Muthanna Journal of Engineering and Technology, Vol. (12), Issue (2), Year (2024)

Muthanna Journal of Engineering and Technology

Website: https://muthjet.mu.edu.iq/

Submitted 20 July 2024, Accepted 27 September 2024, Published online 18 October 2024

Isolation and damping of footing subjected to seismic loads: a review

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DOI:10.52113/3/eng/mjet/2024-12-02/73-79

Abstract

Seismic isolation achieves its purpose by making the structure functionally independent from the ground through seismic isolators, which are devices that mitigate the horizontal earthquake motion that can be transmitted to a building. The adoption of seismic isolation is not only limited to new structures but also included in many existing structures— major earthquakes demonstrated the effectiveness of these systems, so such is adopted. Most past research on seismic isolation techniques have been confined to regional studies; this paper proposes a historical review on evolution of isolations methods chronologically. Classification of seismic isolation techniques is done based on their mechanism with brief descriptions of their advantages and disadvantages and any recent innovations or alternative methods widely used under this category noted at the end of each classification provided within the study. Earthquakes are considered one of the most dangerous natural conditions, so they claim thousands of lives and property annually to reduce these damages to the facility, several studies and research have been conducted on the possibility of reducing the effects of seismic waves either by absorbing that energy or dissipating it using different techniques to isolate the foundations or to isolate the entire building, but the problem of these techniques needs a special work environment with a high material cost. The research aims to study the different methods of seismic isolation or damping for the design of foundations separately or multi-storey buildings as a whole with retarded waves according to the nature and strength of the seismic intensity as well as the materials available in the country and to find the best way to reduce the vibrations resulting from seismic movement.

Keywords: *Seismic isolation, Seismic load, Damping, Isolation for footing, Earthquakes.*

1. Introduction

Earthquakes are a natural phenomenon that occurs in the Earth's interior as a result of the movement of rock plates, see Figure.1. This movement causes concussive vibrations on the Earth's surface. Earthquake forces cause internal rocks to break and cracks to form in the ground [1]. Earthquakes on buildings can be catastrophic, destroying buildings and disrupting transportation networks. To reduce the impact of earthquakes, buildings are designed with seismic structural materials that help absorb seismic energy and reduce damage [2]. Seismic dampers: Seismic dampers are damping systems used in buildings to resist earthquake loads. Dampers are placed in high-rise buildings to control seismic damage. These dampers absorb seismic energy and reduce vibrations and deflections in buildings. There are different types of dampers, such as viscous damper, frictional damper, tuned mass damper, etc. In the end, seismic insulation is considered one of the important and effective ways to qualify buildings to resist earthquakes and strengthen them. The type of seismic damper varies according to its specifications and where it is installed in the structure. The use of dampers helps reduce the intensity of earthquakes and disperse their energy to keep buildings intact and safe [3]. However, when an earthquake has struck, a failure in bearing capacity and/or large deformations can occur during or after the earthquake due to low shear strength and high soil compressibility, and soil liquefaction occurs when saturated soil behaves like a liquid (earthquake liquefaction) [4]. The research aims to study the different methods of seismic isolation or damping for the design of foundations separately or multi-storey buildings as a whole with retarded waves according to the nature and strength of the seismic intensity as well as the materials available in the country and to find the best way to reduce the vibrations resulting from seismic movement.

