HYBRID SPHERICAL ROLLERS UTILIZATION FOR EARTHQUAKE RESISTANT STRUCTURES CHARACTERISTICS

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***Abstract*: The efficacy of four distinct models is investigated in great detail in a very thorough experimental study, as follows: Each model consists of three individual bay frames each with three shops. The naked frame has the greatest reaction in all frames with a peak displacement, whereas the braced frame has the highest reaction. As the braced frame is more rigid and exposed to a higher frequency of excitation, it has the highest acceleration response. The frame with the isolated frame of the hybrid spherical roller base is the least expanded among frames with infill walls owing to the increased energy dissipation. However, owing to the increased rigidity and frequency of excitation, the peak acceleration response of this frame is the greatest among frames with infill wall; however, because to the dampening effect, it has a peak acceleration lower than naked frame. The frames with walls of infill show the highest movement response since the existence of an aperture in the wall lowers its stiffness. In comparison to the frame with the base isolated frame, the peak acceleration and peak displacement responses of the single braced frame are greater. Compared to another frame, the dampening effect of the base isolated frame decreases. Braced frames are more rigid than filled frames. As a result, the brace system's acceleration response is considerably greater than that of the filled systems. However, the peak displacement response is lower compared to a braced system in this study. This may be because filled frames lose more energy than fastened frames.**

***Keywords*: Earthquake Resistant, Rollers Utilization, Hybrid Spherical Rollers, Damping Impact**

I. INTRODUCTION

Seismic isolation devices in buildings may be installed such that the structure's base is isolated from its superstructure or particular elements of the structure, such as separating the main building from its roof, as in the building itself. Energy dissipation mechanisms are the most common kind of seismic isolation measures used in buildings. The devices may be classified in two ways: according to their position in the building and according to their working principles. Isolators may be classified into two sorts based on their position in the building. External and internal isolators are the two sorts of isolators. External devices are normally put in the foundations and are placed outside the structure. Energy dissipation mechanisms are devices of the internal kind. According to Torunbalci, all reaction control systems are characterized as active, passive, or hybrid based on their functioning principles.

Passive Control Systems: Passive control systems do not need any external energy to function. As a result, compared to active systems, the cost of setting up these systems is lower. Up to a certain point, these systems can regulate the displacement. The protection mechanisms in passive control systems are intended to meet the protection level necessary for earthquakes of a certain magnitude. Dampers, isolators, and other devices that are readily obtained and applied make up these systems. There are numerous forms of passive control systems, which are more successful in practice. All of these systems rely on materials that absorb energy at a certain level, either individually or collectively, according to Torunbalci. Balls or rollers are used in irreversible displacement systems (Fig.1.1).

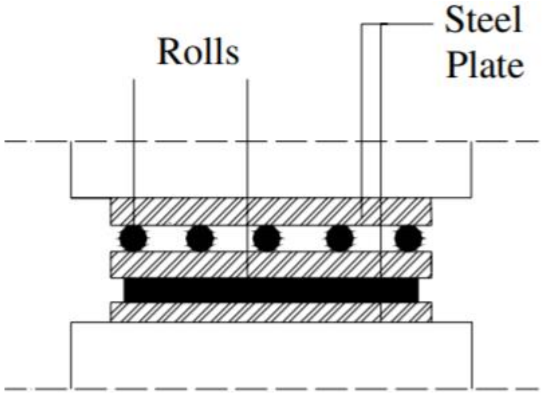

Fig.: Irreversible displacement system

During an earthquake, the building might shift horizontally because to these rolls. The quantity of wasted energy in these systems is calculated by multiplying the friction force and displacement. Because of their simplicity of installation and low cost, sliding systems are commonly employed in applications. When such systems are utilized in constructions, however, there is a chance that the building would drift away from its original site after the earthquake owing to excessive drifting. As a result, additional components like stoppers may be necessary. They are made up of a sufficient number of perpendicularly positioned rolls or spherical steel balls between the steel plates. Because of the flexibility of lead, plastic systems have been created that offer optimal energy absorption for seismic isolation and other vibrations (Fig. 2).

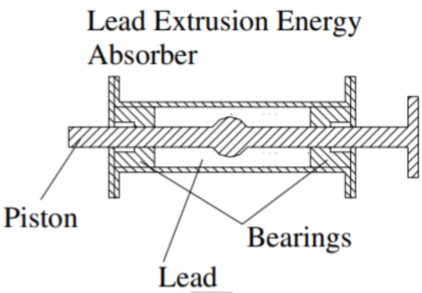

Fig. 2: Plastic system

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.

