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Seismic Analysis of Building on Different Types of Soil Using Base Isolation Technique

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ABSTRACT:The Project considers suitability of base isolation techniques in given site condition. Civil engineering deals with constructing different types of structures with ensuring safety, durability and serviceability. Now days “earthquake” is phenomena that affects the structures with their safety and serviceability. The amount of damage that earthquake can done to structures is depend on Type of building, Type of soil, Technology used for earthquake resistance, and last but not the least Location of building. Effects of earthquake is largely depended on type of soil in which foundation of building is done because earthquake changes the motion of ground that results the failure foundation. So, it is important to study the behaviour of different soil at the time of construction of structures. Also, earthquake can resist by various technologies used in building, one of these are base isolation techniques. It improves the structural performance of building subjected to lateral forces due to earthquake excitation. This study focuses on behaviour of different types of soil at the time of earthquake occurrence and base isolation impact on structures.

KEYWORDS:Earthquake Zone, Soil types, Base Shear, ETABS.

I. INTRODUCTION

The earthquake resistant structures can be categorized into rigid structures and flexible structures. In rigid structures, the control methods that are applied to withstand extreme loads are basically reducing the inter story displacement with the help of diagonal bracing, the installation of shear walls and the use of composite materials. In flexible structures, such as base-isolated buildings, the key control approach is to reduce the excitation input with the use of dampers and isolators. However, significant inter story drift and floor accelerations of highly stiffening structures raise risks of severe devastation of the building, especially under large scale of earthquake. Flexible structures such as high-rise buildings can avoid resonant condition and effectively reduce structural responses.

II. RELATED WORK

Arun Babu M, Ajisha, “Analysis of Multistoried Building in Different Seismic Zones with Different Soil Conditions” 2018

The foundation of a building is the substructure through which loads of the whole structure are transmitted to the soil. There are various types of soil present in India. The types of soil play a major role while designing a structure. Here the analysis and design of the building are done by varying the type of soil. The difference in the analysis of structure is studied. After that, the seismic analysis for various zones is carried out for the same soil conditions, and also by changing the model of the building, the same is done. And the difference is studied.

S. Gyawali, “Effect of Base Isolation in Multi storied RC Regular and Irregular Building by Using Response Spectrum Analysis” 2020

The research is based on analysis of six building models in which two models were geometric regular, another two models were plan irregular and remaining two models were vertical irregular buildings. Regular, plan irregular (re-entrant corners) and vertical irregular (vertical geometric irregularity) buildings were considered for both isolated and non-isolated buildings.

III. METHODOLOGY

The project is based on analysis of buildings in without isolated buildings of different story heights compared with isolated bases. For the G+10, G+15, G+20, G+25 plan of 31.5x20m is considered

Case : G+10, G+15, G+20, G+25. (S1,S2,S3)

Model-1: RC frame building with fixed base.

Model-2: RC frame building with Lead Rubber Bearing (LRB).

Model-3: RC frame building with Frictional Isolator (FI).

Model-4: RC frame building with Triple Friction Pendulum Bearing (TFPB).

LRB Design

1. The first step is to find the maximum shear force (W_i) on the columns for a particular building model with the fixed base system and the minimum rubber diameter of LRBs is calculated based on this vertical force.

2. By setting target period T_{eff} (2 seconds appear to be the desired one) and effective damping 5% according to IS 1893:2016.

3. The spectral acceleration S_a is calculated from the response spectrum graph of IS 1893:2016.

4. The design displacement is calculated by the formula: $dbd = (T_{eff}/2\pi) s_a = 0.477$

5. The effective stiffness (K_{eff}) for U1 value is calculated by the formula

$$K_{eff} = (2\pi/T_{eff})^2 w/g = 13753.057$$

Where, T_{eff} = Effective fundamental period of the superstructure.

W_i = Maximum vertical reaction on the column of fixed base analyzed the model.

K_{eff} = Effective stiffness of the isolation system in the principal horizontal direction at designed displacement (dbd).

6. The dissipated energy at the designed displacement (dbd) is obtained by the formula

$$ED = 2 K_{eff} * dbd = 983.07$$

7. The force at design displacement or Characteristics strength is calculated by the formula

$$F_o = ED/4dbd = 515.235$$

8. The Stiffness of the lead core of LRBs is calculated by the formula: $K_{pb} = F_o/dbd = 1080.15$

9. The stiffness of rubbers of LRBs is calculated by the formula: $K_r = K_{eff} - K_{pb} = 12672.90$ KN/m

10. The total thickness of LRBs is calculated by the formula: $T_r = dbd/\gamma = 0.477$

11. The diameter of lead rubber bearings is calculated by the formula: $D_{bearing} = \sqrt{K_r * T_r / 400\pi} = 8.635$

12. Calculation of total loaded area (AL):

The Diameter of the lead core of LRB is calculated by the formula $D_{bearing} = \sqrt{4F_o / \pi \sigma_{pb}} = 3.315$

Where, σ_{pb} = Total yield stress in lead, (Assume 11 MPa)

