International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 05 Issue: 06 | June-2018 www.irjet.net p-ISSN: 2395-0072

Analytical Study of R.C.C. Frame Building with Triple Friction Pendulum under Earthquake Time History

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Abstract-

During the impact of seismic waves, we observe great collateral damages as ground shakes every structure connected to ground face the impact. What if we detach the structure from ground or base? Friction pendulum as a base isolator works in similar way by decoupling the structure from its base and hence reducing the responses that damages the structure.

As concept of single friction pendulum was introduce it was observed that it displaces in large space which caused difficulty in installing multiple bearing at one site. So to overcome this situation new bearing were designed in which multiple plates slide over each other. Due to its mechanism of sliding over multiple plates, their performances were better than single friction pendulum, though using less space to slide. Triple friction pendulum was highly preferred when it comes to select for base isolation, because of its adoptive nature towards all three level of earthquake (SLE, DBE, and MCE).

This paper summaries response analysis of optimized triple friction pendulum (TFP) at base of 9 storey RCC building under seismic waves. The building is situated in earthquake zone V as per IS1893:2002. As for reference it is compared with fixed base structure under same seismic condition. The results indicate by addition of triple friction pendulum at base of structure, significant decrease in responses like storey drift, storey shear, spectral acceleration, input energy was observed. Also, it obviously leads to increase in fundamental time period of structure. One of major aspect of triple friction pendulum was taken care of, that is, re-centering capability of plates by plotting the displacement-time graph of each link.

Key Words: **Earthquake engineering, Triple friction pendulum, Base isolation, Medium rise structure, Sap 2000.**

1. INTRODUCTION

If in an earthquake, the structure oscillates like a swing and attains its original position as soon as earthquake stops. Seismic isolation is basically decoupling of the superstructure from the substructure by the mean of isolator bearing. As the waves hit the base it transfer the shock waves to upper part of structure, but here in isolation process it minimize the transfer of vibration by isolating the superstructure. Superstructure in such cases are assumed to be rigid, so complete structure moves as rigid frame as we isolate it from base we break the stiffness link from foundation. Triple friction pendulum has 2 sets of spherical plates, which account for total of 16 parameters (including 12 geometry and 4 frictional parameters, as shown in figure 2).Within these 4 spherical plates, there exists 3 friction pendulum mechanisms in each bearing, and each mechanism gets activated at different stages as per the seismic demand. These mechanisms lead to improved hysteresis characteristic so as to control the structure in wide range of excitation. Triple friction pendulum bearing is basically design to control displacement and floor acceleration simultaneously.

During the design of triple friction pendulum, concave plates with various set of coefficient of friction are taken to observe the variation in responses for the most optimized design of that bearing. So after modeling of bearing, sensitivity analysis is performed, which is a way to predict the outcome of decision on selecting design parameter which have key role in optimized design of triple friction pendulum.

Here sensitive analysis is done on six independent design parameters, (refer to figure 2)

a) Effective radius of curvature of surface 1& 4.
b) Effective radius of curvature of surface 2&3.
c) Coefficient of friction on surface 1 & 4.
d) Coefficient of friction on surface 2 & 3.
e) Displacement capacity of surface 1&4.
f) Displacement capacity of surface 2&3.

1.1 MODELING

9 storey SMRF, R.C.C. structure was considered in zone 5 as per I.S. 1893 – 2002. Mid rise is preferred as triple friction pendulum aren't effect over high rise structure.

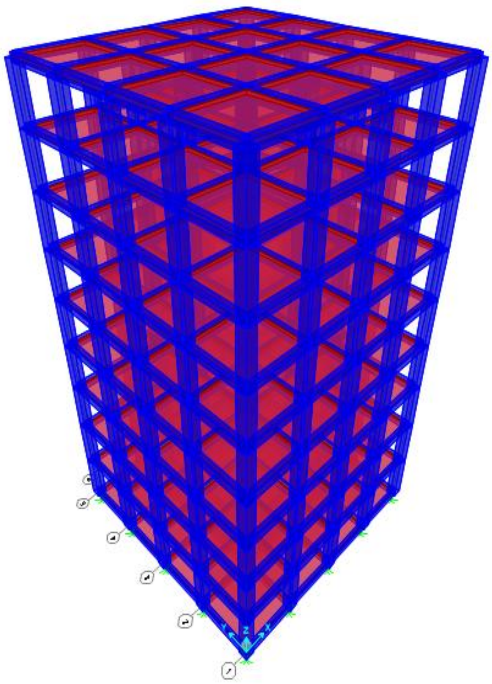

Fig. 1 : 3-D view of 9-Stories Frame Building

1.2 DESIGN OF TRIPLE FRICTION PENDULUM

Designing of triple friction is performed by using parallel model of designing where we consider that this bearing , under any circumstances does not reach final regime.

