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EFFECT OF BASE ISOLATION ON MULTISTOREY STEEL STRUCTURE IN DIFFERENT SOIL CONDITIONS

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ABSTRACT

A quake is a random tremor or movement of the earth's crust, which is developed naturally on or below the surface of earth. While designing a structures in seismically active area, a designer has to make provision of predetermined level of reliability and earthquake resistance of building structures. Now, to improve the seismic resistance, various isolation techniques, including lead rubber bearings, which occupy a leading position in the construction practice utilization, are being increasingly applied. Base isolation (BI) system for buildings is introduced to separate the building structure from potential damage induced by earthquake motion, preventing the building superstructures from absorbing the earthquake energy. A study determining the effectiveness of base isolators is carried out on multi-storey structures with varying height and in different soil condition.

KEYWORDS: Tremor, reliability, isolation, lead rubber bearing.

1. INTRODUCTION

The concept of protecting the structures from damaging effects of earthquakes by introducing some type of support which isolates it from the shaking ground is termed as base isolation [1]. Base isolation systems are one of the most successful and widely-applied methods of mitigating structural vibration and damage during seismic events [2]. Base isolation is nowadays a well-established and viable anti-seismic design strategy for new buildings and bridges, as well as for the retrofit of existing ones, with several thousand applications in over 30 earthquake-prone countries worldwide [3]. The main feature of base isolation technology is that it introduces horizontal flexibility at the base story between the superstructure and the ground to increase the structural period and reduce spectral demand (except for very soft soil sites), dissipates large amount of energy to reduce isolator displacements, and sufficient stiffness at small displacements to provide adequate rigidity for service-level environmental loadings [4-5]. With seismic isolation, flexible devices installed at the base lengthen or shift the building's natural period to the low-acceleration region of the spectrum, along with the energy dissipated by damping, limiting the amount of force that can be transmitted to the superstructure. Consequently, an isolated building accommodates the lower design forces elastically, such that accelerations and interstory drift are reduced to the desired level and structural damage is eliminated or greatly reduced relative to a conventional building that accommodates the design forces through inelastic response [6-7]. Previous results have demonstrated that, increase in the dimensions of structural members and fittings, extra bracings, shear wall or other stiffening members of the structure. Moreover, increase of structural stiffness leads to absorption of more energy from earthquake and requires enhancement of structure's resistance which in turn causes a reduction in economic value of the project. According to the traditional approaches of constructing more resistant structures against earthquake, designing a safe structure is equal to prediction of the non-linear structural behavior which has been designed based on plasticity regulations. Moreover, absorption of vibrational energy is for protecting the structure against destruction [8]. This paper specifically deals with lead rubber bearing (LRB), which consists of alternate layers of rubber and steel plates with one or more lead plugs that are inserted into the holes. The lead core deforms in shear providing the bilinear response (i.e. adds hysteretic damping in the isolated structure) and also provides the initial rigidity against minor earthquakes and strong winds [9].

The specific objectives of the present research focuses on a numerical study to investigate the seismic effectiveness of an Lead rubber bearing base isolator as a seismic protective system for high rising steel structures are summarized as follows: (i) to study the seismic response of fixed base and base isolated steel structure; (ii) to study the effects of storey height on effectiveness of base isolator; and (iii) to investigate the effects of type of soil on seismic performance of of both fixed base and base isolated multi-storey steel structure.

2. MECHANISH OF LEAD RUBBER BEARING

Numerical Modelling

Lead-rubber bearings were first introduced and used in New Zealand in the late 1970s. The horizontal force-deformation relationship, vertical stiffness of lead-rubber bearings along with torsional rigidity is discrete into 2-noded element, having six degree of freedom, which is represented by six springs in six directions as shown in figure 1 [10].

