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Improvement of Structures with Progressive Damage Using Seismic Isolation System

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Abstract

There is always a need to improve the structures for many reasons, including changing the use, changing the design regulations, increasing the life of the structure, and improper implementation of the structures. One of the most influential parameters in the selection of the improvement method is the lateral stiffness of the target structure, which is determined according to the lateral bearing system of the structure. There are many methods for improving structures, including the use of steel jackets to increase the load capacity of columns and the use of FRP fibers, etc. The transfer of ground movement to the structure can be controlled with the help of the base seismic isolator system at the base of the structure; the base seismic isolator isolates the upper structure from the ground shaking movements so that the destructive forces of the earthquake do not enter the building or to a significant extent be reduced. The Malaysian Rubber Materials Research Company in England has produced a type of elastomer with high damping. Using this elastomer, a rubber seismic isolator system with high damping has been used for the seismic isolator of buildings. In some systems, the Teflon layer is used to cause slippage between steel sheets. A central lead core is provided to control lateral displacement and return the system to its original state. Progressive failure is the failure of the entire structure, or a relatively large part of it, caused by events that damage a part of the structure and the inability of adjacent members to redistribute the overload through a path that can maintain the stability and continuity of the entire structure. Progressive failure may occur as a result of abnormal loading such as explosion, severe fire, vehicles hitting a part of the structure, etc. The lateral bearing system is part of a structure that is responsible for resisting lateral loads and directing them from a safe path to the foundation (lateral forces can include wind, earthquake, or other forces). Earthquake-resistant elements should be considered in such a way that the torsion caused by these effective and resistant forces in the floors is minimized. For this purpose, it is suitable for the distance between the center of mass and the center of stiffness in each floor and extension to be less than 5% of the dimension of the building in that extension.

Keywords: Improvement of structures, Rubber base separator, Progressive failure, Lateral bearing system.

1 | Introduction

The base separator is one of the most important seismic protection systems in the world, and it should be taken seriously as a separator system in special structures by separating its superstructure from its direct connection with the earthquake.

As a result, this system keeps the overall structure of the structure as well as the integrity of the non-structural members well stable against earthquake forces. Base isolators can perform well as resistant and efficient

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systems against Near-Field (NF) earthquakes that have high-velocity pulses and permanent displacements. In 2019, Jang Hu investigated this issue by presenting research entitled Steel frame buildings isolated with stable lead core rubber base (LRB) isolators exposed to NF earthquakes [1].

In this research, the comparative advantages of rubber base isolator with lead core LRB are investigated using nonlinear time history dynamic analysis with near field earthquakes. Seismic responses by considering base cuts and drift of floors are also presented according to the placement of LRB separators in building frames. The main function of LRB separators is to extend the seismic period of the structure by increasing the lateral flexibility in the structural frames, which significantly reduces the accelerations of the earthquake on the superstructure.

Therefore, this base separator system is able to reduce the base cut significantly. And it is able to distribute the drift significantly within the floors. Finally, the fact that seismic performance can be achieved by installing seismic isolators in building frames is emphasized by the results of nonlinear dynamic analysis [2]. Also, in this research, dynamic analysis of nonlinear time history for two-dimensional frames with data related to 20 NF earthquakes for structures with an LRB base separator system has been performed. The seismic response of frames isolated by the LRB system is compared with frames without isolators.

In these comparisons, things like roof displacement, base shear force, and floor drift have been investigated and compared [3]. Twenty earthquakes in the nearby area were used to investigate the behavior of these structures. According to the results obtained from the behavior curves in these structures, it can be seen that the building without a separator had a lower period and, as a result, more response to the spectrum acceleration. It can be seen that the LRB separator can increase the period of the structure and, as a result, effectively reduce the seismic foundation shear forces caused by the acceleration of the earthquake.

Due to the fact that the maximum displacement of the roof in structures with separators is well distributed in the frames by LRB separators, more flexible conditions are provided for the behavior of the structure due to the presence of LRB separators, the frames experienced less intra-floor drift than the structure without separators. The seismic base separator is one of the common measures and seismic protection systems. The rubber base isolator is a technique that greatly reduces the impact of earthquakes on structures caused by strong earthquakes, especially in close frequency ranges. The design of the seismic isolator system in this research was completed by adding fibers, which led to the design of the fiber rubber seismic isolator with a lead core (LLRB).