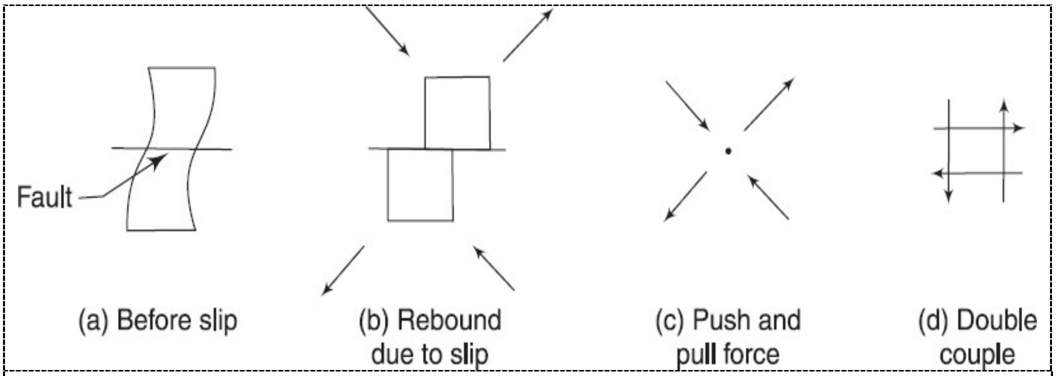

Fig. 1: The earthquake Mechanism along fault sides [1].

2. Seismic load

The use of seismic loading is one of the basic concepts in earthquake engineering because it involves using the motion generated by an earthquake to improve a structure [5]. It takes place either at the contact surfaces of a structure with the ground [6] or another structure [7] or due to gravitational waves from a tsunami. Seismic loading mainly depends on two criteria:

- The expected seismic risk is based on parameters at the location, such as:
  - Magnitude
  - Epicentre distance
  - Site condition
- Other structural properties like mass and stiffness.
- The specifications of the geotechnical parameter areas; the parameters of the object; and the details of any gravity waves that can be expected from a tsunami, if it were to occur.

A study was conducted to investigate the effect of the properties of isolators on the seismic behaviour of a five-story shear-type building. It was found that lead rubber supports and sliding systems are effective isolators and that the shape of the hysteresis loop affects response greatly since low productivity led isolated structures to higher acceleration in super structure with high frequency [8, 9]. Moreover, super structure acceleration increased with flexibility: this behaviour was also noted in analysis involving multi-story concrete buildings having attached or isolated bases [10].
The isolators were HDRB the friction pendulum's (F.P.'s) design was identical, and the fundamental period was the same. They concluded that the base isolation method successfully reduced the studied earthquake responses. Additionally, the F.P. isolators were more effective than the HDRB isolators. They discovered that the isolation systems had a beneficial effect on reducing the magnitude of earthquakes in both horizontally and vertically malformed buildings. The first documented utilization of a rubber-based isolation system to isolate the structure from earthquake danger was in 1969 for a 3-story concrete school in Yugoslavia. A vulcanized rubber block without reinforcements was employed as an isolator. The concept of base isolation has become popular today because of the increased development of base isolation producers. Many types of isolators and techniques are available to be considered in the stage of building design [11–18], analyzed a single degree of freedom structure isolated by using friction pendulum (F.P.) system and double curved friction pendulum (DCFP) under time history implementing the records of near-fault and far-fault earthquakes [19].

3. Effect of Isolation for footing

In linguistic terminology, insulation refers to the isolated part of the object. Therefore, engineering insulation is about using a material to protect a concrete structure. There are many methods available for preventing a structure from undergoing an earthquake. However, seismic base isolation (also known as base isolation or system of base isolation) is considered to be one of the best among them because it completely prevents the structure from experiencing any effects of the earthquake and thus is most effective in safeguarding not just the structure but also its contents and occupants from earthquake impact [20]. This method centres on reducing the seismic pressure instead of increasing the structural capacity for earthquakes. A malleable substance in the horizontal plane above a foundation or other location is present to prevent the energy from flowing into ssuperstructures This flexibility increases the super structure's period over a longer period than the natural period that is fixed, Figure 2. This increasing period can mitigate the pseudo-increase in speed, thus decreasing the magnitude of the induced forces in the structure; however, the deformation is increased as a result. This distortion is primarily concentrated in the isolation system; as a result, only small changes to the structure occur. Additionally, the energy dissipation or damping capacity in the isolators limits the displacement at the isolator level to a desirable range [21, 22].