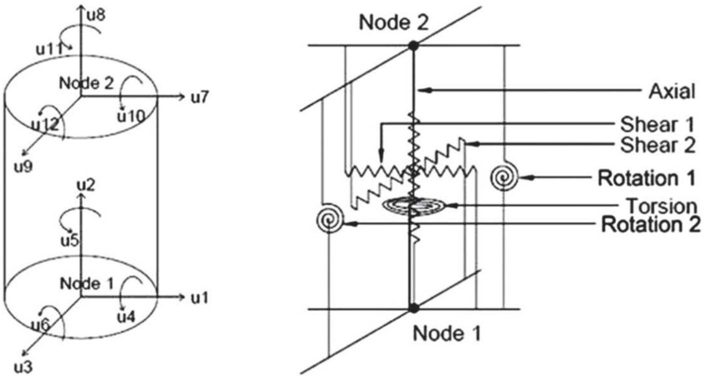


Figure 1: Model showing DOFs and Discrete Springs

Force Displacement Relationship

LRB under lateral displacements produce a hysteresis curve which is a combination of the linear-elastic force-displacement relationship of the rubber bearing plus the elastic-perfectly plastic hysteresis of a lead core in shear. The lead core does not produce a perfectly rectangular hysteresis as there is a shear lag, depending on the effectiveness of the confinement provided by the internal steel shims. The resultant hysteresis curve, as shown in figure, has curved transition on unloading and reloading. For design and analysis an equivalent bi-linear approximation is defined such that the area under the hysteresis curve, which defines the damping, is equal to the measured area [11].

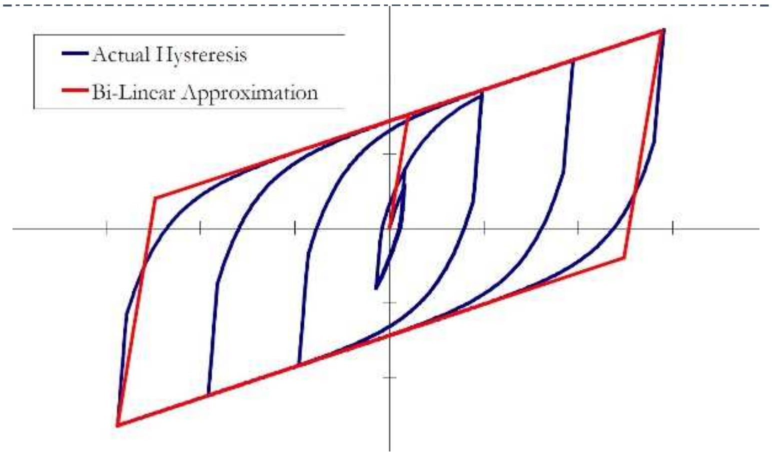


Figure 2: Lead Rubber Bearing Hysteresis

Equation of Motion

The floors of each story of the superstructure are assumed to be rigid and the force-deformation behavior of the superstructure is considered to be linear. The isolation system installed between the base and foundation of the superstructure and it is modelled by the bi-linear behavior as shown in Figure 3

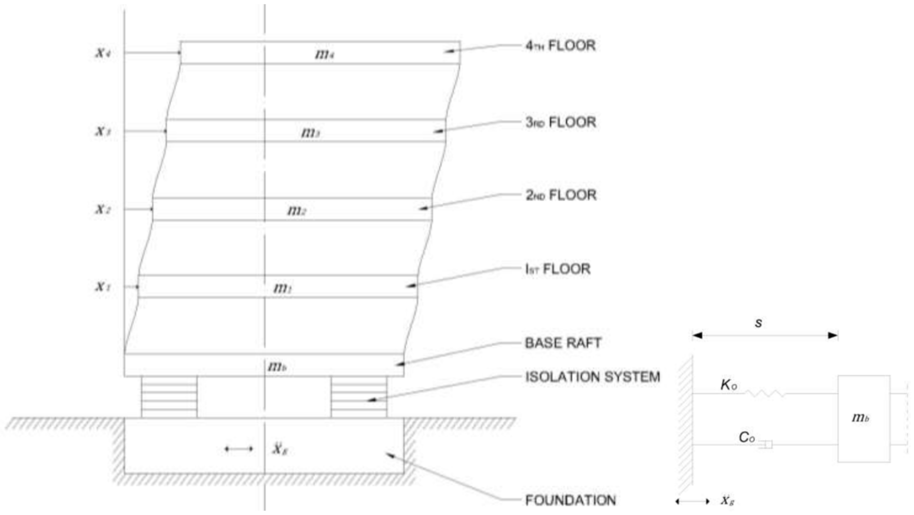


Figure 3: Structural Model of a Four-Story Building with a Base Isolation System and Schematic Diagram of Lead Rubber Bearing Isolation System

