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# DESIGN OF BASE ISOLATED REINFORCED CONCRETE BUILDING SUBJECTED TO SEISMIC EXCITATION USING EC 8

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**ABSTRACT:** From past earthquakes, it is proved that many reinforced concrete (RC) structure are totally or partially damaged due to seismic excitation. The design code for buildings will raise safety standards of structures resistance to earthquakes especially new structures. In this study, the current design of RC 10 story floor building structure was modeled using the standard design of BS8110. British Standard BS8110 was not considering earthquake effect due to the RC structure The modeling was then designed with Eurocode(EC8) seismic design guidelines. The parameters used in this research were taken based on the data provided by the case study in the past works of literature. The behavior of RC structures with and without base isolation was studied to observe the interstorey drift, lateral displacement, and its base shear effect using response spectrum analysis in STAADPRO software. Spring was defined to act as a base isolation system for the reinforced concrete structure. Based on the results, it was expected that the application of the base isolation system significantly contributes to the reduction of story drifts, lateral displacements, and base shear as well as improvement of structure behavior.

*Keywords:* *base isolation system, response spectrum, drift, displacement, base shear*

## 1. INTRODUCTION

The major challenge in the reinforced structure is to consider the seismic excitation and how to reduce the effect of seismic load in the design concept. British Standard BS8110, do not consider seismic loading and detailing such as at the beam-column joint, bracing, bearing as base isolators or dampers. As consequences, the current structure designs were not capable to resist and withstand under field and long distant seismic. Therefore, design reinforced concrete structures using earthquake design standard should be considered so that the effect of earthquake damage in our neighboring countries can be minimized. This study concentrated on the utilization of the spring base isolation system of a structure. Base isolation is becoming an alternative to the current practice with regards to safety measures for earthquake design. The uncoupling of structure from the ground is accomplished by the use of special design devices such as laminated rubber bearing. This system device will set at the base of the structure, that simultaneously provides an increased capacity to dissipate the energy input by the earthquakes and confer additional flexibility and a consequent frequency shifting which usually causes a decrease in the seismic forces transfer to the main structure.

This study concerns an analysis of reinforced concrete frame only. The modeling of the whole building is carried out using the computer program STAADPRO. This study involves a theoretical 10 story building including a ground floor with normal floor loading and no infill walls. This structure modeling is conducted based on research made by Hassaballa [1] in which focusing on Central Khartoum, Sudan. Therefore, the parameters used in this research were taken based on the data provided by the researchers themselves as well as the references used by them. Firstly, for the verification purpose, a comparison of drift displacement by the story was made. The design structure compliance with BS8110:1985 / 1997 [2] as a constant structure. The most important parameters governing the analysis of this frame were both gravity loads which are (dead load and live load) and seismic loads. Next, the modeling was designed using Eurocode 2 with an improvement of the structures were made with the seismic design using Eurocode 8 principle which using base isolator as seismic resistant. Soil spring foundation is defined as the base isolation system. Response spectrum analysis was used to analyze the structural behavior. This study only focuses on the result of story drift, lateral displacement, and base shear after subjected to earthquake excitation of the building with and without base isolation system.

## 2. HISTORY OF SEISMIC ANALYSIS OF BASED ISOLATED RC BUILDINGS

Hassaballa [1] conducted a study on seismic analysis of a multi-story reinforced concrete frame in Central Khartoum, Sudan and it was analyzed under moderate earthquake loads as an application of seismic hazard and in accordance with the seismic provisions proposed for Sudan to investigate the performance of existing buildings if exposed to seismic loads. The results of the analysis indicated that the frame suffered a maximum horizontal displacement of 28.39 cm at its top level. This represents about 0.94% of the frame total height. These nodal displacements caused drifts in excess of the allowable drifts. The result has shown that the drift reached up to 35 mm in some levels while the allowable drift in this frame should not be greater than 0.004 times the story height (12 mm).

Santhosh [3] conducted a dynamic analysis structural of a six-story building under both fixed supported and seismically isolated boundary conditions were studied to demonstrate the effectiveness of seismic isolation. The isolation reduces the fundamental frequency of the structure from its fixed base frequency and thus shifts the position of the structure in the spectrum from the peak-plateau region to the lower regions. Also, it brings additional damping due to the increased damping introduced at the base level, and thus a further reduction in the spectral acceleration is achieved as shown in Fig. 1.

