5.1 Preamble

In this chapter the Base Isolation Bearing: LRB & TFPB are design according to axial load, biaxial load and Tri-axial load (Cumulative load from fixed base modal).

5.2 Design of LRB for G+12 Storey RC Structure.

For the analysis & design of LRB, the cumulative load at the base is obtained from the fixed based design modal in ETABS-2016. This load is categorized into three groups viz. Axial load, Biaxial load and Uniaxial load.

5.2.1 LRB for Biaxial Load - 1638 KN





	= 0.05 For U1.U2.U3.
Effective Damping (ξ_{eff})	= 5%
	$= 0.5 \text{ kN/m}^2.$
Design Shear Strain (ymax)	= 50%
Time Period (T _D)	= 2.5 sec.
Biaxial Load (W)	= 1638 kN.

	EFFECTIVE DAMPING, $\beta_D \text{ OR } \beta_M$ (PERCENTAGE OF CRITICAL)	BD OR BM FACTOR
_	≤ 2 ¹ ‰	0.8
	5%	1.0
	10%	1.2
	20%	1.5
	30%	1.7
	40%	1.9
	≥ 50%	2.0

Table-1. Damping Coefficient, BD or BM

Table-2. Seismic Coefficient Cv

1	SEISMIC ZONE FACTOR, Z				
SOIL PROFILE TYPE	Z=0.075	Z=0.15	Z=0.2	Z=0.3	Z=0.4
S _A	0.06	0.12	0.16	0.24	0.32N ₀
SB	0.08	0.15	0.20	0.30	0.40N _v
Sc	0.13	0.25	0.32	0.45	0.56Ny
SD	0.18	0.32	0.40	0.54	0.64M
Sg	0.26	0.50	0.64	0.84	0.96N _v
SF	See Footnote 1				

Damping Coefficient (B_D)

= 1.0 (UBC-97, Vol-2, Pg. No. 414) = 0.54 (UBC-97, Vol-2, Pg. No. 35)

Seismic Coefficient (S_D)

Table-3. Vulcanized Natural Rubber Compounds

Hardness IRHD±2	Young's Modulus E (MPa)	Shear Modulus G (MPa)	Material Constant k	Elongation at Break Min, %
37	1.35	0.40	0.87	650
40	1.50	0.45	0.85	600
45	1.80	0.54	0.80	600
50	2.20	0.64	0.73	500
55	3.25	0.81	0.64	500
60	4.45	1.06	0.57	400

Choosing 60 for analysis in critical circumstances

E	=	4.45
	=	4450 kN/m ²
G	=	1.06
	=	1060 kN/m ²
Κ	=	0.57
ε _b	=	4
	=	400%
f_{py}	=	8500 kN/m ²
σ_{a}	=	7840 kN/m ²
Typica	ally 7 to	8.5 Mpa, Consult the manufacturer
$\mathbf{F}_{\mathbf{s}}$	=	164640 kN/m ²
f_y	=	274400 kN/m ²

(A) LRB - Analysis

i.

$K_{eff H} = 1054.69 \text{ kN/m}$	Direction U ₂ & U ₃
$K_{effH} = \frac{W}{g} \left(\frac{2\pi}{T_D}\right)^2$	
The effective horizontal stiffness K_{effF}	I

ii. Design displacement (D_D)

$$D_{\rm D} = \left(\frac{\rm g}{4\pi^2}\right) \times \frac{\rm S_{\rm D}T_{\rm D}}{\rm B_{\rm D}}$$
$$= 0.33546 \rm m.$$

iii. Yield strength Qd

$$\mathbf{Q}_{\mathbf{d}} = \frac{W_{\mathrm{D}}}{4 \times \mathrm{D}_{\mathrm{D}}} = \frac{\pi}{4} \times \mathrm{K}_{\mathrm{effH}} \times \xi_{\mathrm{effH}} \times \mathrm{D}_{\mathrm{D}}$$
$$= \mathbf{27.788 \ \mathbf{kN}}$$

iv. Yield Stiffness

K _U	=	10 K _d	
Where,	K _d	=	Post yield stiffness
	\mathbf{K}_{U}	=	Pre yield stiffness

Note- Based on the findings of the trials, the initial elastic stiffness was calculated to be between 9 and 16 Kd.

$$K_{d} = K_{effH} - \frac{Q_{d}}{D_{D}}$$

= 971.854 kN/m.
$$K_{U} = 10 K_{d}$$

= 9718.54 kN/m.

v. Post yield stiffness ratio.

$$\frac{K_{d}}{K_{U}} = \frac{971.854}{9718.54}$$

= 0.1 Direction U2 & U3

(B) LRB - Development

i. Area of lead core (A_p)

$$= \frac{Q_d}{f_{py}}$$
$$= 0.00327 \text{ m}^2.$$

ii. Dia of lead core (d_p)

Ap
$$= \frac{\pi d^2}{4}$$

Ap

$$d_p = \sqrt{\frac{4A_p}{\pi}}$$

iii. Thickness of rubber layer (t_r)

$$t_r = \frac{D_D}{\gamma_{max}}$$
$$= 0.67092 \text{ m.}$$

iv. The Shape factor (S)

$$\frac{E(1+2kS^2)}{G} \ge 400,$$

S = 9.09409
For S < 10, Take S = 10

v. Compressive modulus of rubber & steel (Ec)

Ec =
$$E(1+2kS^2)$$

= 511750 kN/m².

vi. Effective area of bearing (A_o)

$$A_o = W / \sigma_a$$

= 0.20893 m².

vii. Shear strain's effective area (A₁)

$$\frac{6SW}{E_c \times A_1} \leq \frac{\varepsilon_b}{3}$$
$$= 0.14404 \text{ m}^2.$$

viii. Elastic Stiffness Kr

$$K_{d} = K_{r} \times \frac{1+12 \times A_{P}}{A_{o}}$$
$$= 818.219 \text{ kN/m}.$$

ix. Effective area of individual rubber layer (Asf)

$$A_{sf} = \frac{\pi d^2}{4}$$

= 0.51789 m².

x. Diameter of rubber (d)

d
$$= \sqrt{\frac{4A_{sf}}{\pi}}$$
$$= 0.81203 \text{ m.}$$

$$K_{v} = \frac{E_{C} \times A_{sf}}{t_{r}}$$

K_v = 395022 kN/m. Direction U₁

xii. Reduction factor - Damping (
$$\beta$$
)
 $\beta = 2 \times \cos^{-1}\left(\frac{D_D}{d}\right)$
 $= 2.29.$

xiii. Reduced area (A₂)
A₂
$$= \frac{d^2 \times (\beta - \sin \beta)}{4}$$

 $= 0.25348 \text{ m}^2.$

xiv. LRB - Details

xv. Steel Plate thickness (t_s)

$$t_{s} = \frac{2 \times W \times 2t}{A \times Fs}$$

$$t_{s} = 0.00319 \ge 0.002 \text{ m.}$$

- xvi. Total height of bearing (h_b)
 - $h_b = N \; x \; (ts + 2*0.0025) + tr$
 - $h_b = 0.94929 \text{ m}.$

(C) Input Values in ETABS:

Property Name	В	с. С
Direction	U1	
Туре	Rubber Isolato	or
NonLinear	No	
near Properties		
Effective Stiffness	395022	kN/m
Effective Damping	0.05	kN-s/m

Figure-34. LRB Input Values in ETABS for Biaxial Load 1638 KN Direction U₁

Property Name	В	
Direction	U2	
Туре	Rubber Isolate	or
NonLinear	Yes	
inear Properties		
Effective Stiffness	1054.69	kN/n
Effective Damping	0.05	kN-s/m
Shear Deformation Location		
Distance from End-J	0	m
Nonlinear Properties		
Stiffness	9718.54	kN/n
Yield Strength	27.79	kN
Post Yield Stiffness Ratio	0.1	

Figure-35. LRB Input Values in ETABS for Biaxial Load 1638 KN Direction U₂ & U₃

5.2.2 LRB for Uniaxial Load - 2487 KN



Figure-36. LRB Schematic

	= 0.05 For U1,U2,U3
Effective Damping (ξ_{eff})	= 5%
	= 0.5 kN/m2.
Design Shear Strain (γ _{max})	= 50%
Time Period (T _D)	= 2.5 sec.
Uniaxial Load (W)	= 2487 kN.

EFFECTIVE DAMPING, $\beta_D \text{ OR } \beta_M$ (PERCENTAGE OF CRITICAL)	B _D OR B _M FACTOR
≤ 2 [%] /₀	0.8
5%	1.0
10%	1.2
20%	1.5
30%	1.7
40%	1.9
≥ 50%	2.0

Table-4. Damping Coefficient, BD or BM

1	SEISMIC ZONE FACTOR, Z					
SOIL PROFILE TYPE	Z=0.075	Z=0.15	Z=0.2	Z=0.3	Z=0.4	
S _A	0.06	0.12	0.16	0.24	0.32N ₀	
SB	0.08	0.15	0.20	0.30	0.40N ₀	
Sc	0.13	0.25	0.32	0.45	0.56N ₀	
SD	0.18	0.32	0.40	0.54	0.64N ₀	
Sg	0.26	0.50	0.64	0.84	0.96N ₀	
SF	See Footnote 1					

Table-5. Seismic Coefficient Cv

Damping Coefficient (B_D)

Seismic Coefficient (S_D)

= 1.0 (UBC-97, Vol-2, Pg. No. 414)

= 0.54 (UBC-97, Vol-2, Pg. No. 35)

Table-6.	Vulcanized	Natural	Rubber	Compounds
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Hardness IRHD±2	Young's Modulus E (MPa)	Shear Modulus G (MPa)	Material Constant k	Elongation at Break Min, %
37	1.35	0.40	0.87	650
40	1.50	0.45	0.85	600
45	1.80	0.54	0.80	600
50	2.20	0.64	0.73	500
55	3.25	0.81	0.64	500
60	4.45	1.06	0.57	400

Choosing 60 for analysis in critical circumstances

Е	=	4.45
	=	4450 kN/m^2
G	=	1.06
	=	1060 kN/m ²
K	=	0.57
ε _b	=	4
	=	400%
f_{py}	=	8500 kN/m ²

 $\sigma_a \quad = \quad 7840 \; kN/m^2$

Typically 7 to 8.5 Mpa, Consult the manufacturer

(A) LRB - Analysis

i. The effective horizontal stiffness KeffH

$$K_{effH} = \frac{W}{g} \left(\frac{2\pi}{T_D}\right)^2$$

$$K_{effH} = 1601.35 \text{ kN/m}$$

Direction U₂ & U₃

ii. Design displacement (D_D)

$$D_{\rm D} = \left(\frac{g}{4\pi^2}\right) \times \frac{S_{\rm D}T_{\rm D}}{B_{\rm D}}$$
$$= 0.33546 \text{ m.}$$

iii. Yield Strength Qd

$$\mathbf{Q}_{\mathbf{d}} = \frac{W_{\mathrm{D}}}{4 \times \mathrm{D}_{\mathrm{D}}} = \frac{\pi}{4} \times \mathrm{K}_{\mathrm{effH}} \times \xi_{\mathrm{effH}} \times \mathrm{D}_{\mathrm{D}}$$
$$= 42.191 \,\mathrm{kN}$$

iv. Yield stiffness

Note- Based on the findings of the trials, the initial elastic stiffness was calculated to be between 9 and 16 Kd.

$$K_d = K_{effH} - \frac{Q_d}{D_D}$$

= 1475.58 kN/m.**K**_U =10 K_d = 14755.8 kN/m.

v. Post yield stiffness ratio.

$$\frac{K_{d}}{K_{U}} = \frac{1475.58}{14755.8}$$
$$= 0.1$$

Direction U₂ & U₃

(B) LRB - Development

$$Ap = \frac{Q_d}{f_{py}}$$
$$= 0.00496 m^2$$

ii. Dia of lead core
$$(d_p)$$

$$Ap = \frac{\pi d^2}{4}$$
$$d_p = \sqrt{\frac{4A_p}{\pi}}$$
$$= 0.0795 \text{ m.}$$

iii. Thickness of rubber layer (t_r)

$$t_r = \frac{D_D}{\gamma_{max}}$$
$$= 0.67092 \text{ m.}$$

iv. The Shape factor (S)

$$\frac{E(1+2kS^2)}{G} \ge 400,$$

S = 9.09409

For S < 10, Take S = 10

v. Compressive modulus of rubber & steel (Ec)

Ec =
$$E(1+2kS^2)$$

= 511750 kN/m²

vi. Effective area of bearing(A_o)

A_o = W /
$$\sigma_a$$

= 0.31722 m².

vii. Shear strain's effective area (A₁)

$$\frac{6SW}{E_c \times A_1} \leq \frac{\varepsilon_b}{3}$$
$$= 0.21869 \text{ m}^2$$

$$K_d = K_r \times \frac{1+12 \times A_P}{A_o}$$
$$= 1242.31 \text{ kN/m}.$$

ix. Effective area of individual rubber layer (Asf)

$$A_{sf} = \frac{\pi d^2}{4}$$

= 0.78632 m².

x. Diameter of rubber (d)

d
$$= \sqrt{\frac{4A_{sf}}{\pi}}$$
$$= 1.00059 \text{ m.}$$

xi. Effective vertical stiffness (k_v)

$$\begin{split} K_v &= \frac{E_C \times A_{sf}}{t_r} \\ K_v &= 599768 \text{ kN/m.} \qquad \text{Direction } U_1 \end{split}$$

xii. Reduction factor - Damping (
$$\beta$$
)

$$\beta = 2 \times \cos^{-1}\left(\frac{D_{\rm D}}{d}\right)$$
$$= 2.457$$

$$A_2 = \frac{d^2 \times (\beta - \sin \beta)}{4}$$
$$= 0.4567 \text{ m}^2$$

xv. Steel Plate thickness (t_s)

$$t_{s} = \frac{2 \times W \times 2t}{A \times Fs}$$

$$t_{s} = 0.00331 \ge 0.002 \text{ m.}$$

xvi. Total height of bearing (h_b)

 $\begin{array}{ll} h_b & = N \; x \; (ts + 2*0.0025) + tr \\ h_b & = 0.89528 \; m. \end{array}$

(C) Input Values in ETABS:

Property Name	U	
Direction	U1	
Туре	Rubber Isolato	r
NonLinear	No	
near Properties		
Effective Stiffness	599768	kN/m
Effective Damping	0.05	kN-s/m

Figure-37. LRB Input Values in ETABS for Uniaxial Load 2487 KN Direction U₁

Direction	112	
Direction		
lype	Rubber Isolato)F
NonLinear	Yes	
inear Properties		
Effective Stiffness	1601.35	kN/m
Effective Damping	0.05	kN-s/m
Shear Deformation Location		
Distance from End-J	0	m
Nonlinear Properties		
Stiffness	14755.8	kN/m
Yield Strength	42.19	kN
Post Yield Stiffness Ratio	0.1	

Figure-38. LRB Input Values in ETABS for Uniaxial Load 2487 KN Direction U₂ & U₃

5.2.3 LRB for Axial Load - 3920 KN



Figure-39. LRB Schematic

Axial Load (W)	= 3920 kN.
Time Period (T _D)	= 2.5 sec.
Design Shear Strain (γ_{max})	= 50%
	= 0.5 kN/m2.
Effective Damping (ξ_{eff})	= 5%

= 0.05 For U1,U2,U3.