The equations of motion of the super structure remain the same for all base isolation systems as follows;

$$[\mathrm{m}]\{\ddot{x}\} + [\mathrm{C}]\{\dot{x}\} + [\mathrm{K}]\{x\} = -(\ddot{s} + \ddot{x}_{\mathrm{g}})\,[\mathrm{m}]\{1\} \qquad \text{(i)}$$

where, [M], [K] and [C] are the mass, damping and stiffness matrices of the superstructure respectively corresponding to the degrees of freedom (DOF) at the slabs; s is the relative displacement between the base of the structure and the ground, $\ddot{x}_{\mathrm{g}}$ is the horizontal ground acceleration. In this equation, {1} is a vector all of whose elements are unity.

The equation governing the displacement of the isolator is given as,

$$\ddot{s} + 2\zeta_o\omega_o\dot{s} + \omega_o^2 s + \sum_{i=1}^{n} \alpha_i\ddot{x}_i = -\ddot{x}_g \qquad \text{(ii)}$$

Where, the natural circular frequency ω_o and its effective damping ratio ζ_o are defined as;

$$2\zeta_o\omega_o = \frac{C_o}{M} \qquad \text{and} \qquad \omega_o^2 = \frac{K_o}{M} \qquad \text{(iii)}$$

Here C_o and K_o are the damping and the horizontal stiffness of the bearing, respectively.

A natural period T_o of about 2 sec ($\omega_o = \pi$ rad/sec) is commonly suggested and considered in this study for the LRB base isolation systems. The effective damping ratio of the isolator ζ_o varies considerably with the strain of the rubber. It may be as high as 0.3 for low strain and reduced to about 0.05 for high strain rubber.

Since the force-deformation behaviour of the isolation system considered is non-linear, as a result, the governing equations of motion of the flexible base-isolated structure cannot be solved using the classical modal superposition technique. The seismic response of the system is obtained by solving the governing equations of motion in the incremental form using Newmark's step-by-step method with linear variation of acceleration over small time interval, Δt.

The characteristic strength of the bearing is normalized with the total weight of the isolated building and expressed by the parameter μ as;

$$\mu = \frac{Q}{W} \qquad \text{(iv)}$$

The characteristic strength of base isolator is generally estimated from the hysteresis loop of the isolation system which depends upon its yield strength.

$$F_y = Q + K_2 \times D_y,\ \text{kN} \qquad \text{(v)}$$

Where, Q is the force at design displacement, K_2 and D_y are pre-yield and yield displacement in rubber.
The post-yield stiffness of the isolation system is designed in such a way to provide the specific value the isolation period, Tb expressed as

$$T_b = 2\pi\sqrt{\frac{(W/g)}{K_2}} \qquad \text{(vi)}$$

Where, K_2 is expressed in terms of post-yield stiffness to pre-yield stiffness ratio (assumed, n=1) as follows;

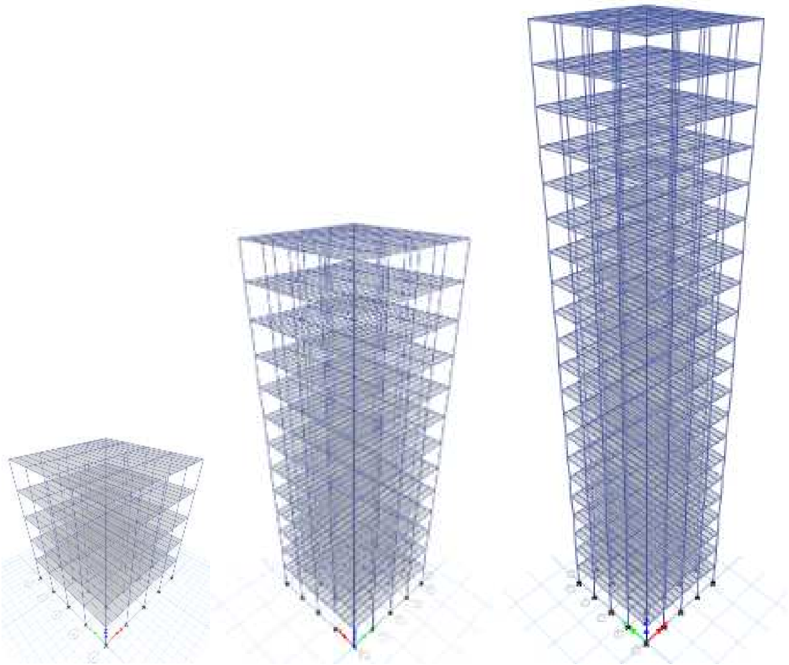
$$n = \frac{K_2}{K_1} \qquad \text{(vii)}$$

