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

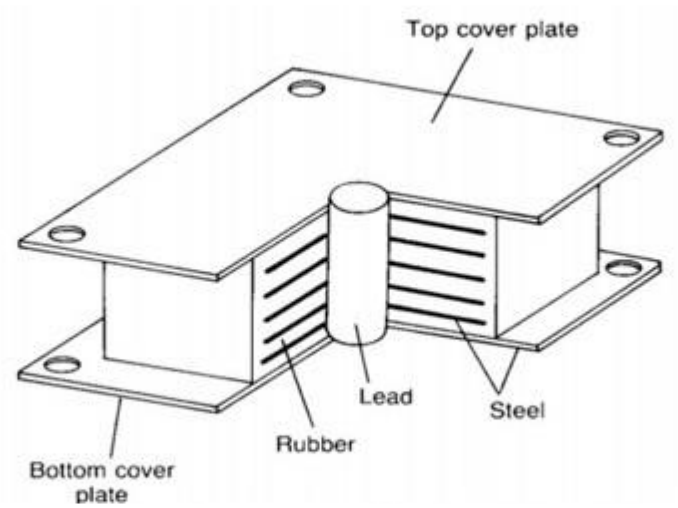

Figure-33. LRB Schematic

Biaxial Load (W)	= 1638 kN.
Time Period (T_D)	= 2.5 sec.
Design Shear Strain (γ_{max})	= 50%
	= 0.5 kN/m^2.
Effective Damping (ξ_{eff})	= 5%
	= **0.05 For U1,U2,U3.**

Table-1. Damping Coefficient, B_D or B_M

EFFECTIVE DAMPING, β_D OR β_M (PERCENTAGE OF CRITICAL)	B_D OR B_M FACTOR
≤ 2%	0.8
5%	1.0
10%	1.2
20%	1.5
30%	1.7
40%	1.9
≥ 50%	2.0

Table-2. Seismic Coefficient C_V

SOIL PROFILE TYPE	SEISMIC ZONE FACTOR, Z				
	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	$0.32N_V$
S_B	0.08	0.15	0.20	0.30	$0.40N_V$
S_C	0.13	0.25	0.32	0.45	$0.56N_V$
S_D	0.18	0.32	0.40	0.54	$0.64N_V$
S_E	0.26	0.50	0.64	0.84	$0.96N_V$
S_F	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-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

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

F_s = 164640 kN/m^2

f_y = 274400 kN/m^2

(A) LRB - Analysis

i. The effective horizontal stiffness K_{effH}

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

$\mathbf{K_{eff\,H}}$ **= 1054.69 kN/m** **Direction U_2 & U_3**

ii. Design displacement (D_D)

$$D_D = \left(\frac{g}{4\pi^2}\right) \times \frac{S_D T_D}{B_D}$$

$$= 0.33546 \text{ m.}$$

iii. Yield strength $\mathbf{Q_d}$

$$\mathbf{Q_d} = \frac{W_D}{4 \times D_D} = \frac{\pi}{4} \times K_{effH} \times \xi_{effH} \times D_D$$

$$= \mathbf{27.788\ kN}$$

iv. Yield Stiffness

K_U = 10 K_d

Where, 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.

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

= 971.854 kN/m.

K_U =10 K_d

= 9718.54 kN/m.

v. Post yield stiffness ratio.

$\frac{K_d}{K_U} = \frac{971.854}{9718.54}$

$= \mathbf{0.1}$ **Direction U2 & U3**

(B) LRB - Development

i. Area of lead core (A_p)

$Ap = \frac{Q_d}{f_{py}}$

= 0.00327 m^2.

ii. Dia of lead core (d_p)

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

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

= 0.06452 m.

iii. Thickness of rubber layer (t_r)

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

= 0.67092 m.

iv. The Shape factor (S)

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

$S = 9.09409$

For $S < 10$, Take $S = 10$

v. Compressive modulus of rubber & steel (Ec)

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

$= 511750$ kN/m^2.

vi. Effective area of bearing (A_o)

$A_o = W / \sigma_a$

$= 0.20893$ m^2.

vii. Shear strain's effective area (A_1)

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

$= 0.14404$ m^2.

viii. Elastic Stiffness K_r

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

$= 818.219$ kN/m.

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

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

$= 0.51789$ m^2.

x. Diameter of rubber (d)

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

$= 0.81203$ m.

xi. Effective vertical stiffness (k_v)

$K_v = \frac{E_C \times A_{sf}}{t_r}$

K_v = 395022 kN/m. **Direction U_1**

xii. Reduction factor - Damping (β)

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

$= 2.29.$

xiii. Reduced area (A_2)

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

$= 0.25348\ m^2.$

xiv. LRB - Details

A = $0.25348\ m^2$. (Max Area of A_O, A1, & A_2)

d = 0.56811 m

No. of rubber layer (N) = t_r/t (where t = 0.0203)

= 33.0491

Say (N) = 34.00

xv. Steel Plate thickness (t_s)

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

$t_s = 0.00319 \geq 0.002$ m.

xvi. Total height of bearing (h_b)

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

h_b = 0.94929 m.

(C) Input Values in ETABS:

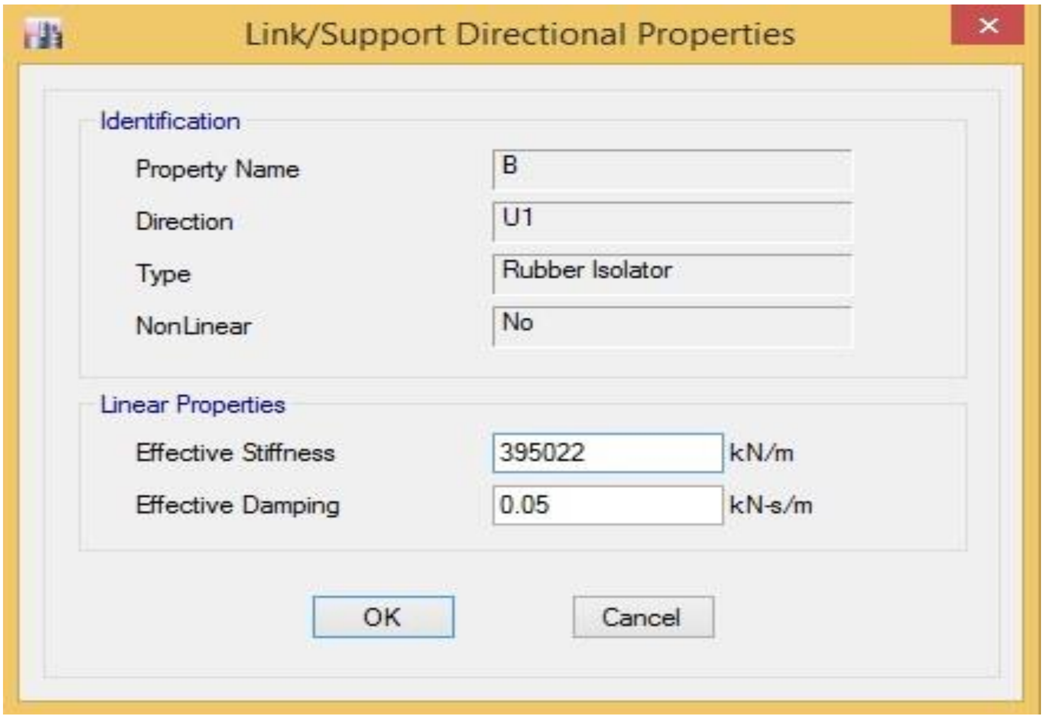

Figure-34. LRB Input Values in ETABS for Biaxial Load 1638 KN Direction U_1

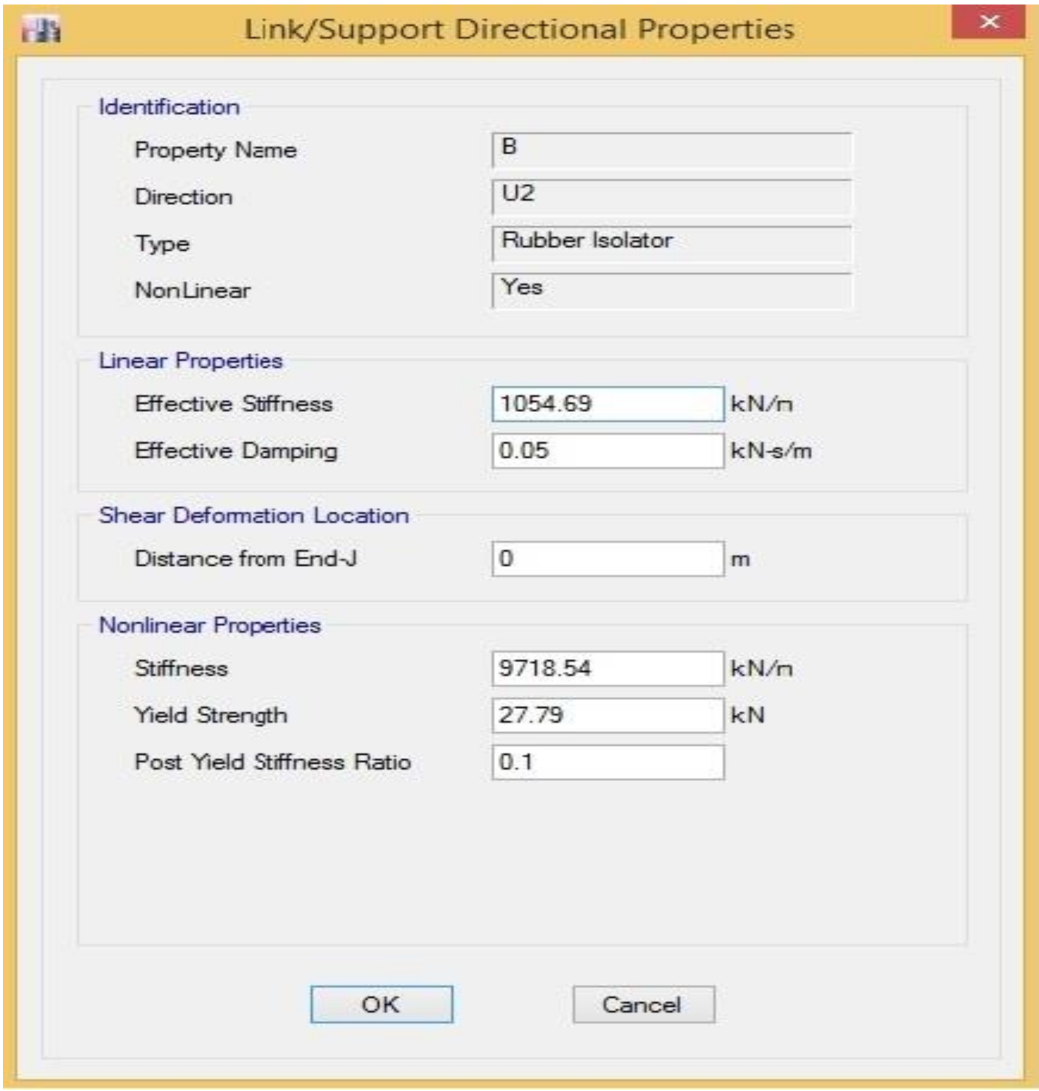

Figure-35. LRB Input Values in ETABS for Biaxial Load 1638 KN Direction U_2 & U_3

5.2.2 LRB for Uniaxial Load - 2487 KN

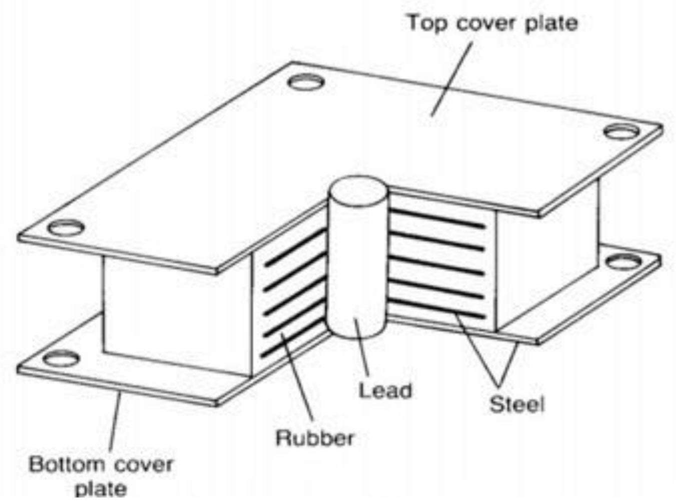

Figure-36. LRB Schematic

Uniaxial Load (W)	= 2487 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-4. Damping Coefficient, B_D or B_M

EFFECTIVE DAMPING, β_D OR β_M (PERCENTAGE OF CRITICAL)	B_D OR B_M FACTOR
≤ 2%	0.8
5%	1.0
10%	1.2
20%	1.5
30%	1.7
40%	1.9
≥ 50%	2.0

Table-5. Seismic Coefficient C_V

SOIL PROFILE TYPE	SEISMIC ZONE FACTOR, Z				
	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	$0.32N_V$
S_B	0.08	0.15	0.20	0.30	$0.40N_V$
S_C	0.13	0.25	0.32	0.45	$0.56N_V$
S_D	0.18	0.32	0.40	0.54	$0.64N_V$
S_E	0.26	0.50	0.64	0.84	$0.96N_V$
S_F	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-6. 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

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

F_s = 164640 kN/m^2

f_y = 274400 kN/m^2

(A) LRB - Analysis

i. The effective horizontal stiffness K_{effH}

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

$K_{eff\,H}$ = 1601.35 kN/m **Direction U_2 & U_3**

ii. Design displacement (D_D)

$$D_D = \left(\frac{g}{4\pi^2}\right) \times \frac{S_D T_D}{B_D}$$

$= 0.33546$ m.

iii. Yield Strength **Q_d**

$$\mathbf{Q_d} = \frac{W_D}{4 \times D_D} = \frac{\pi}{4} \times K_{effH} \times \xi_{effH} \times D_D$$

$$= \mathbf{42.191\ kN}$$

iv. Yield stiffness

K_U = 10 K_d

Where, 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 $= K_{effH} - \frac{Q_d}{D_D}$

= 1475.58 kN/m.

K_U $=10\ K_d$

= 14755.8 kN/m.

v. Post yield stiffness ratio.

$$\frac{K_d}{K_U} = \frac{1475.58}{14755.8}$$

$$= \mathbf{0.1}$$

Direction U_2 & U_3

(B) LRB - Development

i. Area of Lead Core (A_p)

$$A_p = \frac{Q_d}{f_{py}}$$

= 0.00496 m^2

ii. Dia of lead core (d_p)

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

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

= 0.0795 m.

iii. Thickness of rubber layer (t_r)

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

= 0.67092 m.

iv. The Shape factor (S)

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

$S = 9.09409$

For S < 10, Take S = 10

v. Compressive modulus of rubber & steel (Ec)

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

$= 511750\ kN/m^2$

vi. Effective area of bearing(A_o)

$A_o = W / \sigma_a$

$= 0.31722\ m^2$.

vii. Shear strain's effective area (A_1)

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

$= 0.21869\ m^2$

viii. Elastic Stiffness K_r

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

$= 1242.31\ kN/m$.

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

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

$= 0.78632\ m^2$.

x. Diameter of rubber (d)

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

$= 1.00059\ m$.

xi. Effective vertical stiffness (k_v)

K_v $= \frac{E_C \times A_{sf}}{t_r}$

K_v = 599768 kN/m. **Direction U_1**

xii. Reduction factor - Damping (β)

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

= 2.457

xiii. Reduced area (A_2)

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

= 0.4567 m^2

xiv. LRB - Details

A = 0.4567 m^2 (Max Area of A_O, A1, & A_2)

d = 0.76255 m

No. of rubber layer (N) = t_r/t (where t = 0.02501)

= 26.8212

Say (N) = 27.00

xv. Steel Plate thickness (t_s)

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

t_s = 0.00331 ≥ 0.002 m.

xvi. Total height of bearing (h_b)

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

h_b = 0.89528 m.

