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Special based isolation system for low-rise RC building

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Abstract. In the past decade, there were a lot of seismic activities around the world that cause low rise reinforced concrete suffered severe damage and total collapse. A special based isolation system can be equipped to the low rise building to prevent it from damaged and collapse by improving the period, stiffness and damping of the structures. The based isolation system can increase the natural period of a rigid structure under first mode shape by applying low stiffness rubber isolators. These method can provide a better structural behaviour of low rise RC building as compared to moderate or high stiffness rubber isolators. Furthermore, the special based isolation system with maximum damping of 15% for 4 storey and 6 storey RC building. However, the value of optimum damping depends upon the characteristics of ground motions and frequencies of the earthquakes.

1. Introduction

Seismic activities nowadays killed many people due to the design of the structural component of RC buildings still construct using the conventional method that only cater for the vertical loads without taking into consideration of the lateral loads. Normal practice of building design were proved cannot survive under earthquake while seismic design code building or other seismic design code usually attempt to robust under earthquake shaking but result the non-functional building after earthquake due to the piping, electrical and partition that damage after the earthquake. This were more problematic if the public buildings cannot be functional during the disaster for example hospital, police station or fire station after earthquake shaking due to the lack of design method.

Based on the observation after an earthquake, there were a lot of structure damage especially on column and foundation interface such as crack and spalling of concrete. All of this buildings are damaged severely after earthquake and cannot function well. The public building damage after the earthquake such as school, hospital and mosque were effect the daily activities before it can be functional back. Demolish the existing structure and rebuild the buildings using seismic code of practice for example using EC8 not only wasting the money but also consuming lot of the time.

The structural stability of RC buildings under earthquake loads can be achieve by strengthened and retrofitted the column or foundation of existing buildings using base isolation system without demolishing. The idea of base isolation system is to reduce the earthquake forces on structure by isolating the structure from damaging effect of ground movement and shift the fundamental period of the structure out of the range of dominant earthquake energy frequencies and increasing the energy absorbing capability[1][2][3]. This concept explained as in figure 1**Figure *1***. This technique contrasts with conventional design that rely on inelastic structure to dissipate the earthquake energy.

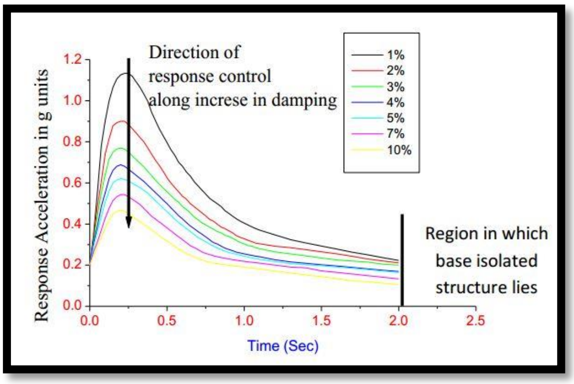

Figure 1. Concept of Base Isolation and Dampers [3]

Base isolation proven as the excellent mechanism to cater the earthquake vibration especially at the medium to high seismic region due to the function of base isolation that can increase the natural period of the rigid structures due to their flexibility[1][4][5][6]. The base isolation consists of alternative layers of rubber and steel. A strong bond between the rubber and steel is critically important to the correct functioning of the bearing. The natural rubber is specially formulated to give the required damping. Researchers and engineers proved Base Isolation System is the best way to control the earthquake vibration toward the buildings.

Yet, practically Base Isolation System depends on some factors which are accurate calculation and build technology, control operational system, good quality maintenance are done and the main factor is the cost of the project can be minimize [7]**.** By adopting the base isolation system in building structure there was only a minimum force form the earthquake will transferred to the building structure due to the base isolation flexibility that move vice versa from the ground motion. Thus, this not only save the human life but also save the buildings from crack or damage and the building can be functional back after the earthquake especially the public buildings.

Usually, the implementation of several type of base isolation for high rise building are common. However, due to the high initial costs of base isolation, this technique only implemented in special projects and rarely for residential buildings in developing countries with high seismic risk especially low-rise buildings. The main attempt of this paper is to present an overview of using the based isolation system as an earthquake protection system for low-rise buildings.