13. Area of lead core in LRB in m^2 , $A_{pb} = \pi/4 * D_{pb}^2 = 0.1787$

14. The Diameter of the force-free section, $D_{eff} = D_{bearing} - 2t_r = 2.361$

15. Force-free area $A_{ff} = \pi/4 * D_{ff}^2 = 4.378$

16. Total Loaded Area, $AL = A_{ff} - A_{pb} = 4.1993$

17. The Circumference of the force-free section is calculated by the formula: $C_f = \pi * t * D_{ff} = 3.5380$

18. Shape Factor, $C_i = AL/C_f = 1.1869$

19. Total Height of LRB, $H = (N * t) + (n-1)t_s + 2tap = 0.467$

Where, $N = 0.2/t = 0.2/0.01 = 20$; N = No. of rubber

t = Single rubber layer thickness (0.01)

t_s = Thickness of steel lamination (0.003) and

tap = Laminated anchor plate thickness (0.04) m

20. The bearing horizontal stiffness for U2 & U3 (Linear Stiffness) is calculated by the formula:

$$K_b = G * A_r / H = 12671.90$$

Where, G = Shear modulus (varying from 0.4 To 1.1 MPa)

Adopt 1 MPa

A_r = Rubber layer area

21. The total bearing vertical stiffness for U2 and U3 (Non-linear Stiffness) is calculated in KN/m

$$K_v = 6 * G * S_i^2 * A_r * K / (6 * G * S_i^2 + K) * H = 109078.78$$

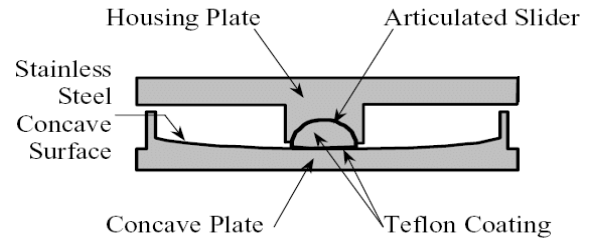
Where, S_i = Shape Factor, and

k = Rubber compression modulus = 2000 MP

		G+10	G+15	G+20	G+25
	Rotational inertia	0.4438	0.9841	0.2911	5.9279
Direction U1	Linear Properties				
	Effective Stiffness	5773500 kn/m	8400733 kn/m	11122160 kn/m	13753057 kn/m
Direction U2 & U3	Linear Properties				
	Effective Stiffness	5773.5 kn/m	8400.733 kn/m	11122.16 kn/m	13753.057 kn/m
	Effective damping	0.05 kn-s/m	0.05 kn-s/m	0.05 kn-s/m	0.05 kn-s/m
	Shear deformation location				
	Distance from end J	0.0031 m	0.003 m	0.003 m	0.0045 m
	Non-Linear Properties				
	Stiffness	51961.9 KN/M	77409.4 KN/M	102486.7 KN/M	126729 KN/M
Yield strength	160.48 KN	233.31 KN	308.87 KN	572.38 KN	
Post yield stiffness ratio	0.1	0.1	0.1	0.1	

Properties of friction isolator

Direction U1	Linear Properties	
	Effective Stiffness	15000000 kn/m
	Non-Linear Properties	
Direction U2 & U3	Effective Stiffness	15000000 kn/m
	Linear Properties	
	Effective Stiffness	750 kn/m
	Non-Linear Properties	
	Stiffness	15000
	Friction coefficient slow	0.03
	Friction coefficient fast	0.05
Rate parameter	40	
Net pendulum Radius	2.23	



Triple Friction Pendulum Bearing

A) Calculation of geometric, frictional and DD

(a) Geometric Properties

$R1 = R4 = 1160 \text{ mm}$ or 1.160 mtrs. $R2 = R3 = 820 \text{ mm}$ or 0.820 mtrs.

$h1 = h4 = 200 \text{ mm}$ or 0.200 mtrsh2 = $h3 = 155 \text{ mm}$ or 0.155 mtrs

$d1 = 170 \text{ mm}$ $d2 = 160 \text{ mm}$

$R1 \text{ eff4} = R4 \text{ eff4} = R1 - h1 = 1160 - 200 = 960 \text{ mm}$.

$R2 \text{ eff4} = R3 \text{ eff4} = R2 - h2 = 820 - 155 = 665 \text{ mm}$.

$d1^* = d4^* = d1 \times R1 \text{ eff} / R1 = 140.68 \text{ mm}$.

$d2^* = d3^* = d2 \times R2 \text{ eff} / R2 = 129.75 \text{ mm}$.

(b) Calculating frictional properties of the bearing Bearing pressure at surfaces 1 and 4

$P = \text{Load} / \text{Area}$

Here $V_k \text{ Load} = 5.738 \text{ ton}$ or 5738 kN,

Area $A = \pi \times r^2$

$r = h1 + h4 = 200 + 200 = 400 \text{ mm}$

$P = 1.128 \times 10^{-3} \text{ ton/mm}^2$,

$P = 0.001128 \times 1450 = 1.63 \text{ ksi}$. 1 ksi = Kilo square inch = 1450 ton/mm².