(C) Input Values in ETABS:

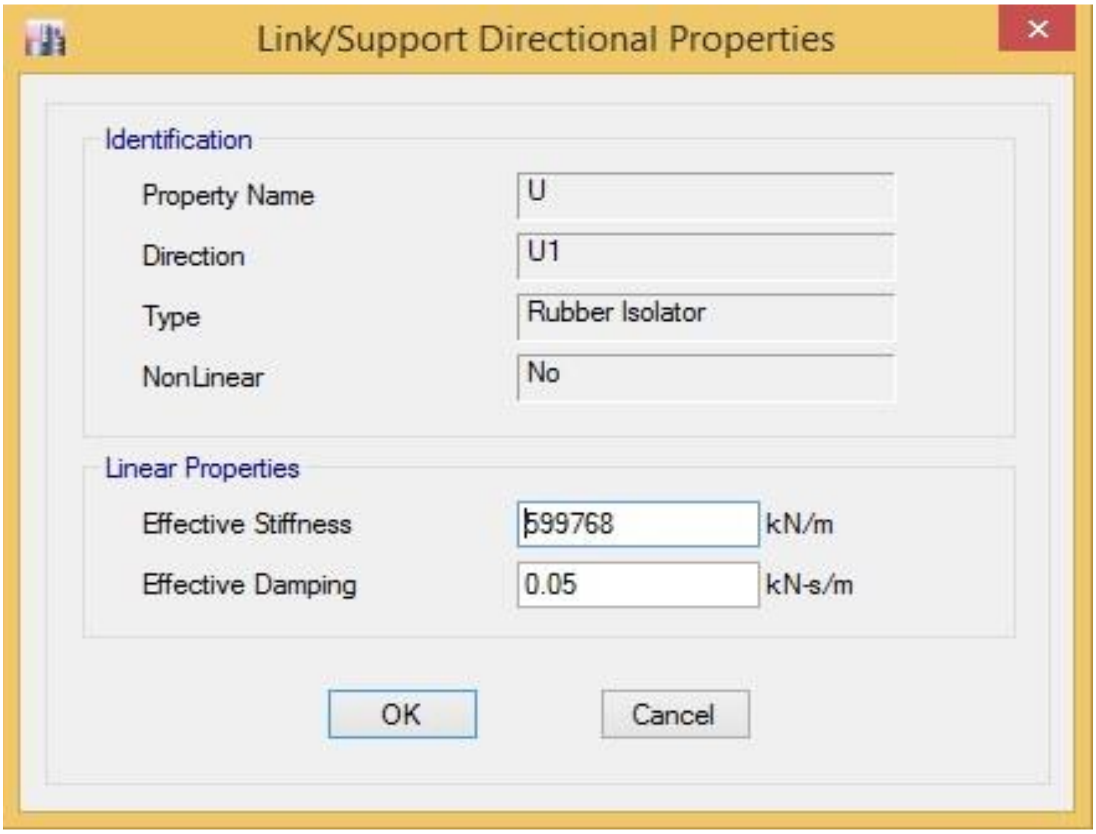

Figure-37. LRB Input Values in ETABS for Uniaxial Load 2487 KN Direction U_1

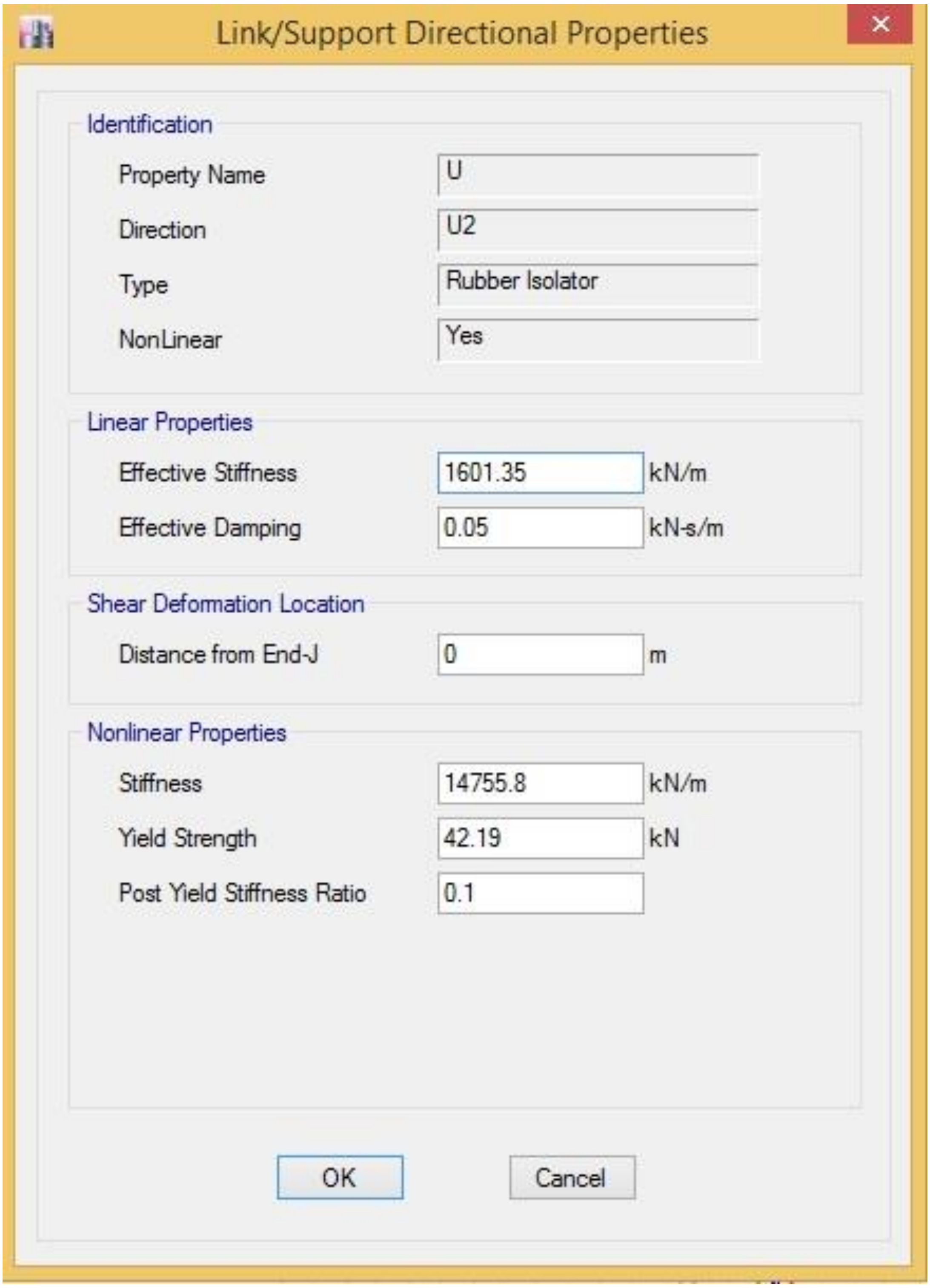

Figure-38. LRB Input Values in ETABS for Uniaxial Load 2487 KN Direction U_2 & U_3

5.2.3 LRB for Axial Load - 3920 KN

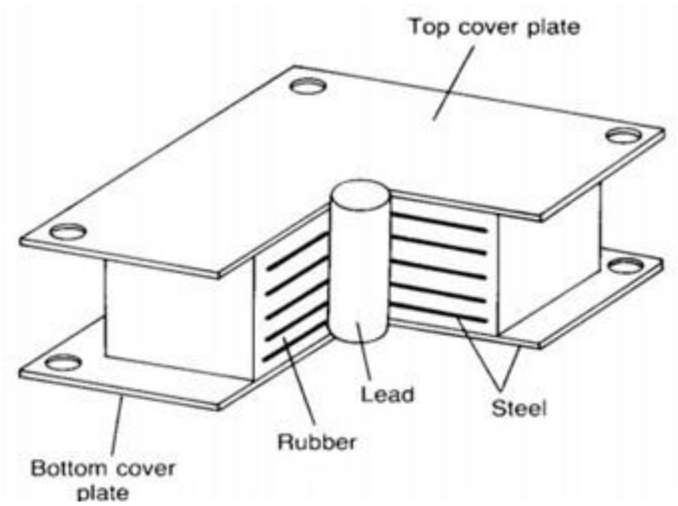

Figure-39. LRB Schematic

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 Coefficient, B_D or B_M

EFFECTIVE DAMPING, β_D OR β_M (PERCENTAGE OF CRITICAL)	B_D OR B_M FACTOR
≤ 2%	0.8
5%	1.0
10%	1.2
20%	1.5
30%	1.7
40%	1.9
≥ 50%	2.0

Table-8. Seismic Coefficient C_V

SOIL PROFILE TYPE	SEISMIC ZONE FACTOR, Z				
	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	$0.32N_V$
S_B	0.08	0.15	0.20	0.30	$0.40N_V$
S_C	0.13	0.25	0.32	0.45	$0.56N_V$
S_D	0.18	0.32	0.40	0.54	$0.64N_V$
S_E	0.26	0.50	0.64	0.84	$0.96N_V$
S_F	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-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

E = 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

F_s = 164640 kN/m^2

f_y = 274400 kN/m^2

(A) LRB - Analysis

i. The effective horizontal stiffness K_{effH}

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

$K_{eff\,H}$ = 2524.04 kN/m **Direction U_2 & U_3**

ii. Design displacement (D_D)

$$D_D = \left(\frac{g}{4\pi^2}\right) \times \frac{S_D T_D}{B_D}$$

$$= 0.33546 \text{ m.}$$

iii. Yield Strength $\mathbf{Q_d}$

$$\mathbf{Q_d} = \frac{W_D}{4 \times D_D} = \frac{\pi}{4} \times K_{effH} \times \xi_{effH} \times D_D$$

$$= \mathbf{66.5012\ kN}$$

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.

$$\frac{K_d}{K_U} = \frac{2325.81}{23258.1}$$

$$= \mathbf{0.1}$$ **Direction U2 & U3**

(B) LRB - Development

i. Area of Lead Core (A_p)

$$Ap = \frac{Q_d}{f_{py}}$$

$= 0.00782 \ m^2$.

ii. Dia of lead core (d_p)

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

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

= 0.09981 m.

iii. Thickness of rubber layer (t_r)

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

= 0.67092 m.

iv. The Shape factor (S)

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

$S = 9.09409$

For $S < 10$, Take $S = 10$

v. Compressive modulus of rubber & steel (Ec)

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

$= 511750$ kN/m^2.

vi. Effective area of bearing(A_o)

A_o $= W / \sigma_a$

$= 0.5$ m^2.

vii. Shear strain's effective area (A_1)

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

= 0.3447 m2.

viii. Elastic Stiffness K_r

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

= 1958.13 kN/m.

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

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

$= 1.23939$ m^2.

x. Diameter of rubber (d)

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

= 1.2562 m.

xi. Effective vertical stiffness (k_v)

K_v $= \frac{E_C \times A_{sf}}{t_r}$

K_v = 945352 kN/m. **Direction U_1**

xii. Reduction factor - Damping (β)

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

$= 2.6$

xiii. Reduced area (A_2)

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

$= 0.82236\ m^2$.

xiv. LRB - Details

A = $0.82236\ m^2$ (Max Area of A_O, A1, & A_2)

d = 1.02326 m

No. of rubber layer (N) = t_r/t (where t = 0.03141)

= 21.3636

Say (N) = 22.00

xv. Steel Plate thickness (t_s)

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

$t_s = 0.00364 \geq 0.002$ 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:

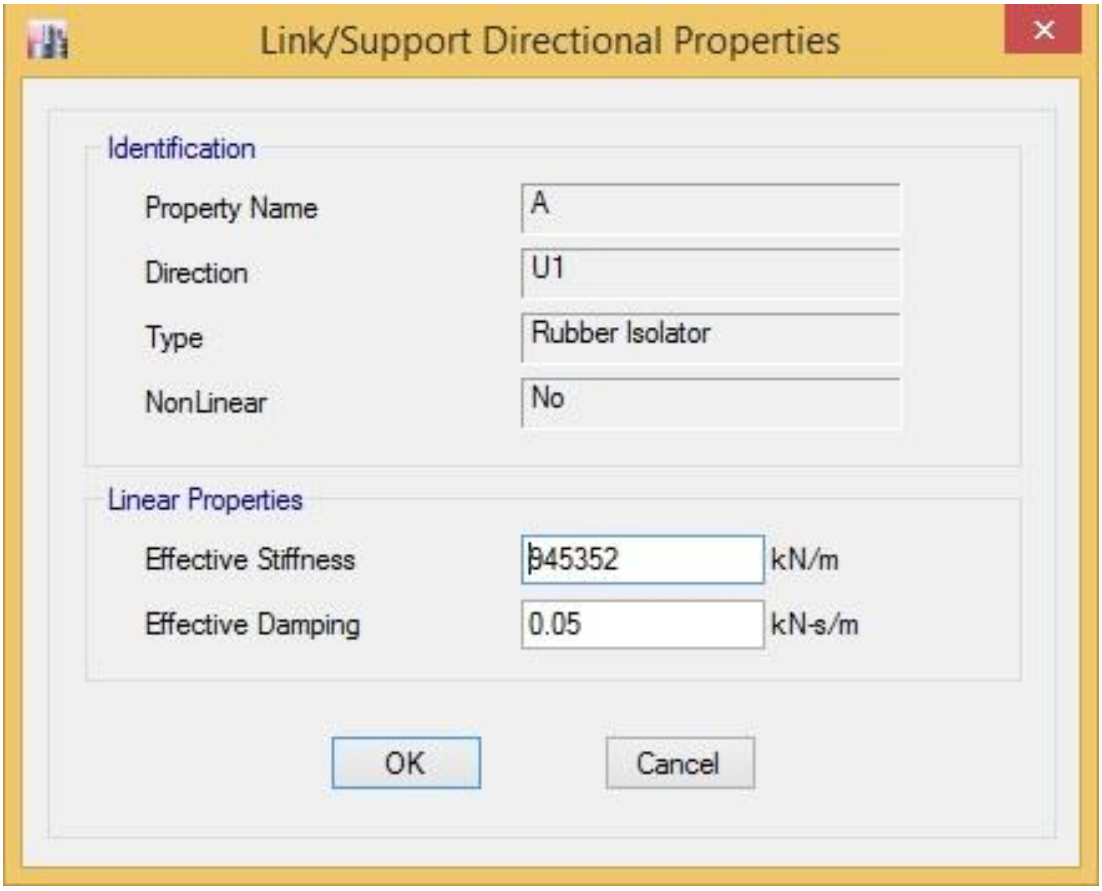

Figure-40. LRB Input Values in ETABS for Axial Load 3920 KN Direction U_1

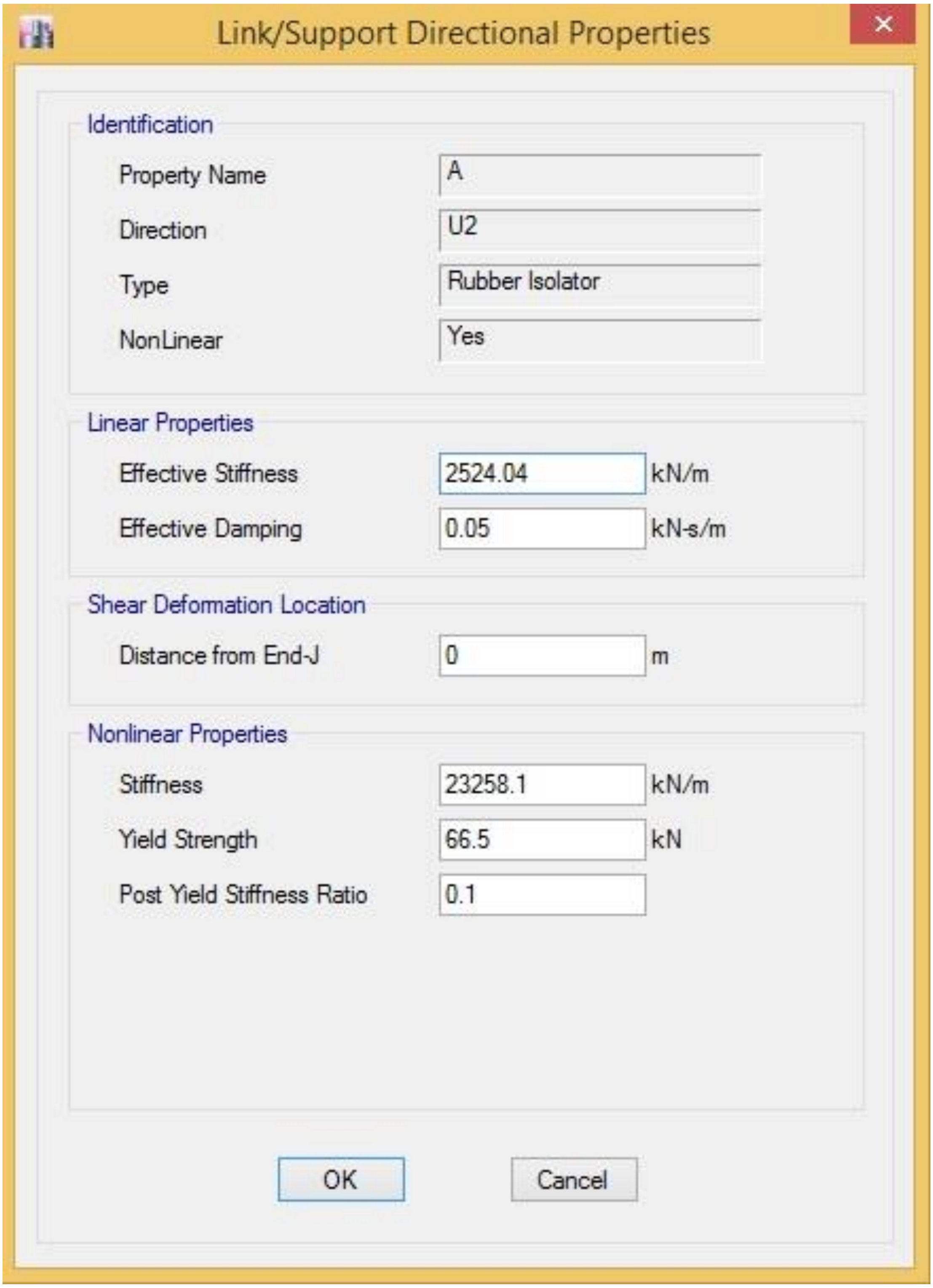

Figure-41. LRB Input Values in ETABS for Axial Load 3920 KN Direction U_2 & U_3

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

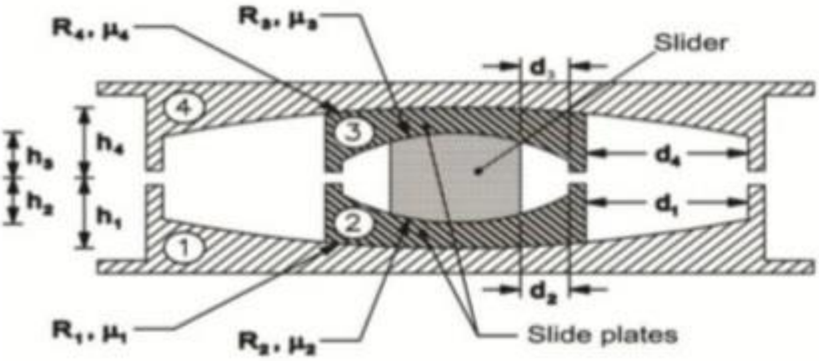

Figure-42. TFPB Schematic

(A) Geometrical, Frictional and D_D Computation

a. Geometrical features

R_4	=	R_1	=	1778 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_{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

P = W / A

Here W Load = 163.8 tonne or 1638 KN.

