled frame, and a braced frame. With a fixed frame, we were able to decrease the maximum amount of the structure's movement by up to 93.1 percent. There was a 93.3 percent reduction in the amount of seismic force that was delivered to the structure (g). When compared to a structure with a fixed frame, the maximum seismic story force distribution can be reduced by up to 93.1 percent, and the base shear can be reduced by up to 92.1 percent. When compared to the stationary frame, the velocity is equivalent to 93 percent. Because of this, it has been shown that the HSR is capable of lowering its displacement, velocity, acceleration, and narrative shear by more than ninety percent. Both theoretically and empirically, the dynamic features and responsiveness of models are evaluated, and the results vary by up to 3 percent. As a consequence, the findings of this investigation may be trusted. The purpose of the thesis has been achieved by the investigation and analysis of the reduced scale base isolated HSR.

Even though the design base shear was only around 92% of what is needed by a prescriptive code, all of the performance goals chosen for immediate occupancy and life-safety were reached by the model during the linear harmonic testing. This was the case despite the fact that the design base shear. This test provided clear evidence that the hybrid base isolation technology is a most efficient earthquake resistant technique in critical earthquake zones, and based on the results, this new pattern of the Hybrid spherical rolling isolator was found to perform well to reduce the response of a structure in the one-dimensional linear harmonic shake table test. It is required that the HSR base isolation be supplied in the building's basement, which also has the capability of being used for parking vehicles. Because the seismic force is decreased by more than 90 percent, the structure needs less force to resist laterally, and as a result, the size and the materials that are necessary for the design are reduced as well.

FUTURE SCOPE

Further in future, it is recommended that the real scale model should be fabricated and tested in shake table. The three-dimensional test should be conducted with time history analysis to establish the exact performance during the earthquake.

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