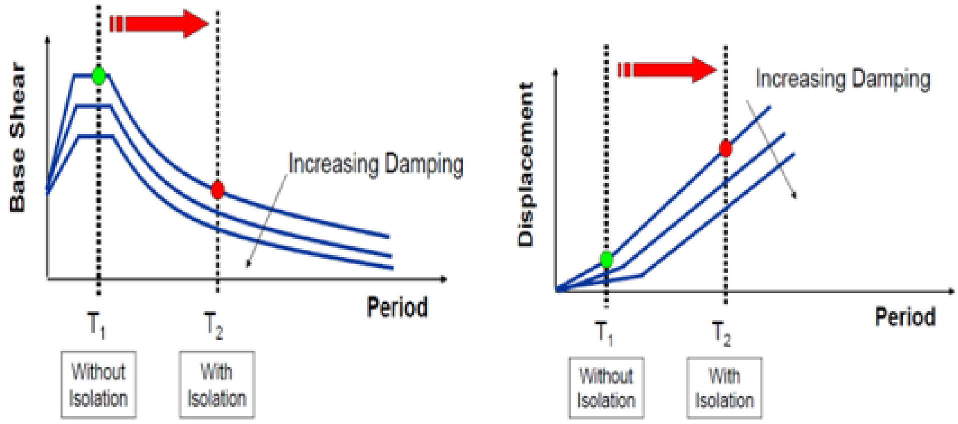

Fig. 2: Displacement and base shear for fixed and isolated bases [**23**]

Base isolation systems isolate a structure from the ground's motion by utilizing special devices inserted between the structure and its foundation. Using base isolation devices is a cutting-edge method of earthquake-resistant design employed in numerous countries. Among the various varieties of devices created, laminated elastomeric bearings are probably the most popular today [24-26]. The layers of rubber increase the horizontal flexibility of the system, which results in a decrease in the fundamental period of the building; this is then shifted to a period that is less common in the area, which decreases the dynamic range of the building, which is then reduced by about 40%. This causes the isolated system to have a different dynamic than the conventi. Using rubber-bearing sheets in different areas of science, like bridges, anti-vibration devices for machinery or building base isolation systems Published results concern tests on elastomeric bearings: low-frequency cyclic loads— with varying vertical loads and horizontal displacements restricted to failure but up to 400 percent of rubber height of both full and reduced scales [27–29]. Previous studies typically used short bars with stiffness and damping derived from experimental tests, presuming the super structure remains elastic during seismic response analysis. Mass is concentrated at floor levels in isolated buildings where seismic isolation is employed: one or three degrees of freedom per floor (translational and rotational) [27, 30, 31]. The purpose of seismic isolation is to prevent the destruction due to earthquake action on structures, buildings, or other objects [31, 32].

One type of seismic isolation system incorporates load-bearing pads called isolators. They're positioned strategically between the base and the building's structure and intended to reduce the magnitude and frequency of the seismic shock that is allowed into the building. They imbue both spring and energy-saving properties. Figure.3 shows the behaviour alteration of structural components without an isolator and with an isolator incorporated [33].

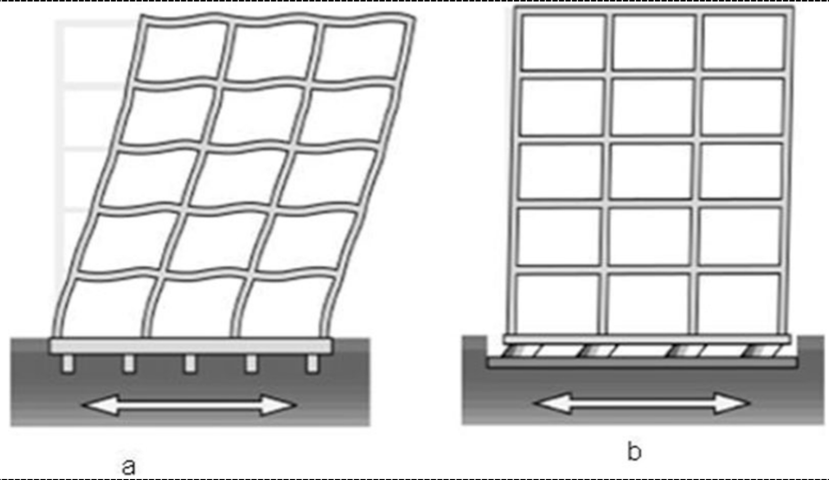

Fig. 3: Behavior changes while using the isolator. (a) Conventional structure (b) base-isolated structure