A = πr^2

r = $h_4 + h_1$

= 161 + 161

r = 322 mm

P = 0.000503 ton/mm^2,

P = 0.000503 x 1450

P = 0.73 ksi, 1 ksi = Kilo square inch

= 1450 ton/mm^2

3- Friction Cycle μ = 0.122 - 0.01 P,

μ = 0.1147

Adjust for high velocity = μ - 0.0333

= 0.1147 - 0.0333

= 0.081 (Lower bound)

1 – Friction Cycle μ = 1.2 x 0.081

= 0.0977

μ_4 = μ_1 = 0.081(Lower bound)

μ_4 = μ_1 = 0.098 (Upper bound)

At 2 and 3

P = W / A

Here W Load = 163.8 tonne or 1638 kN,

A = πr^2

R = $h_2 + h_3$

= 121 + 121,

= 242 mm

P = 0.000890 ton/mm^2,

P = 0.000890 x 1450

P = 1.29 ksi. 1 ksi = Kilo square inch

= 1450 ton/mm^2

3- Friction Cycle μ = 0.122 - 0.01 P

= 0.1091

Adjust for high velocity = μ - 0.036

= 0.1091 - 0.036

= 0.073 (Lower bound)

1 - Friction Cycle μ = 1.2 x 0.073

= 0.0877

μ_2 = μ_3 = 0.073 (Lower bound)

μ_2 = μ_3 = 0.088 (Upper bound)

μ = force at zero deformation

$\mu = \mu_1 - (\mu_1 - \mu_2) \times \frac{R_{2eff}}{R_{1eff}}$ (Lower bound)

μ = 0.080

$\mu = \mu_1 - (\mu_1 - \mu_2) \times \frac{R_{2eff}}{R_{1eff}}$ (Upper bound)

μ = 0.096

c. D_D Computation (Upper bound)

S_d = 0.5074

μ = 0.096

μ_1 = 0.098

D_y = $(\mu_1 - \mu_2) * R_{2eff}$

D_y = 0.005250

F_d = 0.2772

W = 163.8 Ton.

T.B. = 12 Nos. (where T.B. = Total Bearing)

ΣF_d = W x T.B. x F_d

= 163.8 x 12 x 0.2772

ΣF_d = 544.95

Σw = W x T.B.

Σw = 1965.6 Ton.

i. Design displacement D_D = 0.07202 m.

ii. **Effective stiffness**, Qd = $\mu * \Sigma w$

= 0.096 * 1965.6

Q_d = 188.98 Ton

k_D = $\Sigma F_D / D_D$

= 544.95 / 0.07202

k_D = 7566.63 Ton/m.

K_{eff} = $k_D + Q_D / D_D$

= 7566.63 + 188.98 / 0.07202

K_{eff} = 10190.63 Ton/m.

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

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

T_{eff} = 0.88103 sec.

iv. **Effective damping**, β_{eff}

$$\beta_D = \frac{E}{2\pi K_{eff} \times {D_D}^2} = \frac{4\mu\sum w(D_D - D_y)}{2\pi K_{eff} \times {D_D}^2}$$

β_{eff} = β_D = 0.1520

v. **Damping reduction coefficient, β**

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

β = 1.3959

vi. **$D_D{}^1$**

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

$D_D{}^1$ = 0.0701 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

Ø = 0.484 m

Now, Area A = $\frac{\pi \times \emptyset^2}{4}$

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

A = $0.1840\ m^2$

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

K_{eff} = 266.91 Ton/m

I_1 = $\frac{K_{eff} \times h^3}{12E}$ = $\frac{266.91 \times 0.5^3}{12E}$

= 2.78035E-07 m^4.

E = $1x10^7\ N/mm^2$.

ii. Determine 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

M = w / g

= 0.005372 / 9.81

M = 0.000548 Tonne sec^2/m.

b. Direction (U_1)

H = 0.5 m

Ø = 0.484 m

K_{eff} = AE / L

K_{eff} = 3679684.643 Ton/m.

from D_D

K_{eff} = 3679684.643 Ton/m.

β_{eff} = 0.1520

c. Direction (U_2 - U_3)

i. Determination of liner properties.

K_{eff} = 266.914 ton/m

= **2669.14 KN/m**

β_{eff} = 0.1520

Height for outer surface, = h_1 = h_4 = **0.161m.**

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

ii. Determination of Non - liner properties.

$R_{2\,eff}$ = 0.526 m.

D_y = $(\mu_1 - \mu_2)\, R_{2eff}$

= (0.09769 – 0.08771) x 0.526

D_y = 0.00525 m.

Stiffness (Outer Top) = $\frac{\mu_1\, w}{D_y}$

= $\frac{0.09769 \times 163.8}{0.00525}$

= 3047.855 ton/m.

= **30478.55 KN/m.**

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

$= \frac{0.08771 \times 163.8}{0.00526}$

= 2736.448 ton/m.

= **27364.48 KN/m.**

Friction Coefficient, Slow = μ_1 = **0.098 (Outer Top)**

= μ_2 = **0.088 (Inner Top)**

Friction Coefficient, Fast = 2 x μ_1 = **0.195 (Outer Top)**

= 2 x μ_2 = **0.175 (Inner Top)**

Rate Parameter $= \frac{\text{Friction Coeff. Slow}}{\text{Friction Coeff.Fast}}$

= 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:

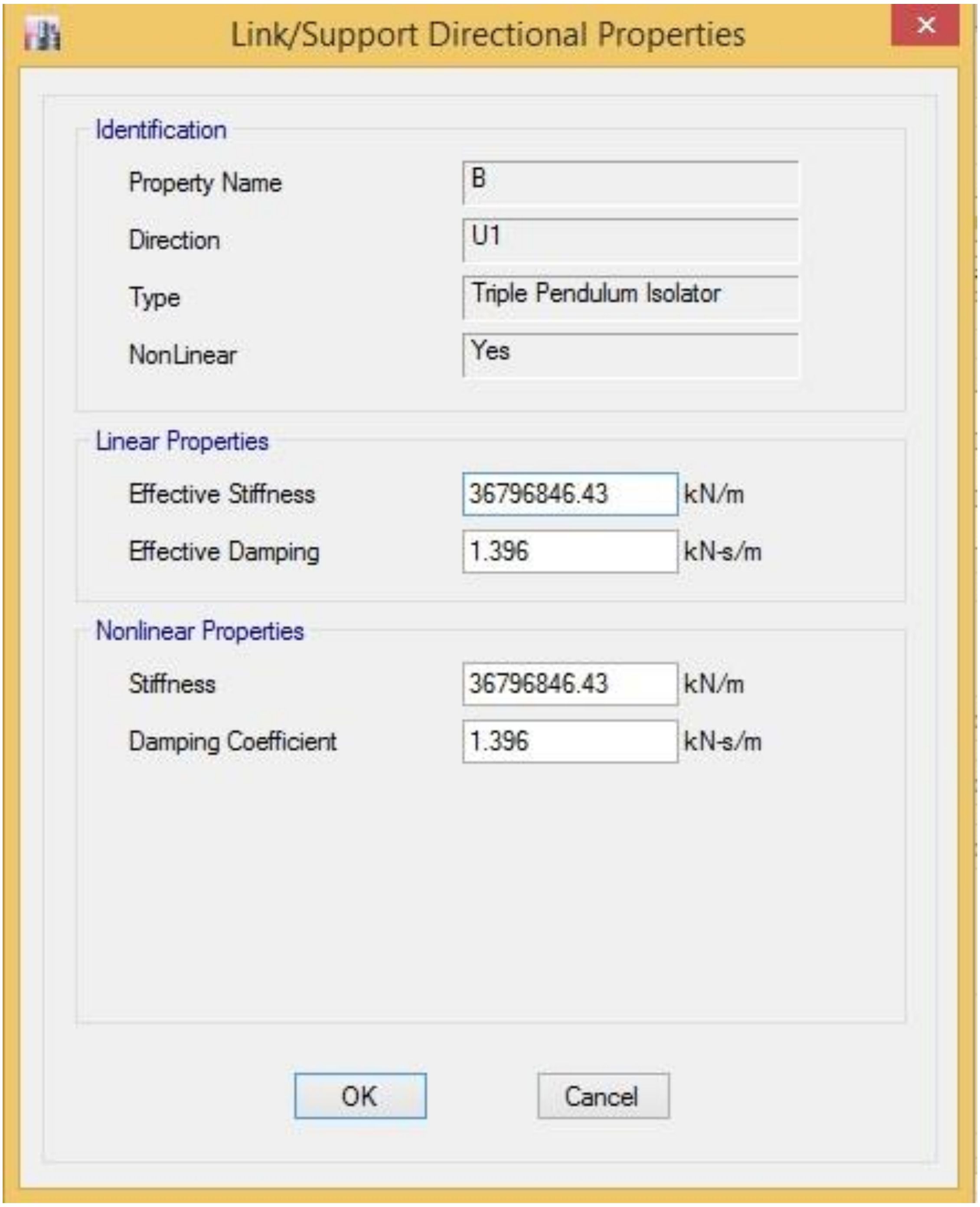

Figure-43. TFPB Input Values in ETABS for Biaxial Load 1638 KN Direction U_1

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

5.3.2 TFPB for Uniaxial Load - 2487 KN

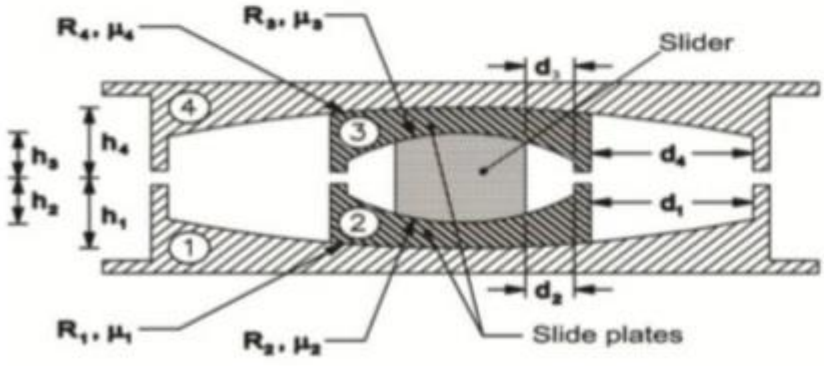

Fig. 45. TFPB Schematic

(A) Geometrical, Frictional and D_D Computation

a. Geometrical features

R_4	=	R_1	=	1778 x 2
			=	3556 mm
			=	3.556 mtrs.
R_2	=	R_3	=	647 mm
			=	0.647 mtrs
h_1	=	h_4	=	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_{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

≈ 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

P = W / A

Here W Load = 248.7 tonne or 2487 KN

A = πr^2

R = $h_4 + h_1$

= 161 + 161

r = 322 mm

P = 0.000764 ton/mm^2,

P = 0.000764 x 1450

P = 01.11 ksi, 1 ksi = Kilo square inch

= 1450 ton/mm^2

3- Friction Cycle μ = 0.122 - 0.01 P

μ = 0.1109

Adjust for high velocity = μ - 0.0333

= 0.1109 - 0.0333

= 0.078 (Lower bound)

1 - Friction Cycle μ = 1.2 x 0.078

= 0.0932

μ_1 = μ_4 = 0.078 (Lower bound)

μ_1 = μ_4 = 0.093 (Upper bound)

At 2 and 3

P = W / A

Here W Load = 248.7 ton or 2487 kN

A = πr^2

r = $h_2 + h_3$

= 121 + 121,

r = 242 mm

P = 0.001352 ton/mm^2

P = 0.001352 x 1450

P = 1.96 ksi. 1 ksi = Kilo square inch

= 1450 ton/mm^2

3- Friction Cycle μ = 0.122 - 0.01 P

= 0.1024

Adjust for high velocity = μ - 0.036

= 0.1024 - 0.036

= 0.066 (Lower bound)

1 - Friction Cycle μ = 1.2 x 0.066

= 0.0797

μ_2 = μ_3 = 0.066 (Lower bound)

μ_2 = μ_3 = 0.080 (Upper bound)

μ = force at zero deformation

μ = $\mu_1 - (\mu_1 - \mu_2) \times \frac{R_{2eff}}{R_{1eff}}$ (Lower bound)

μ = 0.076

μ = $\mu_1 - (\mu_1 - \mu_2) \times \frac{R_{2eff}}{R_{1eff}}$ (Upper bound)

μ = 0.091

c. D_D Computation (Upper bound)

S_d = 0.5074

μ = 0.091

μ_1 = 0.093

D_y = $(\mu_1 - \mu_2) * R_{2eff}$

D_y = 0.007088

F_d = 0.2772

W = 248.7 Ton

T.B. = 12 Nos. (Where T.B. = Total Bearing)

ΣF_d = W x T.B. x F_d

= 248.7 x 12 x 0.2772

ΣF_d = 827.40

Σw = W x T.B.

Σw = 2984.4 Tonne

i. **Design displacement D_D** = 0.07202 mtrs.

ii. **Effective stiffness, Qd** = $\mu * \Sigma w$

= 0.091 * 2984.4

Q_d = 271.78 Ton

k_D = $\Sigma F_D / D_D$

= 827.40 / 0.07202

k_D = 11488.53 Ton/m.

K_{eff} = $k_D + Q_D / D_D$

= 11488.53 + 271.78 / 0.07202

K_{eff} = 15262.22 Ton/m.

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

T_{eff} = $[\sqrt{((\Sigma w)/(K_{eff} \times g))}]\, 2\pi$

T_{eff} = 0.88708 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

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

$$\boldsymbol{\beta} = \mathbf{1.3675}$$

vi. $\mathbf{D_D}^{\mathbf{1}}$

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

$$D_D{}^1 = 0.0726 \text{ mtrs}$$

(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 m

Ø = 0.484 m

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

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

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

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

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

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

= 4.03884E-07 m^4.

E = $1x10^7$ N/mm^2

ii. Determine 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

M = w / g

= 0.005372 / 9.81

M = 0.000548 tonne sec^2/m.

b. Direction (U_1)

H = 0.5 m

Ø = 0.484 m

K_{eff} = AE / L

K_{efF} = 3679684.643 ton/m.

from D_D

K_{eff} = 3679684.643 ton/m.

β_{eff} = 0.1419

c. Direction (U_2 - U_3)

i. Determination of liner properties.

K_{eff} = 387.729 ton/m

= **3877.29 KN/m**

β_{eff} = 0.1419

Height for outer surface, = h_1 = h_4 = **0.161m.**

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

ii. Determination of Non - liner properties.

$R_{2\ eff}$ = 0.526 m.

D_y = $(\mu_1 - \mu_2)\ R_{2eff}$

= (0.093155 – 0.079680) x 0.526

D_y = 0.00709 m.

Stiffness (Outer Top) = $\frac{\mu_1\ w}{D_y}$

= $\frac{0.093155 \times 248.7}{0.00709}$

= 3268.561 ton/m.

= 32685.61 KN/m.

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

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

= 2795.747 ton/m.

= **27957.47 KN/m.**

Friction Coefficient, Slow	=	μ_1	=	**0.093 (Outer Top)**
	=	μ_2	=	**0.080 (Inner Top)**
Friction Coefficient, Fast	=	$2 \times \mu_1$	=	**0.186 (Outer Top)**
	=	$2 \times \mu_2$	=	**0.159 (Inner Top)**

Rate Parameter $= \dfrac{\text{Friction Coeff. Slow}}{\text{Friction Coeff.Fast}}$

= 0.093 / 0.186

= 0.5

= **0.0005 sec/mm**

Radius of sliding surface

Outer Top = $R_{1\ eff}$ = **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* = $2\ D_y$

= 0.0142 m.