Table-7. Damping	g Coefficient, BD or BM
------------------	-------------------------

EFFECTIVE DAMPING, $\beta_D \text{ OR } \beta_M$ (PERCENTAGE OF CRITICAL)	BD OR BM FACTOR
≤ 2 ¹ / ₀	0.8
5%	1.0
10%	1.2
20%	1.5
30%	1.7
40%	1.9
≥ 50%	2.0

			SEISMIC ZONE FACTOR, Z		
SOIL PROFILE TYPE	Z=0.075	Z=0.15	Z=0.2	Z=0.3	Z = 0.4
S _A	0.06	0.12	0.16	0.24	0.32N _v
SB	0.08	0.15	0.20	0.30	0.40M
Sc	0.13	0.25	0.32	0.45	0.56N ₀
SD	0.18	0.32	0.40	0.54	0.64 _W
Sg	0.26	0.50	0.64	0.84	0.96N ₀
SF	See Footnote 1				

Table-8. Seismic Coefficient Cv

Damping Coefficient (B_D)

Seismic Coefficient (S_D)

= 1.0 (UBC-97, Vol-2, Pg. No. 414)

= 0.54 (UBC-97, Vol-2, Pg. No. 35)

Table-9.	Vulcanized	Natural	Rubber	Compounds
----------	------------	---------	--------	-----------

Hardness IRHD±2	Young's Modulus E (MPa)	Shear Modulus G (MPa)	Material Constant k	Elongation at Break Min, %
37	1.35	0.40	0.87	650
40	1.50	0.45	0.85	600
45	1.80	0.54	0.80	600
50	2.20	0.64	0.73	500
55	3.25	0.81	0.64	500
60	4.45	1.06	0.57	400

Choosing 60 for analysis in critical circumstances

Е	=	4.45
	=	4450 kN/m ²
G	=	1.06
	=	1060 kN/m ²
K	=	0.57
ε _b	=	4
	=	400%
f_{py}	=	8500 kN/m ²

 $\sigma_a \quad = \quad 7840 \; kN/m^2$

Typically 7 to 8.5 Mpa, Consult the manufacturer

(A) LRB - Analysis

i. The effective horizontal stiffness KeffH

$$K_{effH} = \frac{W}{g} \left(\frac{2\pi}{T_D}\right)^2$$

 $K_{eff H} = 2524.04 \text{ kN/m}$

Direction U₂ & U₃

ii. Design displacement (D_D)

$$D_{\rm D} = \left(\frac{g}{4\pi^2}\right) \times \frac{S_{\rm D}T_{\rm D}}{B_{\rm D}}$$
$$= 0.33546 \text{ m.}$$

iii. Yield Strength Qd

$$\mathbf{Q}_{\mathbf{d}} = \frac{W_{\mathrm{D}}}{4 \times \mathrm{D}_{\mathrm{D}}} = \frac{\pi}{4} \times \mathrm{K}_{\mathrm{effH}} \times \xi_{\mathrm{effH}} \times \mathrm{D}_{\mathrm{D}}$$
$$= \mathbf{66.5012 \ \mathrm{kN}}$$

iv. Yield Stiffness

K_U	=	10 K _d	
Wherer,	K _d	=	Post yield stiffness
	K_{U}	=	Pre yield stiffness

Note- Based on the findings of the trials, the initial elastic stiffness was calculated to be between 9 and 16 Kd.

$$K_d = K_{effH} - \frac{Q_d}{D_D}$$

= 2325.81 kN/m.
 $K_U = 10 K_d$

= 23258.1 kN/m.

v. Post yield stiffness ratio.

$$\frac{K_{d}}{K_{U}} = \frac{2325.81}{23258.1}$$

= 0.1 Direction U2 & U3

(B) LRB - Development

i. Area of Lead Core (A_p)

Ap
$$= \frac{Q_d}{f_{py}}$$
$$= 0.00782 \text{ m}^2.$$

ii. Dia of lead core
$$(d_p)$$

Ap
$$= \frac{\pi d^2}{4}$$

$$d_p = \sqrt{\frac{4A_p}{\pi}}$$

$$= 0.09981 \text{ m.}$$

iii. Thickness of rubber layer (t_r)

$$t_{\rm r} = \frac{D_{\rm D}}{\gamma_{\rm max}}$$
$$= 0.67092 \text{ m.}$$

iv. The Shape factor (S)

$$\frac{E(1+2kS^{2})}{G} \ge 400,$$

S = 9.09409
For S < 10, Take S = 10

v. Compressive modulus of rubber & steel (Ec)

vi. Effective area of bearing(A_o)

$$\begin{array}{ll} A_o & = W \ / \ \sigma_a \\ & = 0.5 \ m^2. \end{array}$$

vii. Shear strain's effective area (A₁)

$$\frac{6SW}{E_c \times A_1} \leq \frac{\varepsilon_b}{3}$$
$$= 0.3447 \text{ m2.}$$

viii. Elastic Stiffness K_r

$$K_{d} = K_{r} \times \frac{1+12 \times A_{P}}{A_{o}}$$
$$= 1958.13 \text{ kN/m}.$$

ix. Effective area of individual rubber layer (A_{sf})

$$A_{sf} = \frac{\pi d^2}{4}$$

= 1.23939 m².

x. Diameter of rubber (d)

d

$$=\sqrt{\frac{4A_{sf}}{\pi}}$$
$$= 1.2562 \text{ m}.$$

xi. Effective vertical stiffness (k_v)

$$K_{v} = \frac{E_{C} \times A_{sf}}{t_{r}}$$

$$K_{v} = 945352 \text{ kN/m.} \qquad Di$$

Direction U1

xii. Reduction factor - Damping (β)

$$\beta = 2 \times \cos^{-1}\left(\frac{D_{\rm D}}{d}\right)$$
$$= 2.6$$

$$A_2 = \frac{d^2 \times (\beta - \sin \beta)}{4}$$
$$= 0.82236 \text{ m}^2.$$

xv. Steel Plate thickness (t_s)

$$t_{s} = \frac{2 \times W \times 2t}{A \times Fs}$$

$$t_{s} = 0.00364 \ge 0.002 \text{ m.}$$

xvi. Total height of bearing (h_b)

 $h_b = N x (ts + 2*0.0025) + tr$

 $h_b = 0.86094 \ m.$

(C) Input Values in ETABS:

Direction U1	
T. Dubbar laalstar	
Type nubber isolator	
NonLinear	
Linear Properties	
Effective Stiffness 945352	kN/m
Effective Damping 0.05	kN-s/m

Figure-40. LRB Input Values in ETABS for Axial Load 3920 KN Direction U₁

Dentification		
Property Name	A	
Direction	U2	
Туре	Rubber Isolato	r
NonLinear	Yes	
inear Properties		
Effective Stiffness	2524.04	kN/m
Effective Damping	0.05	kN-s/m
hear Deformation Location		
Distance from End-J	0	m
Ionlinear Properties		
Stiffness	23258.1	kN/m
Yield Strength	66.5	kN
Post Yield Stiffness Ratio	0.1	

Figure-41. LRB Input Values in ETABS for Axial Load 3920 KN Direction U₂ & U₃

2

mm.

m.

mm

m

mm

5.3 **Design of TFPB for G+12 Storey RC Structure.**

For the analysis & design of TFPB, the cumulative load at the base is obtained from the fixed based design modal in ETABS-2016. This load is categorized into three groups viz. Axial load, Biaxial load and Uniaxial load.

5.3.1 TFPB for Biaxial Load - 1638 KN



Figure-42. TFPB Schematic

(A) Geometrical, Frictional and D_D Computation

a. Geometrical features

$$R_4 = R_1 = 1778 \times 2$$

 $= 3556 \text{ m}$
 $= 3.556 \text{ m}$
 $R_2 = R_3 = 647 \text{ m}$
 $h_1 = h_4 = 161 \text{ m}$
 $= 0.161 \text{ m}$

=

			=	0.121 m
d_1	=	566.02 mm		
d_2	=	81.05 mm		
R _{1eff4}	=	R 4eff4	=	$R_1 - h_1$
			=	3556 - 161
			=	3395 mm.
R _{2eff4}	=	R _{3eff4}	=	$R_2\ -\ h_2$
			=	647 – 1 21
			=	526 mm.
d_4*	=	d_1*	=	$\frac{d_1 \times R_{1eff}}{R_1}$
			=	540.39 mm
			~	540.40 mm.
d_2^*	=	d ₃ *	=	$\frac{d_2 \times R_{2eff}}{R_2}$
			=	65.89 mm
			≈	65.90 mm.

b. **Frictional characteristics Computation**

At 1 & 4 Р = W/A Here W Load 163.8 tonne or 1638 KN. = А πr^2 = r = $h_4 \ + \ h_1$ 161 + 161 = 322 mm r = $0.000503 \text{ ton/mm}^2$, Р = Р 0.000503 x 1450 =

Р	=	0.73 ksi,	1 ksi	=	Kilo square inch
				=	1450 ton/mm ²
3- Fri	ction Cy	vcle	μ	=	0.122 - 0.01 P,
			μ	=	0.1147
Adjus	t for hig	sh velocity		=	μ - 0.0333
				=	0.1147 - 0.0333
				=	0.081 (Lower bound)
1 – Fr	iction C	lycle	μ	=	1.2 x 0.081
				=	0.0977
μ_4	=	$\mu_1 = 0.08$	1(Lower	bound)	
μ4	=	$\mu_1 = 0.09$	8 (Upper	bound)	
At 2 a	and 3				
Р	=	W / A			
Here V	W Load			=	163.8 tonne or 1638 kN,
А	=	πr^2			
R	=	$h_2 + h_3$			
	=	121 + 121,			
	=	242 mm			
-					
Р	=	$0.000890 \text{ ton/mm}^2$,		
Р	=	0.000890 x 1450			
Р	=	1.29 ksi.	1 ksi	=	Kilo square inch
				=	1450 ton/mm^2
3- Fri	ction Cy	/cle	μ	=	0.122 - 0.01 P
				=	0.1091
Adjus	t for hig	sh velocity		=	μ - 0.036
				=	0.1091 - 0.036
				=	0.073 (Lower bound)
1 - Fri	iction C	ycle	μ	=	1.2 x 0.073
				=	0.0877

μ_2	=	μ3	=	0.0	73 (Lower bound)
μ_2	=	μ3	=	0.0	88 (Upper bound)
μ	=	force a	at zero d	lefoi	rmation
μ	=	μ1 - (μ	1 - μ2)	×	$\frac{R_{2eff}}{R_{1eff}}$ (Lower bound)
μ	=	0.080			
μ	=	μ1 - (μ	1 - μ2)	×	$\frac{R_{2eff}}{R_{1eff}} \text{ (Upper bound)}$
μ	=	0.096			

c. **D**_D Computation (Upper bound)

Sd	=	0.5074				
μ	=	0.096				
μı	=	0.098				
$\mathbf{D}_{\mathbf{y}}$	=	(µ1- µ2) * R2ef	f			
$\mathbf{D}_{\mathbf{y}}$	=	0.005250				
Fd	=	0.2772				
W	=	163.8 Ton.				
T.B.	=	12 Nos. (when	e T.B.	= Tota	l Bearing)	
ΣF_d	=	W x T.B. x Fd				
	=	163.8 x 12 x 0	.2772			
ΣF_d	=	544.95				
Σw	=	W x T.B.				
$\Sigma \mathbf{w}$	=	1965.6 Ton.				
i.	Desig	n displacement	: D _D	=	0.07202 m.	
ii.	Effect	ive stiffness, Q	d	=	$\mu * \Sigma w$	
				=	0.096 * 1965.6	
			\mathbf{Q}_{d}	=	188.98 Ton	
			k _D	=	$\Sigma F_D / D_D$	
				=	544.95 / 0.07202	

$$k_D = 7566.63 \text{ Ton/m}.$$

$$K_{eff} \quad = \quad k_D + Q_D \, / \, D_D$$

= 7566.63 + 188.98 / 0.07202

$$K_{eff} = 10190.63 \text{ Ton/m}.$$

iii. Effective period, T_{eff} $T_{eff} = [\sqrt{((\Sigma w)/(K_{eff} x g))}]2\pi$ $T_{eff} = 0.88103$ sec.

iv. Effective damping, β_{eff}

$$\beta_{D} = \frac{E}{2\pi K_{eff} \times D_{D}^{2}} = \frac{4\mu \Sigma w (D_{D} - D_{y})}{2\pi K_{eff} \times D_{D}^{2}}$$
$$\beta_{eff} = \beta_{D} = 0.1520$$

v. Damping reduction coefficient, β

$$\beta = \left(\frac{\beta_{\text{eff}}}{0.05}\right)^{0.3}$$
$$\beta = 1.3959$$

$$D_{D}^{1} = \frac{T_{eff}^{2} \times S_{D!}}{4\pi^{2} \times \beta} \times g$$
$$D_{D}^{1} = 0.0701 \text{ m}$$

(B) ETABS links directional property computation (upper bound)

a. Principal Features

i. Determine bearing

The isolator had been envisioned as a cylinder with a height of 0.32 metres and a diameter of 0.305 metres

$$H = 0.5 m$$

 $\emptyset = 0.484 m$

Now,	Area		А	=	$\frac{\pi \times \emptyset^2}{4}$
				=	$\frac{\pi \times 0.484^2}{4}$
			А	=	0.1840 m ²
K _{eff}	=	$\frac{W}{R_{1eff}} + \frac{\mu w}{D_D}$			
K _{eff}	=	266.91 Ton/m			
\mathbf{I}_1	=	$\frac{K_{eff} \times h^3}{12E}$		=	$\frac{266.91 \times 0.5^3}{12E}$
				=	2.78035E-07 m ⁴ .
Е	=	$1 \times 10^7 \text{ N/mm}^2$.			
ii.	Deter	mine bearing mass			
D _{m-ma}	_x =	0.0702 m.			
D _{TM}	=	1.15 x D _{m-max}			
	=	1.15 x 0.0702			
D _{TM}	=	0.0807 m.			
D	=	2 D _{TM}			
	=	2 x 0.0807			
D	=	0.16146 m.			
W	=	0.241 D² - 0.00564 D			
W	=	0.0053721 Tonne			
М	=	w / g			
	=	0.005372 / 9.81			
М	=	0.000548 Tonne sec ² /	′m.		

b. Direction (U₁)

Η	=	0.5 m
Ø	=	0.484 m
K _{eff}	=	AE / L
Keff	=	3679684.643 Ton/m.
from	D _D	
K _{eff}	=	3679684.643 Ton/m.
β_{eff}	=	0.1520

c. Direction $(U_2 - U_3)$

i.	Dete	Determination of liner properties.					
Keff	=	266.914 ton/	′m				
	=	2669.14 KN	/m				
β_{eff}	=	0.1520					
Heigl	nt for	outer surface,	=	$h_1 \hspace{0.1 cm} = \hspace{0.1 cm}$	h_4	=	0.161m.
Heigl	ht for :	inner surface,	=	$h_2 =$	h3	=	0.121m.

ii. Determination of Non - liner properties.

R_{2eff}	=	0.526 m.		
Dy	=	$\left(\mu_1 - \mu_2\right) R_{2eff}$		
	=	(0.09769 – 0.08771) x 0.526		
Dy	=	0.00525 m.		
Stiffn	ess (Ou	ter Top)	=	$\frac{\mu_1 w}{D_y}$
			=	$\frac{0.09769 \times 163.8}{0.00525}$
			=	3047.855 ton/m.
			=	30478.55 KN/m.
Stiffn	ess (Inn	er Top)	=	$\frac{\mu_2 w}{D_y}$

		_	0.08771×163.8
		_	0.00526
		=	2736.448 ton/m.
		=	27364.48 KN/m.
Friction Coefficient, Slow	$= \mu_1$	=	0.098 (Outer Top)
	$= \mu_2$	=	0.088 (Inner Top)
Friction Coefficient, Fast	$= 2 \times \mu_1$	=	0.195 (Outer Top)
	$= 2 \times \mu_2$	=	0.175 (Inner Top)
Rate Parameter		=	Friction Coeff. Slow Friction Coeff.Fast
		=	0.098 / 0.195
		=	0.5
		=	0.0005 sec/mm
Radius of sliding surface			
Outer Top = R_{1eff}		=	3.395 m.
Inner Top = R_{2eff}		=	0.526 m.
Stop distance			
Outer Top u ₁ *		=	$2 D_y + 2 d_1*$
		=	1.09130 m.
		=	1091.30 mm
Inner Top u ₂ *		=	2 D _y
		=	0.0105 m.
		=	10.5 mm.

(C) Input Values in ETABS:

Identification	-	
Property Name	В	
Direction	U1	
Туре	Triple Pendulun	n Isolator
NonLinear	Yes	
Linear Properties		
Effective Stiffness	36796846.43	kN/m
Effective Damping	1.396	kN-s/m
Nonlinear Properties		
Stiffness	36796846.43	kN/m
Damping Coefficient	1.396	kN-s/m