The way to reduce the transfer of damaging earthquake ground motions into a structure is having flexibility at the base in horizontal direction plus adding dampers that limit shock absorber-like components (magnitude or duration) introduced by earthquake motion. This relatively recent technology has come into economic feasibility as an alternative approach to conventional seismic engineering this concept is increasingly becoming a subject of interest among scholars and professionals in civil engineering, which they are applying it in their works on different structures within the discipline. To this point, several hundred buildings in Japan, New Zealand, the U.S. and India have employed the seismic isolation technique and technology in their design. It may be unexpected that the rubber components of the foundation can mitigate the damage caused by large earthquakes to buildings, considering the magnitude of the force that these buildings are subject to in a significant earthquake [34, 35]. Unlike the usual way of making structures stronger to withstand earthquakes, seismic isolation works on making the ground vibrations weaker at the building's base by reducing energy transferred from earthquake into the structure [36–38]. Seismic isolation uses flexibility in providing energy dissipation and deformability of its low stiffness to separate the structure from ground motion [39]. The technique involves introducing an isolated device known as isolators between the building's foundation and superstructure, which has been proven in previous researches that have been carried out: that when a building is subjected to an earthquake excitation primarily characterized by its horizontal ground acceleration component, if this component can be minimized then most likely significant reduction of structural damage due to earthquake impact will be achieved [40]. The decrease of this destruction is reached by increasing the structure's natural period which can be raised through seismic isolation. During the process, the natural period of the structure is transferred from high-risk area to low-risk area [41]. The isolated condition transforms it: with less than 1 second to 2-4 seconds [42, 43]. The change in natural period due to structural isolation can be observed on Figure.4 which clearly demonstrates that with increase of period also the effect of damping grows and because of increase in period response decreases acceleration; thus, oscillatory behavior. Moreover, damping influences it positively as well since growth relative displacement and acceleration should be decreased due to higher energy dissipation in damping forces so this underlines importance of proper damping during seismic isolation operation.

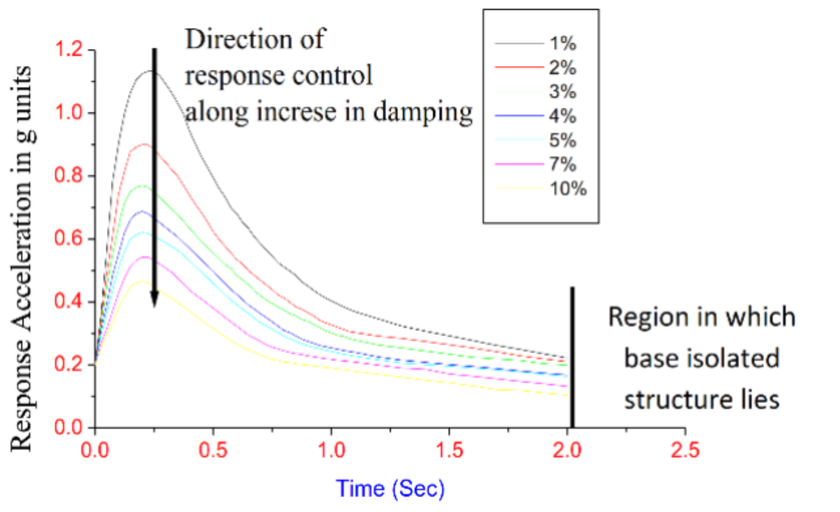

Fig. 4: Effect of the seismic isolation and damping on the structure's natural period and acceleration response [43]