= **14.18 mm.**

(C) Input Values in ETABS:

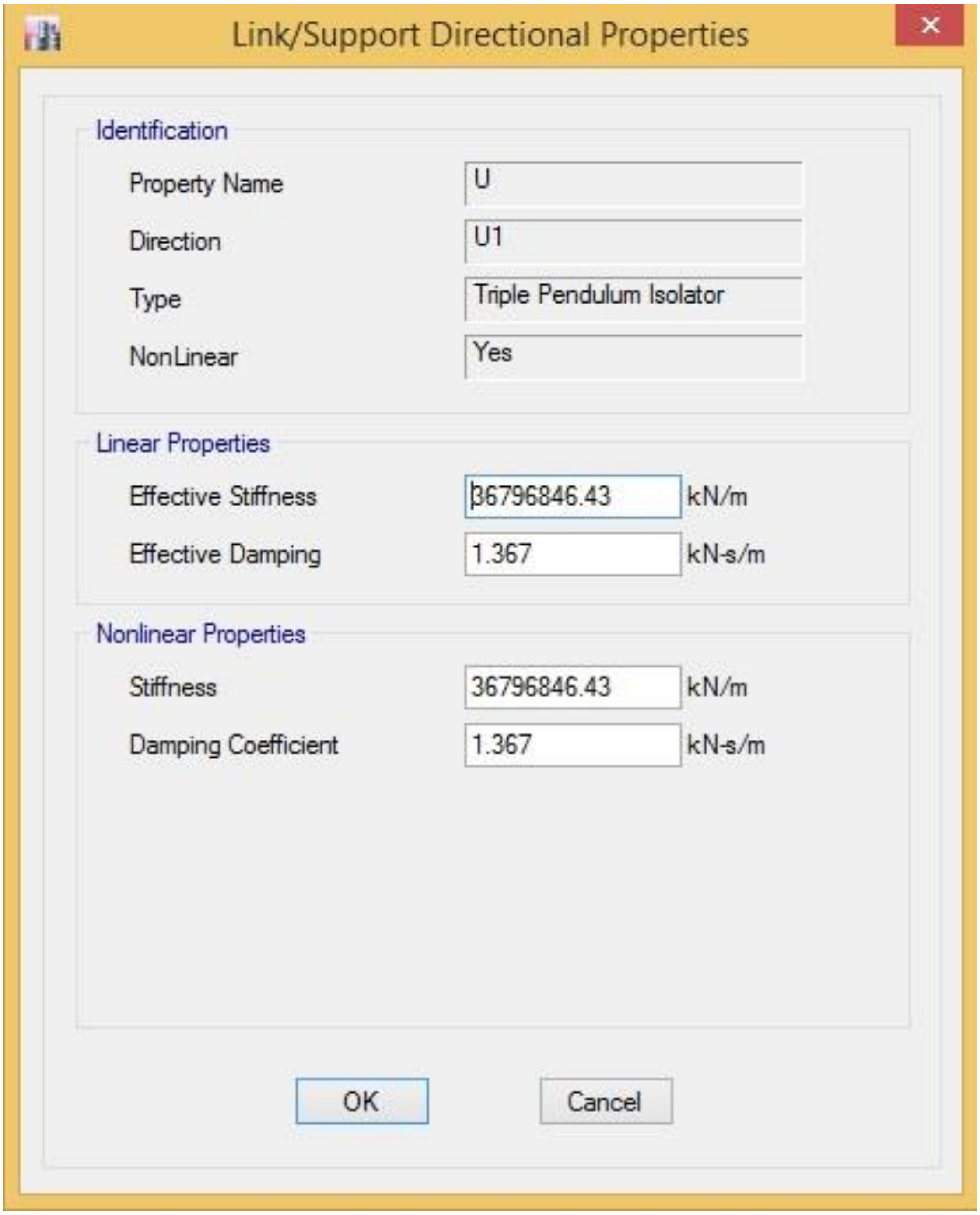

Figure-46. TFPB Input Values in ETABS for Uniaxial Load 2487 KN Direction U_1

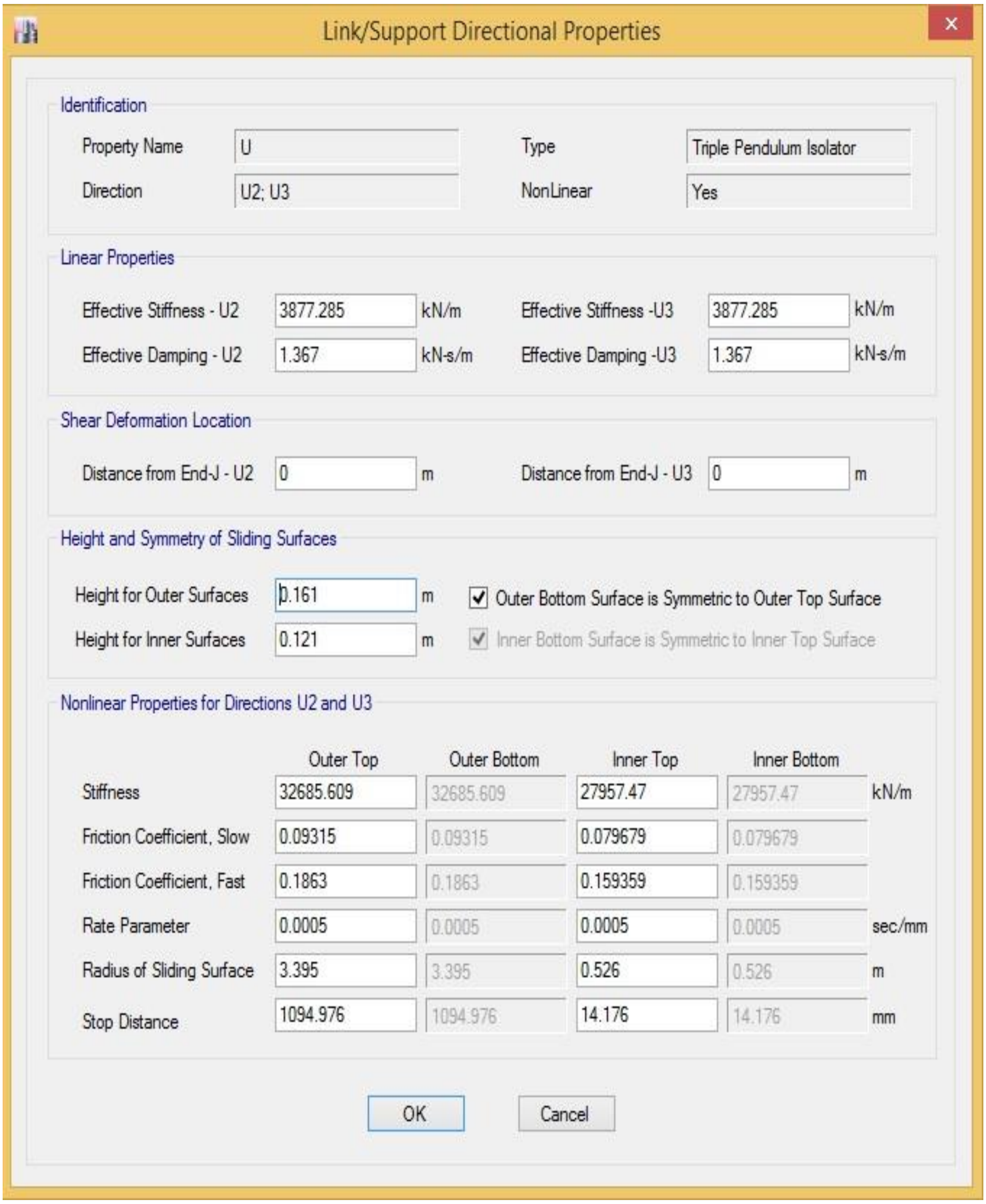

Figure-47. TFPB Input Values in ETABS for Uniaxial Load 2487 KN Direction U_2 & U_3

5.3.3 TFPB for Axial Load - 3920 KN

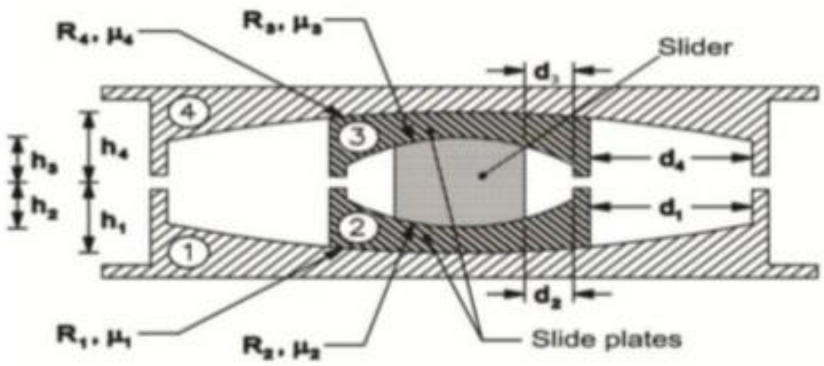

Figure-48. TFPB Schematic

(A) Geometrical, Frictional and D_D Computation

a. Geometrical features

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_{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

≈ 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

P = W / A

Here W Load = 392.0 tonne or 3920 KN,

A = πr^2

r = $h_4 + h_1$

= 161 + 161

r = 322 mm

P = 0.001203 ton/mm^2

P = 0.001203 x 1450

P = 1.74 ksi, 1 ksi = Kilo square inch

= 1450 ton/mm^2

3- Friction Cycle μ = 0.122 - 0.01 P

μ = 0.1046

Adjust for high velocity = μ - 0.0333

= 0.1046 - 0.0333

= 0.071 (Lower bound)

1 - Friction Cycle μ = 1.2 x 0.071

= 0.0855

μ_1 = μ_4 = 0.071 (Lower bound)

μ_1 = μ_4 = 0.086 (Upper bound)

At 2 and 3

P = W / A

Here W Load = 392.0 tonne or 3920 KN

A = πr^2

r = $h_2 + h_3$

= 121 + 121

= 242 mm

P = 0.002131 ton/mm^2,

P = 0.002131 x 1450

P = 3.09 ksi. 1 ksi = Kilo square inch

= 1450 ton/mm^2

3- Friction Cycle μ = 0.122 - 0.01 P

= 0.0911

Adjust for high velocity = μ - 0.036

= 0.0911 - 0.036

= 0.055 (Lower bound)

1 - Friction Cycle 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 at zero deformation

$\mu = \mu_1 - (\mu_1 - \mu_2) \times \frac{R_{2eff}}{R_{1eff}}$ (Lower bound)

μ = 0.069

$\mu = \mu_1 - (\mu_1 - \mu_2) \times \frac{R_{2eff}}{R_{1eff}}$ (Upper bound)

μ = 0.082

c. D_D Computation (Upper bound)

S_d = 0.5074

μ = 0.082

μ_1 = 0.086

D_y = $(\mu_1 - \mu_2) * R_{2eff}$

D_y = 0.010190

F_d = 0.2772

W = 392 Ton

T.B. = 12 Nos. (Where T.B. = Total Bearing)

ΣF_d = W x T.B. x F_d

= 392 x 12 x 0.2772

ΣF_d = 1304.15

Σw = W x T.B.

Σw = 4704 Ton

i. Design displacement, D_D = 0.07202 m.

ii. **Effective stiffness, Qd** = $\mu * \Sigma w$

= 0.082 * 2832

Q_d = 388.07 Ton

k_D = $\Sigma F_D / D_D$

= 1304.15 / 0.07202

k_D = 18108.18 Ton/m.

K_{eff} = $k_D + Q_D / D_D$

= 18108.18 + 388.07 / 0.07202

K_{eff} = 23496.59 Ton/m.

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

T_{eff} = $[\sqrt{((\Sigma w)/(K_{eff} \times g))}]\, 2\pi$

T_{eff} = 0.89759 sec.

iv. **Effective damping**, β_{eff}

$$\beta_D = \frac{E}{2\pi K_{eff} \times {D_D}^2} = \frac{4\mu \sum w(D_D - D_y)}{2\pi K_{eff} \times {D_D}^2}$$

$$\beta_{eff} = \beta_D = 0.1253$$

v. Damping reduction Coefficient, β

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

$$\boldsymbol{\beta} = \mathbf{1.3174}$$

vi. $\mathbf{D_D}^{\mathbf{1}}$

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

$$D_D^{\,1} = 0.0771 \text{ m.}$$

(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

H = 0.5 m.

Ø = 0.484 m

Now, Area $A = \frac{\pi \times \text{Ø}^2}{4}$

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

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

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

$$K_{eff} = 564.50 \text{ Ton/m}$$

$$I_1 = \frac{K_{eff} \times h^3}{12E} = \frac{564.50 \times 0.5^3}{12E}$$

= 5.88019E-07 m^4.

E = $1x10^7$ N/mm^2

ii. **Determine bearing mass**

D_{m-max} = 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.

M = w / g

= 0.005372 / 9.81

M = 0.000548 tonne sec^2/m.

b. Direction (U_1)

H = 0.5 m

Ø = 0.484 m

K_{eff} = AE / L

K_{eff} = 3679684.643 ton/m.

K_{eff} = 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

β_{eff} = 0.1253

Height for outer surface, = h_1 = h_4 = **0.161 m**

Height for inner surface, = h_2 = h_3 = **0.121 m**

ii. Determination of Non - liner properties.

R_{2eff} = 0.526 mtrs.

D_y = $(\mu_1 - \mu_2)\, R_{2eff}$

= (0.08550 – 0.06613) x 0.526

D_y = 0.01091 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) = $\frac{\mu_2\, w}{D_y}$

= $\frac{0.06613 \times 392}{0.01091}$

= 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 μ_1** = **0.171 (Outer Top)**

= **2 x μ_2** = **0.132 (Inner Top)**

Rate Parameter = $\frac{\text{Friction Coeff. Slow}}{\text{Friction Coeff.Fast}}$

= 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:

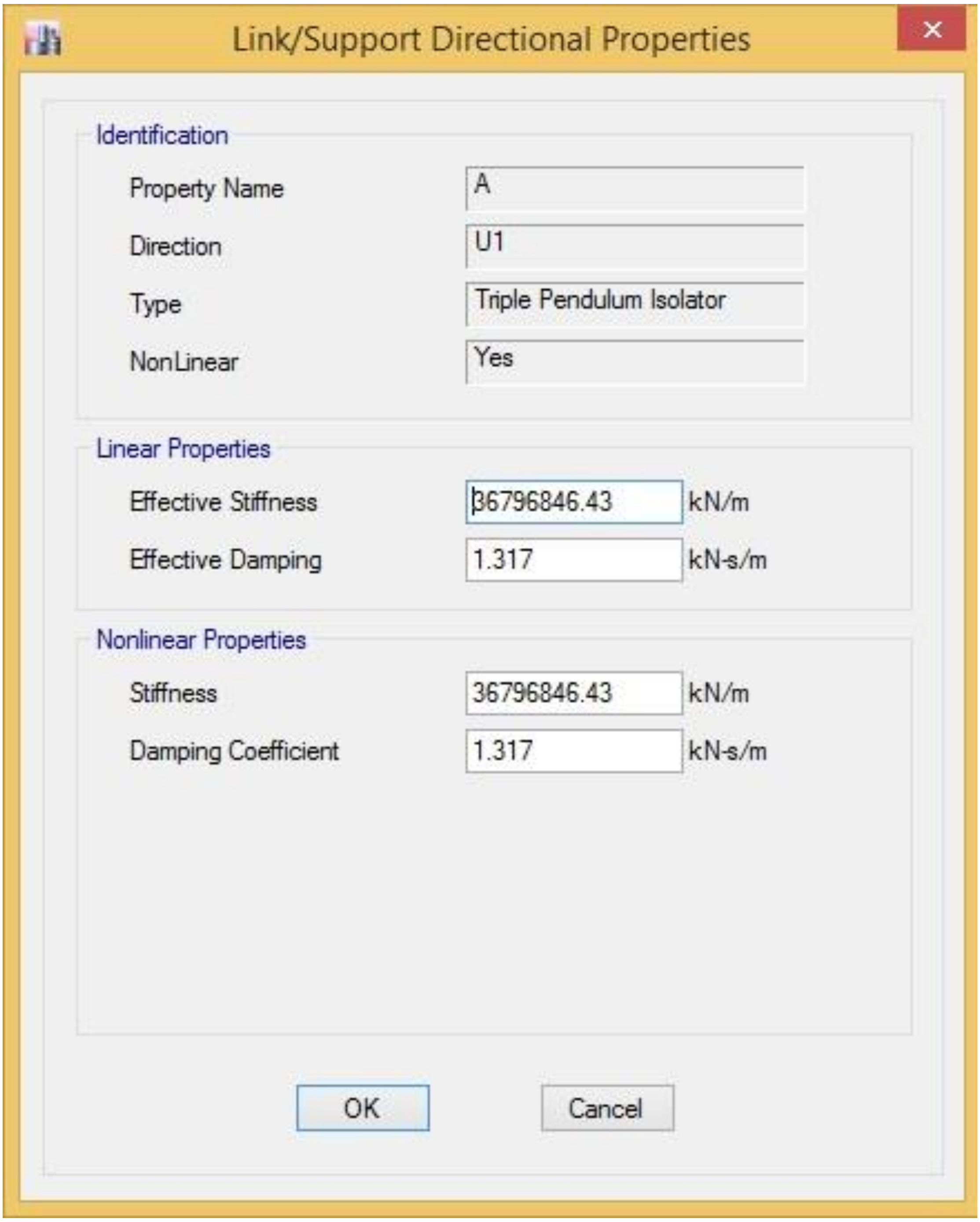

Figure-49. TFPB Input Values in ETABS for Axial Load 3920 KN Direction U_1

Figure-50. TFPB Input Values in ETABS for Axial Load 3920 KN

Direction U_2 & U_3

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

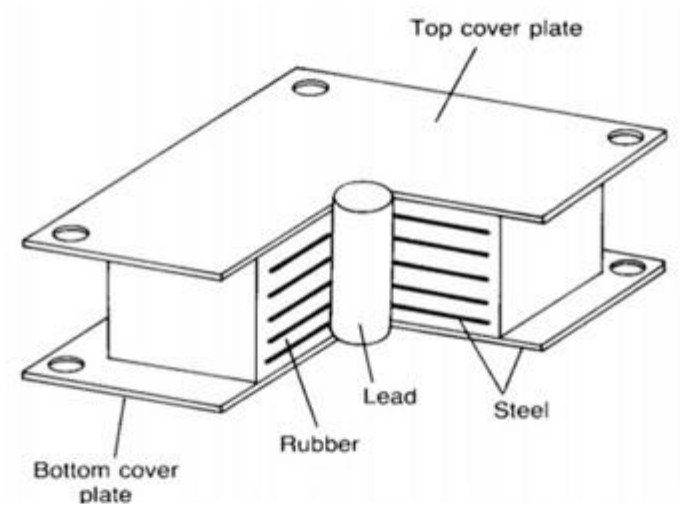

Figure-51. LRB Schematic

Biaxial Load (W)	= 3342 kN.
Time Period (TD)	= 2.5 sec.
Design Shear Strain (γmax)	= 50%
	= 0.5 kN/m^2.
Effective Damping (ξeff)	= 5%
	= 0.05 For U1,U2,U3.