Thus, the three important parameters μ, T_b, and n of the isolator can be used to model the base isolation system considered [5,7,12-13].

3. STRUCTURAL MODEL

The dynamic response of base-isolated building is obtained under two different earthquake ground motions on three different steel structural models with varying height, viz., 20m, 52m and 84 m respectively. The damping matrix of the superstructure is constructed by assuming the modal damping ratio of 0.02 in all modes of vibration. In the present study, one recorded earthquake motions is used namely N00E component of 1942 Imperial Valley earthquake (recorded at El Centro Array). The peak ground accelerations (PGA) of Imperial Valley earthquake motion is 0.348g.

Following figure shows the plan of structure considered along with 3D models of different heights,



G + 4 *G + 12* *G + 20*

Figure 4: Steel Structure

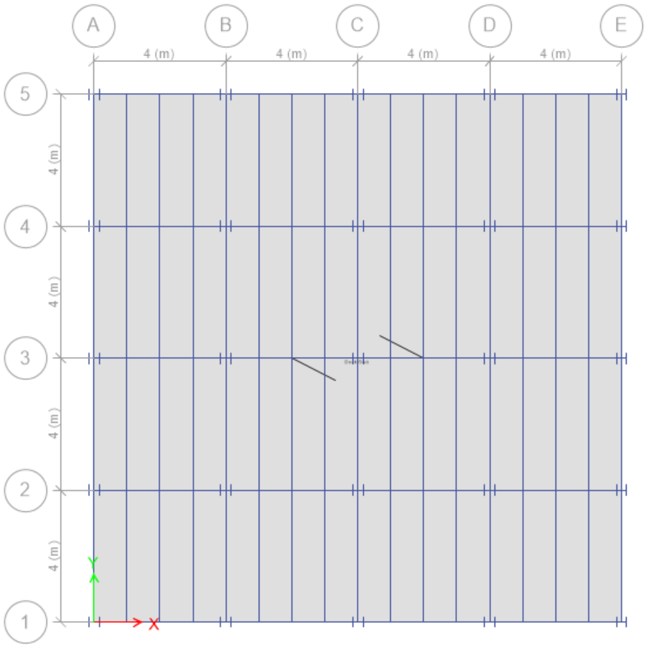


Figure 5: Plan of Steel Structure considered

Table 1. Steel Sections used in Structure

Model	**Fixed Base Structure**		**Base Isolated Structure**	
	Columns	**Beams**	**Columns**	**Beams**
G + 4	356 406 340 (100)	356 171 51 (160)	356 406 340 (125)	356 171 51 (200)
	356 406 509 (25)	406 178 74 (40)	--	--