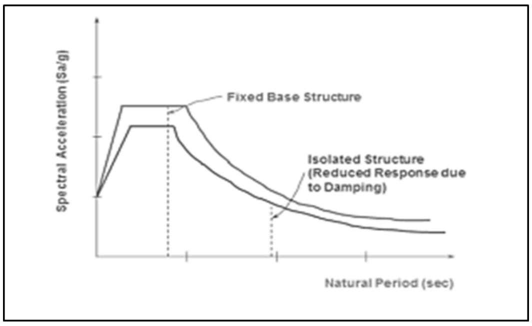


Fig.1 A graph of spectral acceleration against natural period

Kamble [4] studied on 9 stories building symmetric and asymmetric having fixed base and isolation of high damping rubber bearing (HDRB). The results from the study shown that the time period 65% increases when the building is isolated with HDRB compared to the fixed base, time period 67% increases when the building was isolated with LDRB compared to the fixed base. Besides that, a 40% reduction in base shear when the building was isolated with HDRB compared to the fixed base. The results of frequency decreased by 67.70% when the building was isolated with LDRB compared to the fixed base. Frequency 65.98% decreases when the building is isolated with HDRB compared to the fixed base and there was a 43% reduction in base shear when the building was isolated with LDRB compared to the fixed base.

## 3. PROBABILISTIC SEISMIC HAZARD ASSESSMENT OF SUDAN

### 3.1 **Identification of Ground Type**

The parameter used in this study based on the study by Hassaballa [1]. The soil at Central Khartoum can be reasonably represented by curves for soils E and D. Thus, the value peak ground acceleration (PGH) of 0.214g which in ductility class moderate (DCM) with type D soil were considered.

### 3.2 **Spectrum Type**

Table 1 and Table 2 summarize the seismic source region of Sudan and its vicinity and summary of peak ground acceleration (PGA) occurs up 50, 100, 200 and 250 years span in Central Sudan.

Table 1 Seismic source region of Sudan and its vicinity [5]

| Source Region No. | Source Name | Source Boundaries Coordinates (Latitude, Longitude) | Maximum Instrumental Earthquake |
|---|---|---|---|
| I | Northern Sudan | (20.1E,19.3N), (36.2E,16.0N) (30.7E,23.5N), (36.2E,20.4N) | 5.8 |
| II | Central Sudan | (29.6E,13.0N), (33.9E,10.7N) (32.0E,17.0N), (36.1E,15.0N) | 6.4 |
| III | Southwestern Sudan | (26.3E,09.4N), (32.7E,06.6N) (27.2E,10.9N), (10.7E,08.9N) | 6.8 |
| IV | Southern Sudan | (30.9E,03.6N), (33.5E,03.6N) (31.7E,06.5N), (34.4E,06.5N) | 7.2 |
| V | Equatorial Uganda | (28.8E,00.0N), (33.5E,00.0N) (08.9E,03.1N), (33.5E,03.1N) | 7.5 |
| VI | Central Ethiopia | (34.0E,02.0N), (36.5E,00.0N) (38.0E,13.3N), (40.7E,10.7N) | 7.7 |
| VII | Afar and Gulf of Aden | (36.2E,16.0N), (42.5E,09.0N) (40.7E,18.7N), (44.9E,13.8N) | 7.5 |
| VIII | Red Sea | (37.4E,18.7N), (40.0E,18.7N) (37.4E,22.4N), (40.0E,20.0N) | 7.2 |