3- Cycle friction, $\mu = 0.122 - 0.01 P = 0.1057$

Adjust for high velocity = $-0.033 = 0.1057 - 0.033 = 0.0727$ (Lower bound friction)

I - cycle friction $\mu = 1.2 \times 0.072 = 0.0864$

Lower bound $\mu1 = \mu4 = 0.072$

Upper bound $\mu1 = \mu4 = 0.086$

Bearing pressure at surfaces 2 and3

$P = \text{Load} / \text{Area}$

Here $V_k \text{ Load} = 573.8 \text{ ton}$ or 5738 kN,



Area $A = \pi r^2$

$r = h_2 + h_3 = 155 + 155 = 310 \text{ mm}$

$P = 2.724 \text{ ksi}$. $1 \text{ ksi} = 1450 \text{ ton/mm}^2$.

3-Cycle friction, $\mu = 0.122 - 0.01P = 0.09476$

Adjust for high velocity = $-0.033 = 0.09476 - 0.036 = 0.05876$ (Lower bound friction)

I-cycle friction $\mu = 1.2 \times 0.05876 = 0.0705$

Lower bound $\mu_1 = \mu_4 = 0.0587$

Upper bound $\mu_1 = \mu_4 = 0.0705$

$\mu = \text{force at zero displacement} / \text{divided by the normal load}$

For Lower bound

$\mu_1 = \mu_1 - (\mu_1 - \mu_2) \times R_{2\text{eff}} / R_{1\text{eff}} = 0.0627$

For Upper bound

$\mu_1 = \mu_1 - (\mu_1 - \mu_2) \times R_{2\text{eff}} / R_{1\text{eff}} = 0.0752$

Calculating DD (Upper bound Analysis)

$S_d = 0.5$ $\mu = 0.075$

$\mu_1 = 0.086$ $D_y = 0.0021$

$F_d = 0.4W = 570$

No. of Bearing = 10

$\Sigma F_d = F_d \times W \times \text{Total Bearing} = 0.4 \times 570 \times 10$

$\Sigma F_d = 2280$

$\Sigma w = V_k \text{ Load} \times \text{No. of bearing} = 5700 \text{ tons}$

Let the displacement be $DD = 0.16 \text{ mtrs.}$

Effective stiffness, $Q_d = \mu \times \Sigma w = 0.075 \times 5700$

$Q_d = 427.5 \text{ ton}$

$k_D = \Sigma F_d / DD = 2280 / 0.16$

$k_D = 14250 \text{ ton/m.}$

$K_{\text{eff}} = k_D + Q_d / DD = 14250 + 427.5 / 0.16$

$K_{\text{eff}} = 16921.87 \text{ ton/m.}$

Effective period, - refer Eq. 17.5-2, ASCE 7-10

$T_{\text{eff}} = 2\pi \sqrt{(\Sigma w) / (K_{\text{eff}} \times g)}$ $T_{\text{eff}} = 1.162 \text{ sec.}$

Effective damping

$\beta_{\text{eff}} = \beta_D = E / 2k_{\text{eff}} DD^2 = 4 \Sigma w (DD - D_y) / 2k_{\text{eff}} DD^2 = 0.1164 \text{ or } 11.64\%$

Damping reduction factor

$\beta = (\beta_{\text{eff}} / 0.05)^{0.3} = 1.288$

$DD' = (SD \times T_{\text{eff}}^2 / 4 \pi^2 \beta) \times g = 0.1307 \text{ m}$

Calculating Etabs links / support property data (upper bound)

Main Properties

Determine of Bearing (Rotational Inertia)

It had been considered that the isolator is a cylinder with diameter $\phi = 0.305 \text{ m}$ with height $h = 0.32 \text{ m}$ (Total height of the bearing)

$\phi = 0.484 \text{ m}$, $h = 0.5 \text{ m}$

Then C/s Area $A = (\pi \phi^2 / 4) = 0.1840 \text{ m}^2$

$K_{\text{eff}} = (W / R_{1\text{eff}}) + (\mu W / DD) = 268.49 \text{ ton/m}$

$I_1 = K_{\text{eff}} \times h^3 / 12E = 2.79 \times 10^{-7} \text{ m}^4$

Note: - Young's modulus 'E' was assumed $1 \times 10^7 \text{ N/mm}^2$ equal to half of actual steel modulus as the bearing is not a solid piece of metal.

$E = 1.00 \times 10^7 \text{ N/mm}^2$.

Determine of Bearing mass

$D_{\text{max}} = 0.0702 \text{ m}$

$DTM = 1.15 \times 0.072 = 0.0807 \text{ m}$

$D = 2DTM = 0.16416 \text{ m}$

$W = 0.241 D^2 - 0.0564 D = 0.0053721 \text{ ton}$

$M = W / g = 0.000548 \text{ ton sec}^2/\text{m}$

Directional properties (U1)