2. Low Rise Building Structure Damage After an Earthquake

2.1. *Magnitude Sabah Earthquake*

Sabah is prone to earthquake activities if compared to other parts of Malaysia. Sabah has suffered several earthquakes of moderate magnitude. One of the worst earthquakes occurred in 2015 when a 6.0 magnitude on Richter scale temblor rocked some part of Sabah resulting in structural damage to a school, mosque and residential house. The most affected region is Ranau. Ranau is one of the famous tourist attraction in Sabah especially Kundasang because of the magnificent views of Mount Kinabalu and the cool weather. However, after the tremor, the iconic donkey ears of Mount Kinabalu also destroyed as in Figure 2. The total cost damage after the tragedy around 100 million affected 61 buildings , 22 roads, 22 slopes and 200 families in Ranau and Kota Belud as in *Mount Kinabalu after Ranau Earthquake*

earthquake

and Figure 4 [8]. Most of people lost their homes, farms, and plantation as well as disrupted water supply. Typical damages reported were brick wall, shear failure cracks, cracks on columns and beams, roof failure, failure of supporting columns or tilts, concrete spalling, and shattered windows.

Figure 2. Mount Kinabalu after Ranau Earthquake

Figure 3. Properties damaged by the earthquake

Figure 4. A landslide caused by the magnitude 6.0 earthquake

Ramly et al., (2015) have conducted the rapid visual screening on building inventory for particular area in Kundasang, Sabah after an earthquake. There are roughly 717 numbers of structures such as residential, commercial, religious, industrial, government, education and history property surveyed. The parameters included are type of buildings, number storey and occupancy of buildings. Figure *5* shows example of buildings occupancy in Kundasang that have studied. The building type can be observed from timber and concrete. From the 717 numbers of structure analysed in Kundasang, 517 of them are residential buildings while 711(99.2%) buildings categorize as low rise, 5(0.7%) buildings are mid-rise and only 1(0.1%) building consider as high rise building which equal or more than 7 storey as shown in Figure ***6***.

Figure 5. Building in Kundasang, Sabah [9]

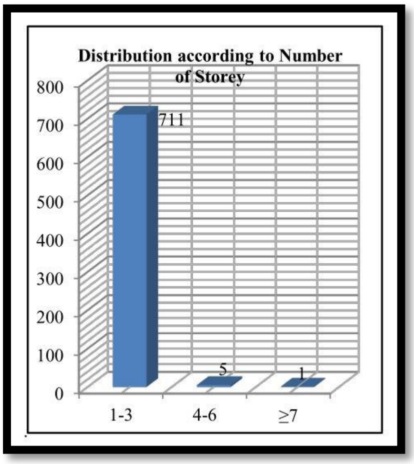

Figure 6. Relation between number of buildings and number of storey [9]

Most of the buildings in the Kundasang region are non-engineered design[10] and some of the building are design using BS 8110 that only considered gravity load and not cater for seismic loading at all. This is not adequate for the areas of medium to high seismic activities such Sabah. Figure 6 show the numbers of building below than four storey are the most building type in Kundasang, Sabah. This is because Kundasang are hilly area and categorize as the rural area that focused on the tourism industry and agricultural only. Then, this is why the numbers of low-rise building construct higher compare to high-rise building. We can concluded that low-rise building such as residential, government service building, mosque and commercial property in moderate to high seismic region can affected by the earthquake excitation and need to be repaired according to the appropriate code or by install the base isolation system. Base isolation are more reliable to the structure without demolish the existing building that will increase the cost and time.

2.2. Magnitude Nepal Earthquake.

On April 25, 2015, a 7.8 magnitude earthquake struck Nepal with epicenter at Gorkha District[11]. This catastrophe caused massive destruction and expected inflict about $5Billion loss to the country[12]. The quake and its aftershocks affected an estimated 8 million people, which are more than a quarter of Nepal’s population. Nearly 9,000 people lost their lives, more than 22,000 were injured, and about 750,000 houses damaged and destroyed including UNESCO World Heritage sites[13]. The 2015 Nepal Earthquake was the worst natural disaster happened since 1934 Bihar-Nepal earthquake.