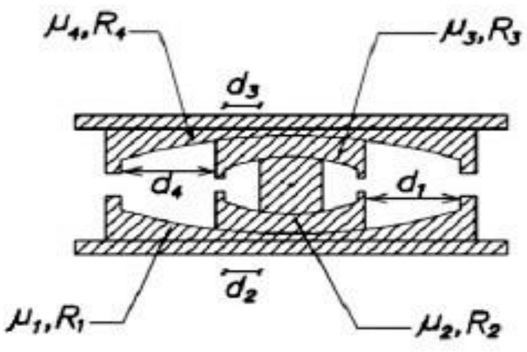

Fig- 2: TRIPLE FRICTION PENDULUM

Table -1: Structural modeling

Type of structure	Symmetric multistory special moment resisting frame (SMRF)
Area	20 x 20 m^2
Seismic zone	Zone V as per is 1893:2002
Number of stories	9
Span in each length	5m in both direction
Material	Concrete grade M30 & rebar grade Fe500
Unit wt. of Masonry	20 kN/m^2
Unit wt. of Concrete	25 kN/m^2
Slab thickness	200mm
Live load	4 kN/m^2 on each floor
Masonry load	13.8 kN/m^2(considered 25% opening)
Size of column	0.8m x 0.8m
Size of beam	0.4m x 0.6m
Type of soil	Medium
Response spectra	As per IS 1893:2002
Time history with different peak ground acceleration (PGA)	i)Imperial valley scaled to zone V IS 1893-2002 (PGA 0.042g) ii)Loma prieta scaled to zone V IS 1893-2002 (PGA 0.279g) iii)Superstition hills scaled to zone V IS 1893-2002 (PGA 0.200g)

Radius of curvature; $R_1 = R_4$; $R_2 = R_3$;

Coefficient of friction; $\mu_1 = \mu_4$; $\mu_2 = \mu_3$;

Displacement capacity; $d_1 = d_4$; $d_2 = d_3$;

Table- 2 : TIME HISTORY DATA

EARTHQUAKE RECORD	STATION	PGA	MAGNI-TUDE
CASE-1 IMPERIAL VALLEY	PLASTER CITY	0.042 g	6.5
CASE-2 LOMA PRIETA	HOLLISTER DIFF. ARRAY	0.279 g	6.9
CASE-3 SUPERSTITION HILL	WILDLIFE LIQUIFACTIO N ARRAY	0.20g	6.7

1.3 RESULTS

The seismic response of structure with fixed base and using designed TFP is obtained using software SAP2000 using three different earthquakes. Various responses were compared with fixed base structure:

1) MODAL ANALYSIS

The table below shows using isolated base increases fundamental period by 70% approximate. Within those three cases we see time period for fixed base remains the same while for isolated base time period vary as time period is independent of mass and stiffness of structure.

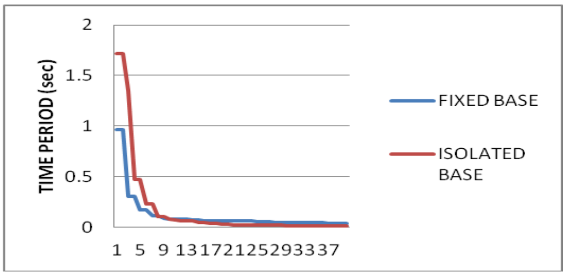

Chart - 1 : MODAL TIME COMPARISION (CASE 1)