$\phi = 0.484 \text{ m}$ or $L = 0.5 \text{ m}$

Effective stiffness = AE / L

$K_{\text{eff}} = 3679684.6 \text{ ton/m.}$

Effective damping from the DD calculation = 14.13%



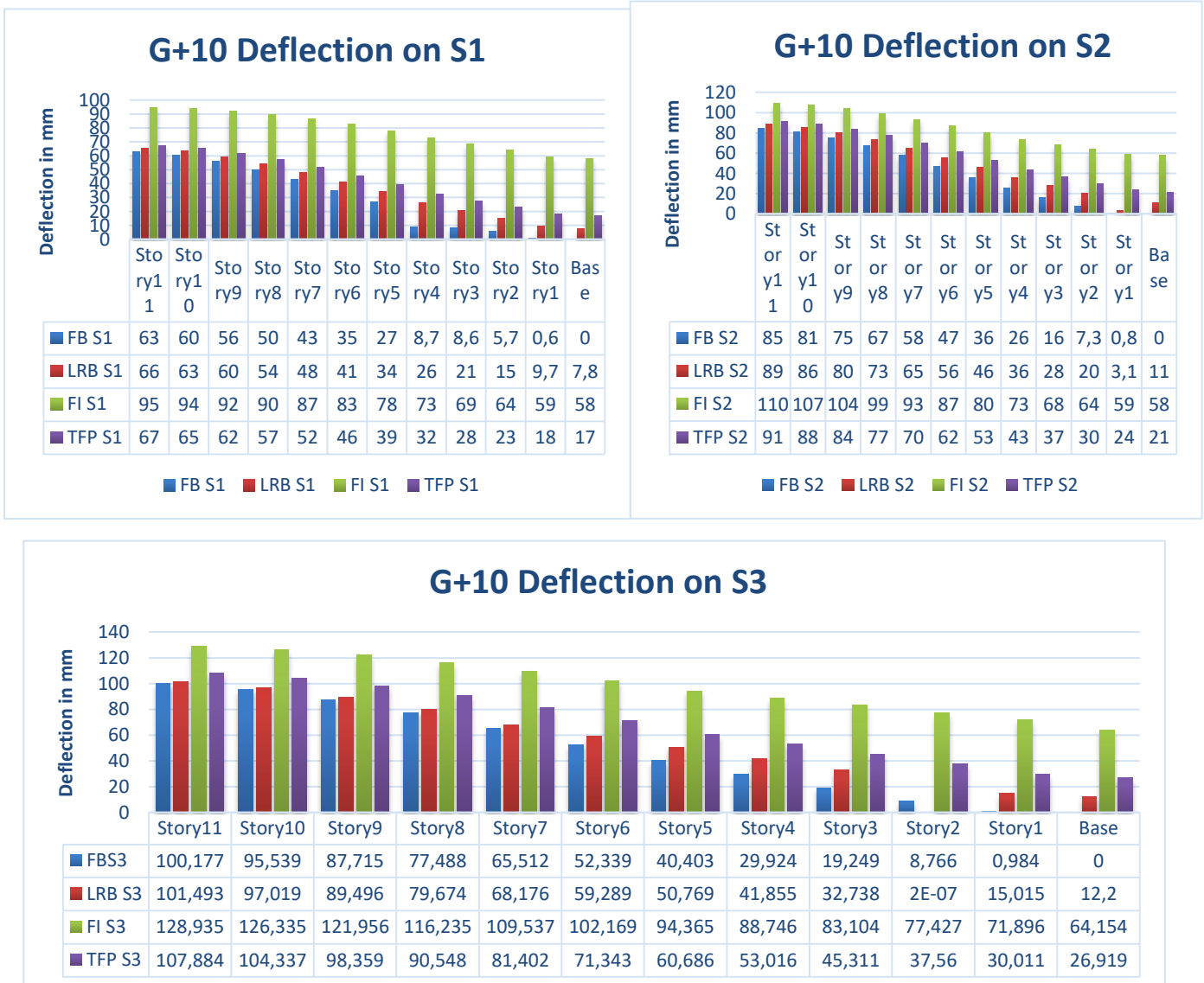
$K_{eff} = 3679684.6 \text{ ton/m} = 36088472 \text{ KN/M}$
 $\beta_{eff} = 1.288$
 Directional properties (U2 -U3)
 Determination of liner properties.
 Effective stiffness $K_{eff} = 268.49 \text{ ton/m} = 2632.98 \text{ KN/M}$
 Effective damping $\beta_{eff} = 1.288$
 Height for outer surface, $= h1 = h4 = 200 \text{ mm}$ or 0.200 mtrs.
 Height for outer surface, $= h2 = h3 = 155 \text{ mm}$ or 0.155 mtrs.
 Determination of Non-linear properties.
 Stiffness $= \mu_1 W/DY = 2334.28$
 $R_{2eff} = 0.665 \text{ m}$
 $Dy = (\mu_1 - \mu_2) R_{2eff} = 0.00931$
 Stiffness of outer surface $= \mu_1 W/DY = 5265.30 \text{ ton/m}$
 Stiffness of inner surface $= \mu_2 W/DY = 4408.16 \text{ ton/m}$
 Friction slow $= \mu_1$ for outer surface $= 0.086$
 $= \mu_2$ for outer surface $= 0.070$
 Friction fast $= 2 \times \mu_1$ for outer surface $= 0.172$
 $= 2 \times \mu_2$ for outer surface $= 0.140$
 Rate Parameter $=$ Friction slow / Friction fast $= 0.093 / 0.187 = 0.5$
 Radius of sliding surface
 For outer $= R_{1eff} = 0.960 \text{ mtrs.}$
 For inner $= R_{2eff} = 0.665 \text{ mtrs.}$
 Stop distance
 For outer surface $u1^* = 2Dy + 2d1^* = 0.298662 \text{ mtrs.}$
 For outer surface $u2^* = 2Dy = 0.01862 \text{ mtrs.}$
 Etabs Input Values
 Nonlinear Link Type: Triple friction
 pendulum. Directional Properties (U1, U2, & U3):