This isolator design technique is economical and suitable for areas with high seismicity. Because the isolators are exposed to severe deformations and loadings during strong earthquakes according to most of the approved and tested seismic design regulations, in some cases, over time, the separators may need to be repaired or even replaced. Testing can determine the correctness of the design details of this type of separator over time. Regardless of these reasons, there should be access to the separators and also the ability to replace them. Referring to this point of view, in 2016, Powell investigated the effect of rubber in the isolator for structures exposed to seismic areas [1]. In this research, a local effort has been made for the development of separators and their testing of rubber base separators with lead core (LRB) and without lead core [1].

The design in this research is based on various regulations such as FEMA 451, ASCE 41, and AASHTO, and the design program is completed using Visual Basic software. The results of this research can be summarized as follows according to the LRB test, the effective hardness obtained is very small or negligible during three different cycles, and in the case of LLRB, it can be seen that a slight change in the effective hardness has taken place in many cycles. Also, energy absorption by LLRB separators is very high compared to LRB separators, and this value is obtained by calculating the area under the diagram. The difference in energy absorption of this type of separator is about 80 to 85% higher. It should be noted that the use of LLRB isolators is increasing worldwide for seismic protection of structures located in seismic areas. In 2007, Jangid worked on the optimization of lead rubber isolators for NF earthquakes [4].

In this research, the seismic response of the analysis of multi-story structures separated by lead rubber spacers LRB has been investigated under earthquakes in the near area. The facade is considered a flexible building with an idealized linear section. The force deformation behavior of the LRB separator is simulated bilinearly with viscous separators. The equations governing the motion of the isolated structural system have been obtained, and the system's response to the normal components of 6 NF earthquake records has been investigated using a numerical step-by-step method. The changes in the upper floor, especially the acceleration and displacement of the isolated structure, were investigated under various system parameters, such as the flexibility of the superstructure, the period of the isolator, and the yield strength of the isolator.

The comparison of the results shows that for the lower yield strength of the separator, a large shift in the resistance is observed under NF earthquakes. In addition, the existence of specific values of the yield strength of LRB occurs in the case where the absolute acceleration of the upper floor of the building reaches its lowest value. Also, the optimal yield strength has been obtained for different parameters of the system under earthquakes near the fault area. The parameter selection index depends on the minimization of the acceleration of the upper floor and the displacement capacity. The optimal yield strength of LRB was obtained in the range of 10-15% of the total weight of the building under NF earthquakes [5].

2 | Progressive Failure

Progressive failure is the failure of the entire structure, or a relatively large part of it, caused by events that damage a part of the structure and the inability of adjacent members to redistribute the overload through a path that can maintain the overall stability and continuity of the structure. Progressive failure may occur as a result of abnormal loading such as explosion, severe fire, vehicles hitting a part of the structure, etc. Progressive failure is the spread of primary local failure from one member to another, which ultimately leads to the failure of the whole or a large part of the structure disproportionately. Although the removal of any of the columns of the bending frame can lead to progressive failure, the failure of the external columns on the first floor increases the probability of its occurrence due to fewer lateral constraints and easy access. Progressive failure is a type of failure that has attracted the attention of the civil engineering community in recent years and is widespread. This type of failure is important from the point of view that the initiating factor causes damage in a small part of the structure. Still, ultimately, the uncontrolled expansion of the failure causes catastrophic damage to a significant part of the structure.

3 | Seismic Isolation

A large population of the world lives in earthquake-prone areas, where there is a risk of earthquakes of different intensity and frequency. Every year, earthquakes cause many casualties and financial losses. Over the years, the technology of construction and design of earthquake-resistant structures has made great progress in order to reduce the effect of earthquakes on buildings, bridges, and their vulnerable accessories. Vibration isolation is a relatively new method in this field. Vibration isolation is actually the installation of a system that isolates the structure or its accessories from the destructive seismic movements of the ground or support. This separation is achieved by increasing the flexibility of the system and also by providing proper damping. In most cases, vibration isolators are installed in the lower part of the structure, which is why they are called foundation isolators.