Figure-43. TFPB Input Values in ETABS for Biaxial Load 1638 KN

Direction U₁

Property Name	P	Type Triple Pendulum kola				
Dimetian	U2.U2		Naclines			
Direction	02; 03		NonLinear		Yes	
Linear Properties						
Effective Stiffness - U2	2669.136	kN/m	Effective Stiffness -U3	2669.136	kN/m	
Effective Damping - U2	2 1.396	kN-s/m	Effective Damping -U3	1.396	kN-s/m	
Shear Deformation Location	n					
Distance from End-J - L	J2 0	m	Distance from End-J - U3	3 0	m	
			1			
Height and Symmetry of S	liding Surfaces					
Height and Symmetry of S Height for Outer Surface	iding Surfaces	m 🔽 Ou	iter Bottom Surface is Sym	imetric to Outer Top	Surface	
Height and Symmetry of S Height for Outer Surface Height for Inner Surface	iding Surfaces es 0.161 s 0.121	m 🗹 Ou m 🕑 Inn	iter Bottom Surface is Sym ner Bottom Surface is Sym	metric to Outer Top metric to Inner Top	Surface Surface	
Height and Symmetry of Si Height for Outer Surface Height for Inner Surface Nonlinear Properties for Di	iding Surfaces 95 0.161 16 0.121 17 rections U2 and U3	m 🕑 Ou m 🕑 Inn	iter Bottom Surface is Sym ner Bottom Surface is Sym	metric to Outer Top	Surface Surface	
Height and Symmetry of Si Height for Outer Surface Height for Inner Surface Nonlinear Properties for Di	iding Surfaces s 0.161 s 0.121 rections U2 and U3 Outer Top	m 🕑 Ou m 📝 Inn Outer Bot	iter Bottom Surface is Sym ner Bottom Surface is Sym tom Inner Top	metric to Outer Top metric to Inner Top Inner Botte	Surface Surface	
Height and Symmetry of Si Height for Outer Surface Height for Inner Surface Nonlinear Properties for Di Stiffness	iding Surfaces es 0.161 s 0.121 rections U2 and U3 Outer Top 30478.548	m Ou m Inn Outer Bot 30478.548	ter Bottom Surface is Sym ner Bottom Surface is Sym tom Inner Top 27364.48	metric to Outer Top metric to Inner Top Inner Bott	Surface Surface omkN/m	
Height and Symmetry of Si Height for Outer Surface Height for Inner Surface Nonlinear Properties for Di Stiffness Friction Coefficient, Slo	iding Surfaces s 0.161 s 0.121 rections U2 and U3 Outer Top 30478.548 w 0.09769	m ✓ Ou m ✓ Inn Outer Bot 30478.548	ter Bottom Surface is Sym ner Bottom Surface is Sym tom Inner Top 27364.48 0.0877	Inner Bott	Surface Surface	
Height and Symmetry of Si Height for Outer Surface Height for Inner Surface Nonlinear Properties for Di Stiffness Friction Coefficient, Slo Friction Coefficient, Fas	iding Surfaces es 0.161 s 0.121 rections U2 and U3 Outer Top 30478.548 w 0.09769 et 0.19538	m ♥ Ou m ♥ Inn Outer Bot 30478.548 0.09769 0.19538	ter Bottom Surface is Sym her Bottom Surface is Sym tom Inner Top 27364.48 0.0877 0.17541	Inner Botto 27364.48 0.0877	Surface Surface m kN/m	
Height and Symmetry of Si Height for Outer Surface Height for Inner Surface Nonlinear Properties for Di Stiffness Friction Coefficient, Slo Friction Coefficient, Fas Rate Parameter	iding Surfaces es 0.161 s 0.121 rections U2 and U3 Outer Top 30478.548 w 0.09769 st 0.19538 0.0005	m ♥ Ou m ♥ Inn Outer Bot 30478.548 0.09769 0.19538 0.0005	ter Bottom Surface is Sym ner Bottom Surface is Sym 27364.48 0.0877 0.17541 0.0005	Inner Bott 27364.48 0.0877 0.17541	Surface Surface omkN/m sec/mm	
Height and Symmetry of Si Height for Outer Surface Height for Inner Surface Nonlinear Properties for Di Stiffness Friction Coefficient, Slo Friction Coefficient, Fas Rate Parameter Radius of Sliding Surfa	iding Surfaces es 0.161 s 0.121 rections U2 and U3 Outer Top 30478.548 w 0.09769 et 0.19538 0.0005 ce 3.395	m ♥ Ou m ♥ Inn Outer Bot 30478.548 0.09769 0.19538 0.0005 3.395	ter Bottom Surface is Sym her Bottom Surface is Sym 27364.48 0.0877 0.17541 0.0005 0.526	Inner Bott 27364.48 0.0877 0.17541 0.0005 0.526	Surface Surface m kN/m sec/mm m	
Height and Symmetry of Si Height for Outer Surface Height for Inner Surface Nonlinear Properties for Di Stiffness Friction Coefficient, Slo Friction Coefficient, Fas Rate Parameter Radius of Sliding Surfa Stop Distance	iding Surfaces es 0.161 s 0.121 rections U2 and U3 Outer Top 30478.548 w 0.09769 et 0.19538 0.0005 ce 3.395 1091.3	m ♥ Ou m ♥ Inn Outer Bot 30478.548 0.09769 0.19538 0.0005 3.395 1091.3	ter Bottom Surface is Sym ner Bottom Surface is Sym 27364.48 0.0877 0.17541 0.0005 0.526 10.5	Inner Bott 27364.48 0.0877 0.17541 0.0005 0.526 10.5	Surface Surface m kN/m sec/mn m mm	

Figure-44. TFPB Input Values in ETABS for Biaxial Load 1638 KN Direction U₂ & U₃

5.3.2 TFPB for Uniaxial Load - 2487 KN



Fig. 45. TFPB Schematic

(A) Geometrical, Frictional and D_D Computation

a.	Geometrical features					
	\mathbf{R}_4	=	R1	=	1778 x 2	
				=	3556 mm	
				=	3.556 mtrs.	
	R_2	=	R ₃	=	647 mm	
				=	0.647 mtrs	
	h_1	=	h4	=	161 mm	
				=	0.161 mtrs	
	h_2	=	h ₃	=	121 mm	
				=	0.121 mtrs	
	d_1	=	566.02 mm			
	d_2	=	81.05 mm			
	$R_{1 eff}$	=	R _{4eff}	=	$R_1\ -\ h_1$	
				=	3556 - 161	
				=	3395 mm.	

R_{2eff}	=	R _{3eff}	=	$R_2-\ h_2$
			=	647 - 121
			=	526 mm.
d4*	=	d_1*	=	$\frac{d_1 \times R_{1eff}}{R_1}$
			=	540.39 mm
			\approx	540.40 mm.
d_2^*	=	d ₃ *	=	$\frac{d_2 \times R_{2eff}}{R_2}$
			=	65.89 mm
			≈	65.90 mm.

b. Frictional Characteristics Computation

At 1 and 4

Р	=	W / A							
Here Y	W Load			=	248.7	tonne	or 2487 KN		
А	=	πr^2							
R	=	$h_4 + \ h_1$							
	=	161 + 161							
r	=	322 mm							
Р	=	0.000764	ton/m	m ² ,					
Р	=	0.000764 x 1	450						
Р	=	01.11 ksi,	1 ksi	=	Kilo s	quare ir	nch		
				=	1450 t	on/mm	2		
3- Fri	ction Cy	ycle	μ	=	0.122	- 0.01	Р		
			μ	=	0.1109)			
Adjust for high velocity				=	μ-0	.0333			
				=	0.1109	9 - 0.0	333		
				=	0.078	(Lowe	r bound)		
1 - Fri	iction C	ycle	μ	=	1.2 x ().078			
				=	0.0932	2			
μ_1	=	μ_4	=	0.078	(Lower	bound)			
----------------	-----------	-----------	-----------------------------------	--------------------------	---------------------	----------	--------------------	----------	----
μ ₁	=	μ4	=	0.093	(Upper	bound)			
At 2 a	and 3								
Р	=	W / A							
Here V	W Load	1			=	248.7	ton	or 2487	kN
А	=	πr^2							
r	=	$h_2 + l$	n 3						
	=	121 +	- 121,						
r	=	242 m	m						
Р	=	0.0013	352 ton/	mm ²					
Р	=	0.0013	352 x 1	450					
Р	=	1.96 k	si.	1 ksi	=	Kilo s	quare ir	nch	
					=	1450 t	on/mm ²	2	
3- Frie	ction Cy	vcle		μ	=	0.122	- 0.01	Р	
					=	0.1024	1		
Adjus	t for hig	gh veloc	ity		=	μ-0.	.036		
					=	0.1024	4 - 0.02	36	
					=	0.066	(Lower	r bound)	
1 - Fri	ction C	ycle		μ	=	1.2 x	0.066		
					=	0.0797	7		
μ_2	=	μ3	=	0.066	(Lower	bound)			
μ_2	=	μ3	=	0.080	(Upper	bound)			
μ	=	force	at zero d	leforma	ation				
μ	=	μ1-(μ	ι ₁ - μ ₂)	$\times \frac{R_2}{R_1}$	eff (Lov	wer bou	nd)		
μ	=	0.076							
μ	=	μ1 - ((μ1 - μ2	$(2) \times \frac{R}{R}$	^{2eff} (Up	oper bou	ind)		
μ	=	0.091							

c. D_D Computation (Upper bound)

$\mathbf{S}_{\mathbf{d}}$	=	0.5074			
μ	=	0.091			
μ_1	=	0.093			
$\mathbf{D}_{\mathbf{y}}$	=	$(\mu_1 - \mu_2) * R_{2e}$	ff		
D_y	=	0.007088			
F_d	=	0.2772			
W	=	248.7 Ton			
T.B.	=	12 Nos. (Whe	ere T.B	. = Tota	l Bearing)
ΣF_d	=	W x T.B. x l	F _d		
	=	248.7 x 12 x 0	0.2772		
ΣF_d	=	827.40			
Σw	=	W x T.B.			
Σw	=	2984.4 Tonn	e		
i.	Desig	n displacemen	t D _D	=	0.07202 mtrs.
ii.	Effect	tive stiffness, ()d	=	$\mu * \Sigma w$
				=	0.091 * 2984.4
			\mathbf{Q}_{d}	=	271.78 Ton
			k_D	=	$\Sigma F_D \ / \ D_D$
				=	827.40 / 0.07202
			k _D	=	11488.53 Ton/m.
			$\mathbf{K}_{\mathrm{eff}}$	=	$k_D + Q_D \ / \ D_D$
				=	11488.53 + 271.78 / 0.07202
			$\mathbf{K}_{\mathrm{eff}}$	=	15262.22 Ton/m.
iii.	Effect	t ive period , T _{ef}	f		

 $T_{eff} = 0.88708 \text{ sec.}$

iv. **Effective damping**, β_{eff}

$$\beta_{D} = \frac{E}{2\pi K_{eff} \times D_{D}^{2}} = \frac{4\mu \sum w(D_{D} - D_{y})}{2\pi K_{eff} \times D_{D}^{2}}$$
$$\beta_{eff} = \beta_{D} = 0.1419$$

v. Damping reduction coefficient, β

$$\beta = \left(\frac{\beta_{eff}}{0.05}\right)^{0.3}$$
$$\beta = 1.3675$$

vi.
$$D_D^1$$

$$D_{D}^{1} = \frac{S_{D!} \times T_{eff}^{2}}{4\pi^{2} \times \beta} \times g$$
$$D_{D}^{1} = 0.0726 \text{ mtrs}$$

(B) ETABS link directional property computation (upper bound)

a. Principal features

i. Determine bearing

The isolator had been envisioned as a cylinder with a height of 0.32 metres and a diameter of 0.305 metres

$$H = 0.5 \text{ m}$$

$$\emptyset = 0.484 \text{ m}$$
Now, C/S Area
$$A = \frac{\pi \times \theta^2}{4}$$

$$= \frac{\pi \times 0.484^2}{4}$$

$$A = 0.1840 \text{ m}^2$$

$$K_{eff} = \frac{W}{R_{1eff}} + \frac{\mu w}{D_D}$$

$$K_{eff} = 387.73 \text{ Ton/m}$$

$$I_1 = \frac{K_{eff} \times h^3}{12E} = \frac{387.73 \times 0.5^3}{12E}$$

=

4.03884E-07 m⁴.

Е	=	1x10 ⁷ N/mm ²
ii.	Deterr	nine bearing mass
D _{m-max}	=	0.0702 m.
D _{TM}	=	1.15 x D _{m-max}
	=	1.15 x 0.0702
D _{TM}	=	0.0807 m.
D	=	2 D _{TM}
	=	2 x 0.0807
D	=	0.16146 m.
W	=	0.241 D ² - 0.00564 D
W	=	0.0053721 tonne
М	=	w / g
	=	0.005372 / 9.81
М	=	0.000548 tonne sec ² /m.

b. Direction (U₁)

Η	=	0.5 m
Ø	=	0.484 m
Keff	=	AE / L
K efF	=	3679684.643 ton/m.
from l	D _D	
K _{eff}	=	3679684.643 ton/m.
Baff	_	0.1410

0.161m.

c. Direction (U₂ - U₃)

i. Determination of liner properties.

$K_{eff} \\$	=	387.729 ton/m	
	=	3877.29 KN/m	
β_{eff}	=	0.1419	
Heigl	ht for	Duter surface , $= h_1 = h_4$	=

Height for inner surface, $= h_2 = h_3 = 0.121m$.

ii. Determination of Non - liner properties.

R_{2eff}	=	0.526 m.
D_y	=	$(\mu_1 - \mu_2) R_{2eff}$
	=	(0.093155 – 0.079680) x 0.526
Dy	=	0.00709 m.

Stiffness (Outer Top)	=	$\frac{\mu_1 w}{D_y}$
	=	0.093155 ×248.7 0.00709
	=	3268.561 ton/m.
	=	32685.61 KN/m.

Stiffness (Inner Top)	=	$\frac{\mu_2 w}{D_y}$
		Dy

$$= \frac{0.079680 \times 248.7}{0.00709}$$

$$=$$
 2795.747 ton/m.

= 27957.47 KN/m.

Friction Coefficient, Slow	=	μ1	=	0.093 (Outer Top)
	=	μ2	=	0.080 (Inner Top)
Friction Coefficient, Fast	=	2 x μ1	=	0.186 (Outer Top)
	=	2 x μ ₂	=	0.159 (Inner Top)
Rate Parameter			=	Friction Coeff. Slow Friction Coeff.Fast
			=	0.093 / 0.186
			=	0.5
			=	0.0005 sec/mm
Radius of sliding surface				
Outer Top = $R_{1 \text{ eff}}$			=	3.395 m.
Inner Top = $R_{2 eff}$			=	0.526 m.
Stop distance				
outer Top u ₁ *			=	$2 D_y + 2 d_1*$
			=	1.09498 m.
			=	1094.98 mm
Inner Top u ₂ *			=	2 Dy
			=	0.0142 m.
			=	14.18 mm.

(C) Input Values in ETABS:

Identification		
Property Name	U	
Direction	U1	
Туре	Triple Pendulum	Isolator
NonLinear	Yes	
Linear Properties		
Effective Stiffness	β6796846.43	kN/m
Effective Damping	1.367	kN-s/m
Nonlinear Properties		
Stiffness	36796846.43	kN/m
Damping Coefficient	1.367	kN-s/m

Figure-46. TFPB Input Values in ETABS for Uniaxial Load 2487 KN Direction U₁

Property Name			Туре	Triple Pendulum Isol	ator
Direction	2; U3		NonLinear	Yes	
Linear Properties					
Effective Stiffness - U2	3877.285	kN/m	Effective Stiffness -U3	3877.285	kN/m
Effective Damping - U2	1.367	kN-s/m	Effective Damping -U3	1.367	kN-s/m
Shear Deformation Location					
Distance from End-J - U2	0	m	Distance from End-J - U3	0	m
Height for Outer Surfaces Height for Inner Surfaces	þ.161 0.121	m 🗹 Out	ter Bottom Surface is Sym er Bottom Surface is Symr	metric to Outer Top netric to Inner Top S	Surface Surface
Height for Outer Surfaces Height for Inner Surfaces Nonlinear Properties for Dire	().161 ().121 ().121 ().121 ().121	m V Out	ter Bottom Surface is Sym er Bottom Surface is Symr	metric to Outer Top netric to Inner Top S	Surface Surface
Height for Outer Surfaces Height for Inner Surfaces Nonlinear Properties for Dire Stiffness	0.121 0.121 ctions U2 and U3 Outer Top 32685.609	m 🗹 Out m 🗹 Inn Outer Bott	ter Bottom Surface is Sym er Bottom Surface is Symr tom Inner Top 27957.47	metric to Outer Top netric to Inner Top S Inner Botto	Surface Surface mkN/m
Height for Outer Surfaces Height for Inner Surfaces Nonlinear Properties for Dire Stiffness Friction Coefficient, Slow	D.161 0.121 ctions U2 and U3 Outer Top 32685.609 0.09315	m ♥ Out m ♥ Inn Outer Bott 32685.609 0.09315	ter Bottom Surface is Sym er Bottom Surface is Sym tom Inner Top 27957.47 0.079679	Inner Botto	Surface Surface mkN/m
Height for Outer Surfaces Height for Inner Surfaces Nonlinear Properties for Dire Stiffness Friction Coefficient, Slow Friction Coefficient, Fast	D.161 0.121 ctions U2 and U3 Outer Top 32685.609 0.09315 0.1863	m ♥ Out m ♥ Inn Outer Bott 32685.609 0.09315 0.1863	ter Bottom Surface is Sym er Bottom Surface is Sym tom Inner Top 27957.47 0.079679 0.159359	Inner Botto 27957.47 0.079679 0.159359	Surface mkN/m
Height for Outer Surfaces Height for Inner Surfaces Nonlinear Properties for Dire Stiffness Friction Coefficient, Slow Friction Coefficient, Fast Rate Parameter	D.161 0.121 ctions U2 and U3 Outer Top 32685.609 0.09315 0.1863 0.0005	m ♥ Out m ♥ Inn Outer Bott 32685.609 0.09315 0.1863 0.1863	ter Bottom Surface is Sym er Bottom Surface is Sym tom Inner Top 27957.47 0.079679 0.159359 0.0005	Inner Botto 27957.47 0.079679 0.159359 0.0005	Surface mkN/m sec/mn
Height for Outer Surfaces Height for Inner Surfaces Nonlinear Properties for Dire Stiffness Friction Coefficient, Slow Friction Coefficient, Fast Rate Parameter Radius of Sliding Surface	D.161 0.121 ctions U2 and U3 Outer Top 32685.609 0.09315 0.1863 0.0005 3.395	m ♥ Out m ♥ Inn Outer Bott 32685.609 0.09315 0.1863 0.0005 3.395	ter Bottom Surface is Sym er Bottom Surface is Sym tom Inner Top 27957.47 0.079679 0.159359 0.0005 0.526	metric to Outer Top netric to Inner Top S Inner Botto 27957.47 0.079679 0.159359 0.0005 0.526	Surface mkN/m sec/mn m
Height for Outer Surfaces Height for Inner Surfaces Nonlinear Properties for Dire Stiffness Friction Coefficient, Slow Friction Coefficient, Fast Rate Parameter Radius of Sliding Surface Stop Distance	D.161 0.121 ctions U2 and U3 Outer Top 32685.609 0.09315 0.1863 0.0005 3.395 1094.976	m ♥ Out m ♥ Inn Outer Bott 32685.609 0.09315 0.1863 0.0005 3.395 1094.976	ter Bottom Surface is Sym er Bottom Surface is Sym 27957.47 0.079679 0.159359 0.0005 0.526 14.176	Inner Botto Inner Botto Inner Botto I0.079679 I0.079679 I0.059359 I0.0005 I0.526 I14.176 I0.179	Surface m kN/m sec/mn m m