Active Control Systems: The functioning of active control systems is reliant on a continual supply of energy from the outside. As a result, the cost of putting these systems together is rather significant. The structure's acceleration, displacement, and velocity may all be controlled by the system. Electronic components such as computers, actuators, and starters make up active control systems. In the following method, the design of active control systems is independent of the intensity of the ground motion. According to the strength of the ground motion, the system's stiffness or amount of motion fluctuates. As a result, in designs that employ active control systems, considerations like the uncertainty or unpredictability of future ground movements are irrelevant. Active control systems may be used in three different ways: Computer systems govern the acceleration, displacement, and velocity of the structure impacted by lateral forces in this system by producing an actuator control force. Active Variable Stiffness: In this system, the actuator control force does not need to be formed. However, eliminating the resonance caused by the fundamental period of the system and the ground motion period requires selecting the suitable stiffness for the system and designing it accordingly. They're designed to be used when there's a lot of ground movement. Active Passive Composite Tuned Mass Dumper: In recent years, hybrid structural control systems have been created that combine the use of active and passive systems.

Earthquakes

Any abrupt shaking of the ground produced by seismic waves passing through the Earth's rocks is referred to as an earthquake. Seismic waves are created when energy held in the Earth's crust is released unexpectedly, generally when masses of rock straining against one another fracture and slide. When two slabs of the ground abruptly move past one another, an earthquake occurs. The fault or fault plane is the surface where they slide. The hypocenter is the point underneath the earth's surface where the earthquake begins, while the epicenter is the position immediately above it on the earth's surface. Foreshocks may occur during an earthquake. These are lesser earthquakes that occur in the same location as the following big earthquake. Scientists can't identify whether an earthquake is a foreshock until the main event occurs. The mainshock is the greatest and most powerful earthquake. Mainshocks are always followed by aftershocks. These are lesser earthquakes that strike around the epicenter of the mainshock. Aftershocks may last for weeks, months, or even years after the mainshock, depending on the magnitude of the mainshock!

Each year, more than 200,000 earthquakes are registered throughout the world. Seismic monitoring at the global, regional, and local levels gives data that may be used to better understand earthquake occurrence and, as a result, map areas of high and low seismic danger. Dense seismic monitoring and modern seismic analysis tools have aided in the finding of previously undiscovered seismic phenomena (slow-slip occurrences, multiple re-rupturing of faults, super-sonic rupture speed), all of which have shed light on earthquake physics. As a result, continuous seismic monitoring offers critical information for earthquake hazard assessment and engineering.

Earthquakes have been the biggest cause of mortality from natural catastrophes over the previous half-century, wreaking havoc on society's cultural, economic, and political fabric. The fact that earthquakes strike without notice and have a fatal fascination for people adds to their inherent physical danger. Most of the world's greatest cities are located in seismically active zones. Earthquake generation is a complicated process that occurs deep inside the Earth's crust. The size of a fault segment and the amount of stress collected there determine the magnitude and timing of a big earthquake. Measuring the tension is an engineering accomplishment in and of itself, since it requires drilling several kilometers into the earth. Furthermore, experts are unsure of the exact amount of stress required to rupture a defect. A low-magnitude earthquake, on the other hand, may cascade into or cause a big tremor if enough tension has built.

Finding a diagnostic precursor might be one technique for predicting earthquakes. This precursor should be an observable signal noticed before any tremors, such as ground deformation, aberrant radon gas emission from the Earth's core, or odd animal behavior. This diagnostic signal then predicts where, when, and with what magnitude an earthquake will occur with high probability and statistical significance. This silver bullet approach to earthquake prediction, on the other hand, has yet to provide a viable and statistically reliable forecast technique. In 2011, the International Commission on Earthquake Forecasting for Civil Protection examined a number of potential earthquake precursors and determined that none of them can reliably predict an upcoming earthquake.