Table-10. Damping Coefficient, B_D or B_M

EFFECTIVE DAMPING, β_D OR β_M (PERCENTAGE OF CRITICAL)	B_D OR B_M FACTOR
≤ 2%	0.8
5%	1.0
10%	1.2
20%	1.5
30%	1.7
40%	1.9
≥ 50%	2.0

Table-11. Seismic Coefficient C_V

SOIL PROFILE TYPE	SEISMIC ZONE FACTOR, Z				
	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	$0.32N_V$
S_B	0.08	0.15	0.20	0.30	$0.40N_V$
S_C	0.13	0.25	0.32	0.45	$0.56N_V$
S_D	0.18	0.32	0.40	0.54	$0.64N_V$
S_E	0.26	0.50	0.64	0.84	$0.96N_V$
S_F	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

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

$E = 4.45$

$= 4450 \text{ kN/m}^2$

$G = 1.06$

$= 1060 \text{ kN/m}^2$

$K = 0.57$

$\varepsilon_b = 4$

$= 400\%$

$f_{py} = 8500 \text{ kN/m}^2$

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

Typically 7 to 8.5 Mpa, Consult the manufacturer

$F_s = 164640 \text{ kN/m}^2$

$f_y = 274400 \text{ kN/m}^2$

(A) LRB - Analysis

i. The effective horizontal stiffness K_{effH}

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

$K_{eff\,H}$ = 2151.88 kN/m **Direction U_2 & U_3**

ii. Design displacement (D_D)

$$D_D = \left(\frac{g}{4\pi^2}\right) \times \frac{S_D T_D}{B_D}$$

$= 0.33546$ m.

iii. Yield Strength Q_d

$$\mathbf{Q_d} = \frac{W_D}{4 \times D_D} = \frac{\pi}{4} \times K_{effH} \times \xi_{effH} \times D_D$$

$= \mathbf{56.6957\ kN}$

iv. Yield Stiffness

K_U = 10 K_d

Where, 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.

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

= 1982.87 kN/m.

K_U =10 K_d

= 19828.7 kN/m.

v. Post yield stiffness ratio.

$$\frac{K_d}{K_U} = \frac{1982.87}{19828.7}$$

$$= \mathbf{0.1}$$ **Direction U_2 & U_3**

(B) LRB - Development

i. Area of Lead Core (A_p)

$Ap = \frac{Q_d}{f_{py}}$

= 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 m.

iii. Thickness of rubber layer (t_r)

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

= 0.67092 m.

iv. The Shape factor (S)

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

S = 9.09409

For S < 10, Take S = 10

v. Compressive modulus of rubber & steel (Ec)

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

$= 511750\ kN/m^2.$

vi. Effective area of bearing(Ao)

$A_o = W / \sigma_a$

$= 0.42628\ m^2.$

vii. Shear strain's effective area (A1)

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

$= 0.29387\ m^2.$

viii. Elastic Stiffness Kr

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

$= 1669.41\ kN/m.$

ix. Effective area of individual rubber layer (Asf)

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

$= 1.05665\ m^2.$

x. Diameter of rubber (d)

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

= 1.1599 m.

xi. Effective vertical stiffness (kv)

K_v $= \frac{E_C \times A_{sf}}{t_r}$

K_v = 805961 kN/m. **Direction U_1**

xii. Reduction factor - Damping (β)

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

= 2.555

xiii. Reduced area (A2)

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

= 0.67318 m^2

xiv. LRB - Details

A = 0.67318 m^2 (Max Area of A_O, A1, & A_2)

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 ≥ 0.002 m.

xvi. Total height of bearing (h_b)

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

h_b = 0.87486 m.

(C) Input Values in ETABS:

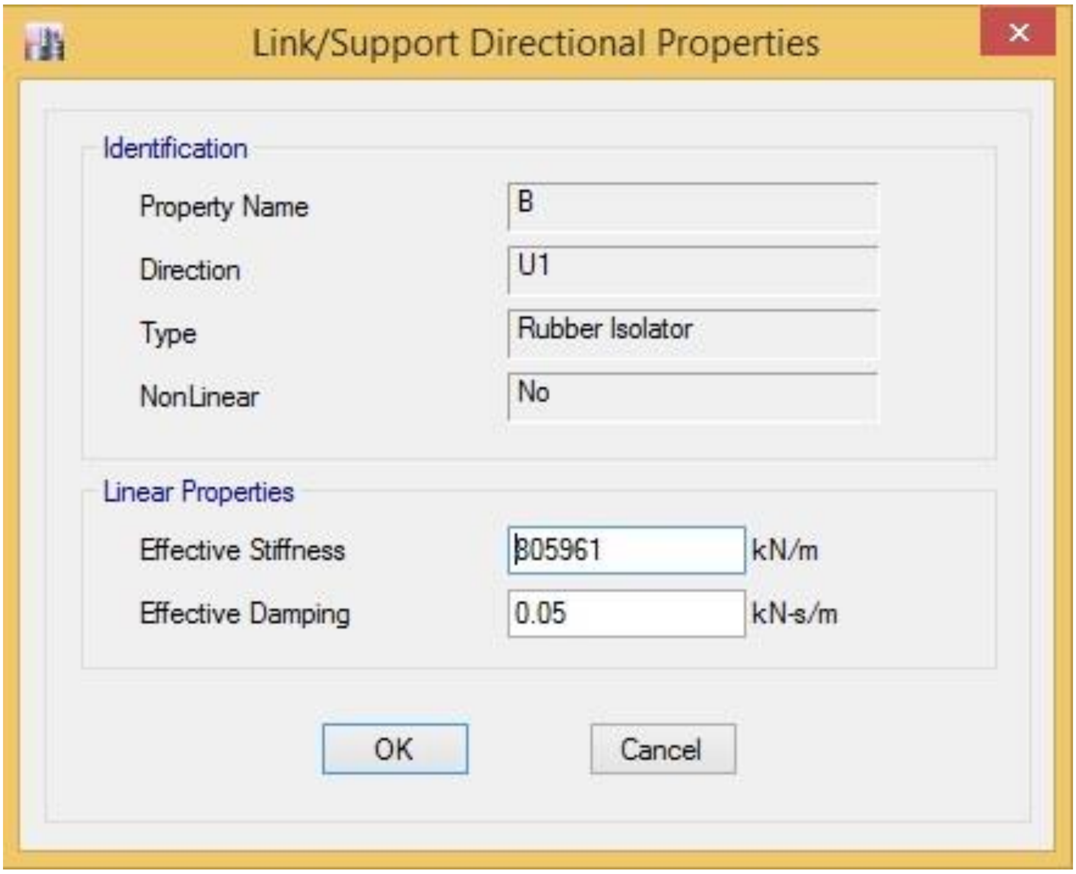

Figure-52. LRB Input Values in ETABS for Biaxial Load 3342 KN Direction U_1

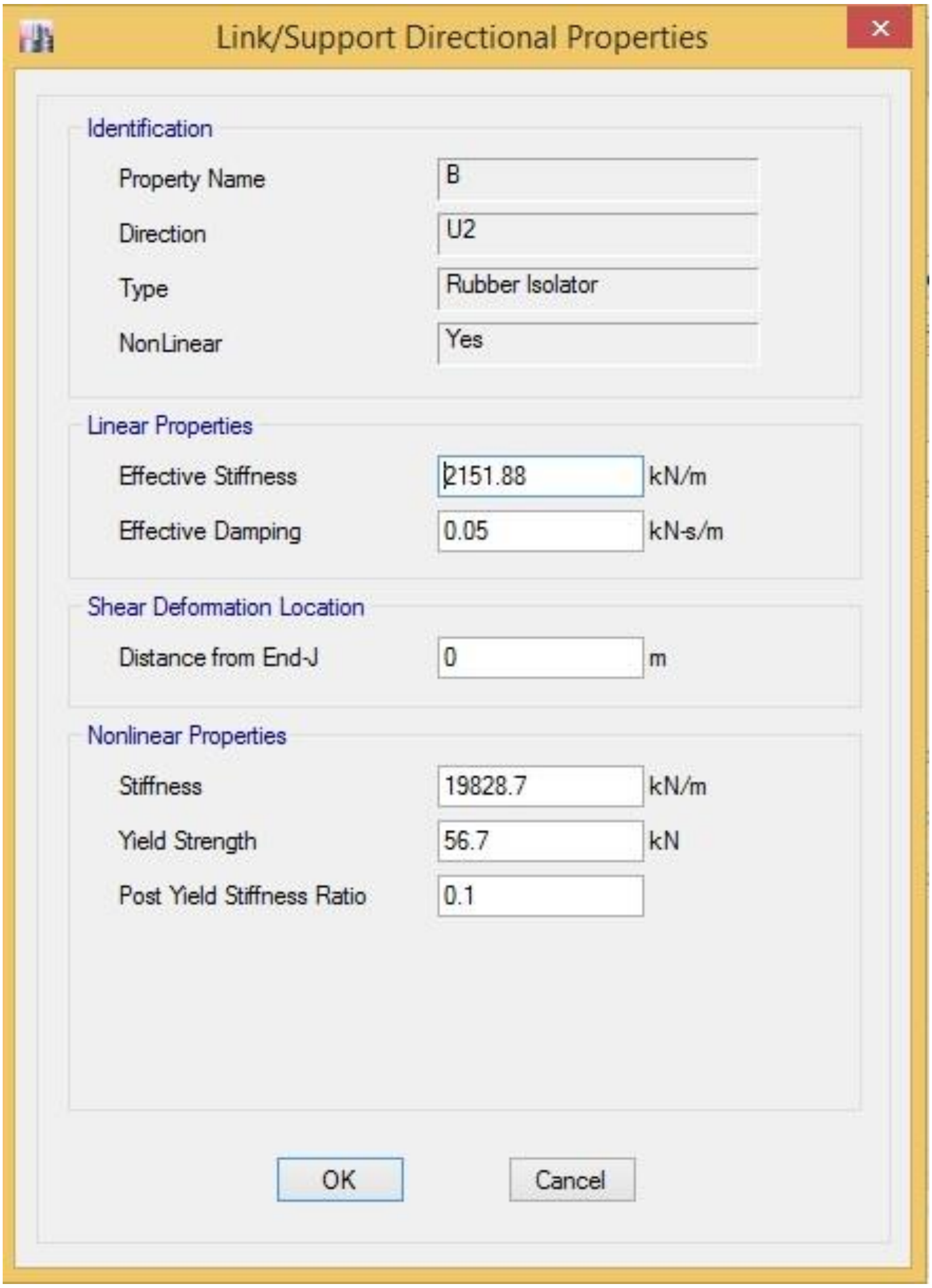

Figure-53. LRB Input Values in ETABS for Biaxial Load 3342 KN Direction U_2 & U_3

5.4.2 LRB for Uniaxial Load - 4627 KN

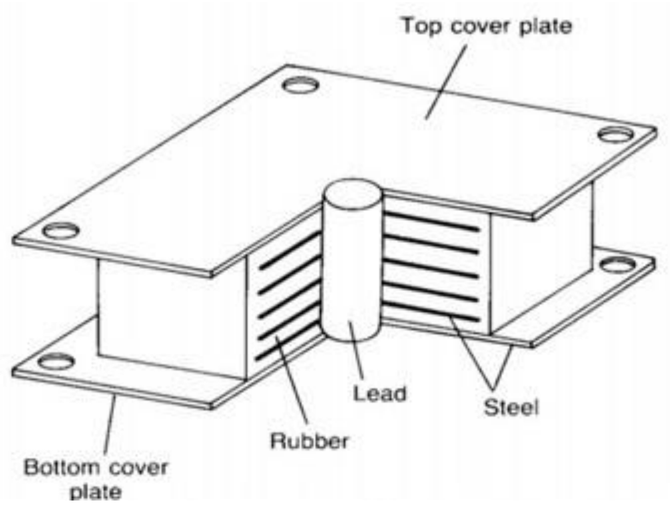

Figure-54. LRB Schematic

Uniaxial Load (W) = 4627 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.**

Table-13. Damping Coefficient, B_D or B_M

EFFECTIVE DAMPING, β_D OR β_M (PERCENTAGE OF CRITICAL)	B_D OR B_M FACTOR
≤ 2%	0.8
5%	1.0
10%	1.2
20%	1.5
30%	1.7
40%	1.9
≥ 50%	2.0

Table-14. Seismic Coefficient C_V

SOIL PROFILE TYPE	SEISMIC ZONE FACTOR, Z				
	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	$0.32N_v$
S_B	0.08	0.15	0.20	0.30	$0.40N_v$
S_C	0.13	0.25	0.32	0.45	$0.56N_v$
S_D	0.18	0.32	0.40	0.54	$0.64N_v$
S_E	0.26	0.50	0.64	0.84	$0.96N_v$
S_F	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-15. 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

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

F_s = 164640 kN/m^2

f_y = 274400 kN/m^2

(A) LRB - Analysis

i. The effective horizontal stiffness K_{effH}

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

$K_{eff\,H}$ = 2979.27 kN/m **Direction U_2 & U_3**

ii. Design displacement (D_D)

$$D_D = \left(\frac{g}{4\pi^2}\right) \times \frac{S_D T_D}{B_D}$$

$= 0.33546$ m.

iii. Yield Strength **Q_d**

$$\mathbf{Q_d} = \frac{W_D}{4 \times D_D} = \frac{\pi}{4} \times K_{effH} \times \xi_{effH} \times D_D$$

$= \mathbf{78.4952\ kN}$

iv. Yield Stiffness

K_U = 10 K_d

Where, 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.

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

= 2745.28 kN/m.

K_U $= 10\ K_d$

= 27452.8 kN/m.

v. Post yield stiffness ratio.

$$\frac{K_d}{K_U} = \frac{2745.28}{27452.8}$$

$= \mathbf{0.1}$ **Direction U_2 & U_3**

(B) LRB - Development

i. Area of Lead Core (A_p)

$$Ap = \frac{Q_d}{f_{py}}$$

$= 0.00923\ m^2$.

ii. Dia of lead core (d_p)

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

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

= 0.10843 m.

iii. Thickness of rubber layer (t_r)

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

= 0.67092 m.

iv. The Shape factor (S)

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

$S = 9.09409$

For $S < 10$, Take $S = 10$

v. Compressive modulus of rubber & steel (Ec)

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

$= 511750 \text{ kN/m}^2$.

vi. Effective area of bearing(A_o)

$A_o = W / \sigma_a$

$= 0.59018 \text{ m}^2$.

vii. Shear strain's effective area (A_1)

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

= 0.40687 m2.

viii. Elastic Stiffness K_r

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

= 2311.29 kN/m.