Table 2 PGA (ing) with a 10% probability of being exceeded in time span [5]

| Regions | Source Name | 50 Years | 100Years | 200Years | 250Years |
|---|---|---|---|---|---|
| I | Northern Sudan | 0.108 | 0.142 | 0.182 | 0.198 |
| II | Central Sudan | 0.117 | 0.153 | 0.198 | 0.215 |
| III | Southwestern Sudan | 0.115 | 0.149 | 0.192 | 0.208 |
| IV | Southern Sudan | 0.339 | 0.437 | 0.562 | 0.608 |
| V | Equatorial Uganda | 0.299 | 0.386 | 0.499 | 0.541 |
| VI | Central Ethiopia | 0.259 | 0.336 | 0.435 | 0.472 |
| VII | Afar Region & Gulf of Aden | 0.329 | 0.425 | 0.547 | 0.592 |
| VIII | Red Sea | 0.347 | 0.446 | 0.572 | 0.619 |

As according to Hassaballa [1], the seismic analysis used horizontal input motion of earthquake with moderate in which ranging of peak ground acceleration (PGAH) between 0.2-0.39. Also, they referred to the design ground acceleration of Central Khartoum, Sudan according to the research conducted by Mohamedzein [6]. The maximum acceleration at the ground surface in Sudan varies over the small range from 0.19 to 0.243g. And it was stated by Mohamedzein [6] and Abdalla [1] that for practical purposes an average value of 0.214g can be adopted for Central Khartoum. Two types of spectra: Type 1 is recommended to be adopted since the earthquakes that contribute most to the seismic hazard defined for the site for the purpose of probabilistic hazard assessment have a surface-wave magnitude, Ms, greater than 5.5 (6.4) as according to Table 1.

### 3.3 Dimension of RC Frame Structure

Table 3 shows the dimensions of cross-section details of 10 story RC frame structure prepared in STAADPRO.

Table 3 Cross-section details for RC structure model

| ***Floor level*** | ***G-5th*** | ***6th to 7Th*** | ***8th to Roof*** |
|---|---|---|---|
| Columns (mm) | 500 ×300 | 400×300 | 300×300 |
| Typical beams (mm) | 400 × 300 | | |
| Slab thickness (mm) | 130 | | |
| Support system | Fixed / Spring base support system | | |

The beam and column sizes are kept the same for both fixed and isolated RC structure. Plan view and side view on the RC structure frame are as shown in Fig. 2 and Fig. 3.

The seismic isolators in the system are defined as spring placed between the fixed base and the columns. The parameters selected to define the utilized isolators in STAADPRO is soil spring with stiffness, K=16000kN/m. As dynamic analysis normally 5% damped response spectra are considered, so the 5% damped response spectrum and the effective damping ratio of the isolation system, as defined in Eurocode 8 [7], does not exceed 30%. Thus, for spring base isolation system the damping ratio was assumed as 20%. The RC models are analyzed using Response Spectrum in STAADPRO using Eurocode 8.

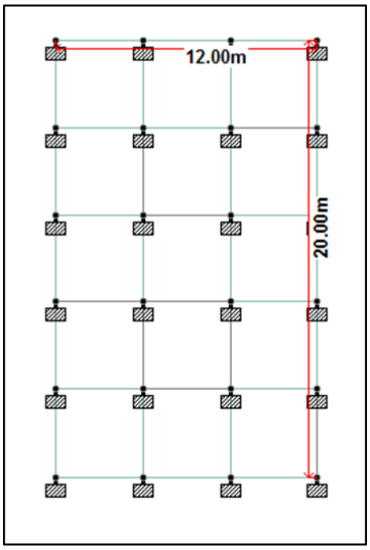


Fig. 2 Plan view of the foundation

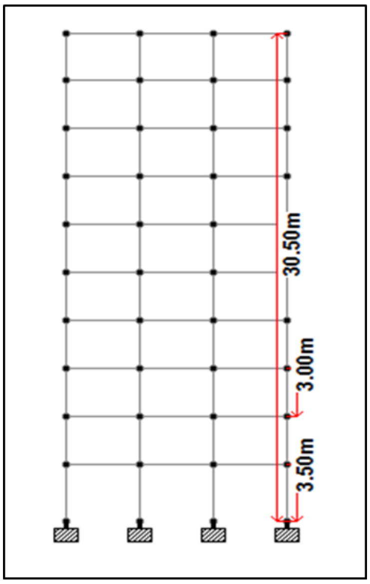


Fig. 3 Side elevation

## 4. RESULTS AND DISCUSSION

### 4.1 Inter-Storey Drift

Table 4 shows a comparative study of inter-story drift. The results that have been observed using response spectrum analysis that the story drifts in spring base isolated building is higher at the ground story than fixed base building and decreasing as the story getting higher. It was expected that the drift of the base isolated building would be less than that of the fixed-base building.