Impact of earthquakes on Buildings

When a significant earthquake strikes, the greatest issues generally arise after the shaking ceases. Earthquakes are a form of natural catastrophe that may result in cascade catastrophes. Broken gas lines causing fires, loss of power, blocked transit routes, landslides, dam ruptures, or any other subsequent calamity induced by the earthquake are examples of cascading disasters. Soft sediments do the most damage to structures, and multi-story structures are more severely affected than smaller ones. Buildings can be engineered to survive most earthquakes, and earthquake-prone areas are increasingly using this method. Turkey is one of these regions, and although having a reasonably rigorous construction code in the 1990s, adherence to the code was poor, as builders cut corners wherever they could, including utilizing incorrect concrete materials and lowering the quantity of steel reinforcement. As a consequence of the 1999 M7.6 Izmit earthquake, nearly 17,000 people died (Figure 11.18). Following two devastating earthquakes in that year, Turkish authorities strengthened the building code even more. However, the new code has only been implemented in a few regions, and enforcement of the code remains weak, as evidenced by the amount of damage caused by an M7.1 earthquake in eastern Turkey in 2011.

Earthquake is the most destructive natural occurrence that causes significant structural damage. Ignoring how an earthquake impacts buildings and faulty construction procedures are two causes of blunders that might jeopardize structures, according to reports. As a result, a thorough knowledge of the seismic impacts on a structure is critical, and designers and contractors should take into account the impact of seismic pressures on structures in order to avoid failures and collapses.

Ground shaking during an earthquake may be enough to weaken rock and unconsolidated materials to the point of breakdown, but it may also contribute to liquefaction, which is the transformation of a solid body of sediment into a liquid mass that may flow. When water-saturated sediments are agitated, the grains reorganize themselves to the point where they no longer support one another. Instead, the water between the grains keeps the grains apart, allowing the substance to flow freely. Liquefaction may cause buildings and other structures to collapse, even if they are otherwise unharmed. The collapse of apartment complexes following the 1964 Niigata earthquake (M7.6) in Japan is an excellent example. In regions where there is loose wet sand behind a layer of more cohesive clay, liquefaction may lead to slope collapses and sandy mud fountains (sand volcanoes).

When a building undergoes an earthquake and the ground shakes, the structure's foundation moves with it. The roof, on the other hand, would move differently than the structure's foundation. Internal forces in columns are created by this difference in movement, which tend to restore the column to its initial location.

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.,

- 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 (Moti Perets 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 and 4. 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.

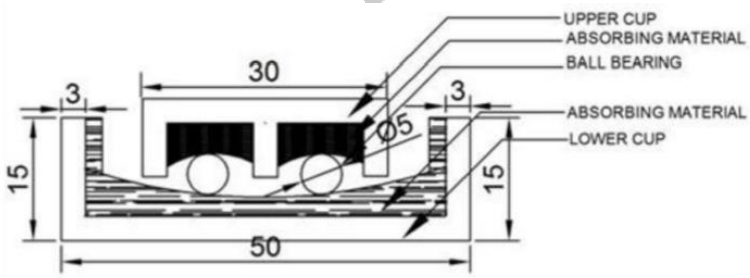

Fig. 3: Analytical model of Base Isolator (Bottom and Top Cup)

Fig. 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 (Malu Girish 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.

III. ANALYSIS AND INTERPRETATIONS

Base Isolated Floor (BIF Result Analysis

A harmonic base motion at frequency 1Hz to 10Hz is applied and frequency response graph is obtained for various frames using Kampana software. The frequency at which peak response occurs is the fundamental natural frequency of the frames. A typical frequency response graph for base isolated frame as recorded is shown in Figure 4.1. Similar graphs are obtained for other types of frames also. 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.

Shear Force Distribution of Models

The shear force is an important parameter in analyzing the lateral loads on the structure. Here, the BIF performs excellently to reduce the seismic force. the BIF carries 9N while comparing the FF 8406N which is 99% of the reduction in shear force on I floor. The other floor distributes 18959N & 4672N for BF & IF. This large reduction in force is due to the reduction of stiffness in BIF. This frame carries only frictional force and it allows the structure to displace with the limit by the HSR isolator. If the displacement is resisted by the structure, then the shear force is proportionally increased. In this pattern of isolation, the stiffness is almost completely eliminated and hence the reduction of shear force arrives. In the second floor the maximum shear force is created by BF (16975N) followed by FF (10378N) & IF (5196N) while comparing to BIF the shear force is 1589N which is 91% of reduction when compared to the braced frame. Whereas on the third -floor the maximum shear force is created by BF (14737N) followed by FF (10935N) & IF (5267N) while comparing to BIF the shear force is 2387N which is 84% less than the peak displacement of other models. The infill frame performs well in second place because of the increased damping ratio by the infill wall and less stiffness when compared to BF. The third is the FF due to lack of damping and less elastic strain energy to absorb the seismic force.