Figure-47. TFPB Input Values in ETABS for Uniaxial Load 2487 KN Direction U₂ & U₃

5.3.3 TFPB for Axial Load - 3920 KN



Figure-48. TFPB Schematic

(A) Geometrical, Frictional and D_D Computation

a.	Geom	etrical				
	\mathbf{R}_4	=	R ₁	=	1778 x 2	
				=	3556 mm	
				=	3.556 m	
	\mathbf{R}_2	=	R ₃	=	647 mm	
				=	0.647 m	
	h_1	=	h_4	=	161 mm	
				=	0.161 m	
	h_2	=	h ₃	=	121 mm	
				=	0.121 m	
	d_1	=	566.02 mm			
	d_2	=	81.05 mm			
	$R_{1 eff}$	=	R _{4eff}	=	$R_1 - \ h_1$	
				=	3556 - 161	
				=	3395 mm	

R_{2eff}	=	R _{3eff}	=	$R_2-\ h_2$
			=	647 - 121
			=	526 mm.
d_4*	=	d_1*	=	$\frac{d_1 \times R_{1eff}}{R_1}$
			=	540.39 mm
			\approx	540.40 mm.
d_2*	=	d ₃ *	=	$\frac{d_2 \times R_{2eff}}{R_2}$
			=	65.89 mm
			≈	65.90 mm.

b. Frictional Characteristics Computation

At 1 a	nd 4				
Р	=	W / A			
Here V	W Load			=	392.0 tonne or 3920 KN,
А	=	πr^2			
r	=	$h_4+\ h_1$			
	=	161 + 161			
r	=	322 mm			
Р	=	0.001203 ton	/mm ²		
Р	=	0.001203 x 1	450		
Р	=	1.74 ksi,	1 ksi	=	Kilo square inch
				=	1450 ton/mm ²
3- Fric	ction Cy	/cle	μ	=	0.122 - 0.01 P
			μ	=	0.1046
Adjus	t for hig	h velocity		=	μ - 0.0333
				=	0.1046 - 0.0333
				=	0.071 (Lower bound)
1 - Fri	ction C	ycle	μ	=	1.2 x 0.071
				=	0.0855

	_		_	0.071	(I	hourd			
μ_1	=	μ_4	=	0.071	(Lower	bound)			
μ_1	=	μ_4	=	0.086	(Upper	bound)			
At 2 a	nd 3								
Р	=	W / A							
Here V	W Load	1			=	392.0	tonne	or 3920	KN
А	=	πr^2							
r	=	$h_2 + h_2$	13						
	=	121 +	- 121						
	=	242 m	m						
Р	=	0.002	131 ton	/mm ² ,					
Р	=	0.002	131 x 1	450					
Р	=	3.09 k	si.	1 ksi	=	Kilo sc	juare in	ch	
					=	1450 to	on/mm ²	2	
3- Fric	ction Cy	vcle		μ	=	0.122	- 0.01	Р	
					=	0.0911			
Adjus	t for hig	h veloc	ity		=	μ - 0.	036		
					=	0.0911	- 0.03	36	
					=	0.055	(Lower	bound)	
1 - Fri	ction C	ycle		μ	=	1.2 x	0.055		
					=	0.0661			
μ_2	=	μ ₃	=	0.055	(Lower	bound)			
μ_2	=	μ ₃	=	0.066	(Upper	bound)			
μ	=	force a	at zero c	leforma	ation				
μ	=	μ1 - (μ1 - μ2) ×	$\frac{R_{2eff}}{R_{1eff}}$ (Lower b	ound)		
μ	=	0.069							
μ	=	μ1 - ((μ1 - μ	2) X	$\frac{R_{2eff}}{R_{1eff}}$	(Upper b	oound)		
μ	=	0.082							

c. D_D Computation (Upper bound)

$\mathbf{S}_{\mathbf{d}}$	=	0.5074			
μ	=	0.082			
μ_1	=	0.086			
D_y	=	$(\mu_1 - \mu_2) * R_{2e}$	ff		
D_y	=	0.010190			
F_d	=	0.2772			
W	=	392 Ton			
T.B.	=	12 Nos. (Whe	ere T.B.	. = Total	l Bearing)
ΣF_d	=	W x T.B. x I	Fd		
	=	392 x 12 x 0.	2772		
ΣF_d	=	1304.15			
Σw	=	W x T.B.			
Σw	=	4704 Ton			
i.	Desig	n displacemen	t, DD	=	0.07202 m.
ii.	Effect	ive stiffness, ()d	=	$\mu * \Sigma w$
ii.	Effect	ive stiffness, ()d	=	μ * Σw 0.082 * 2832
ii.	Effect	ive stiffness, ()d Qd	= =	μ * Σw 0.082 * 2832 388.07 Ton
ii.	Effect	ive stiffness, ()d Qd k _D	= = =	μ * Σw 0.082 * 2832 388.07 Ton ΣF _D / D _D
ii.	Effect	ive stiffness, ()d Q _d k _D	= = = =	μ * Σw 0.082 * 2832 388.07 Ton ΣF _D / D _D 1304.15 / 0.07202
ii.	Effect	ive stiffness, ()d Q₁ k _D	= = = =	μ * Σw 0.082 * 2832 388.07 Ton ΣF _D / D _D 1304.15 / 0.07202 18108.18 Ton/m.
ii.	Effect	ive stiffness, ()d Qd kD kD Keff	= = = = =	$\mu * \Sigma w$ 0.082 * 2832 388.07 Ton $\Sigma F_D / D_D$ 1304.15 / 0.07202 18108.18 Ton/m. $k_D + Q_D / D_D$
ii.	Effect	ive stiffness, ()d Qd kD KD Keff		$\mu * \Sigma w$ 0.082 * 2832 388.07 Ton $\Sigma F_D / D_D$ 1304.15 / 0.07202 18108.18 Ton/m. $k_D + Q_D / D_D$ 18108.18 + 388.07 / 0.07202
ii.	Effect	ive stiffness, ()d Qd kD KD Keff		$\label{eq:multiplicative} \begin{split} \mu & * \ \Sigma w \\ 0.082 & * \ 2832 \\ 388.07 \ Ton \\ \Sigma F_D \ / \ D_D \\ 1304.15 \ / \ 0.07202 \\ 18108.18 \ Ton/m. \\ k_D \ + \ Q_D \ / \ D_D \\ 18108.18 \ + \ 388.07 \ / \ 0.07202 \\ 23496.59 \ Ton/m. \end{split}$
ii.	Effect	ive stiffness, ()d Qd kD KD Keff		$\label{eq:main_state} \begin{array}{l} \mu \ * \ \Sigma w \\ 0.082 \ * \ 2832 \\ 388.07 \ Ton \\ \Sigma F_D \ / \ D_D \\ 1304.15 \ / \ 0.07202 \\ 18108.18 \ Ton/m. \\ k_D \ + \ Q_D \ / \ D_D \\ 18108.18 \ + \ 388.07 \ / \ 0.07202 \\ 23496.59 \ Ton/m. \end{array}$
ii. iii.	Effect	ive stiffness, ()d Qd kD KD Keff Keff		$\label{eq:main_state} \begin{array}{l} \mu \ * \ \Sigma w \\ 0.082 \ * \ 2832 \\ 388.07 \ Ton \\ \Sigma F_D \ / \ D_D \\ 1304.15 \ / \ 0.07202 \\ 18108.18 \ Ton/m. \\ k_D \ + \ Q_D \ / \ D_D \\ 18108.18 \ + \ 388.07 \ / \ 0.07202 \\ 23496.59 \ Ton/m. \end{array}$

 $T_{eff} = 0.89759 \text{ sec.}$

iv.

- Effective damping, β_{eff} $\beta_{D} = \frac{E}{2\pi K_{eff} \times D_{D}^{2}} = \frac{4\mu \Sigma w (D_{D} - D_{y})}{2\pi K_{eff} \times D_{D}^{2}}$ $\beta_{eff} = \beta_{D} = 0.1253$
- v. Damping reduction Coefficient, β

$$\beta = \left(\frac{\beta_{\text{eff}}}{0.05}\right)^{0.3}$$
$$\beta = 1.3174$$

vi.
$$D_D^1$$

$$D_D^{1} = \frac{S_{D!} \times T_{eff}^2}{4\pi^2 \times \beta} \times g$$
$$D_D^{1} = 0.0771 \text{ m.}$$

(B) ETABS links directional property computation (upper bound)

a. Principal features

i. Determine bearing

The isolator had been envisioned cylinder with a height of 0.32 metres and a diameter of 0.305 metres

$$=$$
 5.88019E-07 m⁴.

E =	$1 \times 10^7 \text{N/mm}^2$
E =	$1 \times 10^{7} \text{ N/mm}^{-1}$

ii. Determine bearing mass

D _{m-ma}	x =	0.0702 mtrs.
D _{TM}	=	1.15 x D _{m-max}
	=	1.15 x 0.0702
D _{TM}	=	0.0807 mtrs.
D	=	2 D _{TM}
	=	2 x 0.0807
D	=	0.16146 mtrs.
W	=	0.241 D ² - 0.00564 D
W	=	0.0053721 tonne.
М	=	w / g
	=	0.005372 / 9.81
М	=	0.000548 tonne sec ² /m.

b. Direction (U₁)

Η	=	0.5 m
Ø	=	0.484 m
K _{eff}	=	AE / L
Keff	=	3679684.643 ton/m.
Keff	=	36796846.43 KN/m.
from	D _D	
K _{eff}	=	3679684.64 ton/m.
β_{eff}	=	0.1253

c. Direction $(U_2 - U_3)$

i. Determination of liner properties.

K _{eff}	=	564.498	ton/m

= 5644.98 KN/m

 $\beta_{eff} = 0.1253$

Height for outer surface, $= h_1 = h_4 = 0.161 \text{ m}$ Height for inner surface, $= h_2 = h_3 = 0.121 \text{ m}$

ii. Determination of Non - liner properties.

Dy	=	0.01091 mtrs.
	=	(0.08550 – 0.06613) x 0.526
D_y	=	$(\mu_1 - \mu_2) R_{2eff}$
R_{2eff}	=	0.526 mtrs.

Stiffness (Outer Top)			=	$\frac{\mu_1 w}{D_y}$
			=	$\frac{0.08550 \times 392}{0.01091}$
			=	3289.068 ton/m.
			=	32890.68 KN/m.
Stiffness (Inner Top)			=	$\frac{\mu_2 w}{D_y}$
			=	0.06613 ×392 0.01091
			=	2543.821 ton/m.
			=	25438.21 KN/m.
Friction Coefficient, Slow	=	μ_1	=	0.086 (Outer Top)
	=	µ 2	=	0.066 (Inner Top)

Friction Coefficient, Fast	=	$2 x \mu_1 =$	0.171 (Outer Top)
	=	$2 \ge \mu_2 =$	0.132 (Inner Top)
Rate Parameter		=	Friction Coeff. Slow Friction Coeff.Fast
		=	0.086 / 0.171
		=	0.5
		=	0.0005 sec/mm
Radius of sliding surface			
Outer Top = $R_{1 eff}$		=	3.395 mtrs.
Inner Top = $R_{2 eff}$		=	0.526 mtrs.
Stop distance			
Outer Top u ₁ *		=	$2 D_y + 2 d_1 *$
		=	1.10118 mtrs.
		=	1101.18 mm
Inner Top u ₂ *		=	2 D _y
		=	0.0204 mtrs.
		=	20.380 mm.

(C) Input Values in ETABS:

	Δ.		
Property Name	A		
Direction	01		
Туре	Triple Pendulum Isolator		
NonLinear	Yes		
Linear Properties			
Effective Stiffness	36796846.43	kN/m	
Effective Damping	1.317	kN-s/m	
Nonlinear Properties			
Stiffness	36796846.43	kN/m	
Damping Coefficient	1.317	kN-s/m	

Figure-49. TFPB Input Values in ETABS for Axial Load 3920 KN Direction U₁

Property Name A		T	vpe	Triple Pendulum Isol	ator
Direction U2	; U3	N	onLinear	Yes	
I State Stat					
Linear Properties					
Effective Stiffness - U2	5644.98	kN/m E	ffective Stiffness -U3	5644.98	kN/m
Effective Damping - U2	1.317	kN-s/m E	ffective Damping -U3	1.317	kN-s/m
Shear Deformation Location					
Distance from End-J - U2	0	m D	istance from End-J - U3	0	m
Height for Outer Surfaces Height for Inner Surfaces	0.161	m 🗸 Outer	Bottom Surface is Sym Bottom Surface is Sym	metric to Outer Top	Surface Surface
Height for Outer Surfaces Height for Inner Surfaces Nonlinear Properties for Direct	0.161 0.121 tions U2 and U3	m 🗹 Outer m 🗹 Inner	Bottom Surface is Sym Bottom Surface is Sym	metric to Outer Top metric to Inner Top S	Surface
Height for Outer Surfaces Height for Inner Surfaces Nonlinear Properties for Direc Stiffness	0.161 0.121 tions U2 and U3 Outer Top 32890.679	m Vouter m Inner	r Bottom Surface is Sym Bottom Surface is Sym n Inner Top 25438 208	metric to Outer Top metric to Inner Top S Inner Botto	Surface Surface mkN/m
Height for Outer Surfaces Height for Inner Surfaces Nonlinear Properties for Direc Stiffness Friction Coefficient, Slow	0.161 0.121 tions U2 and U3 Outer Top 32890.679 0.0855	m ♥ Outer m ♥ Inner Outer Bottor 32890.679	n Bottom Surface is Sym Bottom Surface is Sym n Inner Top 25438.208 0.0661	Inner Botto	Surface Surface mkN/m
Height for Outer Surfaces Height for Inner Surfaces Nonlinear Properties for Direc Stiffness Friction Coefficient, Slow Friction Coefficient, Fast	0.161 0.121 tions U2 and U3 Outer Top 32890.679 0.0855 0.171	m ♥ Outer m ♥ Inner Outer Bottor 32890.679 0.0855 0.171	r Bottom Surface is Sym Bottom Surface is Sym n Inner Top 25438.208 0.0661 0.13225	Inner Botto 25438.208 0.0661 0.13225	Surface mkN/m
Height for Outer Surfaces Height for Inner Surfaces Nonlinear Properties for Direc Stiffness Friction Coefficient, Slow Friction Coefficient, Fast Rate Parameter	0.161 0.121 tions U2 and U3 Outer Top 32890.679 0.0855 0.171 0.0005	m ♥ Outer m ♥ Inner Outer Bottor 32890.679 0.0855 0.171 0.0005	r Bottom Surface is Sym Bottom Surface is Sym n Inner Top 25438.208 0.0661 0.13225 0.0005	Inner Botto 25438.208 0.0661 0.13225 0.0005	Surface mkN/m sec/mm
Height for Outer Surfaces Height for Inner Surfaces Nonlinear Properties for Direc Stiffness Friction Coefficient, Slow Friction Coefficient, Fast Rate Parameter Radius of Sliding Surface	0.161 0.121 tions U2 and U3 Outer Top 32890.679 0.0855 0.171 0.0005 3.395	m ♥ Outer m ♥ Inner Outer Bottor 32890.679 0.0855 0.171 0.0005 3.395	Bottom Surface is Sym Bottom Surface is Sym n Inner Top 25438.208 0.0661 0.13225 0.0005 0.526	Inner Botto 25438.208 0.0661 0.13225 0.0005 0.526	Surface mkN/m sec/mm m
Height for Outer Surfaces Height for Inner Surfaces Nonlinear Properties for Direct Stiffness Friction Coefficient, Slow Friction Coefficient, Fast Rate Parameter Radius of Sliding Surface Stop Distance	0.161 0.121 tions U2 and U3 Outer Top 32890.679 0.0855 0.171 0.0005 3.395 1101.18	m ♥ Outer m ♥ Inner 0uter Bottor 32890.679 0.0855 0.171 0.0005 3.395 1101.18	Bottom Surface is Sym Bottom Surface is Sym n Inner Top 25438.208 0.0661 0.13225 0.0005 0.526 20.38	Inner Botto 25438.208 0.0661 0.13225 0.0005 0.526 20.38	Surface mkN/m sec/mm m

Figure-50. TFPB Input Values in ETABS for Axial Load 3920 KN Direction U₂ & U₃

5.4 Design of LRB for G+22 Storey RC Structure.

For the analysis & design of LRB, the cumulative load at the base is obtained from the fixed based design modal in ETABS-2016. This load is categorized into three groups viz. Axial load, Biaxial load and Uniaxial load.

5.4.1 LRB for Biaxial Load - 3342 KN





	= 0.05 For U1,U2,U3.
Effective Damping (¿eff)	= 5%
	$= 0.5 \text{ kN/m}^2.$
Design Shear Strain (ymax)	= 50%
Time Period (TD)	= 2.5 sec.
Biaxial Load (W)	= 3342 kN.