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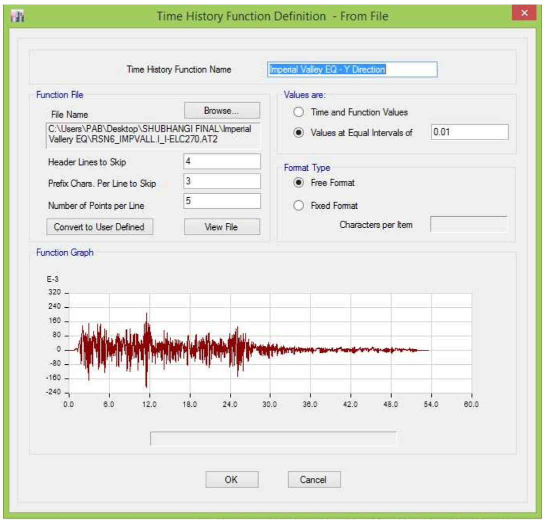
G + 12	356 406 340 (125)	356 171 51 (200)	356 406 340 (225)	356 171 51 (360)
	356 406 509 (100)	406 178 74 (160)	356 406 509 (50)	406 178 74 (80)
	356 406 677 (75)	457 191 98 (120)	356 406 677 (50)	457 191 98 (80)
	356 406 818 (25)	533 210 101 (40)	--	--
G + 20	356 406 340 (150)	356 171 51 (240)	356 406 340 (250)	356 171 51 (400)
	356 406 509 (125)	406 178 74 (200)	356 406 509 (50)	406 178 74 (80)
	356 406 677 (75)	457 191 98 (120)	356 406 677 (50)	457 191 98 (80)
	356 406 818 (75)	533 210 101 (120)	356 406 818 (75)	533 210 101 (120)
	356 406 900 (50)	533 210 122 (80)	356 406 900 (100)	533 210 122 (160)
	356 406 990 (50)	610 229 140 (80)	--	--



Time History Function Definition - From File

Time History Function Name: Imperial Valley EQ - Y Direction

Function File

File Name: C:\Users\PAB\Desktop\SHUBHANGI FINAL\Imperial Valley EQ\RSN6_IMPVALL.I_I-ELC270.AT2

Header Lines to Skip: 4

Prefix Chars. Per Line to Skip: 3

Number of Points per Line: 5

Values are:

○ Time and Function Values

● Values at Equal Intervals of: 0.01

Format Type

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Characters per Item:

Figure 6: Snapshot of Imperial Valley Earthquake Time History function

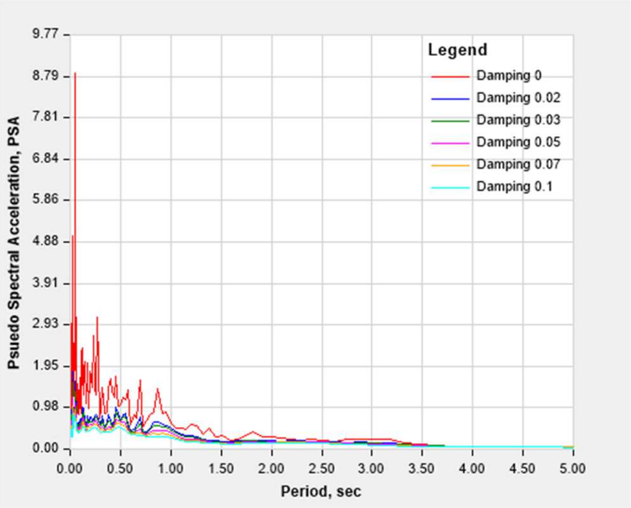

Figure 7: Response Spectrum Plot for Specified Damping Ratios

4. ANALYSIS AND RESULTS

The response behavior of bare multi-storey steel structure with fixed base and steel structure with supplemental device such as lead rubber bearing base isolator, subjected to real time history earthquake record has been investigated. Dynamic responses of Fixed Base and Base Isolated models have been calculated for one real earthquake time history data of Imperial Valley Earthquake of 1997, scaled to 0.3g and taken from Peer Ground Motion Database. It was found that proper implementation of such supplemental devices like base isolators limits the energy dissipated by the building. Different performance indices are evaluated considering various response measures; such as Modal properties, Base Shear, and Storey Displacement. These indices help to assess the optimal performance of base isolators in the frame structure. In this analysis stage, modal properties, base shear, and story displacement of both the fixed-base and base isolated multi-story steel structure were found at DBE level by means of non-linear time history examinations.

Modal period and Mass Participating ratio

The modal period and modal mass participation ratio of base isolated steel structure is greater than that of fixed base structure. It is also observed that, modal period increases as the overall height of building increases. And the mass participation factor reduces as the overall height of structure increases, this critical observation is due to introduction of sway mechanism in high rising structures.