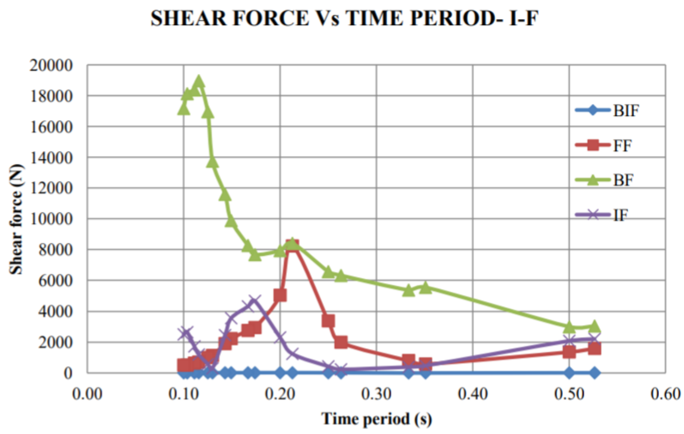

Fig. 5: Comparative shear force distribution for I floor

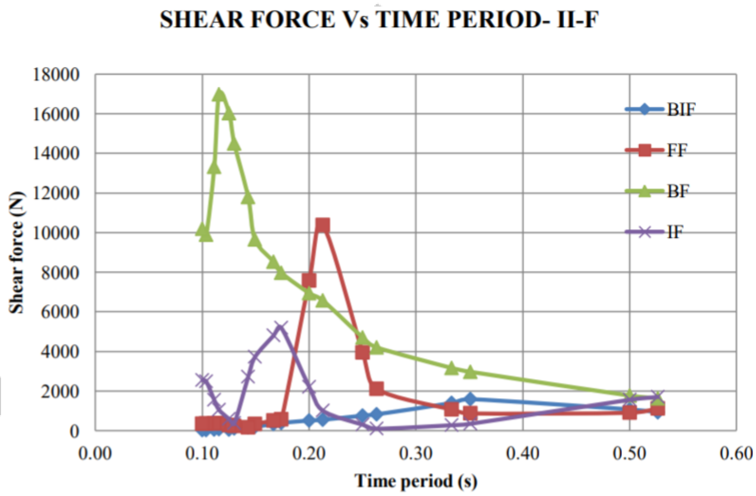

Fig. 6: Comparative shear force distribution for II floor

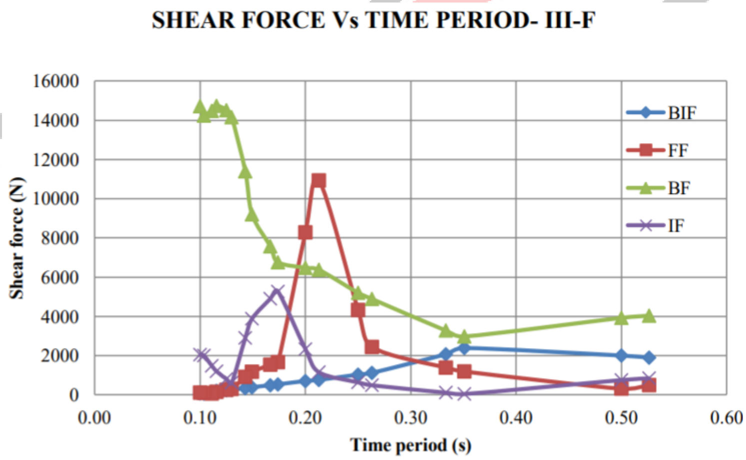

Fig. 7: Comparative shear force distribution for III floor

Velocity Spectra of Models

The ground floor velocity of four models is evenly distributed as shown in Figure below. This graph shows all the models were almost displaced equally at a period of time in the ground floor. If the velocity of the model is less and distributed evenly then that structure will perform well during the seismic excitation. In the first floor note that the BIF velocity is distributed evenly and it extends the natural time period which is the essential parameter of an earthquake resistant structure. In the Figure below the fixed frame transfers most of the velocity to the structure. The third floor of the fixed frame has the peak velocity of 351.06 mm/s whereas in BIF for the same frequency of 4.7Hz it is 24.5 mm/s which is 93% reduction. In the II floor, similar percentage of reduction is 94.6% is achieved. The IF and BF reduce the velocity due to its damping property. And finally, the BIF model is the least velocity transferring model than the others this is due to increased damping at the HSR which is located near the first floor. The elastomeric rubbers and sheets absorb some energy to restrict velocity.