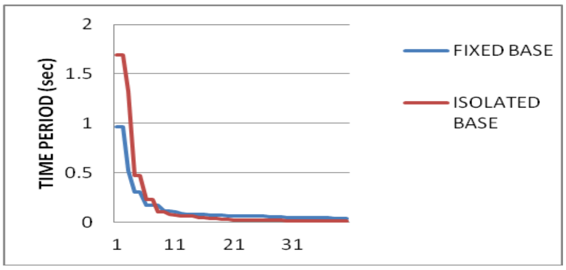

Chart - 2: MODAL TIME COMPARISION (CASE 2)

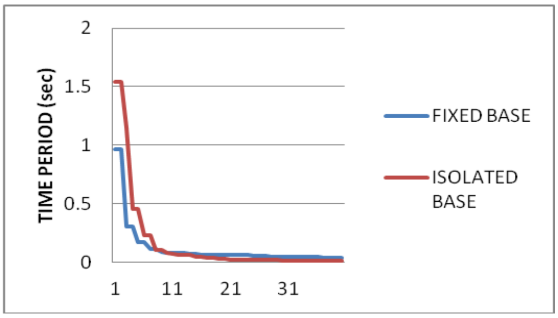

Chart - 3: MODAL TIME COMPARISION (CASE 3)

2) BASE SHEAR

The base shear in structure was significantly reduced due to the effect of TFP as base isolator. The reduction was 85% as compared to fixed base structure.

EQ. RECORD	FIXED	ISOLATED	%REDUC-TION
IMPERIAL VALLEY	25439.5	3425.797	86.5%
LOMA PRIETA	25295.8	3458.906	86.32%
SUPERSTITION HILL	29451.7	5081.179	82.74%

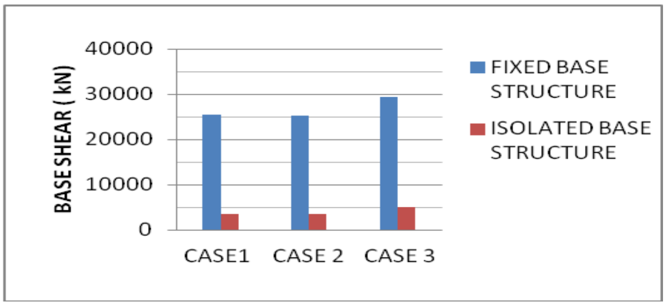

Chart - 4: BASE SHEAR COMPARISION

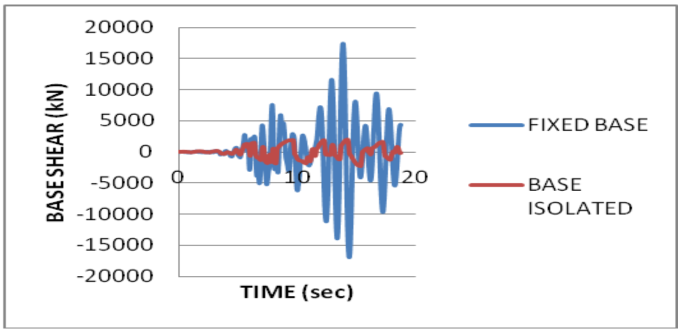

Chart - 5: BASE SHEAR TIME HISTORY (CASE1)

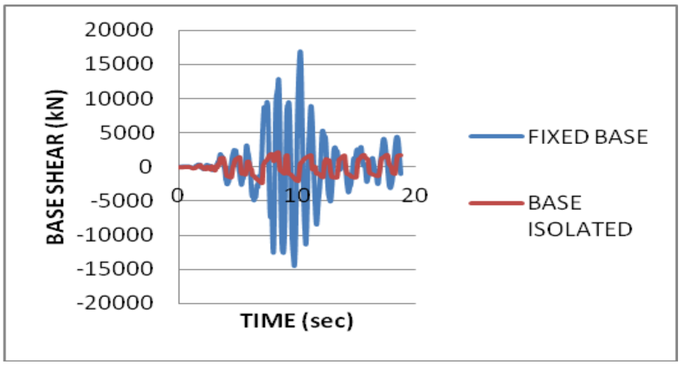

Chart - 6: BASE SHEAR TIME HISTORY (CASE-2)