Regarding choosing or not choosing a vibration isolation system for a structure, the engineer must consider various factors. The first issue that should be considered is the risk of an earthquake, which depends on the local geological characteristics (proximity to the fault, local soil), the history of earthquakes recorded in the area, and any other known factor in the possible characteristics of the earthquake (intensity, periodicity, etc.). According to the shape and system of the structure as well as the materials used, vibration separators can be used and not used in some others. Then, the probability of damage caused by an earthquake can be specified for each design. Damage caused by an earthquake can be classified as follows:

I. Minor damage

II. Repairable damage

III. Irreparable damage, as a result of which the structure must be destroyed

The main emphasis in vibration isolation systems is to change the level of failure from 1, 2, and 3 rows, which reduces financial losses and possibly reduces insurance costs.

3.1 | The benefits of Using Seismic Isolators

I. Removal or reduction of structural and non-structural injuries.

II. Increasing the safety of building contents and architectural facades and reducing earthquake force

III. Economic justification in case of mass production of the building using this method.

3.2 | Advantages and Disadvantages of Seismic Isolators

The main advantage of the seismic isolator system is that it increases the main periodicity of the structure in order to transfer it from the periodicity of the structure with the retaining base and the dominant periodicity to the time of higher periodicities. Another advantage of seismic isolators is the consumption of energy input to the structure, which leads to the reduction of the acceleration transferred to the upper structure in an earthquake. Among the main disadvantages of these systems, we can point out the high cost of their implementation and their limitation to short-story and medium-story structures (it is not recommended to implement them in high-rise structures).

4 | Basic Seismic Isolation System

The transmission of ground motion to the structure can be controlled with the help of the base seismic isolation system at the base of the structure. Therefore, the basic seismic isolator isolates the upper structure from the seismic movements of the ground so that the destructive forces of the earthquake do not enter the building or are significantly reduced. In practice, due to the fact that the vertical seismic movements of the earth are not considered an important risk for the building, it is generally considered to separate the building from the horizontal seismic movements of the earth. Of course, in cases where the goal is to reduce the vibration of the structure against traffic loads, then the base seismic isolator is used to prevent vertical vibrations from being transmitted to the structure.

In general, the basic seismic isolation systems used in the world consist of the following three main elements.

I. Soft support to increase the vibration period of the whole assembly and reduce the force response.

II. Damping or absorbing energy to control the change of relative location between the building and the ground within the limits of practical design.

III. A device to provide rigidity against small lateral forces such as wind or mild earthquakes.

5 | Types of Basic Seismic Isolation Systems

In a general classification, the basic seismic isolation systems can be divided into two groups: rubber system with lead core LRB and Friction Pendulum System (FPS).

5.1 | Rubber System with Lead Core

Fig. 1 shows a picture of this type of seismic isolation system. So far, this type of system has been used in the construction of a number of bridges and important buildings, as well as in the seismic strengthening and improvement of some historical buildings.

Fig. 1. Rubber seismic isolator system with lead core.

Malaysian rubber materials research company has produced a type of elastomer with high damping in England. Using this elastomer, a rubber seismic isolator system with high damping has been used in America for seismic isolation of buildings. Teflon is a material of interest to the designers of seismic isolation systems. In some systems, Teflon layers are used to create sliding between steel sheets. A central lead core is intended to control lateral displacement and return the system to its original state.

5.2 | Sliding Isolation Pendulum Bearings (SIP)

Frictional pendulum isolators are a type of sliding isolation system that provides a restoring force to restore the structure to its original state after vibration by means of its special geometry. In other words, the pendulous frictional seismic isolator, with the help of its special geometry, combines the sliding between the surfaces and the restoring force. The FPS consists of an articulated slider that moves on a concave stainless steel surface. A composite material with low friction covers this contact surface.