In the case of a fixed base structure, story drift is comparatively lower than spring base apart from the ground floor which is 0.196% while spring base isolation system is 0.312%. However, although the spring based isolated structures shown drastic increased in story drift at the ground story and reduced significantly up to roof level.

Table 4: Comparative study of story drift (mm) in the x-direction

| Story | Storey Drift (mm) | |
|---|---|---|
| | Fixed Support System | Spring Based Isolation System |
| Roof | 15.265 | 12.444 |
| 8 | 25.574 | 16.034 |
| 7 | 24.281 | 15.401 |
| 6 | 29.686 | 17.182 |
| 5 | 39.740 | 20.585 |
| 4 | 45.273 | 22.410 |
| 3 | 50.064 | 24.156 |
| 2 | 54.026 | 26.251 |
| 1 | 56.952 | 31.826 |
| Ground | 60.254 | 95.254 |

### 4.2 Lateral Displacement

Table 5 shows a comparative study of percentage drift without base isolators (fixed) and with base isolators system (spring) while Figure 4 shows story against lateral displacement ratio between fixed support and spring based support system.

Table 5 Comparative study of percentage drift in the X direction

| Story | Fixed Support System | Spring Based Isolation System |
|---|---|---|
| Roof | 1.315% | 0.923% |
| 8 | 1.265% | 0.882% |
| 7 | 1.181% | 0.829% |
| 6 | 1.102% | 0.779% |
| 5 | 1.004% | 0.723% |
| 4 | 0.874% | 0.655% |
| 3 | 0.726% | 0.582% |
| 2 | 0.561% | 0.502% |
| 1 | 0.384% | 0.417% |
| Ground | 0.197% | 0.312% |

The percentage of lateral displacement ratio at the ground story to the first story of the reinforced concrete structure in fixed based system is lower compared to spring based isolation system. At the ground floor, the ratio gives a smaller value of 0.139% for a fixed support system and 0.312% for spring based isolation system. However, the lateral displacement ratio has been decreased at the spring base isolation system compared to fixed base systems as the story getting higher. The percentage of lateral displacement ratio of the roof or top story obtained in the fixed support system is 1.315% and spring based isolation system is 0.923%.

The lateral displacement of spring based isolation system building is expected to be less than that of the fixed-base building. Spring base isolated structures are likely to have a larger displacement at a lower level, as they are separated from the ground. In other words, base isolation lets the buildings to move over the ground so that they have less frequency.

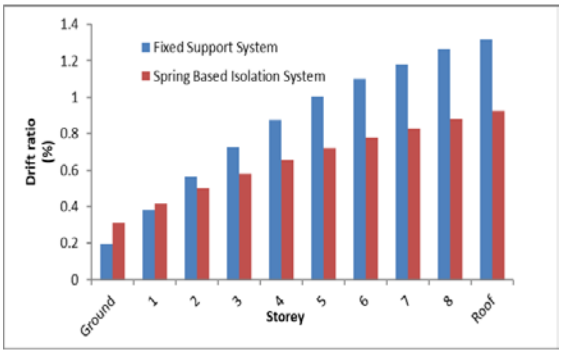


Fig. 4 Storey against lateral displacement ratio in the x-direction

### 4.3 Base Shear

Table 6 shows the comparative study of base shear without base isolators and with base isolation support system while Figure 4 illustrates the base shear against the direction of the earthquake

Table 6 Comparative study of base shear (kN)

| Study case | Base Shear (kN) | |
|---|---|---|
| | X direction | Z-direction |
| Fixed Support System | 5572.36 | 6400.91 |
| Spring Based Isolation System | 2197.29 | 3384.36 |

The base shear value for a fixed support system is 5572.36kN and the base shear for spring base isolation system is 2197.29kN for x-direction earthquake whereas 6400.91kN for fixed support system and 3384.36kN for spring base isolation support system in z-direction earthquake. It has been observed that the base shear for the base isolated building is reduced to an average range of in x-direction 60.57% and 47.13% in the z-direction from the fixed base building. The comparison is shown in Fig. 5.