	EFFECTIVE DAMPING, $\beta_D \text{ OR } \beta_M$ (PERCENTAGE OF CRITICAL)	BD OR BM FACTOR
_	≤ 2 ¹ ‰	0.8
	5%	1.0
	10%	1.2
	20%	1.5
	30%	1.7
	40%	1.9
	≥ 50%	2.0

Table-10. Damping Coefficient, $B_{\rm D}$ or $B_{\rm M}$

Table-11. Seismic Coefficient Cv

1	SEISMIC ZONE FACTOR, Z				
SOIL PROFILE TYPE	Z=0.075	Z=0.15	Z=0.2	Z=0.3	Z=0.4
SA	0.06	0.12	0.16	0.24	0.32N ₀
SB	0.08	0.15	0.20	0.30	0.40N ₀
Sc	0.13	0.25	0.32	0.45	0.56Ny
SD	0.18	0.32	0.40	0.54	0.64N;
SE	0.26	0.50	0.64	0.84	0.96N ₂
SF	See Footnote 1				

Damping Coefficient (B _D)	= 1.0 (UBC-97, Vol-2, Pg. No. 414)
Seismic Coefficient (S _D)	= 0.54 (UBC-97, Vol-2, Pg. No. 35)

Table-12.	Vulcanized	Natural	Rubber	Compounds
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Hardness IRHD±2	Young's Modulus E (MPa)	Shear Modulus G (MPa)	Material Constant k	Elongation at Break Min, %
37	1.35	0.40	0.87	650
40	1.50	0.45	0.85	600
45	1.80	0.54	0.80	600
50	2.20	0.64	0.73	500
55	3.25	0.81	0.64	500
60	4.45	1.06	0.57	400

Choosing 60 for analysis in critical circumstances

E	=	4.45
	=	4450 kN/m ²
G	=	1.06
	=	1060 kN/m ²
K	=	0.57
ε _b	=	4
	=	400%
\mathbf{f}_{py}	=	8500 kN/m ²
σ_{a}	=	7840 kN/m ²
Typic	ally 7 to	o 8.5 Mpa, Consult
F_s	=	164640 kN/m ²
f_v	=	274400 kN/m ²

(A) LRB - Analysis

i.

$K_{effH} = \frac{1}{g} \left(\frac{T_D}{T_D} \right)$	
$K_{effH} = \frac{W}{\pi} \left(\frac{2\pi}{\pi}\right)^2$	
The effective horizontal stiffn	ess K _{effH}

the manufacturer

Design displacement (D_D) ii.

$$D_{\rm D} = \left(\frac{g}{4\pi^2}\right) \times \frac{S_{\rm D}T_{\rm D}}{B_{\rm D}}$$
$$= 0.33546 \text{ m.}$$

$$\mathbf{Q}_{\mathbf{d}} = \frac{W_{\mathrm{D}}}{4 \times \mathrm{D}_{\mathrm{D}}} = \frac{\pi}{4} \times \mathrm{K}_{\mathrm{effH}} \times \xi_{\mathrm{effH}} \times \mathrm{D}_{\mathrm{D}}$$
$$= 56.6957 \text{ kN}$$

iv. Yield Stiffness

Note- Based on the findings of the trials, the initial elastic stiffness was calculated to be between 9 and 16 Kd.

 $K_{d} = K_{effH} - \frac{Q_{d}}{D_{D}}$ = 1982.87 kN/m. $K_{U} = 10 K_{d}$ = 19828.7 kN/m.

$$\frac{K_{d}}{K_{U}} = \frac{1982.87}{19828.7} = 0.1$$

Direction U₂ & U₃

(B) LRB - Development

$$Ap = \frac{Q_d}{f_{py}}$$
$$= 0.00667 m^2.$$

ii. Dia of lead core (d_p)

$$Ap = \frac{\pi d^2}{4}$$
$$d_p = \sqrt{\frac{4A_p}{\pi}}$$
$$= 0.09216 \text{ m.}$$

iii. Thickness of rubber layer (t_r)

$$t_r = \frac{D_D}{\gamma_{max}}$$

= 0.67092 m.

$$\frac{E(1+2kS^2)}{G} \ge 400,$$

S = 9.09409

For S < 10, Take S = 10

v. Compressive modulus of rubber & steel (Ec) Ec = $E(1+2kS^2)$ = 511750 kN/m².

$$A_o = W / \sigma_a$$

= 0.42628 m².

vii. Shear strain's effective area (A1) $\frac{6SW}{E_c \times A_1} \leq \frac{\varepsilon_b}{3}$ $= 0.29387 \text{ m}^2.$

viii. Elastic Stiffness Kr

$$K_{d} = K_{r} \times \frac{1+12 \times A_{P}}{A_{o}}$$
$$= 1669.41 \text{ kN/m}.$$

ix. Effective area of individual rubber layer (Asf)

$$A_{sf} = \frac{\pi d^2}{4}$$

= 1.05665 m².

x. Diameter of rubber (d)

d =
$$\sqrt{\frac{4A_{sf}}{\pi}}$$

= 1.1599 m.

$$K_{v} = \frac{E_{C} \times A_{sf}}{t_{r}}$$

Kv = 805961 kN/m. Direction U₁

xii. Reduction factor - Damping (
$$\beta$$
)
 $\beta = 2 \times \cos^{-1}\left(\frac{D_D}{d}\right)$
 $= 2.555$

xiii. Reduced area (A2)

$$A_2 = \frac{d^2 \times (\beta - \sin \beta)}{4}$$

$$= 0.67318 \text{ m}^2$$

xiv.

LRB - Details
A = 0.67318 m² (Max Area of A₀, A1, & A₂)
d = 0.92581 m
No. of rubber layer (N) =
$$t_r/t$$
 (where t = 0.029)
= 23.1373
Say (N) = 24.00

xv. Steel Plate thickness (t_s)

$$t_{s} = \frac{2 \times W \times 2t}{A \times Fs}$$

$$t_{s} = 0.0035 \ge 0.002 \text{ m.}$$

- xvi. Total height of bearing (h_b)
 - $h_b \qquad = N \; x \; (ts + 2*0.0025) + tr$
 - $h_b = 0.87486 \ m.$

(C) Input Values in ETABS:

Property Name	В	
Direction	U1	
Туре	Rubber Isolato	r
NonLinear	No	
near Properties		
Effective Stiffness	B05961	kN/m
Effective Damping	0.05	kN-s/m

Figure-52. LRB Input Values in ETABS for Biaxial Load 3342 KN Direction U₁

Property Name	В	
Direction	U2	
Туре	Rubber Isolato	0F
NonLinear	Yes	
inear Properties		
Effective Stiffness	Þ151.88	kN/m
Effective Damping	0.05	kN-s/m
Shear Deformation Location		
Distance from End-J	0	m
Nonlinear Properties		
Stiffness	19828.7	kN/m
Yield Strength	56.7	kN
Post Yield Stiffness Ratio	0.1	

Figure-53. LRB Input Values in ETABS for Biaxial Load 3342 KN Direction U₂ & U₃

5.4.2 LRB for Uniaxial Load - 4627 KN



Figure-54. LRB Schematic

	= 0.05 For U1,U2,U3
Effective Damping (ξeff)	= 5%
	= 0.5 kN/m2.
Design Shear Strain (ymax)	= 50%
Time Period (TD)	= 2.5 sec.
Uniaxial Load (W)	= 4627 kN.

EFFECTIVE DAMPING, $\beta_D \text{ OR } \beta_M$ (PERCENTAGE OF CRITICAL)	BD OR BM FACTOR
$\leq 2^{0}/_{0}$	0.8
5%	1.0
10%	1.2
20%	1.5
30%	1.7
40%	1.9
≥ 50%	2.0

1	SEISMIC ZONE FACTOR, Z				//
SOIL PROFILE TYPE	Z=0.075	Z=0.15	Z=0.2	Z=0.3	Z=0.4
S _A	0.06	0.12	0.16	0.24	0.32N ₀
Sg	0.08	0.15	0.20	0.30	0.40N _v
Sc	0.13	0.25	0.32	0.45	0.56M;
SD	0.18	0.32	0.40	0.54	0.64.Nr
Sg	0.26	0.50	0.64	0.84	0.96N ₀
SF	See Footnote 1				

Table-14. Seismic Coefficient Cv

Damping Coefficient (B_D)

Seismic Coefficient (S_D)

= 1.0 (UBC-97, Vol-2, Pg. No. 414)

= 0.54 (UBC-97, Vol-2, Pg. No. 35)

Table-15. vulcanized Natural Kubber Compounds	Table-15.	Vulcanized	Natural	Rubber	Compounds
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Hardness IRHD±2	Young's Modulus E (MPa)	Shear Modulus G (MPa)	Material Constant k	Elongation at Break Min, %
37	1.35	0.40	0.87	650
40	1.50	0.45	0.85	600
45	1.80	0.54	0.80	600
50	2.20	0.64	0.73	500
55	3.25	0.81	0.64	500
60	4.45	1.06	0.57	400

Choosing 60 for analysis in critical circumstances

Е	=	4.45
	=	4450 kN/m ²
G	=	1.06
	=	1060 kN/m ²
K	=	0.57
ε _b	=	4
	=	400%

f _{py} =	8500 kN/m ²
-------------------	------------------------

 $\sigma_a = 7840 \text{ kN/m}^2$

Typically 7 to 8.5 Mpa, Consult the manufacturer

F_s	=	164640 kN/m ²
$\mathbf{f}_{\mathbf{y}}$	=	274400 kN/m ²

(A) LRB - Analysis

i. The effective horizontal stiffness K_{effH}

$$K_{effH} = \frac{W}{g} \left(\frac{2\pi}{T_D}\right)^2$$

Keff H = 2979.27 kN/m Direction U₂ & U₃

$$D_{\rm D} = \left(\frac{g}{4\pi^2}\right) \times \frac{S_{\rm D}T_{\rm D}}{B_{\rm D}}$$
$$= 0.33546 \text{ m.}$$

Yield Strength
$$\mathbf{Q}_{\mathbf{d}}$$

 $\mathbf{Q}_{\mathbf{d}} = \frac{W_{\mathrm{D}}}{4 \times \mathrm{D}_{\mathrm{D}}} = \frac{\pi}{4} \times \mathrm{K}_{\mathrm{effH}} \times \xi_{\mathrm{effH}} \times$
= 78.4952 kN

iv. Yield Stiffness

iii.

K _U =	10 K _d		
Where,	K _d	=	Post yield stiffness
	$K_{\rm U}$	=	Pre yield stiffness

Note- Based on the findings of the trials, the initial elastic stiffness was calculated to be between 9 and 16 Kd.

 D_D

$$K_{d} = K_{effH} - \frac{Q_{d}}{D_{D}}$$
$$= 2745.28 \text{ kN/m}.$$

$$K_U$$
 =10 K_d
= 27452.8 kN/m.

v. Post yield stiffness ratio.

$$\frac{K_{d}}{K_{U}} = \frac{2745.28}{27452.8} = 0.1$$

Direction U₂ & U₃

(B) LRB - Development

$$Ap = \frac{Q_d}{f_{py}}$$
$$= 0.00923 \text{ m}^2.$$

$$Ap = \frac{\pi d^2}{4}$$
$$d_p = \sqrt{\frac{4A_p}{\pi}}$$
$$= 0.10843 \text{ m.}$$

iii. Thickness of rubber layer (t_r)

$$t_r = \frac{D_D}{\gamma_{max}}$$
$$= 0.67092 \text{ m.}$$

iv. The Shape factor (S)

$$\frac{E(1+2kS^{2})}{G} \ge 400,$$

S = 9.09409
For S < 10, Take S = 10

v. Compressive modulus of rubber & steel (Ec)

Ec =
$$E(1+2kS^2)$$

= 511750 kN/m².

vi. Effective area of bearing(A_o)

vii. Shear strain's effective area (A₁)

$$\frac{6SW}{E_{c} \times A_{1}} \leq \frac{\varepsilon_{b}}{3}$$
$$= 0.40687 \text{ m2.}$$

viii. Elastic Stiffness K_r

$$K_{d} = K_{r} \times \frac{1+12 \times A_{P}}{A_{o}}$$
$$= 2311.29 \text{ kN/m}.$$

ix. Effective area of individual rubber layer (A_{sf})

$$A_{sf} = \frac{\pi d^2}{4}$$

= 1.46293 m².

x. Diameter of rubber (d)

$$d = \sqrt{\frac{4A_{sf}}{\pi}}$$
$$= 1.36479 \text{ m}.$$

xi. Effective vertical stiffness (k_v)

$$K_{v} = \frac{E_{C} \times A_{sf}}{t_{r}}$$

K_v = 1115853 kN/m. Direction U₁

xii. Reduction factor - Damping (β) $\beta = 2 \times \cos^{-1}\left(\frac{D_D}{d}\right)$

$$= 2 \times \cos^{-1}\left(\frac{-p}{d}\right)$$
$$= 2.645$$

$$A_2 = \frac{d^2 \times (\beta - \sin \beta)}{4}$$
$$= 1.00982 \text{ m}^2$$

xiv. LRB - Details
A = 1.00982 m² (Max Area of A₀, A1, & A₂)
d = 1.13391 m
No. of rubber layer (N) =
$$t_r/t$$
 (where t = 0.03412)
= 19.6638
Say (N) = 20

xv. Steel Plate thickness
$$(t_s)$$

$$t_{s} = \frac{2 \times W \times 2t}{A \times Fs}$$
$$t_{s} = 0.0038 \ge 0.002 \text{ m}.$$

vi. Total height of bearing (h_b)

 $h_b = N \ x \ (ts + 2*0.0025) + tr$ $h_b = 0.84689 \ m.$

(C) Input Values in ETABS:

Property Name	U	
Direction	U1	
Туре	Rubber Isolato	r
NonLinear	No	
inear Properties		
Effective Stiffness	1115853	kN/m
Effective Damping	0.05	kN-s/m

Figure-55. LRB Input Values in ETABS for Uniaxial Load 4627 KN Direction U₁

Direction U2 Type Rubber Iso NonLinear Yes inear Properties Effective Stiffness 2979.27	olator
Type Rubber Isi NonLinear Yes inear Properties Effective Stiffness	olator
NonLinear Yes inear Properties Effective Stiffness	
Effective Stiffness	
Effective Stiffness 2979.27	
in the second	kN/m
Effective Damping 0.05	kN-s/m
Shear Deformation Location	
Distance from End-J 0	m
Nonlinear Properties	
Stiffness 27452.8	kN/m
Yield Strength 78.5	kN
Post Yield Stiffness Ratio 0.1	
Stiffness27452.8Yield Strength78.5Post Yield Stiffness Ratio0.1	kN/m kN

Figure-56. LRB Input Values in ETABS for Uniaxial Load 4627 KN Direction U₂ & U₃

5.4.3 LRB for Axial Load - 6860 KN



Figure-57. LRB Schematic

Axial Load (W)	= 6860 kN.
Time Period (TD)	= 2.5 sec.
Design Shear Strain (γmax)	= 50%
	= 0.5 kN/m2.
Effective Damping (ξeff)	= 5%
	= 0.05 For U1,U2,U3.