The earthquake had a significant impact on housing, institutional facilities, heritage buildings, schools, hospitals, and lifelines. About 98% property in Nepal are low-rise building that constructed by owner-builders that only follow the advice from the local craftsman without any consideration of engineering factor and seismic activities as in Figure 7. They used as residential buildings for extended families, which is a common housing pattern in Nepal. The space at the ground floor level in these buildings often used for commercial purposes (small retail stores) as in Figure 8. We can concluded that low-rise building in moderate to high seismic region can affected by the earthquake excitation and need to repair by install the base isolation system. The old and traditional ways of construction not reliable and increase fatalities.

Figure 7. Low rise RC frame building due to the 2015 Nepal earthquake [13]

Figure 8. Open storefront buildings [13]

3. Special Base Isolation System For Low Rise Structure

Base isolation are the technology build using rubber as the isolators. The isolators, having low horizontal stiffness or low friction, provide lateral flexibility at the base and separate the main structure from ground motions. By increasing the flexibility of the isolated building, the isolators shift the fundamental period of the structure beyond the range where the maximum effect of ground motions occurs. There are many varieties of the base isolation but few numbers are compatible to low rise structure due to the total mass of structure that too small effect difficulty to designer to create the isolator with effective stiffness suit with customer need and budget. Rubber bearing with low horizontal stiffness such as small cross area and low shear modulus can induces buckling[14].

Kilinc, (2012) have studied the three difference parameter of stiffness as in Figure 9 of the isolator high, medium and low stiffness for low rise four-storey building frame under difference earthquake motion and compared with the fixed building. In this studies effect of high damping isolators on seismic excitation of a 4-storey reinforced concrete building conducted. Time history analyses using SAP 2000 structural analysis program (2000) of Marmara Earthquake in August 1999 ground motion are used. Results of the analyses show that periods of base isolated structure are increase than the original structure as illustrated in Figure 10. The increase in stiffness of the base isolator decreases the period among the base-isolated structural models. Moreover, application of low stiffness rubber isolators also provides better structural behavior rather than application of high stiffness rubber isolator and medium stiffness rubber isolators on structure[15].

Stiffness	Vertical stiffness (kN/m)	Initial stiffness (kN/m)	Effective stiffness (kN/m)	Yield Force (kN)	Stiffness ratio	Mass(kg)
Low	1750.10^3	1.750	263	22,24	0,2	175,5
Moderate	1373.10^3	7.786	1.079	77,87	0,043	175,5
High	2746.10^3	12.454	1.863	124,54	0,055	175,5

Figure 9. Characteristic properties of rubber layers with high damping (Karabork 2009)

Period (s)				
4-Storey	Isolator stiffness	T_1	T_2	T_3
	Fixed support	0,370	0,348	0,325
	Low	2,977	2,974	2,704
	Moderate	1,491	1,485	1,351
	High	1,156	1,148	1,046

Figure 10. Periods of the original structure and the base isolated structures

Base isolated structures show a better performance regarding the inter-storey drifts compared to the original structure, since inter-storey drifts reduce significantly. In addition, the storey accelerations decrease, when rubber isolators are applied. Both base shear forces and base flexural moments decrease upon the application of rubber isolators [15].

Braga & Laterza, (2004) conducted the experiment of a real low-rise isolated building with a hybrid isolation system (HDRB & Sliding bearing), and an isolation system made of HDRB only for three-storey building in Italy that are high seismic activities. The building are 12-meter height with 3-meter inter-storey height includes rooftop. The base isolation system placed in between foundation and 28 columns with the specification of isolator illustrated in *Figure 11*. Meanwhile, for hybrid isolation system only 12 numbers of HDRB used and another 16 numbers are sliding bearing.