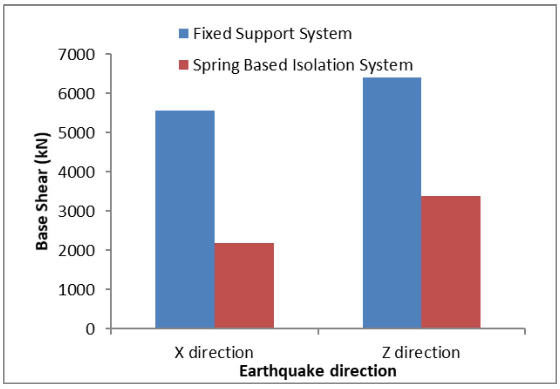


Fig. 5 Base shear against the direction of the earthquake

### 4.4 Mode Shapes, Period and Frequency

Table 7 and Table 8 show the value of time period and frequency for their respective modes that are obtained by analysis of the structure using response spectrum method for building with fixed base and spring based isolation system building.

The period for both support system cases decreasing from first mode shape to fifteenth mode shape. However, the spring base isolation support system has a higher period compared to a fixed base support system. By referring with the frequency equation of the spring based isolation system has a smaller frequency from first mode shape to fifteenth mode shape compared to a fixed support system.

Table 7 Comparative study of the period in seconds

| Mode | Period (second) | | Percentage of different (%) |
|---|---|---|---|
| | Fixed Support System | Spring Based Isolation System | |
| 1 | 1.78184 | 2.51416 | 41.10 |
| 2 | 1.51689 | 1.93852 | 27.80 |
| 3 | 1.46657 | 1.89474 | 29.20 |
| 4 | 0.59524 | 0.75258 | 26.43 |
| 5 | 0.54349 | 0.64193 | 18.11 |
| 6 | 0.52399 | 0.61449 | 17.27 |
| 7 | 0.35886 | 0.39802 | 10.91 |
| 8 | 0.31198 | 0.39494 | 26.59 |
| 9 | 0.30711 | 0.36704 | 19.514 |
| 10 | 0.24816 | 0.34852 | 40.44 |
| 11 | 0.21963 | 0.34007 | 54.84 |
| 12 | 0.21522 | 0.33538 | 55.831 |
| 13 | 0.20689 | 0.31177 | 50.69 |
| 14 | 0.19432 | 0.29632 | 52.49 |
| 15 | 0.18627 | 0.26714 | 43.41 |

Spring-based isolation system has a lower frequency compared to a fixed support system. The period needs to be increased to reduce the frequency in order for the structure to survive under the earthquake excitation. In this study, the base isolation model was intentionally designed to limit the earthquake force transmitted to the structures. Considerably, the higher target period of isolation is obtained using spring which can lead to better performance. Mode shapes of buildings depend on the overall geometry of the building, geometric and material properties of structural members, and connections between the structural members and the ground at the base of the building.

Table 8 Comparative study of frequency in cycle per second

| Mode | Frequency (cycle/second) | | Percentage of different (%) |
|---|---|---|---|
| | Fixed Support System | Spring Based Isolation System | |
| 1 | 0.561 | 0.398 | 29.06 |
| 2 | 0.659 | 0.516 | 21.70 |
| 3 | 0.682 | 0.528 | 22.58 |
| 4 | 1.680 | 1.329 | 20.9 |
| 5 | 1.840 | 1.558 | 15.32 |
| 6 | 1.908 | 1.627 | 14.73 |
| 7 | 2.787 | 2.512 | 9.87 |
| 8 | 3.205 | 2.532 | 21.00 |
| 9 | 3.256 | 2.752 | 15.48 |
| 10 | 4.030 | 2.869 | 28.8 |
| 11 | 4.553 | 2.941 | 35.41 |
| 12 | 4.646 | 2.982 | 35.82 |
| 13 | 4.834 | 3.207 | 33.66 |
| 14 | 5.146 | 3.375 | 34.41 |
| 15 | 5.369 | 3.743 | 30.28 |

The data was presented in the graph of the period against mode as in Fig. 6 and Fig. 7 for frequency against mode.