		G+10		G+15		G+20		G+25	
Direction U1	Linear Properties								
	Effective Stiffness	36088472 kn/m		36088472 kn/m		36088472 kn/m		36088472 kn/m	
	Effective Damping	1.288		1.332		1.3456		1.362	
	Non-Linear Properties								
	Effective Stiffness	36088472 kn/m		36088472 kn/m		36088472 kn/m		36088472 kn/m	
	Effective Damping	1.288		1.332		1.3456		1.362	
Direction U2 & U3	Linear Properties								
	Effective Stiffness	2632.98 kn/m		3921.38 kn/m		17390.03 kn/m		15060.46 kn/m	
	Effective Damping	1.288		1.332		1.3456		1.362	
	Height for outer surface	0.200 m		0.200 m		0.200 m		0.200 m	
	Height for inner surface	0.155 m		0.155 m		0.155 m		0.155 m	
	Non-Linear Properties								
		Outer top	Outer top	Outer top	Outer top	Inner top	Inner top	Outer top	Inner top
	Stiffness	51634.95	73925.96	97914.49	121050.83	100909.54	81619.17	97914.49	81619.17



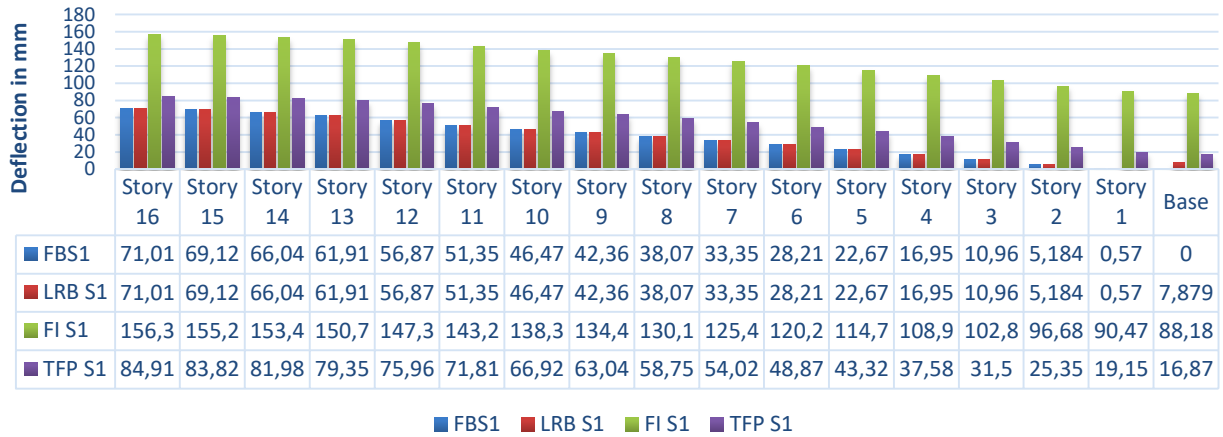
Friction coefficient slow	0.086	0.077	0.0685	0.0595	0.0244	0.043	0.0685	0.043
Friction coefficient fast	0.172	0.154	0.137	0.119	0.0488	0.086	0.137	0.086
Rate parameter	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Radius of sliding surface	0.960 m	0.960 m	0.960 m	0.960 m	0.665 m	0.665 m	0.960 m	0.665 m
Stop distance (m)	0.29862	0.357236	0.29652	0.353167	0.013167	0.015162	0.29652	0.015162