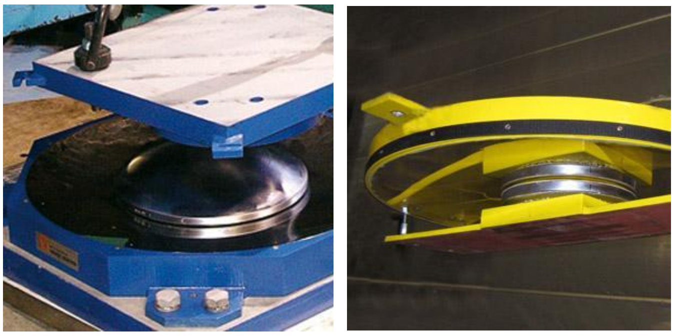

Fig. 2. Frictional pendulum separators.

The inner part of this separator consists of a concave surface on which a convex piece with the same radius of curvature moves. The performance of these SIP isolators is caused by the relative displacement of the potential force in the main structure, which causes the structure to return to its original state. In mild earthquakes, where the base shear force is smaller than the friction force, the structure with the friction pendulum isolator vibrates like a normal structure, while the non-isolated structure vibrates periodically. When this force exceeds the amount of friction force, the response of the isolated periodic resistance structure will be determined, and the characteristics of the isolators control the dynamic response and damping.

These separators can meet different user needs, such as buildings, bridges, and industrial equipment. The biggest advantage of the Maurer friction pendular seismic isolator system is the automatic adjustment of the lateral stiffness of the structure by vertical loads because the lateral stiffness is directly proportional to the amount of vertical load and inversely proportional to the radius of curvature. In these separators, the transfer of load is safe and guaranteed, and twisting of the structure is prevented. High service life, the ability to change symmetrical locations with respect to the center of the separator during an earthquake, and sufficient resistance and hardness against service side loads (wind and braking force...) are other characteristics of friction pendulum separators.

Pendulum friction separators, in combination with sliding materials with high durability and high load capacity, have smaller dimensions than other separators. Pendulum Friction Isolators (SIP) are an advanced and improved type of spherical bearings with a friction pendulum.

A view of this type of system can be seen in *Fig. 3*. The working basis of this system is similar to that of the swinging pendulum, with the difference being that the friction of the contact surfaces in this system causes energy absorption.

Fig. 3. Friction pendulum seismic isolator system (FPS).

Fig. 4. Installation of pendulum separators.

Friction between surfaces causes energy consumption, and also the transmission force is limited to the structure under an earthquake. The restoring force is also provided due to the concavity of the sliding surface. In the pendular friction separator, the concavity radius is a fundamental parameter, so the hardness of the separator and the periodicity of the separated surface completely depend on this parameter. Friction-Pendulum System (FPS) The friction system combines the behavior of friction and restoration due to its geometry. As seen in *Fig. 2* and *Fig. 3*, the system FPS has a sliding joint that moves on a spherical surface made of stainless steel. One side of the sliding joint that is in contact with the spherical surface is covered by composite materials with low damping. The other face is a spherical sliding member. Like the previous face, it is covered by composite materials with low damping and placed inside a spherical concave surface with a steel cover. The effective stiffness of the insulator and the period of the isolated structure is determined by the radius of curvature of the concave surface.

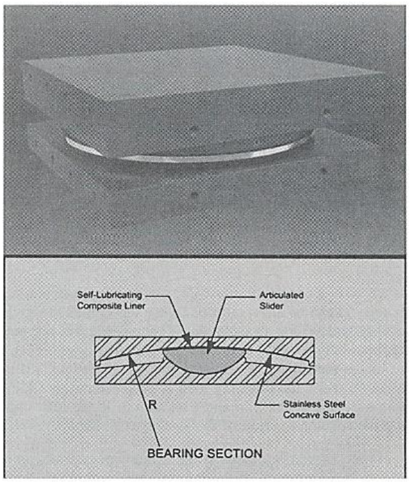

Fig. 5. Schematic of FPS.

6 | Conclusion

This section summarizes the key findings obtained from the experimental investigation on fiber-reinforced concrete incorporating rice husk ash. The main conclusions derived from the analysis of mechanical performance parameters under different fiber types and configurations are presented as follows.

Authors' Contributions

The author was responsible for all stages of the research and manuscript preparation and approved the final version.

Data Availability

All data are included in the text.

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Conflict of Interest

There are no competing interests to declare.

Consent for Publication

The author confirms consent for the publication of this work

Ethics Approval and Consent to Participate

This article does not contain any studies with human participants performed by the author.

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