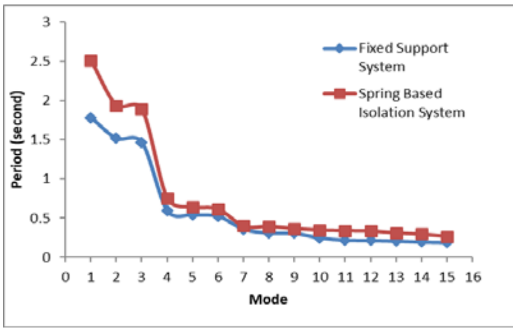


Fig. 6 The period against the mode

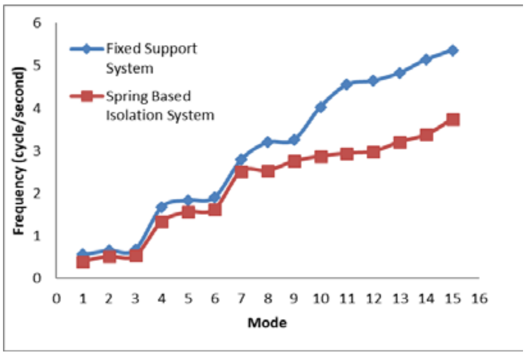


Fig. 7 The frequency against the mode

### 4.5 Elastic Spectral Acceleration

Figure 8 shows a graph of elastic spectrum acceleration against period. The elastic spectral acceleration for spring based isolation system is smaller compared to the fixed support system. The base isolation system reduces the frequency of the structure from its fixed base frequency thus reduces the structure in the higher spectrum to lower regions.

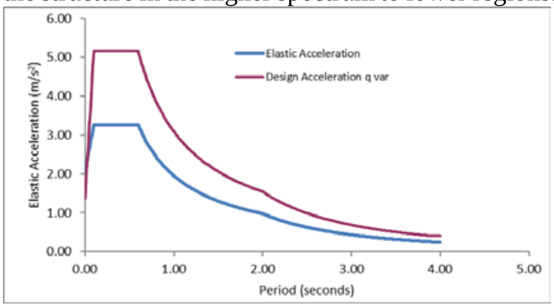


Fig. 8 Elastic spectral acceleration against period

Spring base isolation system brought to a large reduction in the range of short periods and high frequencies compared to the fixed based system. The damping causes high frequencies by an increase in transmissibility at a short period. Since the damping of the isolated building (20%) is 4 times that of the fixed base building (5%), the damping coefficient contributes a positive effect to the behavior of the structure flexibility. The spring based isolation system structure reduces the response of the first fixed base mode of the upper structure. A base isolation system must be sufficiently flexible to cause the fixed base excitation period (frequency) of the isolated structure to be significantly longer than the first fixed base system excitation period.

## 5. CONCLUSION

The story drifts for base isolated building with spring from response analysis was more compared to fixed based building at ground level and reduced as the height increases. The displacement of spring based isolation system building was smaller compared to the fixed base building due to provided flexibility controlled by the base isolators. From the analysis data, it can be summarized that base isolated building has more favorable behavior compared to the fixed base building. The base isolation system substantially increases the time period of the building and reduces the base shear. A base isolation system must also carry sufficient damping to suppress possible large displacement of the upper structure caused by seismic excitation. Thus, the period needs to increase to reduce the frequency in order for the structure to survive under seismic load.

- According to the analytical study following conclusion were drawn:
- Base-isolated structures shown drastic increased in story drift at the ground story and but reduced significantly up to roof level.
- In case of fixed based structure displacement was lesser only at the lower story of a structure but increased significantly when the story height increases compared to spring base isolation system height in which it has higher at ground level but lesser at the top story.
- The base shear for a fixed base from response spectrum analysis was 60% times of base-isolated structure. Therefore, the base shear value of base-isolated structure was smaller compared to the fixed base structure
- The base-isolated structure substantially increases the time period of the building and hence correspondingly reduces the frequency.

## 6. ACKNOWLEDGMENTS

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