IV. EXPERIMENTAL RESULT



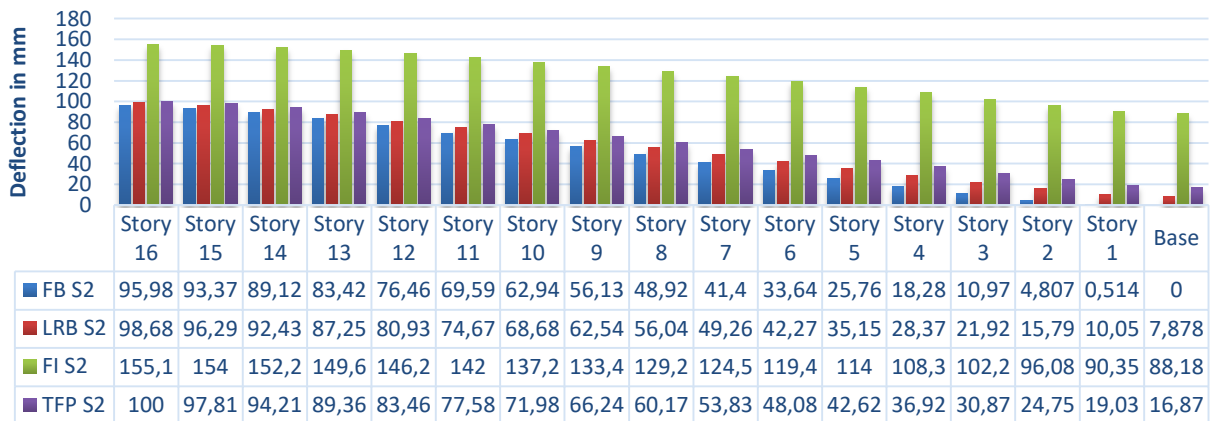


G+15 Deflection on S1

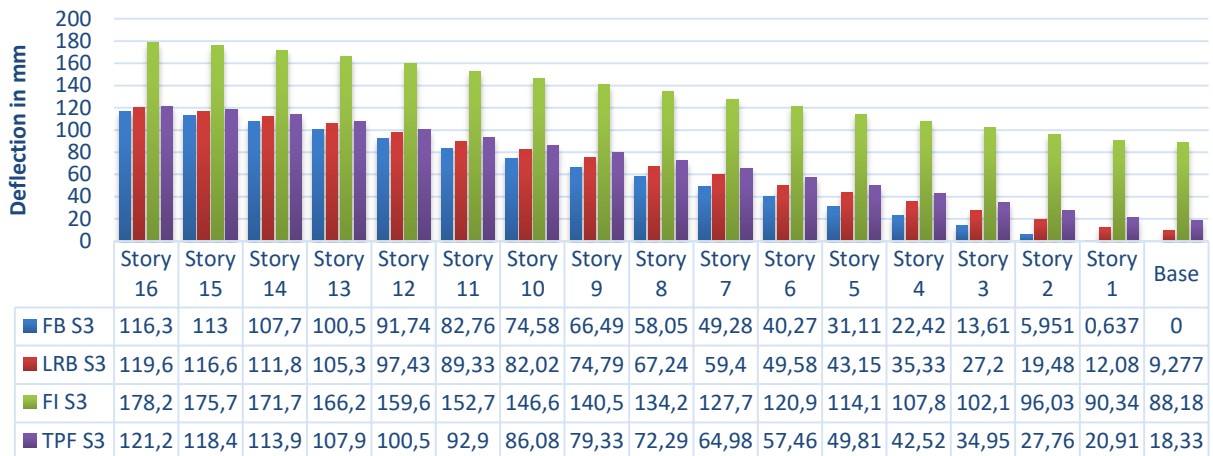


■ FBS1 ■ LRB S1 ■ FI S1 ■ TFP S1

G+15 Deflection on S2

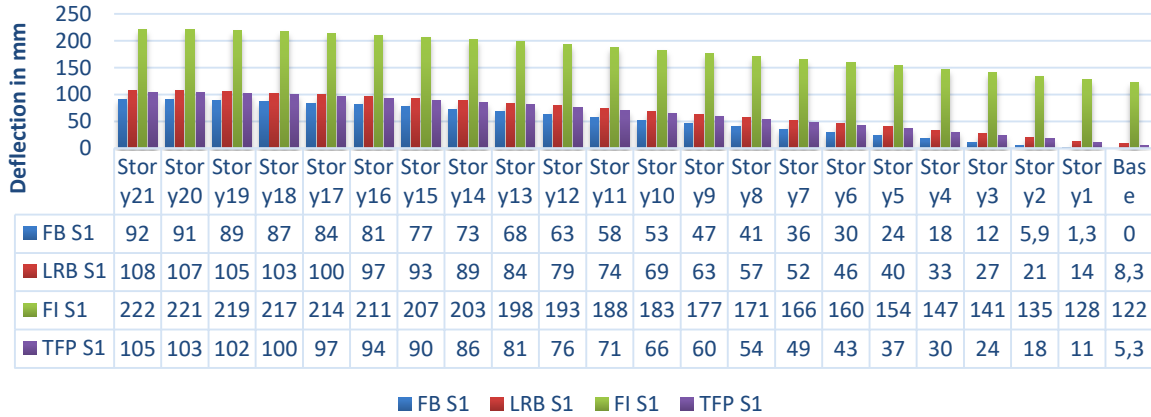


G+15 Deflection on S3

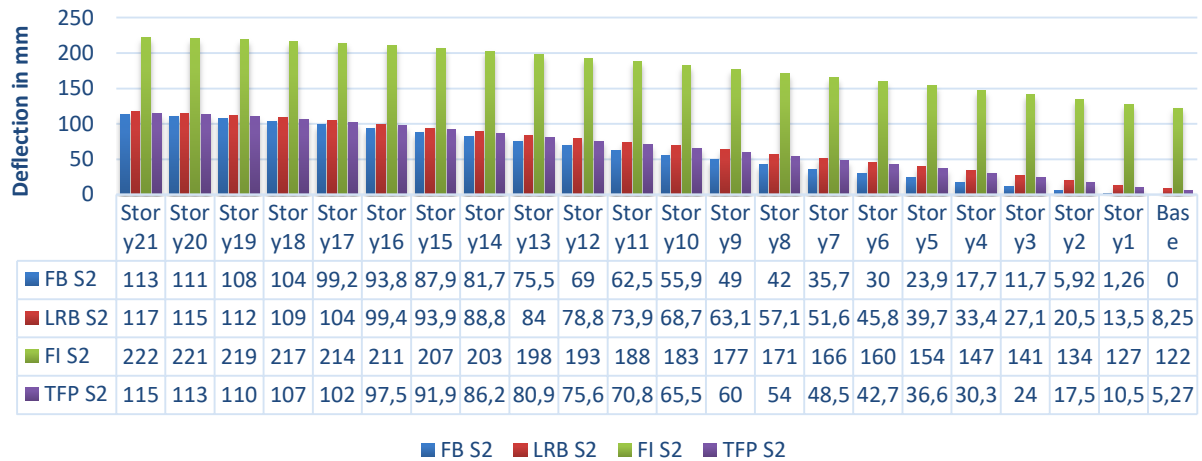




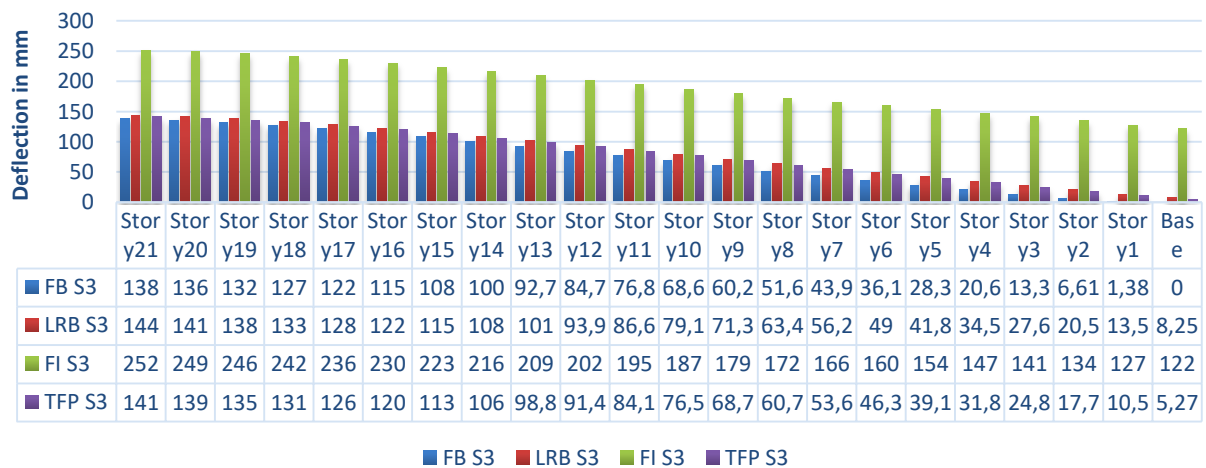
G+20 Deflection on S1



G+20 Deflection on S2

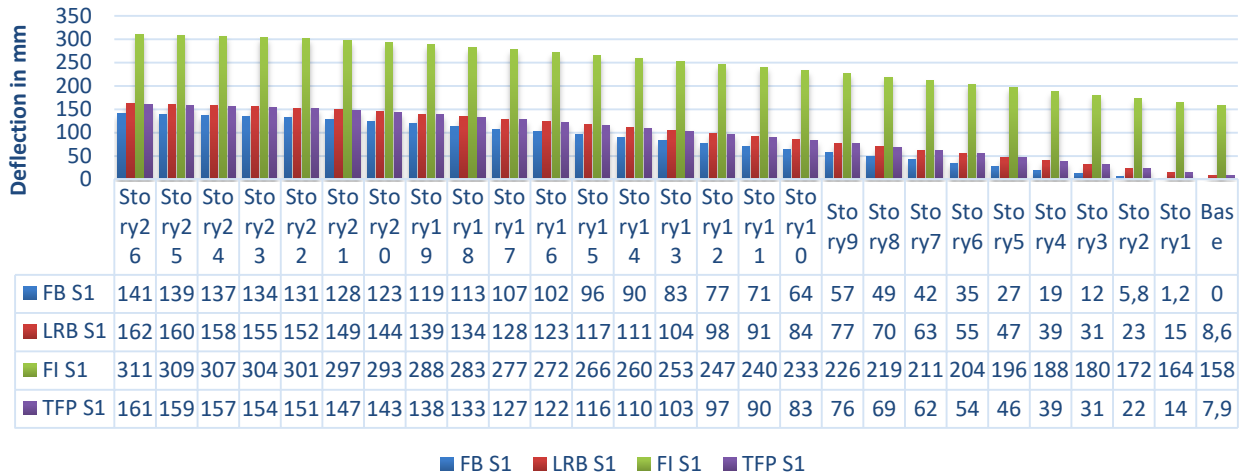


G+20 Deflection on S3

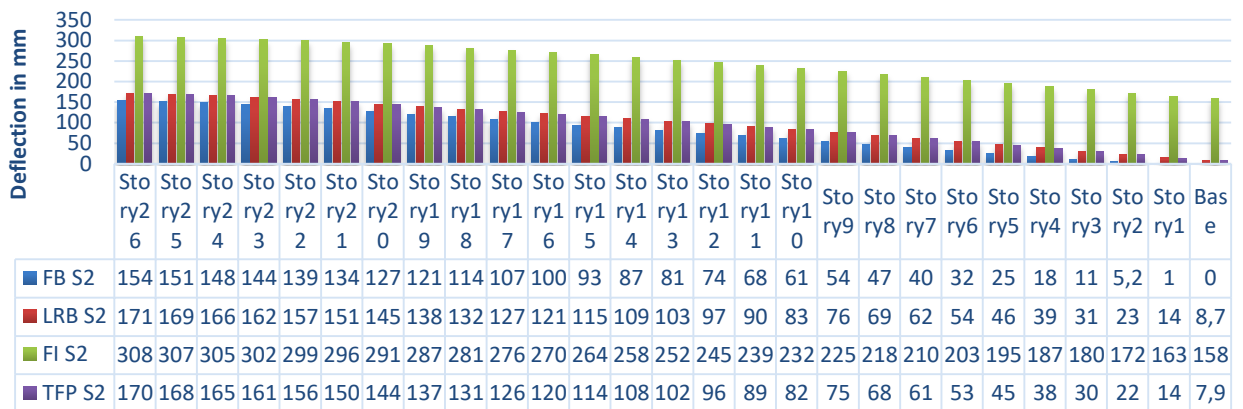




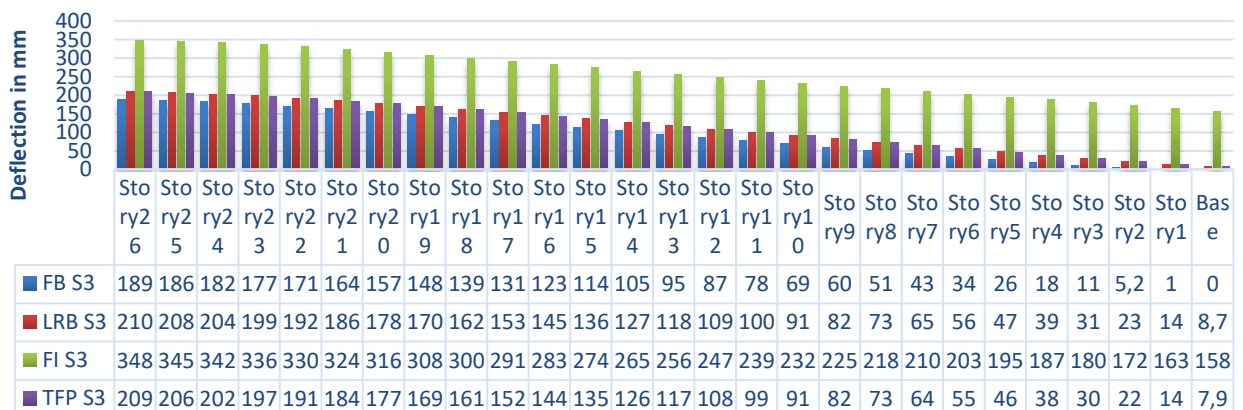
G+25 Deflection on S1



G+25 Deflection on S2



G+25 Deflection on S3



V. CONCLUSION

For G+10 Lead rubber bearing (LRB) have 8% less deflection than fixed base for hard soil. And 8.2% for medium soil and 10.86% for soft soil.