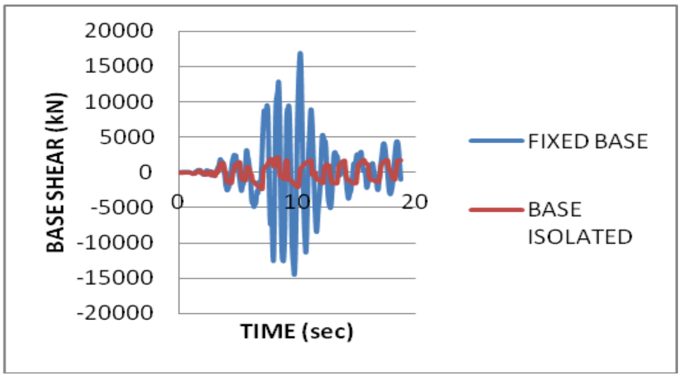

Chart - 7: BASE SHEAR TIME HISTORY (CASE-3)

3) INPUT ENERGY

Input energy is energy transferred from the base to the superstructure.

In graphs, spikes and non uniform flow of energy from base to superstructure were observed, while for isolated base energy transfer is smooth compared to fixed base.

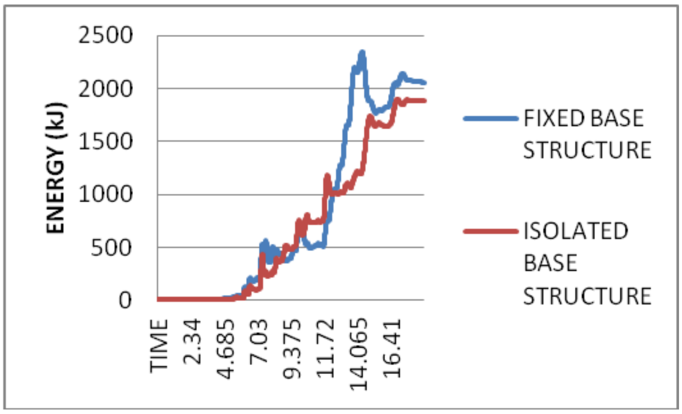

Chart - 8: INPUT ENERGY COMPARISION (CASE-1)

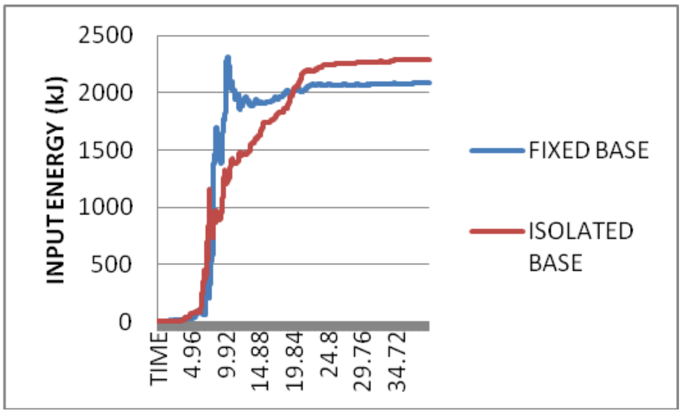

Chart - 9: INPUT ENERGY COMPARISION (CASE-2)

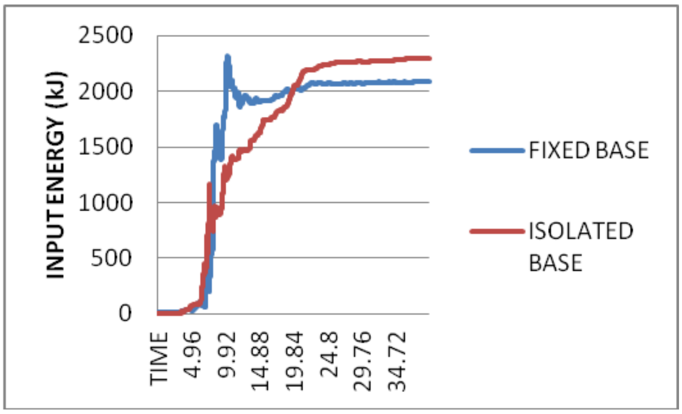

Chart - 10: INPUT ENERGY COMPARISION (CASE-3)

4) STOREY DRIFT

It is the relative displacement between two adjacent storeys. As per the graphs, introducing triple friction pendulum reduced storey drift by 90% approx.