Table 2. Modal Properties

Model	Fixed Base Structure		Base Isolated Structure	
	Modal Period	**Modal Mass Participating ratio (UY)**	**Modal Period**	**Modal Mass Participating ratio (UY)**
G + 4	1.841	0.8258	2.74	0.9914
G + 12	2.451	0.7829	3.614	0.9051
G + 20	3.402	0.7139	4.313	0.8242

Base Shear and Storey Displacement

Base shear and storey displacement both reduces upto a great extent with the provision of base isolator. But it is observed that, base isolator reduces significant amount of base shear in low rising structures, than in high rising structures. Similarly, storey displacement is also arrested in appreciable amount.

Table 3. Base Shear in Different Soil Conditions

Model	Hard Soil		Medium Soil		Soft Soil	
	Fixed Base	**Base Isolated**	**Fixed Base**	**Base Isolated**	**Fixed Base**	**Base Isolated**
G + 4	1050.31	481.95	1428.42	518.95	1754.01	741.95
G + 12	1434.45	883.17	1950.85	1038.17	2395.52	1181.55
G + 20	1686.13	1356.25	2293.13	1453.55	2815.83	1545.39

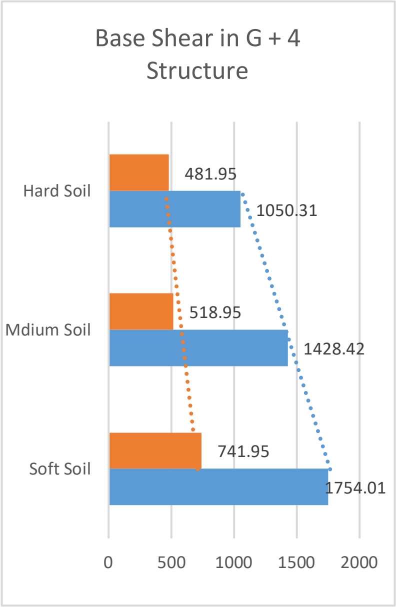

Figure 8: Base Shear of G + 4 storey Steel Structure

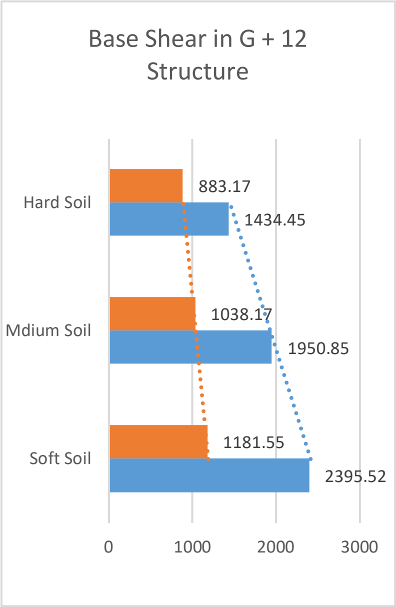

Figure 9: Base Shear of G + 12 storey Steel Structure

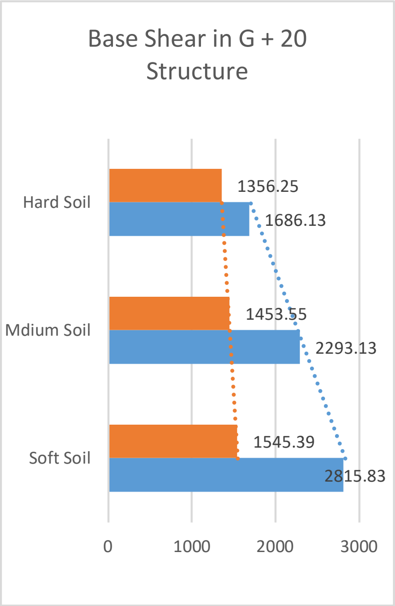

Figure 10: Base Shear of G + 20 storey Steel Structure

Besides the varying height of structure, soil condition at site also plays an important role in mitigating earthquake hazard. It was observed that, base isolators are more efficient in hard soil, rather in medium or soft soil.