1 able - 10, Damping Coefficient, DD of DM	Table-16.	Damping	Coefficient,	BD	or	Вм
--	-----------	---------	--------------	----	----	----

EFFECTIVE DAMPING, $\beta_D OR \beta_M$ (PERCENTAGE OF CRITICAL)	BD OR BM FACTOR
≤ 2 ⁰ ⁄₀	0.8
5%	1.0
10%	1.2
20%	1.5
30%	1.7
40%	1.9
≥ 50%	2.0

	SEISMIC ZONE FACTOR, Z				
SOIL PROFILE TYPE	Z=0.075	Z=0.15	Z=0.2	Z=0.3	Z = 0.4
S _A	0.06	0.12	0.16	0.24	0.32N _v
SB	0.08	0.15	0.20	0.30	0.40N ₀
Sc	0.13	0.25	0.32	0.45	0.56Nj
SD	0.18	0.32	0.40	0.54	0.64M;
Sg	0.26	0.50	0.64	0.84	0.96N ₀
SF	See Footnote 1				

Table-17. Seismic Coefficient Cv

Damping Coefficient (B_D)

Seismic Coefficient (S_D)

= 1.0 (UBC-97, Vol-2, Pg. No. 414)

= 0.54 (UBC-97, Vol-2, Pg. No. 35)

Hardness IRHD±2	Young's Modulus E (MPa)	Shear Modulus G (MPa)	Material Constant k	Elongation at Break Min, %
37	1.35	0.40	0.87	650
40	1.50	0.45	0.85	600
45	1.80	0.54	0.80	600
50	2.20	0.64	0.73	500
55	3.25	0.81	0.64	500
60	4.45	1.06	0.57	400

Choosing 60 for analysis in critical circumstances

Е	=	4.45
	=	4450 kN/m ²
G	=	1.06
	=	1060 kN/m ²
K	=	0.57
ε _b	=	4
	=	400%
f _{py} =	8500 kN/m ²	
-------------------	------------------------	
-------------------	------------------------	

σ_{a}	=	7840 kN/m ²
~~		

Typically 7 to 8.5 Mpa, Consult the manufacturer

(A) LRB - Analysis

i. The effective horizontal stiffness K_{effH}

$$K_{effH} = \frac{W}{g} \left(\frac{2\pi}{T_D}\right)^2$$

K_{eff H} = 4417.08 kN/m Direction U₂ & U₃

$$D_{\rm D} = \left(\frac{g}{4\pi^2}\right) \times \frac{S_{\rm D}T_{\rm D}}{B_{\rm D}}$$
$$= 0.33546 \text{ m.}$$

iii. Yield Strength Q_d

$$\mathbf{Q}_{\mathbf{d}} = \frac{W_{D}}{4 \times D_{D}} = \frac{\pi}{4} \times K_{effH} \times \xi_{effH} \times D_{D}$$

= **116.377 kN**

iv. Yield Stiffness

Note- Based on the findings of the trials, the initial elastic stiffness was calculated to be between 9 and 16 Kd.

$$\begin{split} K_{d} &= K_{effH} - \frac{Q_{d}}{D_{D}} \\ &= 4070.16 \text{ kN/m}. \end{split}$$

$$K_U$$
 =10 K_d
= 40701.6 kN/m.

v. Post yield stiffness ratio.

$$\frac{K_{\rm d}}{K_{\rm U}} = \frac{4070.16}{40701.6}$$
$$= 0.1$$

Direction U₂ & U₃

(B) LRB - Development

$$Ap = \frac{Q_d}{f_{py}}$$
$$= 0.01369 m^2.$$

$$Ap = \frac{\pi d^2}{4}$$
$$d_p = \sqrt{\frac{4A_p}{\pi}}$$
$$= 0.13203 \text{ m.}$$

iii. Thickness of rubber layer (tr)

$$t_r = \frac{D_D}{\gamma_{max}}$$
$$= 0.67092 \text{ m.}$$

iv. The Shape factor (S)

$$\frac{E(1+2kS^2)}{G} \ge 400,$$

S = 9.09409

For S < 10, Take S = 10

v. Compressive modulus of rubber & steel (Ec)

Ec =
$$E(1+2kS^2)$$

= 511750 kN/m².

$$\begin{array}{ll} A_o & = W \ / \ \sigma_a \\ & = 0.875 \ m^2. \end{array}$$

vii. Shear strain's effective area (A₁)

$$\frac{6SW}{E_c \times A_1} \leq \frac{\varepsilon_b}{3}$$

$$= 0.60322 \text{ m2.}$$

viii. Elastic Stiffness K_r

$$K_d = K_r \times \frac{1+12 \times A_P}{A_0}$$

= 3426.73 kN/m.

ix. Effective area of individual rubber layer (A_{sf})

$$A_{sf} = \frac{\pi d^2}{4}$$

= 2.16894 m².

X. Diameter of rubber (d)

$$d = \sqrt{\frac{4A_{sf}}{\pi}}$$
$$= 1.6618 \text{ m.}$$

xi. Effective vertical stiffness (k_v)

$$K_{v} = \frac{E_{C} \times A_{sf}}{t_{r}}$$

K_v = 1654366 kN/m. Direction U₁

β

xii. Reduction factor - Damping (β)

$$= 2 \times \cos^{-1}\left(\frac{D_{\rm D}}{d}\right)$$
$$= 2.735$$

xiii. Reduced area (A₂)
A₂ =
$$\frac{d^2 \times (\beta - \sin \beta)}{4}$$

= 1.61519 m²

xiv. LRB - Details
A = 1.61519 m² (Max Area of A₀, A1, & A₂)
d = 1.43406 m
No. of rubber layer (N) =
$$t_r/t$$
 (where t = 0.04154)
= 16.1493
Say (N) = 17

xv. Steel Plate thickness (t_s)

$$t_s = \frac{2 \times W \times 2t}{A \times Fs}$$

 $t_s = 0.00429 \ge 0.002$ m.

xvi. Total height of bearing
$$(h_b)$$

 $h_b = N x (ts + 2*0.0025) + tr$
 $h_b = 0.8288 m.$

(C) Input Values in ETABS:

Property Name	A	
Direction	U1	
Туре	Rubber Isolato	r
NonLinear	No	
inear Properties		
Effective Stiffness	1654366	kN/m
Effective Damping	0.05	kN-s/m

Figure-58. LRB Input Values in ETABS for Axial Load 6860 KN Direction U₁

Property Name	A	
Direction	U2	
Туре	Rubber Isolate	or
NonLinear	Yes	
Linear Properties		
Effective Stiffness	4417.08	kN/m
Effective Damping	0.05	kN-s/m
Shear Deformation Location		
Distance from End-J	0	m
Nonlinear Properties		
Stiffness	40701.6	kN/m
Yield Strength	116.38	kN
Post Yield Stiffness Ratio	0.1	



5.5 Design of TFPB for G+22 Storey RC Structure.

For the analysis & design of TFPB, the cumulative load at the base is obtained from the fixed based design modal in ETABS-2016. This load is categorized into three groups viz. Axial load, Biaxial load and Uniaxial load.

5.5.1 TFPB for Biaxial Load - 3342 KN



Figure-60. TFPB Schematic

(A) Geometrical, Frictional and D_D Computation

a. Geometrical features

$$\begin{array}{rcrcrcrcrc} R_4 & = & R_1 & = & 1778 \ x \ 2 \\ & = & 3556 \ mm \\ & = & 3.556 \ mms. \\ R_2 & = & R_3 & = & 647 \ mm \\ & & = & 0.647 \ mms \\ h_1 & = & h_4 & = & 161 \ mm \\ & & = & 0.161 \ mms \\ h_2 & = & h_3 & = & 121 \ mm \\ & & = & 0.121 \ mms \\ d_1 & = & 566.02 \ mms \end{array}$$

d_2	=	81.05 mm		
$R_{1 eff}$	=	R _{4eff}	=	$R_1-\ h_1$
			=	3556 - 161
			=	3395 mm
R_{2eff}	=	R _{3eff}	=	$R_2 - h_2$
			=	647 – 121
			=	526 mm
d 4*	=	d_1*	=	$\frac{d_1 \times R_{1eff}}{R_1}$
			=	540.39 mm
			≈	540.40 mm
d_2*	=	d ₃ *	=	$\frac{d_2 \times R_{2eff}}{R_2}$
			=	65.89 mm
			≈	65.90 mm.

b. Frictional Characteristics Computation

At 1 a	nd 4				
Р	=	W / A			
Here V	W Load			=	334.2 tonne or 3342 KN,
А	=	πr^2			
r	=	$h_4 + \ h_1$			
	=	161 + 161			
r	=	322 mm			
Р	=	0.001026 ton	/mm ² ,		
Р	=	0.001026 x 1	450		
Р	=	1.49 ksi,	1 ksi	=	Kilo square inch
				=	1450 ton/mm ²
3- Fric	ction Cy	vcle	μ	=	0.122 - 0.01 P,
			μ	=	0.1071

Adjust	t for hig	h velocity		=	μ-0	.0333		
				=	0.1071	1 - 0.03	333	
				=	0.074	(Lowe	r bound)
1 - Fri	ction C	ycle	μ	=	1.2 x	0.074		
				=	0.0886	5		
μ_1	=	$\mu_4 =$	0.074	(Lower	bound)	I		
μ_1	=	μ ₄ =	0.089	(Upper	bound)			
At 2 a	nd 3							
Р	=	W / A						
Here V	W Load	l		=	334.2	tonne	or 334	42 KN,
А	=	πr^2						
r	=	$h_2 + h_3$						
	=	121 + 121						
	=	242 mm						
Р	=	0.001816 tor	n/mm ² ,					
Р	=	0.001816 x 1	450					
Р	=	2.63 ksi.	1 ksi	=	Kilo s	quare in	nch	
				=	1450 t	on/mm	2	
3- Fric	tion Cy	vcle	μ	=	0.122	- 0.01	Р	
				=	0.0957	7		
Adjust	t for hig	h velocity		=	μ - 0	.036		
				=	0.0957	7 - 0.0	36	
				=	0.060	(Lower	bound)	
1 - Fri	ction C	ycle	μ	=	1.2 x (0.060		
				=	0.0716	5		
Lower	bound			μ_2	=	μ₃	=	0.060
Upper	bound			μ_2	=	μ ₃	=	0.072
μ	=	force at zero	deforma	ation				
μ	=	μ1 - (μ1 - μ	2) ×	$\frac{R_{2eff}}{R_{1eff}}$ (L	lower b	ound)		
μ	=	0.072						

c.

μ	=	μ1 - (μ1 - μ2	e) ×	$\frac{R_{2eff}}{R_{1eff}}$	(Upper bound)
μ	=	0.086			
D _D Co	omputa	tion (Upper bo	und)		
\mathbf{S}_{d}	=	0.5074			
μ	=	0.086			
μ_1	=	0.089			
D_y	=	$(\mu_1 - \mu_2) * R_{2eff}$	f		
$\mathbf{D}_{\mathbf{y}}$	=	0.008939			
F_d	=	0.2772			
W	=	334.2 Ton			
T.B.	=	12 Nos. (When	re T.E	$B_{\cdot} = Tot$	al Bearing)
ΣF_d	=	W x T.B. x F	Fd		
	=	334.2 x 12 x	0.277	2	
ΣF_d	=	1111.86			
Σw	=	W x T.B.			
Σw	=	4010.4 Ton			
i.	Desig	n displacement	t, DD	=	0.07202 m.
	Fffoo	tivo stiffnoss ()	d	_	u * Xw
11.	Life	uve sunness, Q	u	—	μ 2w
				=	0.086 * 4010.4
			\mathbf{Q}_{d}	=	344.71 Ton
			k _D	=	$\Sigma F_D / D_D$
				=	1111.86 / 0.07202
			kD	=	15438.15 Ton/m.
			$K_{eff} \\$	=	$k_D \ + \ Q_D \ / \ D_D$
				=	15438.15 + 344.71 / 0.07202
			K _{eff}	=	20224.50 Ton/m.

- iii. Effective period, T_{eff} $T_{eff} = [\sqrt{((\Sigma w)/(K_{eff} x g))}] 2\pi$ $T_{eff} = 0.89331$ sec.
- iv. **Effective damping**, β_{eff}
 - $\beta_{D} = \frac{E}{2\pi K_{eff} \times D_{D}^{2}} = \frac{4\mu \sum w(D_{D} D_{y})}{2\pi K_{eff} \times D_{D}^{2}}$ $\beta_{eff} = \beta_{D} = 0.1320$
- v. Damping reduction Coefficient, β

$$\beta = \left(\frac{\beta_{\text{eff}}}{0.05}\right)^{0.3}$$
$$\beta = 1.3380$$

vi. D_D^1

$$D_{D}^{1} = \frac{S_{D!} \times T_{eff}^{2}}{4\pi^{2} \times \beta} \times g$$
$$D_{D}^{1} = 0.0752 \text{ mtrs}$$

(B) ETABS links directional property computation (upper bound)

a. Principal features

i. Determine bearing

The isolator had been envisioned cylinder with a height of 0.32 metres and a diameter of 0.305 metres

$$H = 0.5 m$$

Ø = 0.484 m
Now, Area

 $A = \frac{\pi \times \emptyset^2}{4}$ $= \frac{\pi \times 0.484^2}{4}$ $A = 0.1840 \text{ m}^2$

K _{eff}	=	$\frac{W}{R_{1eff}} + \frac{\mu w}{D_D}$		
K _{eff}	=	497.30 Ton/m		
I_1	=	$\frac{K_{eff} \times h^3}{12E}$	=	$\frac{497.30\times0.5^3}{12E}$
			=	5.18022E-07 m ⁴ .
E	=	$1 \times 10^7 \text{ N/mm}^2$		
ii.	Deter	mine bearing mass		
D _{m-ma}	_x =	0.0702 m.		
D _{TM}	=	1.15 x D _{m-max}		
	=	1.15 x 0.0702		
D _{TM}	=	0.0807 m.		
D	=	2 D _{TM}		
	=	2 x 0.0807		
D	=	0.16146 m.		
W	=	0.241 D ² - 0.00564 D		
W	=	0.0053721 tonne.		
М	=	w / g		
	=	0.005372 / 9.81		
М	=	0.000548 tonne sec ² /m.		

b. Direction (U1)

Kef	=	36796846.43 KN/m.
Keff	=	3679684.643 ton/m.
K _{eff}	=	AE / L
Ø	=	0.484 m
Н	=	0.5 m

from D_D

K_{eff}	=	3679684.64 ton/m.
β_{eff}	=	0.1320

c. Direction $(U_2 - U_3)$

i.	Dete	ermination of liner properties.
Keff	=	497.301 ton/m
	=	4973.01 KN/m
β_{eff}	=	0.1320

Height for outer surface,	=	=	h_1	=	h_4	=	0.161 m.
Height for inner surface,	=	=	h_2	=	h3	=	0.121 m.

ii. Determination of Non - liner properties.

R_{2eff}	=	0.526 mtrs.
Dy	=	$(\mu_1 - \mu_2) R_{2eff}$
	=	(0.08859 – 0.07159) x 0.526
Dy	=	0.00894 mtrs.

Stiffness (Outer Top)	$= \frac{\mu_1 w}{D_y}$	
	$=$ $\frac{0.08859}{0.003}$	×334.2 394
	= 3312.04	l ton/m.
	= 33120.42	l KN/m.
Stiffness (Inner Top)	$=$ $\frac{\mu_2 w}{D_y}$	
	$=$ $\frac{0.07159}{0.003}$	×334.2 394

				=	26766.80 KN/m.
Friction Co	efficient, Slow	=	μ1 μ2	=	0.089 (Outer Top) 0.072 (Inner Top)
Friction Co	efficient, Fast	=	2 x μ ₁ 2 x μ ₂	=	0.177 (Outer Top) 0.143 (Inner Top)
Rate Param	neter			=	Friction Coeff. Slow Friction Coeff.Fast
				=	0.089 / 0.177
				=	0.5
				=	0.0005 sec/mm
Radius of sl	liding surface				
Outer Top	= R _{1 eff}	-		=	3.395 m
Inner Top	= R _{2 eff}			=	0.526 m
Stop distan	ce				
Outer Top u	1*			=	$2 D_y + 2 d_1 *$
				=	1.09868 m
				=	1098.68 mm
Inner Top u ₂	2*			=	$2 D_y$
				=	0.0179 m
				=	17.878 mm

(C) Input Values in ETABS:

Identification		
Property Name	В	
Direction	U1	
Туре	Triple Pendulum	Isolator
NonLinear	Yes	
Linear Properties		
Effective Stiffness	\$6796846.43	kN/m
Effective Damping	1.338	kN-s/m
Nonlinear Properties		
Stiffness	36796846.43	kN/m
Damping Coefficient	1.338	kN-s/m
		-

Figure-61. TFPB Input Values in ETABS for Biaxial Load 3342 KN

Direction U₁

identification					
Property Name B		Ту	/pe	Triple Pendulum Isolator	
Direction U2	2; U3	No	onLinear	Yes	
Linear Properties					
Effective Stiffness - U2	4973.014	kN/m Eff	fective Stiffness -U3	4973.014	kN/m
Effective Damping - U2	1.338	kN-s/m Eff	fective Damping -U3	1.338	kN-s/m
Shear Deformation Location					
Distance from End-J - U2	0	m Dis	stance from End-J - U3	0	m
Height and Symmetry of Slidi Height for Outer Surfaces Height for Inner Surfaces	p Surfaces	m 🔽 Outer	Bottom Surface is Sym Bottom Surface is Sym	metric to Outer Top	Surface
Height and Symmetry of Slidi Height for Outer Surfaces Height for Inner Surfaces Nonlinear Properties for Direc	ng Surfaces ().161 ().121 tions U2 and U3	m 🗹 Outer m 📝 Inner I	Bottom Surface is Sym Bottom Surface is Sym	metric to Outer Top metric to Inner Top S	Surface Surface
Height and Symmetry of Slidi Height for Outer Surfaces Height for Inner Surfaces Nonlinear Properties for Direc	ID Surfaces	m v Outer m v Inner	Bottom Surface is Sym Bottom Surface is Sym	metric to Outer Top metric to Inner Top S Inner Botto	Surface Surface mkN/m
Height and Symmetry of Slidi Height for Outer Surfaces Height for Inner Surfaces Nonlinear Properties for Direc Stiffness	Dufaces D.161 0.121 tions U2 and U3 Outer Top 33120.415	m v Outer m v Inner Outer Bottom 33120.415	Bottom Surface is Sym Bottom Surface is Sym Inner Top 26766.8	metric to Outer Top metric to Inner Top S Inner Botto	Surface Surface mkN/m
Height and Symmetry of Slidi Height for Outer Surfaces Height for Inner Surfaces Nonlinear Properties for Direc Stiffness Friction Coefficient, Slow	Duter Top 33120.415 0.127	m ✓ Outer m ✓ Inner 1 Outer Bottom 33120.415 0.088587	Bottom Surface is Sym Bottom Surface is Sym Inner Top 26766.8 0.071593	Inner Botto	Surface Surface mkN/m
Height and Symmetry of Slidi Height for Outer Surfaces Height for Inner Surfaces Nonlinear Properties for Direc Stiffness Friction Coefficient, Slow Friction Coefficient, Fast	ng Surfaces ().161 ().121 tions U2 and U3 Outer Top ().120,415 ().088587 ().177175 ().0895	m ✓ Outer m ✓ Inner 1 Outer Bottom 33120.415 0.088587 0.177175	Bottom Surface is Sym Bottom Surface is Sym n Inner Top 26766.8 0.071593 0.143187	Inner Botto 26766.8 0.071593 0.143187	Surface Surface mkN/m
Height and Symmetry of Slidi Height for Outer Surfaces Height for Inner Surfaces Nonlinear Properties for Direc Stiffness Friction Coefficient, Slow Friction Coefficient, Fast Rate Parameter	ng Surfaces ().161 ().121 tions U2 and U3 Outer Top 33120.415 ().088587 ().177175 ().0005 ().107	m ♥ Outer m ♥ Inner 1 Outer Bottom 33120.415 0.088587 0.177175 0.0005	Bottom Surface is Sym Bottom Surface is Sym 26766.8 0.071593 0.143187 0.0005	Inner Botto 26766.8 0.071593 0.143187 0.0005	Surface Surface mkN/m sec/mm
Height and Symmetry of Slidi Height for Outer Surfaces Height for Inner Surfaces Nonlinear Properties for Direc Stiffness Friction Coefficient, Slow Friction Coefficient, Fast Rate Parameter Radius of Sliding Surface	ng Surfaces ().161 ().121 tions U2 and U3 Outer Top 33120.415 ().088587 ().177175 ().0005 ().3395	m ✓ Outer m ✓ Inner 1 0uter Bottom 33120.415 0.088587 0.177175 0.0005 3.395	Bottom Surface is Sym Bottom Surface is Sym 26766.8 0.071593 0.143187 0.0005 0.526	Inner Botto 26766.8 0.071593 0.143187 0.0005 0.526	Surface Surface kN/m sec/mm m
Height and Symmetry of Slidi Height for Outer Surfaces Height for Inner Surfaces Nonlinear Properties for Direc Stiffness Friction Coefficient, Slow Friction Coefficient, Fast Rate Parameter Radius of Sliding Surface Stop Distance	ng Surfaces ().161 ().121 etions U2 and U3 Outer Top 33120.415 ().088587 ().177175 ().0005 ().3395 ().098.677	m ✓ Outer m ✓ Inner 1 0.088587 0.088587 0.177175 0.0005 3.395 1098.677	Bottom Surface is Sym Bottom Surface is Sym 26766.8 0.071593 0.143187 0.0005 0.526 17.877	Inner Botto 26766.8 0.071593 0.143187 0.0005 0.526 17.877	Surface Surface kN/m sec/mm m mm