D_g (mm)	D_s (mm)	T_g (mm)	N_g	H_g (mm)	T_s (mm)	T_e (mm)	H (mm)	K_h (kN/m)	K_v (kN/m)
500	480	4	34	136	2	20	242	657	19,00000

D_g, rubber layers diameter (mm); D_s, steel layers diameter (mm); T_g, rubber layer thickness (mm); N_g, number of rubber layers; H_g, total rubber height (mm); T_s, steel sheets thickness (mm); T_e, external plates thickness (mm); H, total isolator height (mm); K_h, horizontal stiffness; K_v, vertical stiffness.

Figure 11. The HDRB design dimensions and stiffness

The tests on the hybrid system gave an equivalent damping ratio ξ_{eq} of about 30% for the first and second couple of peaks. The HDRB system gave an equivalent damping ratio ξ_{eq} about 15% as shown in Figure 12**.** It shows that the hybrid system (HDRB & Sliding bearing) provide double damping amount compared to the HDRB system only. Figure 13 shows base and top-floor accelerations of the HDRB system and the hybrid structure. It reveals higher values of accelerations for the HDRB system. The first period in the test direction identified during the release is about 1.47s for the HDRB system and 2.05s for the hybrid.

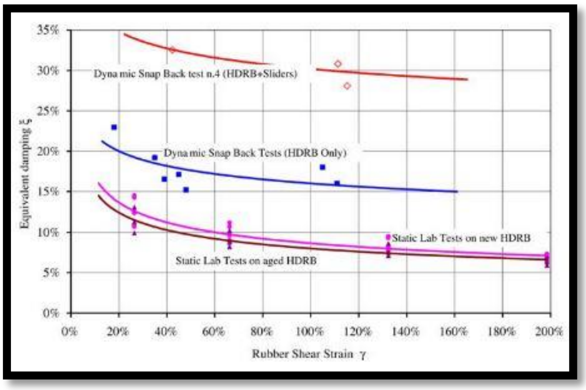

Figure 12. Experimental evaluation of equivalent damping

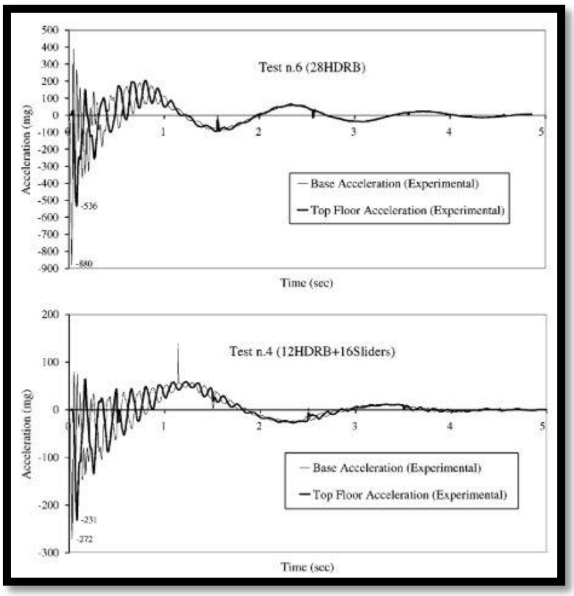

Figure 13. Floors acceleration histories during free vibrations

Hybrid isolation can be very effective in overcoming typical design problems connected with the use of HDRB systems only, such as instability, extremely low stiffness for low-rise buildings, and vertical dimensions in the seismic gap[14].

4. Conclusion

The implementation of several type of base isolation for high rise building are common but developer usually avoid the implementation of base isolation structure for low-rise buildings due to costs. The special based isolation for low rise buildings are high in demand due to the numbers of low-rise buildings structure highly damaged and cannot function after seismic activities. Based on the observation, application of rubber isolators significantly increase periods of the original structure. The increase in stiffness of the base isolator decreases the period of the structure. Low-rise building such as residential, commercial building, mosque and government property required low stiffness due to the minimum total mass of building. The application of low stiffness rubber isolators provides a better structural behaviour compared to application of moderate or high stiffness rubber isolators on the low-rise structure. In general, not more than 15% damping is required in the base isolation system. The value of optimum damping depends upon the characteristics of ground motion and has low value for earthquake motions with high frequency contents.

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