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

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

$= 1.46293 \text{ m}^2$.

x. Diameter of rubber (d)

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

= 1.36479 m.

xi. Effective vertical stiffness (k_v)

$$K_v = \frac{E_C \times A_{sf}}{t_r}$$

K_v = 1115853 kN/m. **Direction U_1**

xii. Reduction factor - Damping (β)

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

$= 2.645$

xiii. Reduced area (A_2)

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

$= 1.00982\ m^2$

xiv. LRB - Details

$A = 1.00982\ m^2$ (Max Area of A_O, A1, & A_2)

$d = 1.13391$ m

No. of rubber layer (N) = t_r/t (where t = 0.03412)

= 19.6638

Say (N) = 20

xv. Steel Plate thickness (t_s)

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

$t_s = 0.0038 \geq 0.002$ 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:

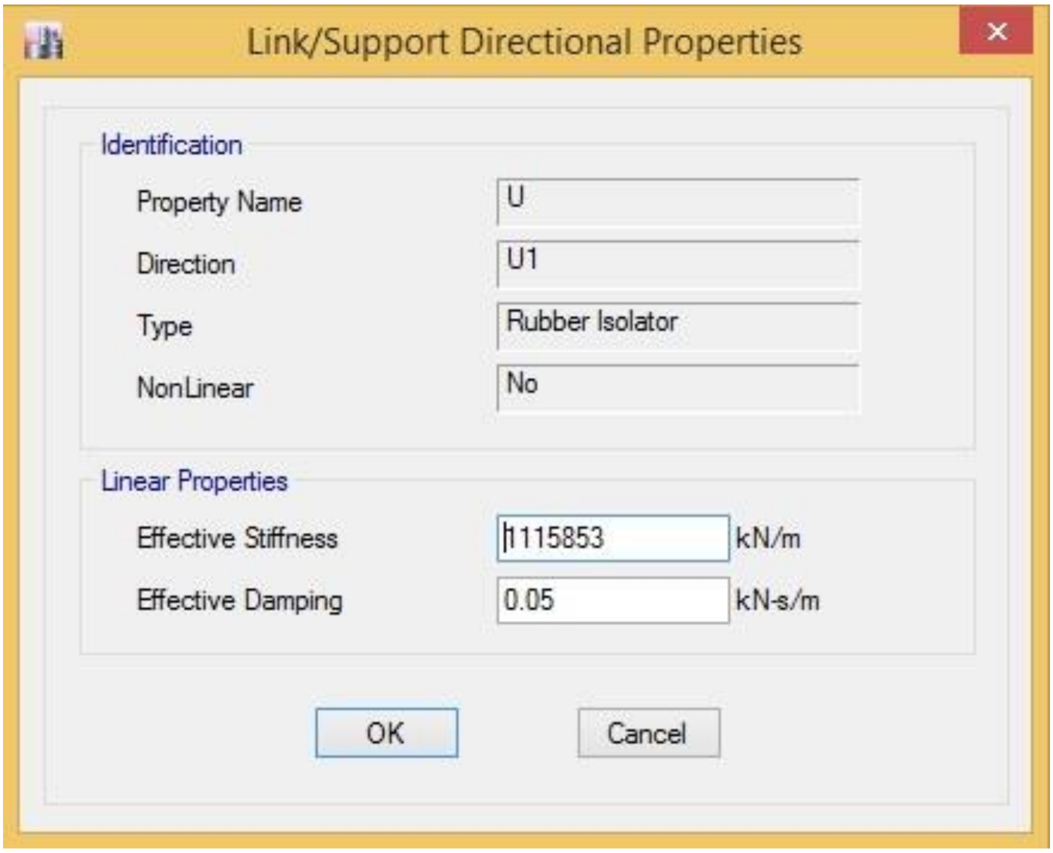

Figure-55. LRB Input Values in ETABS for Uniaxial Load 4627 KN Direction U_1

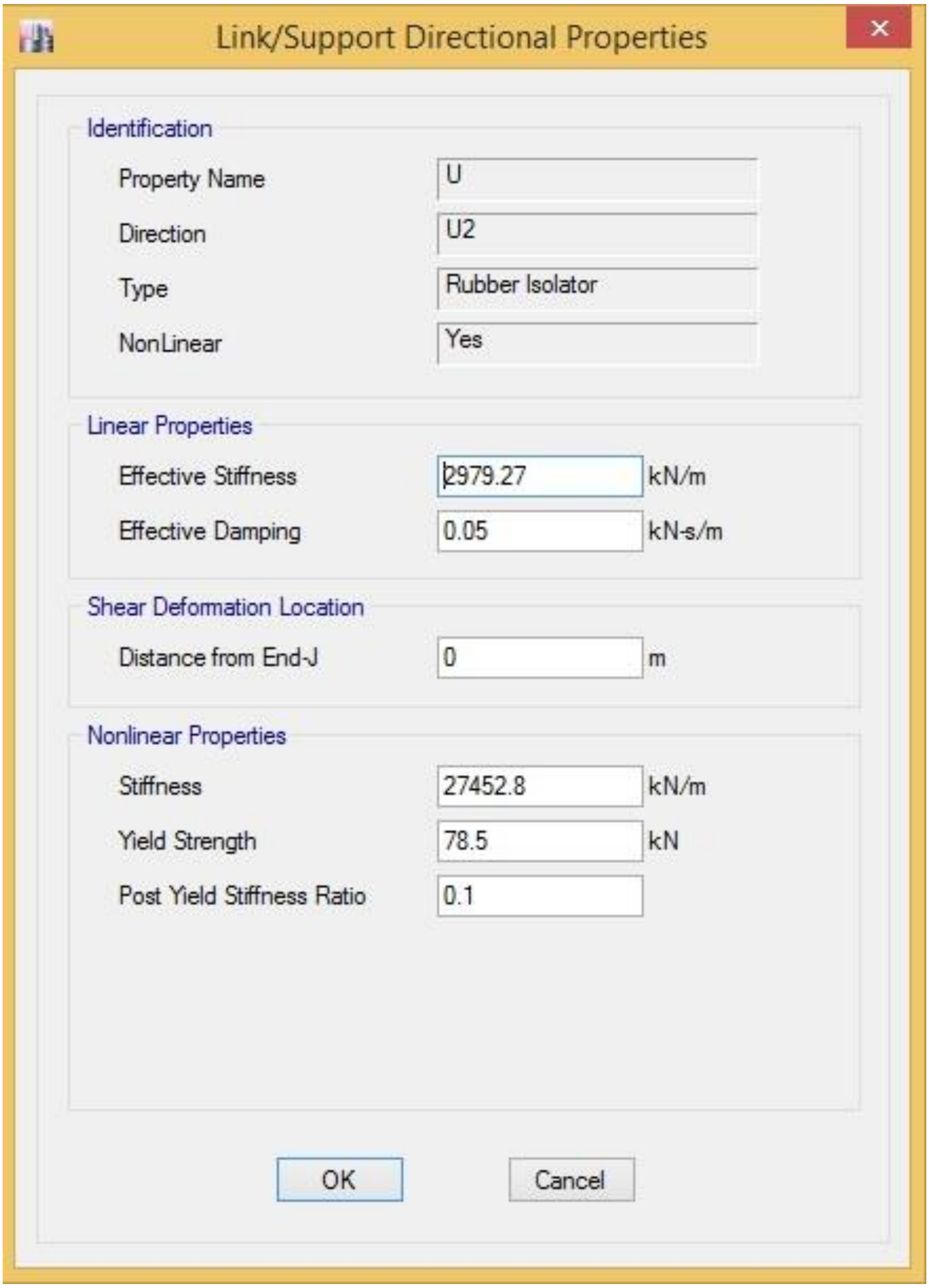

Figure-56. LRB Input Values in ETABS for Uniaxial Load 4627 KN Direction U_2 & U_3

5.4.3 LRB for Axial Load - 6860 KN

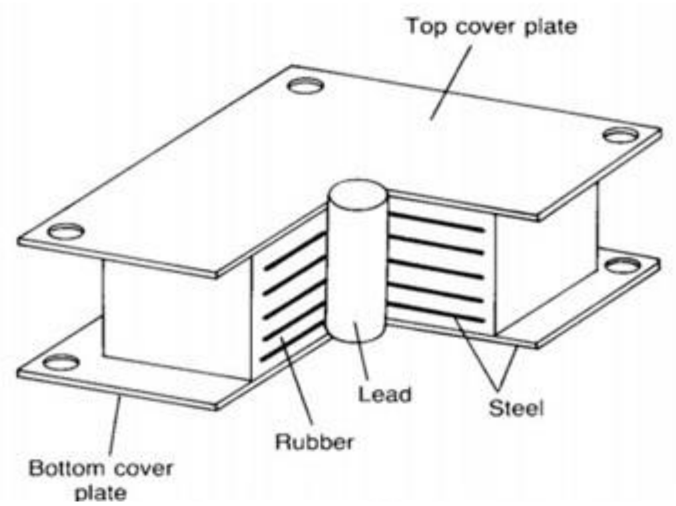

Figure-57. LRB Schematic

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.

Table-16. Damping Coefficient, B_D or B_M

EFFECTIVE DAMPING, β_D OR β_M (PERCENTAGE OF CRITICAL)	B_D OR B_M FACTOR
≤ 2%	0.8
5%	1.0
10%	1.2
20%	1.5
30%	1.7
40%	1.9
≥ 50%	2.0

Table-17. Seismic Coefficient C_V

SOIL PROFILE TYPE	SEISMIC ZONE FACTOR, Z				
	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	$0.32N_v$
S_B	0.08	0.15	0.20	0.30	$0.40N_v$
S_C	0.13	0.25	0.32	0.45	$0.56N_v$
S_D	0.18	0.32	0.40	0.54	$0.64N_v$
S_E	0.26	0.50	0.64	0.84	$0.96N_v$
S_F	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-18. 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

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

F_s = 164640 kN/m^2

f_y = 274400 kN/m^2

(A) LRB - Analysis

i. The effective horizontal stiffness K_{effH}

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

$K_{eff\,H}$ = 4417.08 kN/m **Direction U_2 & U_3**

ii. Design displacement (D_D)

$$D_D = \left(\frac{g}{4\pi^2}\right) \times \frac{S_D T_D}{B_D}$$

$= 0.33546$ m.

iii. Yield Strength Q_d

$$\mathbf{Q_d} = \frac{W_D}{4 \times D_D} = \frac{\pi}{4} \times K_{effH} \times \xi_{effH} \times D_D$$

$= \mathbf{116.377\ kN}$

iv. Yield Stiffness

K_U = 10 K_d

Where, 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 $= K_{effH} - \frac{Q_d}{D_D}$

= 4070.16 kN/m.

K_U $=10\ K_d$

= 40701.6 kN/m.

v. Post yield stiffness ratio.

$$\frac{K_d}{K_U} = \frac{4070.16}{40701.6}$$

$$= \mathbf{0.1}$$ **Direction U_2 & U_3**

(B) LRB - Development

i. Area of Lead Core (Ap)

$$Ap = \frac{Q_d}{f_{py}}$$

$= 0.01369\ m^2$.

ii. Dia of lead core (dp)

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

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

= 0.13203 m.

iii. Thickness of rubber layer (tr)

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

= 0.67092 m.

iv. The Shape factor (S)

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

$S = 9.09409$

For $S < 10$, Take $S = 10$

v. Compressive modulus of rubber & steel (Ec)

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

$= 511750$ kN/m^2.

vi. Effective area of bearing(A_o)

A_o $= W / \sigma_a$

$= 0.875$ m^2.

vii. Shear strain's effective area (A_1)

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

= 0.60322 m2.

viii. Elastic Stiffness K_r

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

= 3426.73 kN/m.

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

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

$= 2.16894$ m^2.

x. Diameter of rubber (d)

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

= 1.6618 m.

xi. Effective vertical stiffness (k_v)

K_v $= \frac{E_C \times A_{sf}}{t_r}$

K_v = 1654366 kN/m. **Direction U_1**

xii. Reduction factor - Damping (β)

$\beta \quad = 2 \times \cos^{-1}\left(\frac{D_D}{d}\right)$

$= 2.735$

xiii. Reduced area (A_2)

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

$= 1.61519\ m^2$

xiv. LRB - Details

A = 1.61519 m^2 (Max Area of A_O, A1, & A_2)

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)

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

t_s = 0.00429 ≥ 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:

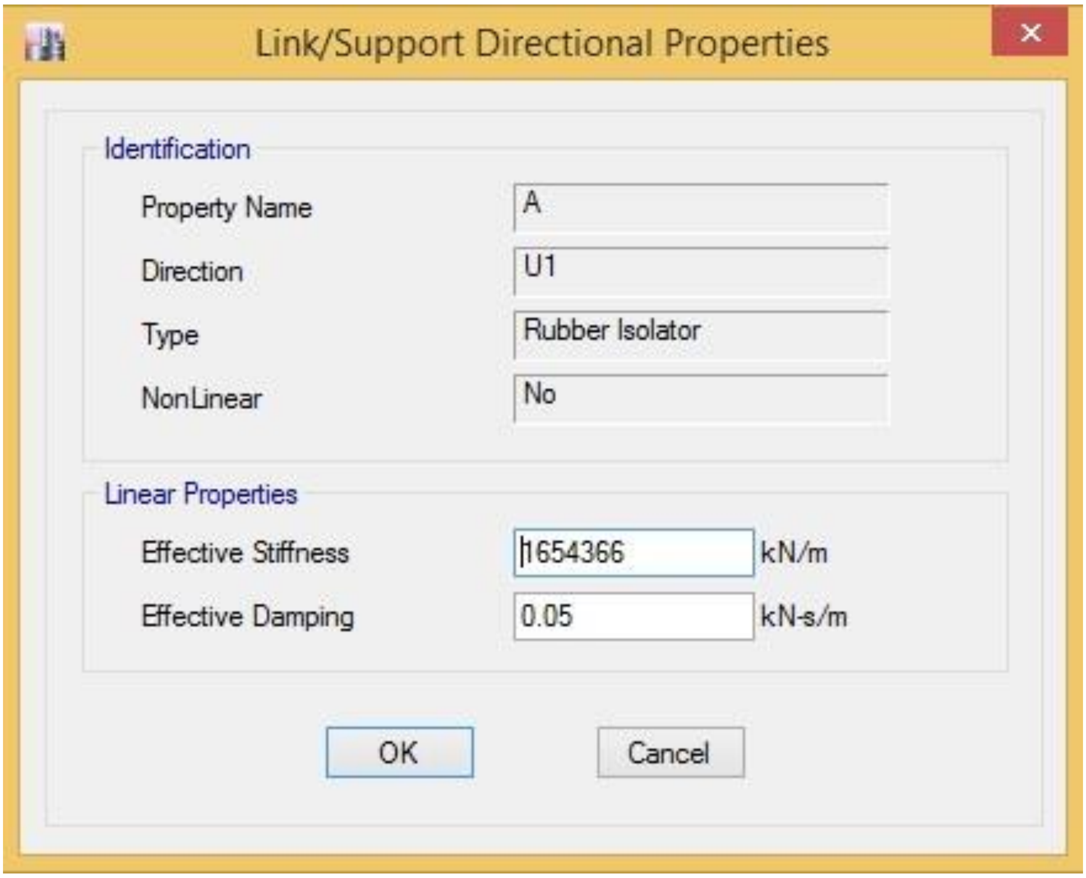

Figure-58. LRB Input Values in ETABS for Axial Load 6860 KN Direction U1

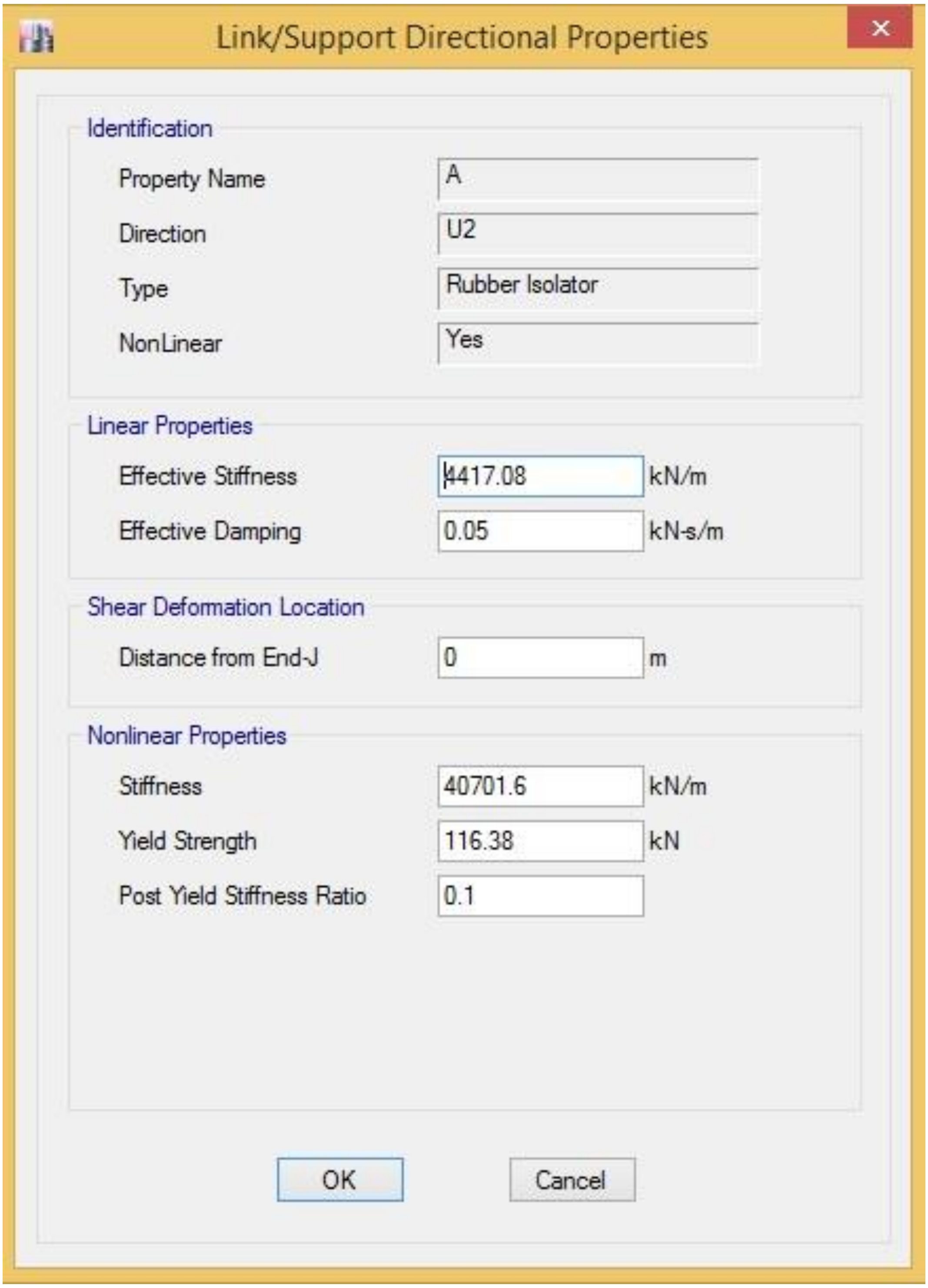

Figure-59. LRB Input Values in ETABS for Axial Load 6860 KN Direction U_2 & U_3

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

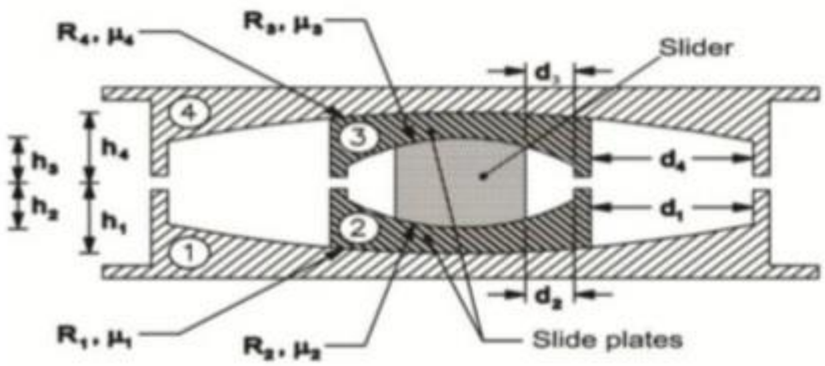

Figure-60. TFPB Schematic

(A) Geometrical, Frictional and D_D Computation

a. Geometrical features

R_4	=	R_1	=	1778 x 2
			=	3556 mm
			=	3.556 mtrs.
R_2	=	R_3	=	647 mm
			=	0.647 mtrs
h_1	=	h_4	=	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_{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
			≈	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