Table 4. Storey Displacement in Different Soil Conditions

Model	**Hard Soil**		**Medium Soil**		**Soft Soil**	
	Fixed Base	**Base Isolated**	**Fixed Base**	**Base Isolated**	**Fixed Base**	**Base Isolated**
G + 4	38.971	17.53	58.02	37.56	71.25	56.37
G + 12	51.99	34.88	121.19	56.04	148.73	65.40
G + 20	88.88	47.49	183.76	70.96	225.64	87.69

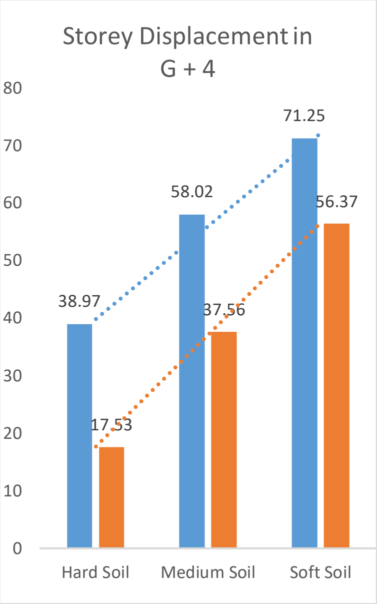

Figure 11: Storey Displacement of G + 4 storey Steel Structure

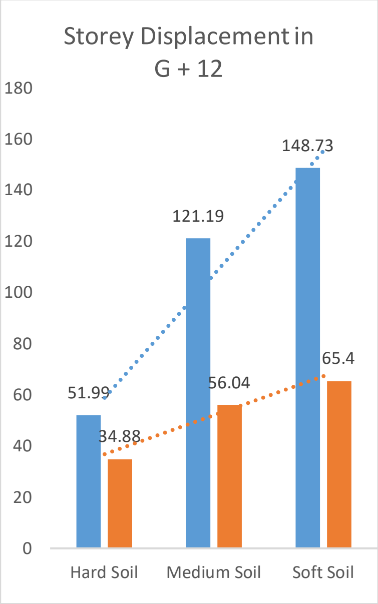

Figure 12: Storey Displacement of G + 12 storey Steel Structure

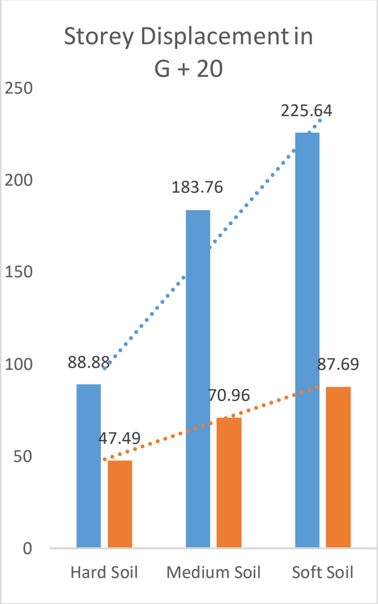

Figure 13: Storey Displacement of G + 20 storey Steel Structure

5. CONCLUSION

Based on the results obtained, following observations and conclusions are drawn;

1. The base shear in multi-storey steel structure decreases in the range of 35 to 55 percent.
2. Reduction of the base-shear force is evident in the model with implemented seismic isolation.
3. The increase in storey displacements observed was in the range of 1.24 to 3.2 times that of fixed base structure for bottom storey.
4. Fixed base building have zero displacement at base whereas, base isolated building shows appreciable amount of lateral displacements at base (due to presence of Base Isolator).
5. Increased flexibility of the system led to increase of the total displacements due to the elasticity of the existing isolation.
6. Base isolators reduces appreciable amount of base shear in hard soil.
7. As the floor height increases, storey acceleration increases drastically in fixed base building as compared to base isolated building where it is almost constant.
8. Increase in modal period in the range of 1.17 to 1.94 times is the result of the increased flexibility of the system.

Finally it is concluded that base isolation system is significantly effective to protect the structures against moderate as well as strong earthquake ground motion preferably in hard soil, than in medium or soft soil..

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