Figure-62. TFPB Input Values in ETABS for Biaxial Load 3342 KN Direction U₂ & U₃

5.5.2 TFPB for Uniaxial Load - 4627 KN



Figure-63. TFPB Schematic

(A) Geometrical, Frictional and D_D Computation

a.	Geom	etrical			
	R ₄	=	R ₁	=	1778 x 2
				=	3556 mm
				=	3.556 m
	R_2	=	R ₃	=	647 mm
				=	0.647 m
	h_1	=	h_4	=	161 mm
				=	0.161 m
	h_2	=	h ₃	=	121 mm
				=	0.121 m
	d_1	=	566.02 mm		
	d_2	=	81.05 mm		
	$R_{1 eff}$	=	R _{4eff}	=	R_1-h_1

			=	3556 – 1 61
			=	3395 mm
R_{2eff}	=	R _{3eff}	=	$R_2-\ h_2$
			=	647 - 121
			=	526 mm
d ₄ *	=	d_1*	=	$\frac{d_1 \times R_{1eff}}{R_1}$
			=	540.39 mm
			≈	540.40 mm.
d_2*	=	d ₃ *	=	$\frac{d_2 \times R_{2eff}}{R_2}$
			=	65.89 mm
			\approx	65.90 mm.

b. Frictional Characteristics Computation

At surfaces 1 and 4

Р	=	W / A			
Here V	W Load			=	462.7 tonne or 4627 KN,
А	=	πr^2			
r	=	$h_4 + h_1$			
	=	161 + 161			
r	=	322 mm			
Р	=	0.001420 ton	/mm ² ,		
Р	=	0.001420 x 1	450		
Р	=	02.06 ksi,	1 ksi	=	Kilo square inch
				=	1450 ton/mm^2
3- Frie	ction Cy	vcle	μ	=	0.122 - 0.01 P
			μ	=	0.1014
Adjus	t for hig	h velocity		=	μ - 0.0333
				=	0.1014 - 0.0333

					=	0.068	(Lower	bound)	
1 - Frie	ction C	ycle		μ	=	1.2 x	0.068		
					=	0.0817	7		
μ_1	=	μ4	=	0.068	(Lower	bound))		
μ_1	=	μ_4	=	0.082	(Upper	bound)			
At 2 a	nd 3								
Р	=	W / A							
Here W	V Load	l			=	462.7	tonne	or 4627	KN,
А	=	πr^2							
r	=	$h_2 + h_2$	1 3						
	=	121 +	121						
	=	242 m	m						
Р	=	0.002	515 ton	/mm ²					
Р	=	0.0025	515 x 1	450					
Р	=	3.65 k	si.	1 ksi	=	Kilo s	quare in	ch	
					=	1450 t	con/mm ²	2	
3- Fric	tion Cy	cle		μ	=	0.122	- 0.01	Р	
					=	0.085	5		
Adjust	for hig	h veloc	ity		=	μ-0	.036		
					=	0.085	5 - 0.03	36	
					=	0.050	(Lower	bound)	
1 - Frie	ction C	ycle		μ	=	1.2 x	0.050		
					=	0.0594	4		
μ_2	=	μ ₃	=	0.050	(Lower	bound))		
μ_2	=	μ ₃	=	0.059	(Upper	bound)			
μ	=	force a	at zero c	leforma	ation				
μ	=	μ _{1 -} (μ	ι ₁ - μ ₂)	$\times \frac{R}{R}$	R _{2eff} (Lo	ower bo	ound)		
μ	=	0.065							
μ	=	μ1 - (μ1 - μ2	2) ×	$\frac{R_{2eff}}{R_{1eff}}$ (U	Jpper b	ound)		

 μ = 0.078

c. D_D Computation (Upper bound)

S_d	=	0.5074			
μ	=	0.078			
μ_1	=	0.082			
D_y	=	$(\mu_1 - \mu_2) * R_{2eff}$			
D_y	=	0.011721			
F_d	=	0.2772			
W	=	462.7 Ton			
T.B.	=	12 Nos. (Where	e T.B.	= Total	Bearing)
ΣF_d	=	W x T.B. x Fa	1		
	=	462.7 x 12 x 0	0.2772		
ΣF_d	=	1539.36			
Σw	=	W x T.B.			
Σw	=	5552.4 Ton			
i.	Desig	n displacement,	, D D	=	0.07202 mtrs.
i.	Desig	n displacement,	, D D	=	0.07202 mtrs.
i. ii.	Desig Effec	n displacement, tive stiffness, Qa	, D D	=	0.07202 mtrs. μ * Σw
i. ii.	Desig Effec	n displacement, tive stiffness, Qa	, D D	=	0.07202 mtrs. μ * Σw 0.078 * 5552.4
i. ii.	Desig Effec	n displacement, tive stiffness, Qa	р D D I	= = =	0.07202 mtrs. μ * Σw 0.078 * 5552.4 434.59 Ton
i. ii.	Desig Effec	n displacement, tive stiffness, Qa	, D D I Qd kD	= = =	0.07202 mtrs. μ * Σw 0.078 * 5552.4 434.59 Ton ΣF _D / D _D
i. ii.	Desig Effec	n displacement, tive stiffness, Qa	D D I Qd kD	= = = =	0.07202 mtrs. μ * Σw 0.078 * 5552.4 434.59 Ton ΣF _D / D _D 1539.36 / 0.07202
i. ii.	Desig Effec	n displacement, tive stiffness, Qa	, D D I Qd kD	= = = =	0.07202 mtrs. μ * Σw 0.078 * 5552.4 434.59 Ton ΣF _D / D _D 1539.36 / 0.07202 21374.12 Ton/m.
i. ii.	Desig Effect	n displacement, tive stiffness, Qa	, D D I Qd kD K _{eff}		0.07202 mtrs. $\mu * \Sigma w$ 0.078 * 5552.4 434.59 Ton $\Sigma F_D / D_D$ 1539.36 / 0.07202 21374.12 Ton/m. $k_D + Q_D / D_D$
i. ii.	Desig Effect	n displacement, tive stiffness, Qa	DD A Qd kD K _{eff}		0.07202 mtrs. $\mu * \Sigma w$ 0.078 * 5552.4 434.59 Ton $\Sigma F_D / D_D$ 1539.36 / 0.07202 21374.12 Ton/m. $k_D + Q_D / D_D$ 21374.12 + 434.59 / 0.07202
i. ii.	Desig Effect	n displacement, tive stiffness, Qo	, D D I Qd kD K _{eff}		0.07202 mtrs. $\mu * \Sigma w$ 0.078 * 5552.4 434.59 Ton $\Sigma F_D / D_D$ 1539.36 / 0.07202 21374.12 Ton/m. $k_D + Q_D / D_D$ 21374.12 + 434.59 / 0.07202 27408.45 Ton/m.

iii. **Effective period**, T_{eff}

 $T_{eff} = [\sqrt{((\Sigma w)/(K_{eff} x g))}] 2\pi$ $T_{eff} = 0.90291 \text{ sec.}$

iv. **Effective damping**, β_{eff} $= \frac{E}{2\pi K_{eff} \times D_D{}^2} = \frac{4\mu \sum w (D_D - D_y)}{2\pi K_{eff} \times D_D{}^2}$ βd = β_D 0.1174 β_{eff} = **Damping reduction Coefficient**, β v. $= \left(\frac{\beta_{eff}}{0.05}\right)^{0.3}$ β ß 1.2917 =

vi. D_D^1

 $D_{D}^{1} = \frac{S_{D!} \times T_{eff}^{2}}{4\pi^{2} \times \beta} \times g$ $D_{D}^{1} = 0.0796 \text{ mtrs}$

(**B**) ETABS links directional property Computation (upper bound)

a. Principal features

i. Determine bearing

The isolator had been envisioned cylinder with a height of 0.32 metres and a diameter of 0.305 metres

Η	=	0.5 m.			
Ø	=	0.484 m,			
Now	, Area		А	=	$\frac{\pi \times \emptyset^2}{4}$
				=	$\frac{\pi \times 0.484^2}{4}$
			А	=	0.1840 m^2
Keff	=	$\frac{W}{R_{1eff}} + \frac{\mu w}{D_D}$			
K _{eff}	=	639.15 Ton/m			
I_1	=	$\frac{K_{eff} \times h^3}{12E}$		=	$\frac{639.15 \times 0.5^3}{12E}$
				=	6.65781E-07 m ⁴

E	=	1x10 ⁷ N/mm ²
ii.	Deterr	nine bearing mass
D _{m-max}	=	0.0702 m.
D _{TM}	=	1.15 x D _{m-max}
	=	1.15 x 0.0702
D _{TM}	=	0.0807 m.
D	=	2 D _{TM}
	=	2 x 0.0807
D	=	0.16146 m.
W	=	0.241 D ² - 0.00564 D
W	=	0.0053721 tonne.
Μ	=	w / g
	=	0.005372 / 9.81
М	=	0.000548 tonne sec ² /m.

b. Direction (U1)

Η	=	0.5 m
Ø	=	0.484 m
K _{eff}	=	AE / L
K _{eff}	=	3679684.643 ton/m.
Keff	=	36796846.43 KN/m.
from	D _D	
K _{eff}	=	3679684.64 ton/m.
β_{eff}	=	0.1174

c. Direction (U₂ - U₃)

i. Determination of liner properties.

K_{eff}	=	639.150 ton/m
	=	6391.50 KN/m
β_{eff}	=	0.1174

Height for outer surface,	=	$h_1 =$	h_4	=	0.161 mtrs.
Height for inner surface,	=	$h_2 \;=\;$	h ₃	=	0.121 mtrs.

ii. Determination of Non - liner properties.

R_{2eff}	=	0.526 mtrs.
D_y	=	$(\mu_1 - \mu_2) R_{2eff}$
	=	(0.08172 – 0.05944) x 0.526
Dy	=	0.01172 mtrs.

Stiffness (Outer Top)			=	$\frac{\mu_1 w}{D_y}$
			=	$\frac{0.08172 \times 462.7}{0.01172}$
			=	3226.231 ton/m.
			=	32262.31 KN/m.
Stiffness (Inner Top)			=	$\frac{\mu_2 w}{D_y}$
			=	$\frac{0.05944 \times 462.7}{0.01172}$
			=	2346.573 ton/m.
			=	23465.73 KN/m.
Friction Coefficient, Slow	=	μ_1	=	0.082 (Outer Top)
	=	μ2	=	0.059 (Inner Top)

Friction Coefficient, Fas	t =	$2 \ge \mu_1 =$	0.163 (Outer Top)	
	=	$2 \ge \mu_2 =$	0.119 (Inner Top)	
Rate Parameter		=	Friction Coeff. Slow Friction Coeff.Fast	
		=	0.082 / 0.163	
		=	0.5	
		=	0.0005 sec/mm	
Radius of sliding surface	9			
Outer Top = R_1	eff	=	3.395 mtrs.	
Inner Top = R_2	eff	=	0.526 mtrs.	
Stop distance				
Outer Top u ₁ *		=	$2 D_y + 2 d_1 *$	
		=	1.10424	mtrs
		=	1104.24	mm
Inner Top u ₂ *		=	2 D _y	
		=	0.0234	mtrs
		=	23.441	mm

(C) Input Values in ETABS:

dentification		
Property Name	U	
Direction	U1	
Туре	Triple Pendulum	Isolator
NonLinear	Yes	
inear Properties		
Effective Stiffness	36796846.43	<mark>k</mark> N/m
Effective Damping	1.292	kN-s/m
Nonlinear Properties		
Stiffness	36796846.43	kN/m
Damping Coefficient	1.292	kN-s/m

Figure-64. TFPB Input Values in ETABS for Uniaxial Load 4627 KN

Direction U₁

Property Name		T	ype	Triple Pendulum Iso	lator
Direction	2; U3	N	onLinear	Yes	
Linear Properties					
Effective Stiffness - U2	6391. <mark>4</mark> 99	kN/m B	ffective Stiffness -U3	6391.499	kN/m
Effective Damping - U2	1.292	kN-s/m E	ffective Damping -U3	1.292	kN-s/m
Shear Deformation Location					
Distance from End-J - U2	0	m D	istance from End-J - U3	0	m
Height and Symmetry of Slid Height for Outer Surfaces Height for Inner Surfaces	ng Surfaces 0.161	m 🗹 Outer	Bottom Surface is Sym Bottom Surface is Symr	metric to Outer Top	Surface Surface
Height and Symmetry of Slid Height for Outer Surfaces Height for Inner Surfaces Nonlinear Properties for Dire	ng Surfaces (b.161 0.121 ctions U2 and U3	m 🕑 Outer m 💽 Inner	Bottom Surface is Sym Bottom Surface is Symm	metric to Outer Top	Surface Surface
Height and Symmetry of Slid Height for Outer Surfaces Height for Inner Surfaces Nonlinear Properties for Dire Stiffness	ng Surfaces (b.161 0.121 ctions U2 and U3 Outer Top 32262.308	m Outer m Inner	Bottom Surface is Sym Bottom Surface is Symm n Inner Top 23465.73	metric to Outer Top netric to Inner Top : Inner Botto 23465.73	Surface Surface m
Height and Symmetry of Slid Height for Outer Surfaces Height for Inner Surfaces Nonlinear Properties for Dire Stiffness Friction Coefficient, Slow	ng Surfaces (b.161 0.121 ctions U2 and U3 Outer Top 32262.308 0.081723	m ✓ Outer m ✓ Inner Outer Botton 32262.308	Bottom Surface is Sym Bottom Surface is Symm n Inner Top 23465.73 0.05944	metric to Outer Top netric to Inner Top Inner Botto 23465.73	Surface Surface mkN/m
Height and Symmetry of Slid Height for Outer Surfaces Height for Inner Surfaces Nonlinear Properties for Dire Stiffness Friction Coefficient, Slow Friction Coefficient, Fast	ng Surfaces (b.161 0.121 ctions U2 and U3 Outer Top 32262.308 0.081723 0.163446	m ♥ Outer m ♥ Inner Outer Bottor 32262.308 0.081723 0.163446	Bottom Surface is Sym Bottom Surface is Symm n Inner Top 23465.73 0.05944 0.11888	Inner Botto 23465.73 0.05944	Surface Surface mkN/m
Height and Symmetry of Slid Height for Outer Surfaces Height for Inner Surfaces Nonlinear Properties for Dire Stiffness Friction Coefficient, Slow Friction Coefficient, Fast Rate Parameter	ng Surfaces [).161 0.121 ctions U2 and U3 Outer Top 32262.308 0.081723 0.163446 0.0005	m ♥ Outer m ♥ Inner Outer Bottor 32262.308 0.081723 0.163446 0.0005	Bottom Surface is Sym Bottom Surface is Sym n Inner Top 23465.73 0.05944 0.11888 0.0005	metric to Outer Top netric to Inner Top Inner Botto 23465.73 0.05944 0.11888 0.0005	Surface Surface mkN/m sec/mn
Height and Symmetry of Slid Height for Outer Surfaces Height for Inner Surfaces Nonlinear Properties for Dire Stiffness Friction Coefficient, Slow Friction Coefficient, Fast Rate Parameter Radius of Sliding Surface	ng Surfaces [).161 0.121 ctions U2 and U3 Outer Top 32262.308 0.081723 0.163446 0.0005 3.395	m ♥ Outer m ♥ Inner Outer Bottor 32262.308 0.081723 0.163446 0.0005 3.395	Bottom Surface is Sym Bottom Surface is Sym 23465.73 0.05944 0.11888 0.0005 0.526	metric to Outer Top netric to Inner Top : 23465.73 0.05944 0.11888 0.0005 0.526	Surface Surface kN/m sec/mn m