Al-Mosawi [44], analyzed multi-storey reinforced concrete buildings with fixed and isolated bases. The buildings were symmetrical and horizontally and vertically irregular. They concluded that the base isolation technique was very effective in reducing the studied earthquake responses. They found that the isolation systems were efficient in reducing the earthquake response in both horizontally and vertically irregular buildings. [45], analyzed the effect of isolation location on 10-storey RC structure. Three models were considered: no isolator, isolator at base and isolator at middle storey. Elastomeric rubber bearings isolators were considered. The results indicated that the accelerations of base isolated building were about 25% of the accelerations found in case of fixed bases for all storeys. For the structure isolated in the middle storey, accelerations of storeys 1 to 5 increase compared to the fixed base structure and accelerations for storeys 6 to 10 decreased to half compared to the base isolated structure and by 1/8 for the fixed base structure. The displacements were increased in isolated cases but this increment resulted from the isolators deformations. Shear forces of the first floor decreased by 90% for the base isolated structure and by 33% for the middle storey isolated structure, as compared to fixed base structure.

4. Effect of damping

Structure reacts to different conditions based on mechanical properties and type of excitation. Some effective mechanical properties in reducing the structure response to specific triggers while other triggers are present, those detrimental to the structure. Earthquakes' ground motions differ in various ways, such as soil conditions, distance and direction from fault location and magnitude. Control of demand for displacement is primarily through control of energy dissipation capacity because it is about ensuring that the structure can take in all the input energy without any structural damage; hence, various energy dissipation mechanisms have been proposed to enhance structural responsivity [46]. The modes through which energy is dissipated are diverse, consisting of plastic, elastic and their hybrid. Long-duration seismic waves subject a structure to numerous cycles. Thus, during the response phase that is forced, dependency of the response arises more from the amount of energy dissipated in each cycle (area under force displacement loop) than from the type of dissipative force. The average ratio of dissipation properties traditionally is taken over a motion period and derived from linear theory of structural dynamics because viscous, frictional, elastoplastic or viscoelastic forces have differing natures [1, 47]. These isolators are made with steel and rubber plates that are vulcanized into a series of layers, as illustrated in Figure 5. This type of behavior can be described as a linear spring and damper. The low horizontal tensile strength is derived from the rubber layers, while the high vertical tensile strength is derived from steel shims [11, 12].

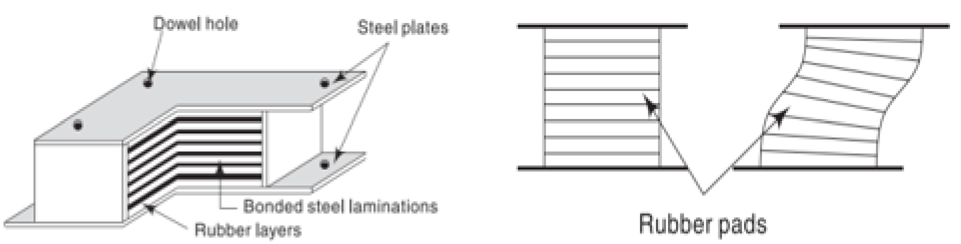

Fig. 5: Typical laminated rubber isolators [11]

Depending on the rubber layers' properties, two varieties of rubber-bearing isolators are commonly employed in the construction industry. These are the typical rubber isolators and high-damping rubber isolators. Natural rubber layers are composed of low (around 5%) damping capacity. High-damping rubber isolators have recently been invented with sufficient inherent damping. The additional small carbon blocks or oils help in enhancing the damping. The increase was such that the damping ratio increased from 10% to 20% at a shear strain of 100%, which also helped in releasing energy to reduce the total displacement [13]. Energy dissipation is typically achieved through fluid viscosities for hysterical dampers or hysteresis for high-damping rubber supports, among others.It will refer to this as hysteretic damping, although it does not constitute a formal definition of hysteretic damping. Many investigations have looked at the effect of base isolation structure response with varying amounts of damping. While a lot has been done, some questions remain unanswered yet despite all these studies. Some prior studies have looked at the negative impacts of adding more damping, and even the type of damping used, certain references imply that extra dampening is disadvantageous. In particular, it says:

- High linear viscous damping can sometimes produce more force and acceleration than low damping [48-50].
- Hysteretic damping is less effective than linear viscous damping because it causes greater accelerations, mainly due to the increased participation of higher modes [51, 52].