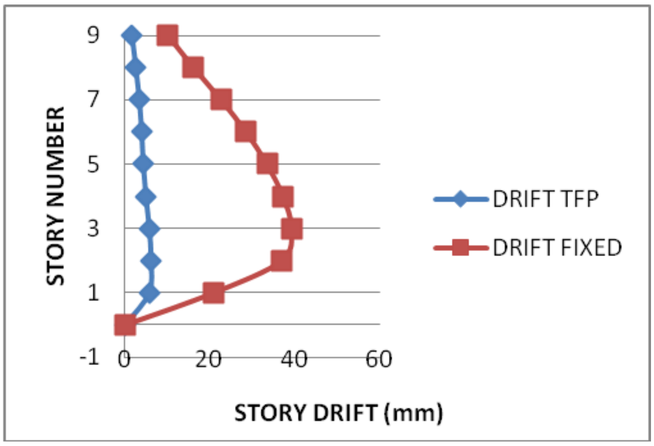

Chart - 11 :STOREY DRIFT (CASE-1)

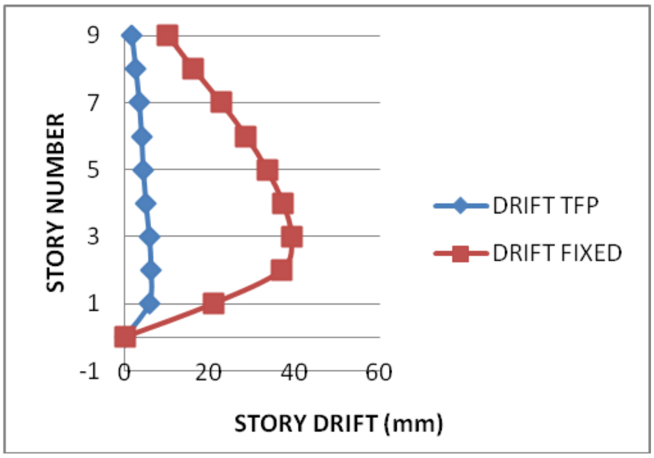

Chart - 12: STOREY DRIFT (CASE-2)

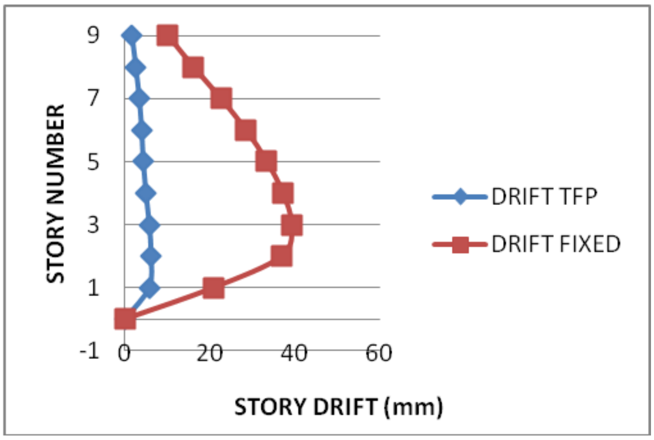

Chart - 13: STOREY DRIFT (CASE-3)

1.4 RE-CENTERING CAPABILITY OF TRIPLE FRICTION PENDULUM:

Re-centering capability is property of all friction bearing to return to its original position. It is one of the major check in designing triple friction pendulum for its proper working and centering mechanism.

Checks for re-centering can be done by either equation of by checking displacement graph of bearing under excitation.

a) Equation check

$$T = 2\pi\sqrt{\frac{2\,R_1}{g}} = 2\pi\sqrt{\frac{2*2.235}{9.81}} = 4.241 \text{ sec}$$

$$T_1 < 28\left(\frac{0.05}{\mu}\right)^{1/4}\sqrt{\frac{D}{g}} = 28\left(\frac{0.05}{0.024}\right)^{1/4}\sqrt{\frac{0.4}{9.81}} = 6.792 \text{ sec}$$

$$T_2 < 28\left(\frac{0.05}{\mu}\right)^{1/4}\sqrt{\frac{D}{g}} = 28\left(\frac{0.05}{0.025}\right)^{1/4}\sqrt{\frac{0.4}{9.81}} = 6.723 \text{ sec}$$

$$T_3 < 28\left(\frac{0.05}{\mu}\right)^{1/4}\sqrt{\frac{D}{g}} = 28\left(\frac{0.05}{0.045}\right)^{1/4}\sqrt{\frac{0.4}{9.81}} = 5.804 \text{ sec}$$