For G+10 Friction isolator (FI) have 41.59 % less deflection than fixed base for hard soil. And 39.12% for medium soil and 35.33% for soft soil.

For G+10 Triple pendulum isolator (TPF) have 9.49 % less deflection than fixed base for hard soil. And 17.61% for medium soil and 19.26% for soft soil.

For G+15 Lead rubber bearing (LRB) have 11.08 % less deflection than fixed base for hard soil. And 5.38% for medium soil and 4.27% for soft soil.

For G+15 Friction isolator (FI) have 40.42 % less deflection than fixed base for hard soil. And 30.25% for medium soil and 22.45% for soft soil.

For G+15 Triple pendulum isolator (TPF) have 4.1 % less deflection than fixed base for hard soil. And 13.33% for medium soil and 11.56% for soft soil.

For G+20 Lead rubber bearing (LRB) have 7.64 % less deflection than fixed base for hard soil. And 3.45% for medium soil and 2.17% for soft soil.

For G+20 Friction isolator (FI) have 7.40 % less deflection than fixed base for hard soil. And 11.22% for medium soil and 6% for soft soil.

For G+20 Triple pendulum isolator (TPF) have 7.70 % less deflection than fixed base for hard soil. And 2.58% for medium soil and 1.86% for soft soil.

For G+25 hard soil all isolator have 8.19% higher deflection than fixed base.

For G+25 medium soil friction isolator have 2.43% less deflection than fixed base. and Triple pendulum isolator (TPF) and Lead rubber bearing (LRB) have 5.55% higher deflection than fixed base.

For G+25 soft soil friction isolator have same deflection as fixed base. and Triple pendulum isolator (TPF) and Lead rubber bearing (LRB) have 5.97% higher deflection than fixed base.

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