Figure-65. TFPB Input Values in ETABS for Uniaxial Load 4627 KN Direction U₂ & U₃

5.5.3 TFPB for Axial Load - 6860 KN



Figure-66. TFPB Schematic

(A) Geometrical, Frictional and D_D Computation

a. Geometrical features

\mathbf{R}_4	=	R_1	=	1778 x 2
			=	3556 mm
			=	3.556 m
\mathbf{R}_2	=	R ₃	=	647 mm
			=	0.647 m
h_1	=	h4	=	161 mm
			=	0.161 m
h ₂	=	h ₃	=	121 mm
			=	0.121 m
d_1	=	566.02 mm		
d_2	=	81.05 mm		
R_{1eff}	=	R 4eff	=	$R_1 - h_1$
			=	3556 - 161
			=	3395 mm

R_{2eff}	=	R _{3eff}	=	$R_2-\ h_2$
			=	647 – 121
			=	526 mm
d_4*	=	d_1*	=	$\frac{d_1 \times R_{1eff}}{R_1}$
			=	540.39 mm
			\approx	540.40 mm
d_2*	=	d ₃ *	=	$\frac{d_2 \times R_{2eff}}{R_2}$
			=	65.89 mm
			\approx	65.90 mm

b. Frictional Characteristics Computation

At 1 a	nd 4				
Р	=	W/ A			
Here V	W Load			=	686.0 tonne or 6860 KN
А	=	πr^2			
r	=	$h_4+h_1\\$			
	=	161 + 161			
r	=	322 mm			
Р	=	0.002106 ton	/mm ² ,		
Р	=	0.002106 x 1	450		
Р	=	3.05 ksi,	1 ksi	=	Kilo square inch
				=	1450 ton/mm ²
3- Frie	ction Cy	/cle	μ	=	0.122 - 0.01 P,
			μ	=	0.0915
Adjus	t for hig	sh velocity		=	μ - 0.0333
				=	0.0915 - 0.0333
				=	0.058 (Lower bound)
1 - Fri	ction C	ycle	μ	=	1.2 x 0.058
				=	0.0698

μ_1	=	μ_4	=	0.05	8 (Lowe	er bound)		
μ_1	=	μ_4	=	0.07	0 (Uppe	er bound)		
At 2 a	nd 3							
Р	=	W / A						
Here V	W Load	1			=	686.0	tonne	or 6860 KN
А	=	πr^2						
r	=	$h_2 + h_2$	13					
	=	121 +	121					
	=	242 m	m					
Р	=	0.003	729 ton	/mm ² ,	,			
Р	=	0.0037	29 x 1	450				
Р	=	5.41 k	si.	1 ksi	=	Kilo squ	uare in	ch
					=	1450 to	n/mm ²	
3- Fric	ction Cy	vcle		μ	=	0.122 -	0.01	Р
					=	0.0679		
Adjus	t for hig	h veloc	ity		=	μ - 0.0	36	
					=	0.0679	- 0.03	6
					=	0.032 (Lower	bound)
1 – Fr	iction C	ycle		μ	=	1.2 x 0	0.032	
					=	0.0383		
μ_2	=	μ ₃	=	0.032	2 (Lowe	er bound)		
μ_2	=	μ ₃	=	0.03	8 (Uppe	er bound)		
μ	=	force a	at zero c	leforn	nation			
μ	=	μ1 - (μ	u1 - μ2) ×	$\frac{R_{2eff}}{R_{1eff}}$	(Lower bou	und)	
μ	=	0.054						
μ	=	μ1 - (μ	u ₁ - μ ₂) ×	$rac{R_{2eff}}{R_{1eff}}$ (Upper bou	ind)	
μ	=	0.065						

c. D_D Computation (Upper bound)

$\mathbf{S}_{\mathbf{d}}$	=	0.5074			
μ	=	0.065			
μ_1	=	0.070			
D_y	=	$(\mu_1 - \mu_2) * R_{2e}$	ff		
D_y	=	0.016555			
F_d	=	0.2772			
W	=	686 Ton			
T.B.	=	12 Nos. (Whe	ere T.B.	= Tota	l Bearing)
ΣF_d	=	W x T.B. x F	d		
	=	686 x 12 x	0.2772		
ΣF_d	=	2282.26			
Σw	=	W x T.B.			
Σw	=	8232 Tonne			
i.	Desig	n displacemen	t, DD	=	0.07202 m.
ii.	Effect	tive stiffness, ()d	=	$\mu * \Sigma w$
				=	0.065 * 8232
			Q_d	=	534.41 Ton
			Q _d k _D	=	534.41 Ton ΣF _D / D _D
			Q _d k _D	= = =	534.41 Ton ΣF _D / D _D 2282.26 / 0.07202
			Qd k _D k _D	= = =	534.41 Ton ΣF _D / D _D 2282.26 / 0.07202 31689.31 Ton/m.
			Qd kD KD Keff	= = =	534.41 Ton $\Sigma F_D / D_D$ 2282.26 / 0.07202 31689.31 Ton/m. $k_D + Q_D / D_D$
			Qd k _D K _D K _{eff}	= = = =	534.41 Ton $\Sigma F_D / D_D$ 2282.26 / 0.07202 31689.31 Ton/m. $k_D + Q_D / D_D$ 31689.31 + 534.41 / 0.07202
			Qd k _D K _D K _{eff}		534.41 Ton $\Sigma F_D / D_D$ $2282.26 / 0.07202$ 31689.31 Ton/m. $k_D + Q_D / D_D$ $31689.31 + 534.41 / 0.07202$ 39109.67 Ton/m.
			Qd k _D K _D K _{eff}		534.41 Ton ΣF _D / D _D 2282.26 / 0.07202 31689.31 Ton/m. k _D + Q _D / D _D 31689.31 + 534.41 / 0.07202 39109.67 Ton/m.
iii.	Effect	t ive period , T _{ef}	Qd k _D K _D K _{eff}		534.41 Ton ΣF _D / D _D 2282.26 / 0.07202 31689.31 Ton/m. k _D + Q _D / D _D 31689.31 + 534.41 / 0.07202 39109.67 Ton/m.

 $T_{eff} = 0.92036$ sec.

iv.

v.

Effective damping, β_{eff} $\beta_D = \frac{E}{2\pi K_{eff} \times D_D^2} = \frac{4\mu \Sigma w (D_D - D_y)}{2\pi K_{eff} \times D_D^2}$ $\beta_{eff} = \beta_D = 0.0930$ Damping reduction Coefficient, β

$$\beta = \left(\frac{\beta_{\text{eff}}}{0.05}\right)^{0.3}$$
$$\beta = 1.2047$$

vi.
$$D_D^1$$

$$D_{D}^{1} = \frac{S_{D!} \times T_{eff}^{2}}{4\pi^{2} \times \beta} \times g$$
$$D_{D}^{1} = 0.0887 \text{ mtrs}$$

(B) ETABS links directional property computation (upper bound)

a. Principal features

i. Determine bearing

The isolator had been envisioned as a cylinder with a height of 0.32 metres and a diameter of 0.305 metres

Η	=	0.5 m			
Ø	=	0.484 m			
Now,	Area		А	=	$\frac{\pi \times \emptyset^2}{4}$
				=	$\frac{\pi \times 0.484^2}{4}$
			А	=	0.1840 m^2
Keff	=	$\frac{W}{R_{1eff}} + \frac{\mu w}{D_D}$			
K _{eff}	=	820.42 Ton/m	ı		
I_1	=	$\frac{K_{eff} \times h^3}{12E}$		=	$\frac{820.42 \times 0.5^3}{12E}$
				=	8.54609E-07 m ⁴ .

Е	=	$1 \times 10^7 \text{N/mm}^2$
ii.	Deterr	nine bearing mass
D _{m-max}	=	0.0702 m.
D _{TM}	=	1.15 x D _{m-max}
	=	1.15 x 0.0702
D_{TM}	=	0.0807 m.
D	=	2 D _{TM}
	=	2 x 0.0807
D	=	0.16146 m.
W	=	0.241 D ² - 0.00564 D
W	=	0.0053721 tonne.
М	=	w / g
	=	0.005372 / 9.81
М	=	0.000548 tonne sec ² /m.

b. Direction (U1)

Η	=	0.5 m	
Ø	=	0.484 m	
Keff	=	AE / L	
K _{eff}	=	3679684.643	ton/m.
Keff	=	36796846.43	KN/m.
from	D _D		
K _{eff}	=	3679684.64	ton/m.
β_{eff}	=	0.0930	

$O_{1} O_{1} O_{1} O_{1} O_{2} O_{3}$

i. Determination of liner properties.

\mathbf{K}_{eff}	=	820.425 ton/m
	=	8204.25 KN/m
β_{eff}	=	0.0930

Height for outer surface, = $h_1 = h_4 = 0.161$ mtrs. Height for inner surface, = $h_2 = h_3 = 0.121$ mtrs.

ii. Determination of Non - liner properties.

R_{2eff}	=	0.526 mtrs.
D_y	=	$(\mu_1 - \mu_2) R_{2eff}$
	=	(0.06980 - 0.03832) x 0.526
D_v	=	0.01655 mtrs.

		=	$\frac{\mu_1 w}{D_y}$
		=	$\frac{0.06980 \times 686}{0.01655}$
		=	2892.227 ton/m.
		=	28922.27 KN/m.
		=	$\frac{\mu_2 w}{D_y}$
		=	$\frac{0.03832 \times 686}{0.01655}$
		=	1588.044 ton/m.
		=	15880.44 KN/m.
=	μ	=	0.070 (Outer Top)
=	μ2	=	0.038 (Inner Top)
	=	= μ1 = μ2	= $=$ $=$ $=$ $=$ $=$ $=$ $=$ $=$ $=$

Friction Coefficient	, Fast	$= 2 \mathbf{x} \boldsymbol{\mu}_1$	=	0.140 (Outer Top)
		$= 2 \times \mu_2$	=	0.077 (Inner Top)
Rate Parameter			=	Friction Coeff. Slow Friction Coeff.Fast
			=	0.070 / 0.140
			=	0.5
			=	0.0005 sec/mm
Radius of sliding su	rface			
Outer Top =	R 1 eff		=	3.395 mtrs.
Inner Top =	R $_{2 eff}$		=	0.526 mtrs.
Stop distance				
Outer Top u ₁ *			=	$2 D_y + 2 d_1*$
			=	1.11391 mtrs.
			=	1113.91 mm
Inner Top u ₂ *			=	2 D _y
			=	0.0331 mtrs.
			=	33.109 mm.

(C) Input Values in ETABS:

Link/Supp	port Directional Pro	operties
Identification		
Property Name	A	
Direction	U1	
Туре	Triple Pendulum	Isolator
NonLinear	Yes	
Linear Properties		
Effective Stiffness	36796846.43	kN/m
Effective Damping	1.205	kN-s/m
Nonlinear Properties		
Stiffness	36796846.43	kN/m
Damping Coefficient	1.205	kN-s/m
0	K	
0	K Cancel	

Figure-67. TFPB Input Values in ETABS for Axial Load 6860 KN Direction U₁

Property Name	٨		Tuna	Triala Dandulum laal	atar
Property Name	n		Type	Inple Fendulum Isol	ator
Direction	U2; U3		NonLinear	Yes	
Linear Properties					
Effective Stiffness - U2	8204.247	kN/m	Effective Stiffness -U3	8204.247	kN/m
Effective Damping - U2	1.205	kN-s/m	Effective Damping -U3	1.205	kN-s/m
Shear Deformation Locatio	n				
Distance from End-J - L	12 0	m	Distance from End-J - U3	3 0	m
Height and Symmetry of SI Height for Outer Surface Height for Inner Surface:	ding Surfaces s ().161 s ().121	m 🗹 Ou m 🕑 lar	uter Bottom Surface is Sym ner Bottom Surface is Sym	metric to Outer Top metric to Inner Top S	Surface Surface
Height and Symmetry of SI Height for Outer Surface Height for Inner Surface Nonlinear Properties for Dir	ding Surfaces s [0.161 s [0.121 ections U2 and U3	m 🗹 Ou m 🗹 Inn	uter Bottom Surface is Sym ner Bottom Surface is Sym	metric to Outer Top	Surface
Height and Symmetry of SI Height for Outer Surface Height for Inner Surface Nonlinear Properties for Di Stiffness	ding Surfaces s ().161 o .121 ections U2 and U3 Outer Top 28922.265	m v Ou m v Inn Outer Bot	ter Bottom Surface is Sym ner Bottom Surface is Sym ttom Inner Top 15880.44	Inner Botto	Surface Surface mkN/m
Height and Symmetry of SI Height for Outer Surface Height for Inner Surface Nonlinear Properties for Dir Stiffness Friction Coefficient, Slov	ding Surfaces s [0.161 0.121 ections U2 and U3 Outer Top 28922.265 w 0.069795	m ♥ Ou m ♥ In Outer Bot 28922.265	tter Bottom Surface is Sym ner Bottom Surface is Sym ttom Inner Top 15880.44 0.03832	Inner Botto	Surface Surface mkN/m
Height and Symmetry of SI Height for Outer Surface Height for Inner Surface Nonlinear Properties for Dir Stiffness Friction Coefficient, Slor Friction Coefficient, Fas	ding Surfaces s [0.161 o 0.121 ections U2 and U3 Outer Top 28922.265 v 0.069795 t 0.13959	m ♥ Ou m ♥ In Outer Bot 28922.265 0.069795 0.13959	tter Bottom Surface is Sym ner Bottom Surface is Sym ttom Inner Top 15880.44 0.03832 0.076645	Inner Botto 15880.44 0.03832 0.076645	Surface Surface mkN/m
Height and Symmetry of SI Height for Outer Surface Height for Inner Surface Nonlinear Properties for Dir Stiffness Friction Coefficient, Slor Friction Coefficient, Fas Rate Parameter	ding Surfaces s [0.161 0.121 ections U2 and U3 Outer Top 28922.265 v 0.069795 t 0.13959 0.0005	m ♥ Ou m ♥ In Outer Bot 28922.265 0.069795 0.13959 0.0005	tter Bottom Surface is Sym ner Bottom Surface is Sym 15880.44 0.03832 0.076645 0.0005	Inner Botto 15880.44 0.03832 0.076645 0.0005	Surface Surface mkN/m sec/mn
Height and Symmetry of SI Height for Outer Surface Height for Inner Surface Nonlinear Properties for Dir Stiffness Friction Coefficient, Slor Friction Coefficient, Fas Rate Parameter Radius of Sliding Surface	ding Surfaces s [0.161 o.121 ections U2 and U3 Outer Top 28922.265 v 0.069795 t 0.13959 0.0005 ce 3.395	m ♥ Ou m ♥ In Outer Bot 28922.265 0.069795 0.13959 0.0005 3.395	tter Bottom Surface is Sym ner Bottom Surface is Sym 15880.44 0.03832 0.076645 0.0005 0.526	Inner Botto 0.03832 0.076645 0.526	Surface Burface kN/m sec/mn m
Height and Symmetry of SI Height for Outer Surface Height for Inner Surface Nonlinear Properties for Di Stiffness Friction Coefficient, Slov Friction Coefficient, Fas Rate Parameter Radius of Sliding Surfac Stop Distance	ding Surfaces s [0.161 o .121 ections U2 and U3 Outer Top 28922.265 w 0.069795 t 0.13959 0.0005 se 3.395 1113.909	m ♥ Ou m ♥ In Outer Bot 28922.265 0.069795 0.13959 0.0005 3.395 11113.909	tter Bottom Surface is Sym ner Bottom Surface is Sym 15880.44 0.03832 0.076645 0.0005 0.526 33.109	Inner Botto Inner	Surface Burface kN/m sec/mn m mm

Figure-68. TFPB Input Values in ETABS for Axial Load 6860 KN

Direction U₂ & U₃
5.6 Summary

The Base Isolation System's attributes are discussed in this chapter.: 1) Lead Rubber Bearing (LRB) in Direction U_1 viz. Effective stiffness & Effective damping for linear properties and in Direction U_2 & U_3 viz. Effective stiffness & Effective damping for linear properties and Stiffness, Yield strength & post yield strength ratio for nonlinear properties. 2) Triple Friction Pendulum Bearing (TFPB) in Direction U_1 viz. Effective stiffness & Effective damping for linear properties and in Direction U_2 & U_3 viz. Effective stiffness & Effective damping for linear properties and Height of outer & inner surface, Stiffness, friction coefficient for slow & fast, Rate parameter, Radius of sliding surface and stop distance for non-linear properties are design according to axial load, biaxial load and Tri-axial load (Cumulative load from fixed base modal). Using this link/support properties the design of case(a)-Model-2 & 3 and case(b)-Model 5-6 are analyzed and the results will be compare with fixed base support in next chapter.