Here, $\mu = (\mu 1 \text{ or } \mu 4)/2$, D = Displacement capacity

For sufficient re-centering capability in triple friction pendulum isolator T should be less than T_1.

b) Displacement graph of bearing:

If the variation in displacement ends at zero value, it signifies that slider returns back to its original position hence re-centering capability is good.

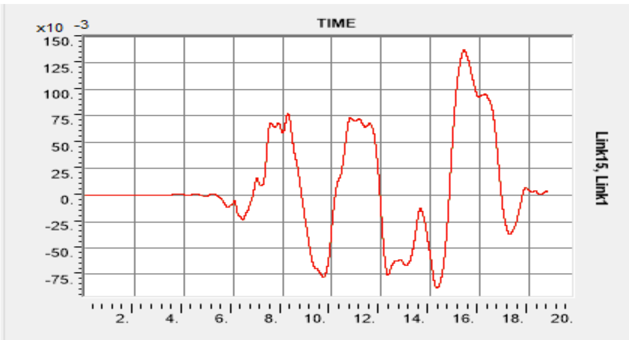

Chart - 14: DISPLACEMENT OF TFP (CASE-1)

($\mu_1 = 0.048$, $\mu_2 = 0.036$)

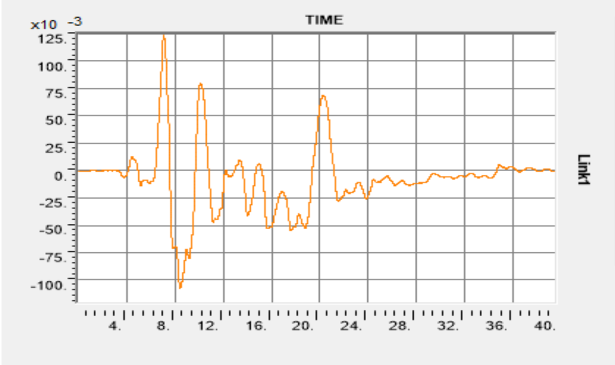

Chart - 15: DISPLACEMENT OF TFP (CASE-2)

($\mu_1 = 0.05$ $\mu_2 = 0.042$)

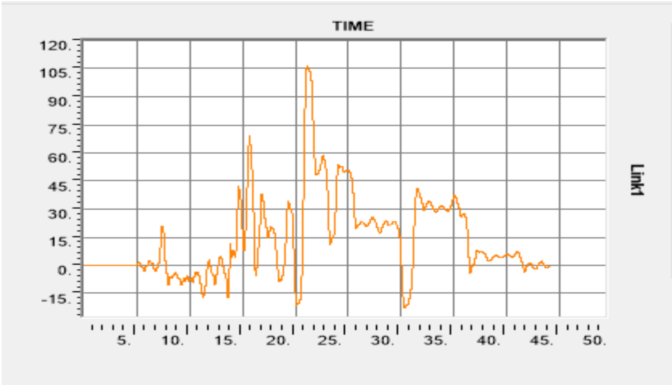

Chart - 16: DISPLACEMENT OF TFP (CASE-3)

($\mu_1 = 0.09$, $\mu_2 = 0.08$)

1.5 CONCLUSIONS

1) Introducing triple friction pendulum leads to increase in fundamental time period of structure with roughly 70% higher.
2) There was great reduction in base shear when base isolation was provided.
3) Transfer of energy from base to superstructure was smooth and somewhat linear, no spikes were seen as in fixed base structure showed.
4) Storey drift was also reduced to great extend and was almost close value for all storey in base isolated structure.
5) With increase in radius of curvature of plate of bearing at constant coefficient of friction, re-centering capability reduces, while larger radius of curvature leads to more flexible structure i.e. less lateral stiffness.
6) With decrease in coefficient of friction of inner and outer plate at constant radius, re-centering capability increases.

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