P = W / A

Here W Load = 334.2 tonne or 3342 KN,

A = πr^2

r = $h_4 + h_1$

= 161 + 161

r = 322 mm

P = 0.001026 ton/mm^2,

P = 0.001026 x 1450

P = 1.49 ksi, 1 ksi = Kilo square inch

= 1450 ton/mm^2

3- Friction Cycle μ = 0.122 - 0.01 P,

μ = 0.1071

Adjust for high velocity = μ - 0.0333

= 0.1071 - 0.0333

= 0.074 (Lower bound)

1 - Friction Cycle μ = 1.2 x 0.074

= 0.0886

μ_1 = μ_4 = 0.074 (Lower bound)

μ_1 = μ_4 = 0.089 (Upper bound)

At 2 and 3

P = W / A

Here W Load = 334.2 tonne or 3342 KN,

A = πr^2

r = $h_2 + h_3$

= 121 + 121

= 242 mm

P = 0.001816 ton/mm^2,

P = 0.001816 x 1450

P = 2.63 ksi. 1 ksi = Kilo square inch

= 1450 ton/mm^2

3- Friction Cycle μ = 0.122 - 0.01 P

= 0.0957

Adjust for high velocity = μ - 0.036

= 0.0957 - 0.036

= 0.060 (Lower bound)

1 - Friction Cycle μ = 1.2 x 0.060

= 0.0716

Lower bound μ_2 = μ_3 = 0.060

Upper bound μ_2 = μ_3 = 0.072

μ = force at zero deformation

$\mu = \mu_1 - (\mu_1 - \mu_2) \times \frac{R_{2eff}}{R_{1eff}}$ (Lower bound)

μ = 0.072

μ = μ_1 - (μ_1 - μ_2) × $\frac{R_{2eff}}{R_{1eff}}$ (Upper bound)

μ = 0.086

c. D_D Computation (Upper bound)

S_d = 0.5074

μ = 0.086

μ_1 = 0.089

D_y = (μ_1- μ_2) * R_{2eff}

D_y = 0.008939

F_d = 0.2772

W = 334.2 Ton

T.B. = 12 Nos. (Where T.B. = Total Bearing)

ΣF_d = W x T.B. x F_d

= 334.2 x 12 x 0.2772

ΣF_d = 1111.86

Σw = W x T.B.

Σw = 4010.4 Ton

i. Design displacement, D_D = 0.07202 m.

ii. **Effective stiffness, Qd** = μ * Σw

= 0.086 * 4010.4

Q_d = 344.71 Ton

k_D = ΣF_D / D_D

= 1111.86 / 0.07202

k_D = 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}

$$T_{eff} = [\sqrt{((\Sigma w)/(K_{eff} \times g))}]\, 2\pi$$

$$T_{eff} = 0.89331 \text{ sec.}$$

iv. **Effective damping**, β_{eff}

$$\beta_D = \frac{E}{2\pi K_{eff} \times {D_D}^2} = \frac{4\mu \sum w (D_D - D_y)}{2\pi K_{eff} \times {D_D}^2}$$

$$\beta_{eff} = \beta_D = 0.1320$$

v. **Damping reduction Coefficient, β**

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

$$\boldsymbol{\beta} = \mathbf{1.3380}$$

vi. $\mathbf{D_D}^{\mathbf{1}}$

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

$$D_D^{1} = 0.0752 \text{ mtrs}$$

(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 = $\frac{K_{eff} \times h^3}{12E}$ = $\frac{497.30 \times 0.5^3}{12E}$

= 5.18022E-07 m^4.

E = $1x10^7$ N/mm^2

ii. **Determine 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.

M = w / g

= 0.005372 / 9.81

M = 0.000548 tonne sec^2/m.

b. Direction (U_1)

H = 0.5 m

Ø = 0.484 m

K_{eff} = AE / L

K_{eff} = 3679684.643 ton/m.

K_{ef} = 36796846.43 KN/m.

from D_D

K_{eff} = 3679684.64 ton/m.

β_{eff} = 0.1320

c. Direction (U_2 - U_3)

i. Determination of liner properties.

K_{eff} = 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 = h_3 = **0.121 m.**

ii. Determination of Non - liner properties.

$R_{2\,eff}$ = 0.526 mtrs.

D_y = $(\mu_1 - \mu_2)\, R_{2eff}$

= (0.08859 – 0.07159) x 0.526

D_y = 0.00894 mtrs.

Stiffness (Outer Top) = $\frac{\mu_1 \, w}{D_y}$

= $\frac{0.08859 \times 334.2}{0.00894}$

= 3312.041 ton/m.

= 33120.41 KN/m.

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

= $\frac{0.07159 \times 334.2}{0.00894}$

= 2676.680 ton/m.

= **26766.80 KN/m.**

Friction Coefficient, Slow **=** **μ_1** **=** **0.089 (Outer Top)**

= **μ_2** **=** **0.072 (Inner Top)**

Friction Coefficient, Fast **=** **2 x μ_1** **=** **0.177 (Outer Top)**

= **2 x μ_2** **=** **0.143 (Inner Top)**

Rate Parameter = $\frac{\text{Friction Coeff. Slow}}{\text{Friction Coeff.Fast}}$

= 0.089 / 0.177

= 0.5

= **0.0005 sec/mm**

Radius of sliding surface

Outer Top = $R_{1\,eff}$ = **3.395 m**

Inner Top = $R_{2\,eff}$ = **0.526 m**

Stop distance

Outer Top u_1* = $2\ D_y + 2\ d_1$*

= 1.09868 m

= **1098.68 mm**

Inner Top u_2* = $2\ D_y$

= 0.0179 m

= **17.878 mm**

(C) Input Values in ETABS:

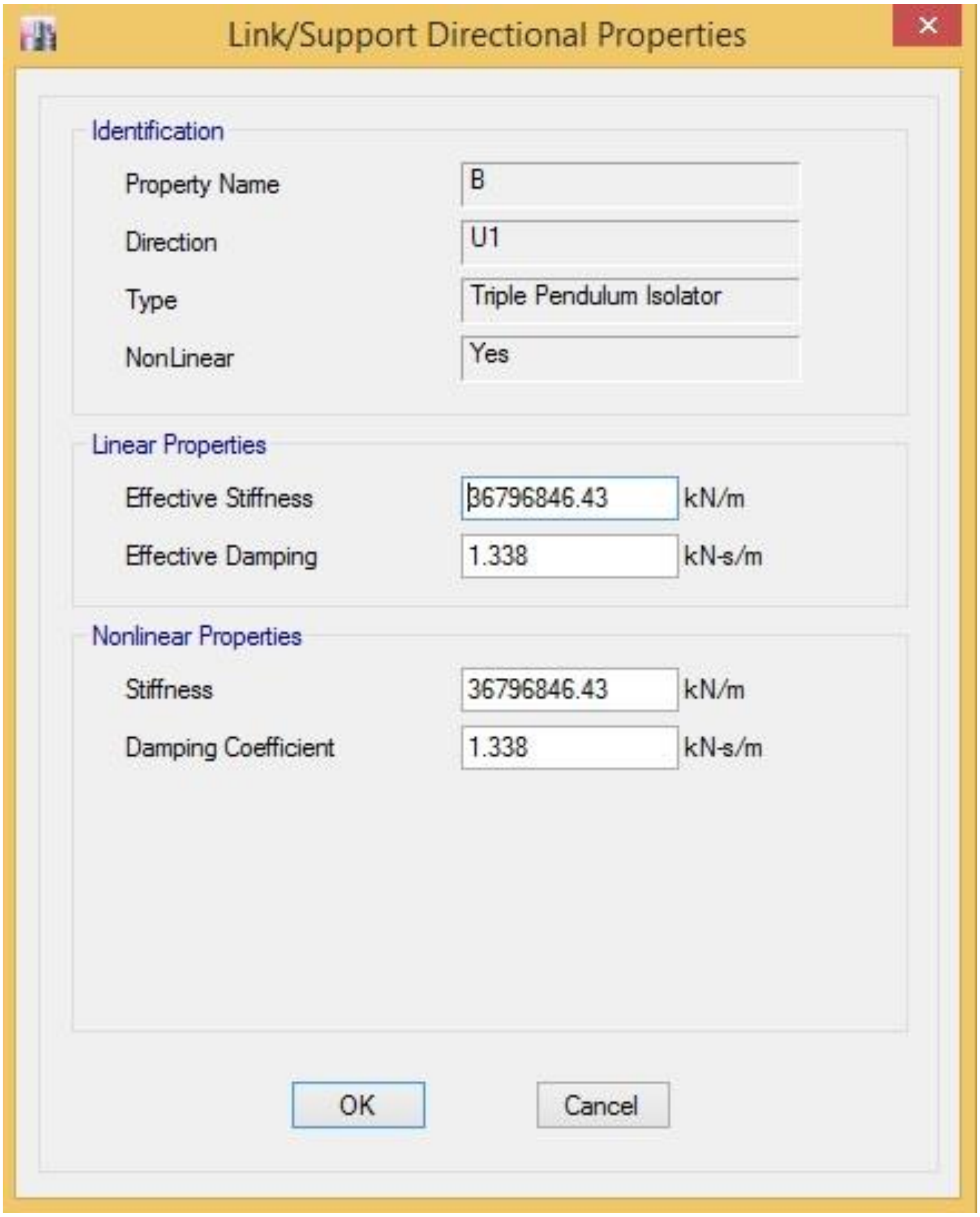

Figure-61. TFPB Input Values in ETABS for Biaxial Load 3342 KN Direction U_1

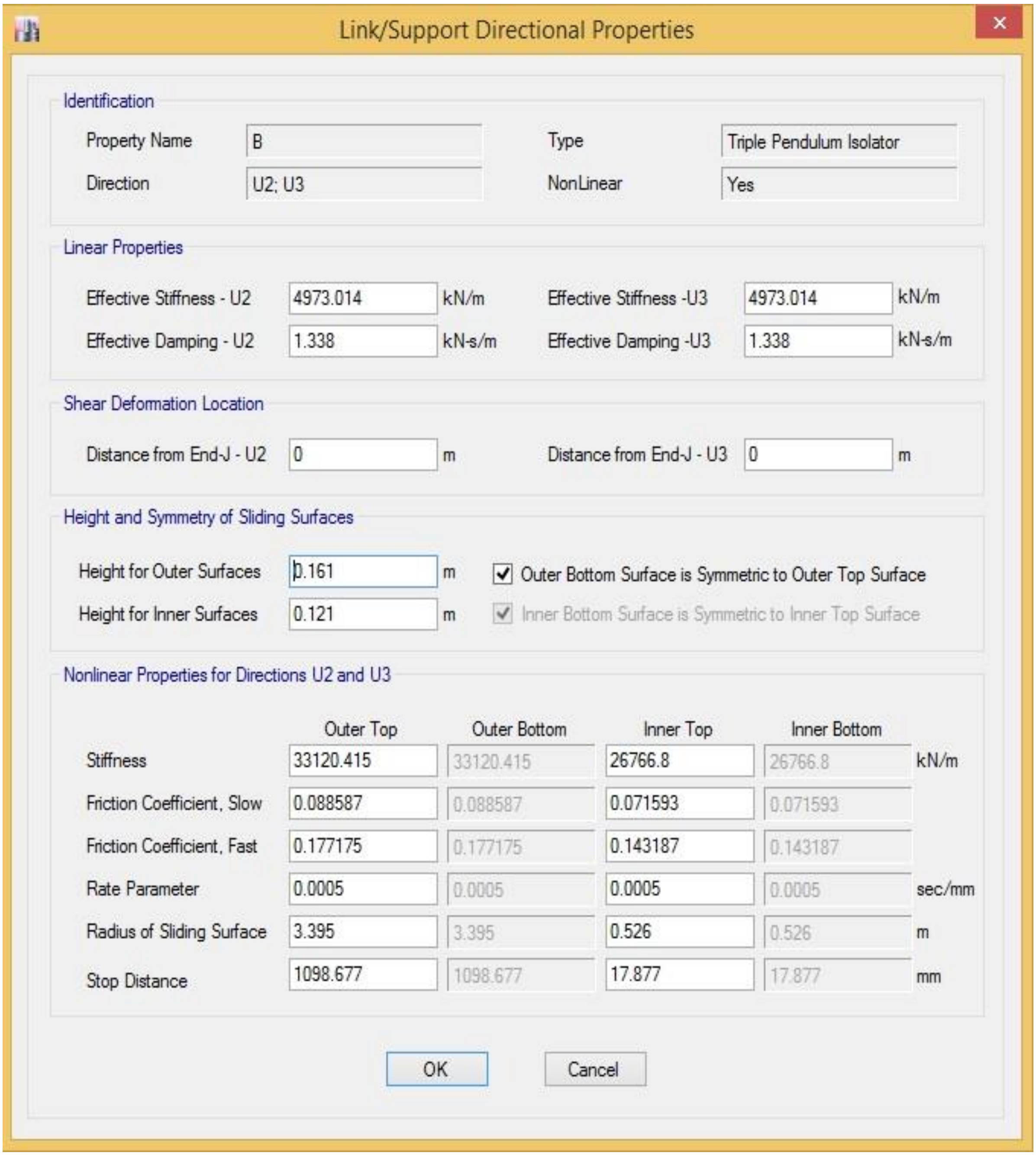

Figure-62. TFPB Input Values in ETABS for Biaxial Load 3342 KN Direction U_2 & U_3

5.5.2 TFPB for Uniaxial Load - 4627 KN

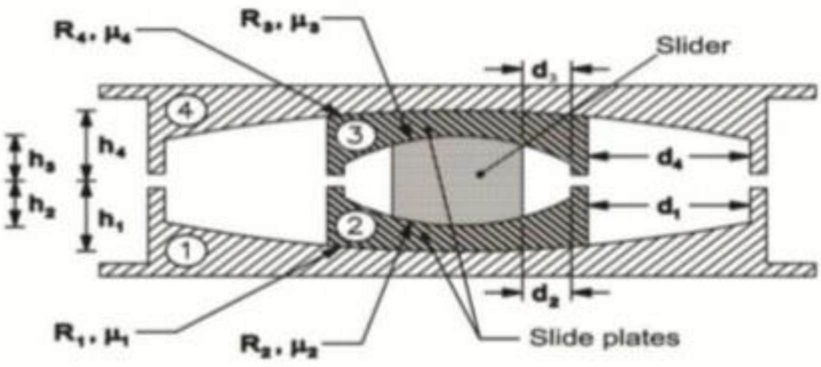

Figure-63. TFPB Schematic

(A) Geometrical, Frictional and D_D Computation

a. Geometrical features

$R_4 = R_1 = 1778 \times 2$

$= 3556$ 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

$R_{1eff} = R_{4eff} = R_1 - h_1$

= 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

≈ 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 surfaces 1 and 4

P = W / A

Here W Load = 462.7 tonne or 4627 KN,

A = πr^2

r = $h_4 + h_1$

= 161 + 161

r = 322 mm

P = 0.001420 ton/mm^2,

P = 0.001420 x 1450

P = 02.06 ksi, 1 ksi = Kilo square inch

= 1450 ton/mm^2

3- Friction Cycle μ = 0.122 - 0.01 P

μ = 0.1014

Adjust for high velocity = μ - 0.0333

= 0.1014 - 0.0333

= 0.068 (Lower bound)

1 - Friction Cycle μ = 1.2 x 0.068

= 0.0817

μ_1 = μ_4 = 0.068 (Lower bound)

μ_1 = μ_4 = 0.082 (Upper bound)

At 2 and 3

P = W / A

Here W Load = 462.7 tonne or 4627 KN,

A = πr^2

r = $h_2 + h_3$

= 121 + 121

= 242 mm

P = 0.002515 ton/mm^2

P = 0.002515 x 1450

P = 3.65 ksi. 1 ksi = Kilo square inch

= 1450 ton/mm^2

3- Friction Cycle μ = 0.122 - 0.01 P

= 0.0855

Adjust for high velocity = μ - 0.036

= 0.0855 - 0.036

= 0.050 (Lower bound)

1 - Friction Cycle μ = 1.2 x 0.050

= 0.0594

μ_2 = μ_3 = 0.050 (Lower bound)

μ_2 = μ_3 = 0.059 (Upper bound)

μ = force at zero deformation

$\mu = \mu_1 - (\mu_1 - \mu_2) \times \frac{R_{2eff}}{R_{1eff}}$ (Lower bound)

μ = 0.065

$\mu = \mu_1 - (\mu_1 - \mu_2) \times \frac{R_{2eff}}{R_{1eff}}$ (Upper bound)

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 T.B. = Total Bearing)

ΣF_d = W x T.B. x F_d

= 462.7 x 12 x 0.2772

ΣF_d = 1539.36

Σw = W x T.B.