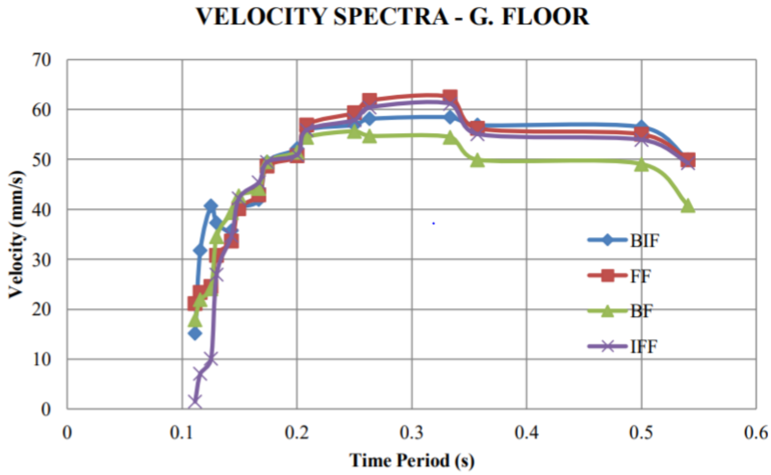

Fig. 8: Comparative velocity spectra for Ground floor

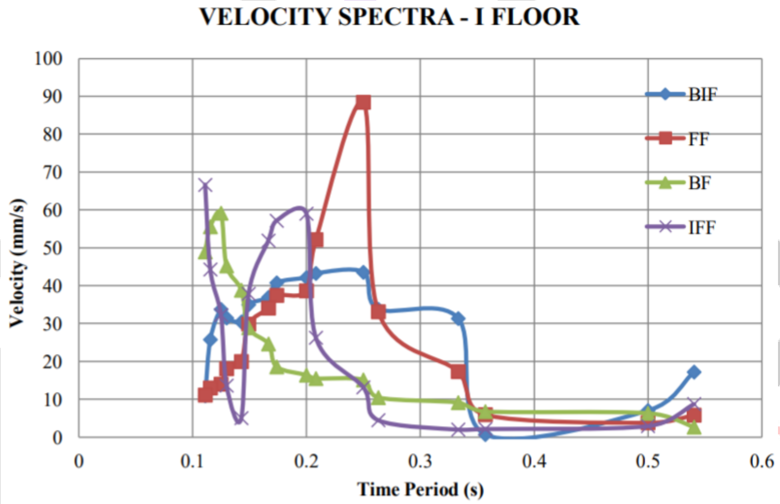

Fig. 9: Comparative velocity spectra for I floor

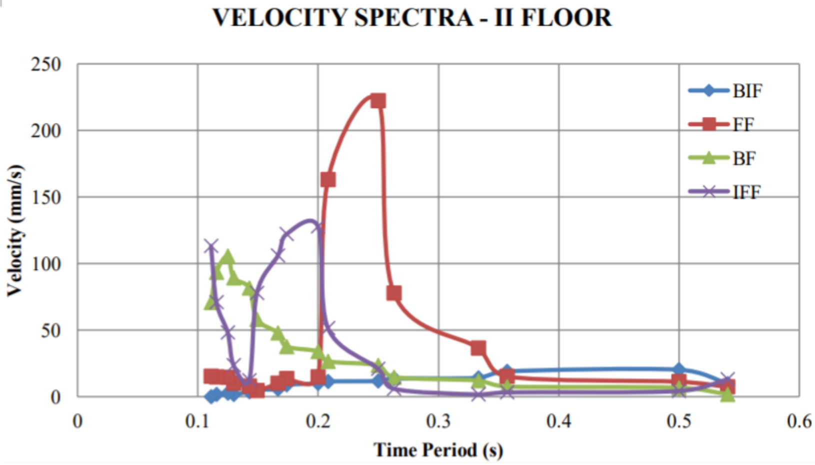

Fig. 10: Comparative velocity spectra for II floor

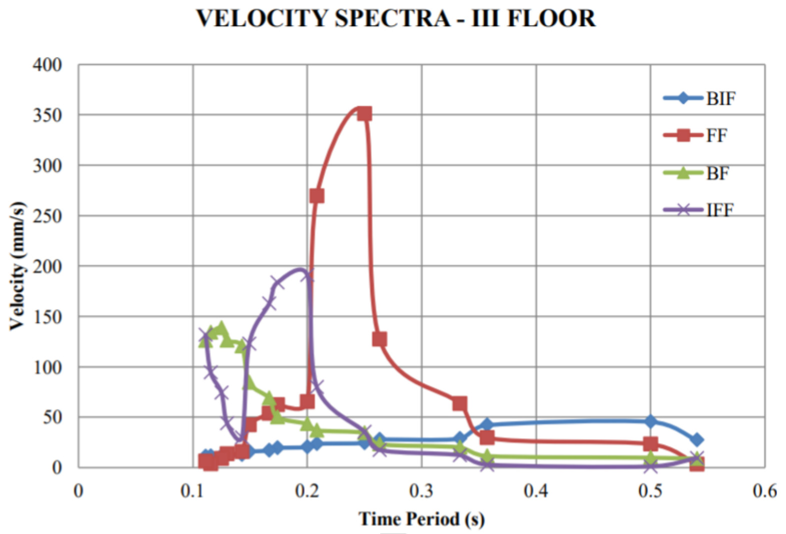

Fig. 11: Comparative velocity spectra for III floor

IV. CONCLUSION

The efficiency of four alternative models is investigated in a reasonably extensive experimental study. Each model is made up of three single bay frames, each with three stories. The naked frame has the greatest peak displacement reaction of all the frames, whereas the frame with the braced frame has the greatest peak acceleration response. The fact that the braced frame has a greater stiffness and is exposed to a higher excitation frequency results in the highest acceleration response. Due to higher energy dissipation, the frame with designed hybrid spherical roller base isolated frame has the lowest peak displacement response among the frames with infill walls. Because the existence of an aperture in the wall diminishes its stiffness, the frames with infill walls have the largest peak displacement response. When compared to the frame with the base isolated frame, the peak acceleration and peak displacement responses of the single braced frame are greater. When compared to another frame, the dampening effect of the base isolated frame is reduced. The braced frame is more rigid than the in-filled frame. As a result, the brace system's acceleration response is substantially greater than the in-filled systems. However, as compared to a braced system, the peak displacement reaction is less. This might be related to the fact that in-filled frames dissipate more energy than braced frames.

The maximum displacement of the structure was reduced up to 93.1% with a fixed frame. The first and second story displacements were found to be well below the isolator limit and only the top floor has relative displacement. The seismic force transferred to the structure (g) was reduced by 93.3%. When comparing the story drift in BIF it is 1.7%, hence, it is within the prescribed ultimate limit state when comparing with NZS 1170.5 (Uma, S. R. King A. B. 2012). The maximum seismic story force