Even though the latter point is widely accepted, the former encounters much resistance. For example, [52, 53] argues that stiffening improves the dynamic characteristics more effectively compared to mass modification in most practical situations. Moreover, there is the limited research efforts that study building equipment behaviour as opposed to their structural systems and architectural components. [54], studied the behaviour of a 6-storey RC building with isolated top floor and tuned mass (TMD). The used TMD had the same damping ratio of the main building. Real ground motions were considered in the study. Lead rubber isolators were introduced at the base of top storey columns. Time history analysis has been carried out on building with a fixed base and building with base-isolated top floor to compare the axial force, bending moment, shear force, displacement and acceleration response. They concluded that using TMD with base isolated systems strategy is quite effective. Imran et al., [55], introduced a case study of design procedure and evaluation of the performance of base isolated RC building. The building consisting of 10-storey was studied for both cases of fixed base and with double concave friction pendulum isolator (DCFP). The maximum earthquake in Jakarta, the capital of Indonesia city was subjected to the building. Nonlinear finite element analysis was used with time history analysis. The results showed that the isolated building had good performance under seismic risk where the base shear, top storey acceleration and the interstorey drift were reduced.

5. Conclusion

There have been numerous studies on seismic isolation, however few have real world applications in low to moderate seismic activity zones. The main goal of earthquake protective systems is to seismically uncouple the structure from the earthquake's damaging input motion components—depriving the superstructure from being impacted by energy introduced into the system. A viable technique is a passive control that uses special energy dissipation devices with a high level of attenuation designed only for this task and not any other task. Many methods have been attempted. However, a few have taken over the market globally (elastomeric bearings, lead-rubber bearings, Friction Pendulum, Triple Pendulum, trench around the structure and piles) and possess the greatest market share. The study showed that individual structures can be retrofitted to resist larger earthquakes than those for which they were designed by triggering one or more ultimate limit behaviors such as unrestrained uplift, breaking contact between elastomeric bearings, engagement of a displacement limiting device, or significant post-yielding stiffening. Many such final behaviors of the isolation system will reconfigure demands to the superstructure and be ductile in nature. Recent full-scale shake table tests on base isolated building demonstrated capabilities of LRB-CLB and TP in bi-directional earthquake activity but also revealed unknown aspects regarding additional features of systems when tested for a particular direction. Nonstructural elements and contents are vulnerable to harm if the movement is maintained for long periods, causing large floor velocities along with a sizeable vertical component of acceleration. Damage to these components leads to loss of post event operational capabilities in those parts of essential facilities that are isolated from their surrounding structure. The E-Defense tests provided limited information on the systems' response due to the high cost of the tests and though it revealed many details, it has several implications. In these systems, seismic vulnerabilities in nonstructural systems are typically caused by a single parameter related to damage such as horizontal acceleration of the floor but from testing suggested that observed damage might be more complex. It might involve multiple components like maximum horizontal acceleration, maximum vertical acceleration with frequency or spectrum of accelerations as well. The response of the demands placed on non-structural components in base-isolated buildings varies significantly from those placed on conventional buildings. This should be considered with respect to the horizontal and vertical components, and also the frequency content of these demands for an impact across all building typologies as different effects apply to each type.

Acknowledgement

The authors appreciate the Dean and faculty of the College of Engineering at Al-Muthanna University for their continued support and assistance with this endeavor.

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