Σw = 5552.4 Ton

i. Design displacement, D_D = 0.07202 mtrs.

ii. **Effective stiffness, Q_d** = $\mu * \Sigma w$

= 0.078 * 5552.4

Q_d = 434.59 Ton

k_D = $\Sigma F_D / D_D$

= 1539.36 / 0.07202

k_D = 21374.12 Ton/m.

K_{eff} = $k_D + Q_D / D_D$

= 21374.12 + 434.59 / 0.07202

K_{eff} = 27408.45 Ton/m.

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

T_{eff} = $[\sqrt{((\Sigma w)/(K_{eff} \times g))}]\ 2\pi$

T_{eff} = 0.90291 sec.

iv. **Effective damping**, β_{eff}

$$\beta_D = \frac{E}{2\pi K_{eff} \times {D_D}^2} = \frac{4\mu\sum w(D_D - D_y)}{2\pi K_{eff} \times {D_D}^2}$$

$$\beta_{eff} = \beta_D = 0.1174$$

v. Damping reduction Coefficient, β

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

$$\boldsymbol{\beta} = \mathbf{1.2917}$$

vi. $\mathbf{D_D}^{\mathbf{1}}$

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

$$D_D{}^1 = 0.0796 \text{ mtrs}$$

(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

H = 0.5 m.

Ø = 0.484 m,

Now, Area $A = \frac{\pi \times \emptyset^2}{4}$

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

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

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

$$K_{eff} = 639.15 \text{ Ton/m}$$

$$I_1 = \frac{K_{eff} \times h^3}{12E} = \frac{639.15 \times 0.5^3}{12E}$$

$$= 6.65781\text{E-07 m}^4$$

E = $1 x 10^7$ N/mm^2

ii. **Determine 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.

M = w / g

= 0.005372 / 9.81

M = 0.000548 tonne sec^2/m.

b. Direction (U_1)

H = 0.5 m

Ø = 0.484 m

K_{eff} = AE / L

K_{eff} = 3679684.643 ton/m.

K_{eff} = 36796846.43 KN/m.

from D_D

K_{eff} = 3679684.64 ton/m.

β_{eff} = 0.1174

c. Direction (U_2 - U_3)

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

D_y = 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)

= μ_2 = 0.059 (Inner Top)

Friction Coefficient, Fast	**=**	**2 x μ_1**	**=**	**0.163 (Outer Top)**
	=	**2 x μ_2**	**=**	**0.119 (Inner Top)**

Rate Parameter $= \frac{\text{Friction Coeff. Slow}}{\text{Friction Coeff.Fast}}$

= 0.082 / 0.163

= 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*	=	$2\ D_y + 2\ d_1$*	
	=	1.10424	mtrs.
	=	**1104.24**	**mm**
Inner Top u_2*	=	$2\ D_y$	
	=	0.0234	mtrs.
	=	**23.441**	**mm.**

(C) Input Values in ETABS:

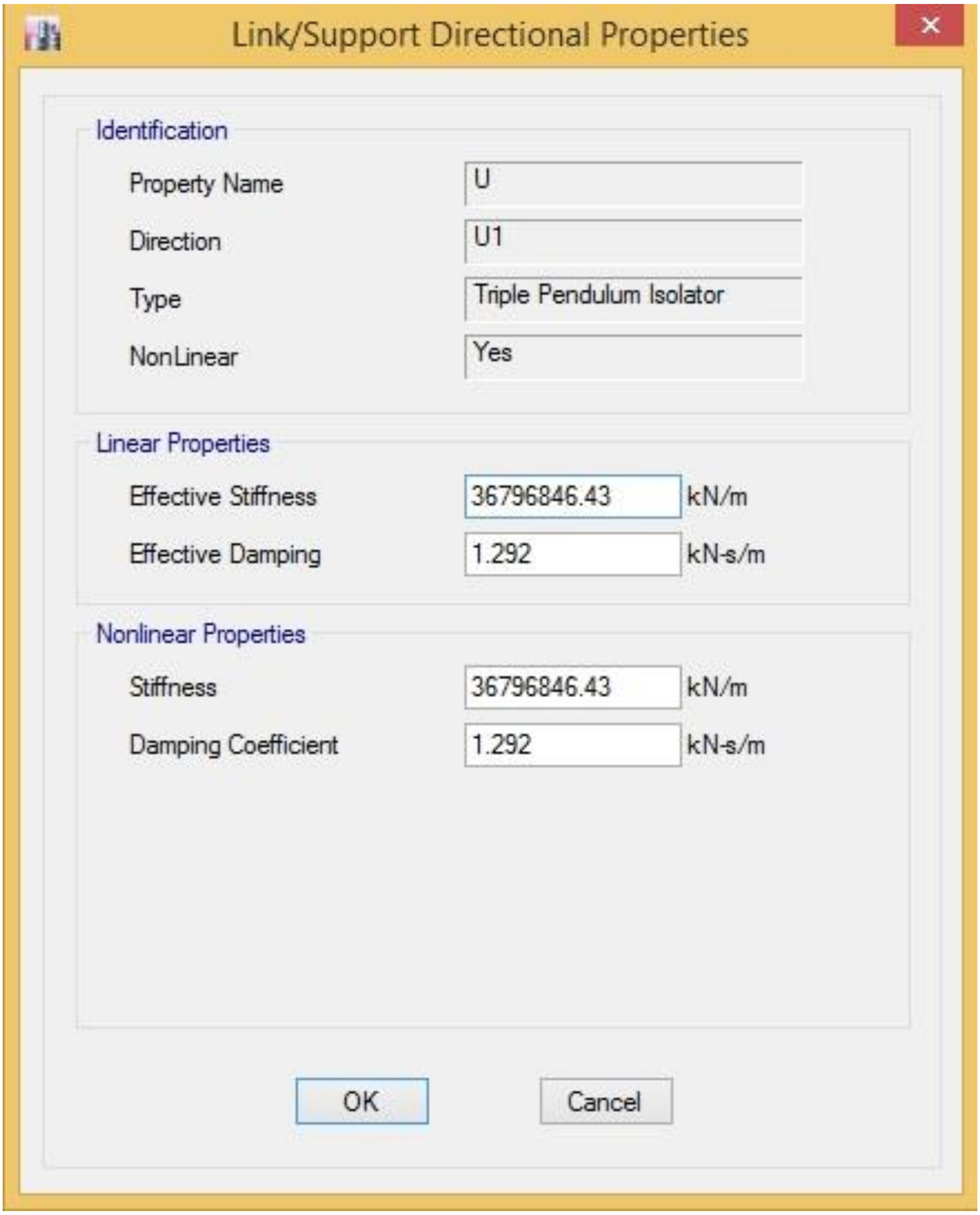

Figure-64. TFPB Input Values in ETABS for Uniaxial Load 4627 KN Direction U_1

Figure-65. TFPB Input Values in ETABS for Uniaxial Load 4627 KN Direction U_2 & U_3

5.5.3 TFPB for Axial Load - 6860 KN

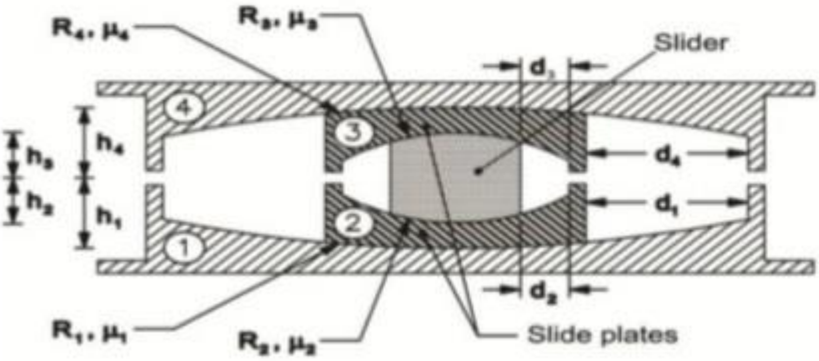

Figure-66. TFPB Schematic

(A) Geometrical, Frictional and D_D Computation

a. Geometrical features

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_{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

≈ 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

P = W/ A

Here W Load = 686.0 tonne or 6860 KN

A = πr^2

r = $h_4 + h_1$

= 161 + 161

r = 322 mm

P = 0.002106 ton/mm^2,

P = 0.002106 x 1450

P = 3.05 ksi, 1 ksi = Kilo square inch

= 1450 ton/mm^2

3- Friction Cycle μ = 0.122 - 0.01 P,

μ = 0.0915

Adjust for high velocity = μ - 0.0333

= 0.0915 - 0.0333

= 0.058 (Lower bound)

1 - Friction Cycle μ = 1.2 x 0.058

= 0.0698

μ_1 = μ_4 = 0.058 (Lower bound)

μ_1 = μ_4 = 0.070 (Upper bound)

At 2 and 3

P = W / A

Here W Load = 686.0 tonne or 6860 KN

A = πr^2

r = $h_2 + h_3$

= 121 + 121

= 242 mm

P = 0.003729 ton/mm^2,

P = 0.003729 x 1450

P = 5.41 ksi. 1 ksi = Kilo square inch

= 1450 ton/mm^2

3- Friction Cycle μ = 0.122 - 0.01 P

= 0.0679

Adjust for high velocity = μ - 0.036

= 0.0679 - 0.036

= 0.032 (Lower bound)

1 – Friction Cycle μ = 1.2 x 0.032

= 0.0383

μ_2 = μ_3 = 0.032 (Lower bound)

μ_2 = μ_3 = 0.038 (Upper bound)

μ = force at zero deformation

$\mu = \mu_1 - (\mu_1 - \mu_2) \times \frac{R_{2eff}}{R_{1eff}}$ (Lower bound)

μ = 0.054

$\mu = \mu_1 - (\mu_1 - \mu_2) \times \frac{R_{2eff}}{R_{1eff}}$ (Upper bound)

μ = 0.065

c. D_D Computation (Upper bound)

S_d = 0.5074

μ = 0.065

μ_1 = 0.070

D_y = $(\mu_1 - \mu_2) * R_{2eff}$

D_y = 0.016555

F_d = 0.2772

W = 686 Ton

T.B. = 12 Nos. (Where T.B. = Total 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. **Design displacement, D_D** = 0.07202 m.

ii. **Effective stiffness, Qd** = μ * Σw

= 0.065 * 8232

Q_d = 534.41 Ton

k_D = $\Sigma F_D / D_D$

= 2282.26 / 0.07202

k_D = 31689.31 Ton/m.

K_{eff} = $k_D + Q_D / D_D$

= 31689.31 + 534.41 / 0.07202

K_{eff} = 39109.67 Ton/m.

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

T_{eff} = $[\sqrt{((\Sigma w)/(K_{eff} \times g))}]\, 2\pi$

T_{eff} = 0.92036 sec.

iv. **Effective damping**, β_{eff}

$$\beta_D = \frac{E}{2\pi K_{eff} \times {D_D}^2} = \frac{4\mu\sum w(D_D - D_y)}{2\pi K_{eff} \times {D_D}^2}$$

$$\beta_{eff} = \beta_D = 0.0930$$

v. Damping reduction Coefficient, β

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

$$\boldsymbol{\beta} = \mathbf{1.2047}$$

vi. $\mathbf{{D_D}^1}$

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

$${D_D}^1 = 0.0887 \text{ mtrs}$$

(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

H = 0.5 m

Ø = 0.484 m

Now, Area

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

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

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

$$K_{eff} = 820.42 \text{ Ton/m}$$

$$I_1 = \frac{K_{eff} \times h^3}{12E} = \frac{820.42 \times 0.5^3}{12E} = 8.54609\text{E-07 m}^4.$$

E = $1x10^7$ N/mm^2

ii. Determine 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.

M = w / g

= 0.005372 / 9.81

M = 0.000548 tonne sec^2/m.

b. Direction (U_1)

H = 0.5 m

Ø = 0.484 m

K_{eff} = AE / L

K_{eff} = 3679684.643 ton/m.

K_{eff} = 36796846.43 KN/m.

from D_D

K_{eff} = 3679684.64 ton/m.

β_{eff} = 0.0930

c. Direction (U_2 - U_3)

i. Determination of liner properties.

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.

$R_{2\,eff}$ = 0.526 mtrs.

D_y = $(\mu_1 - \mu_2)\, R_{2eff}$

= (0.06980 – 0.03832) x 0.526

D_y = 0.01655 mtrs.

Stiffness (Outer Top) = $\frac{\mu_1\, w}{D_y}$

= $\frac{0.06980 \times 686}{0.01655}$

= 2892.227 ton/m.

= **28922.27 KN/m.**

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

= $\frac{0.03832 \times 686}{0.01655}$

= 1588.044 ton/m.

= **15880.44 KN/m.**

Friction Coefficient, Slow = μ_1 = **0.070 (Outer Top)**

= μ_2 = **0.038 (Inner Top)**

Friction Coefficient, Fast = **2 x μ_1** = **0.140 (Outer Top)**

= **2 x μ_2** = **0.077 (Inner Top)**

Rate Parameter = $\frac{\text{Friction Coeff. Slow}}{\text{Friction Coeff.Fast}}$

= 0.070 / 0.140

= 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* = $2\ D_y + 2\ d_1$*

= 1.11391 mtrs.

= **1113.91 mm**

Inner Top u_2* = $2\ D_y$

= 0.0331 mtrs.

= **33.109 mm.**

(C) Input Values in ETABS:

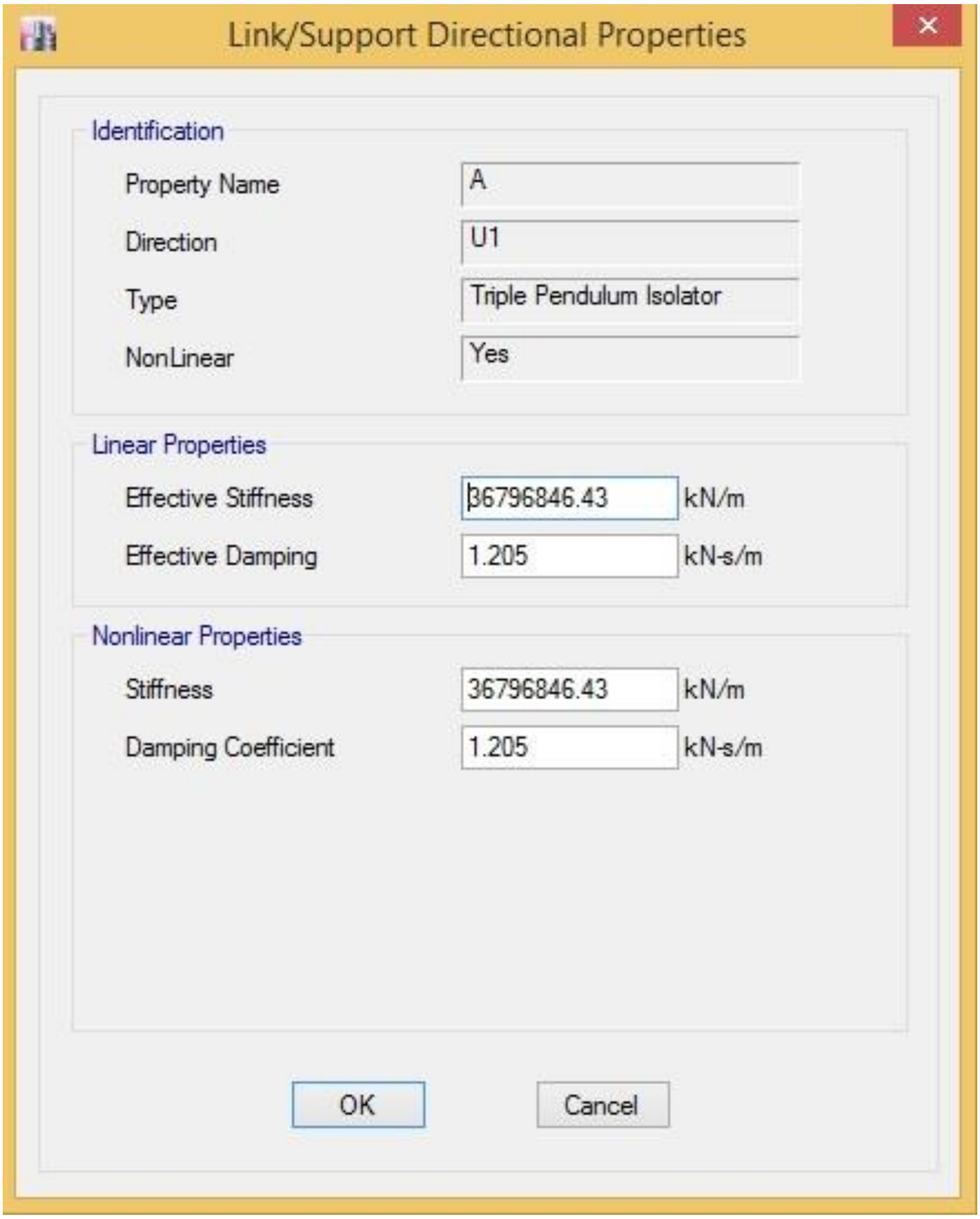

Figure-67. TFPB Input Values in ETABS for Axial Load 6860 KN Direction U_1

Figure-68. TFPB Input Values in ETABS for Axial Load 6860 KN Direction U_2 & U_3

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 non-linear 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.