distribution is reduced up to 93.1% than the fixed frame structure and the base shear is reduced up to 92.1%. The velocity is reduced from 351.06N to 24.5N which is 93% reduction from fixed frame. Other observations that were resulting from this experiment are, the frictional force due to the rubber is induced to the structure which caused the relative displacement. This paper is finally recalled for confirmation, A new pattern of Hybrid Spherical Rollers (HSR) is introduced for constructing earthquake resistant base-isolated structure. A linear harmonic shake table test for four types of reduced scale models (fixed frame, base isolated frame, In-filled frame, and braced frame) was tested. The maximum displacement of the structure was reduced up to 93.1% with a fixed frame. The seismic force transferred to the structure (g) was reduced by 93.3%. The maximum seismic story force distribution is reduced up to 93.1% than the fixed frame structure and the base shear is reduced up to 92.1%. The velocity is to 93% when comparing fixed frame. Hence, it is proven that the HSR is capable of reducing more than 90% of its displacement, velocity, acceleration and story shear. The dynamic characteristics and response of models are compared both analytically and experimentally and the result differs up to 3%. Hence, this research provides a reliable result. The research analysis of reduced scale base isolated HSR satisfies the objective of the thesis. In the linear harmonic tests of the model, all the performance objectives selected for immediate occupancy and life-safety were met despite the design base shear was about 92% of that required by a prescriptive code. This test provided clear evidence that the hybrid base isolation technology is a most efficient earthquake resistant technique in critical earthquake zones and from 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. The base isolation of HSR shall be provided at the basement of the building, which can be utilized for car parking. The seismic force is reduced more to 90 % hence the structure requires less force to resist laterally and the less size and materials required for the design.

FUTURE SCOPE

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

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