

MIDAS Training Series

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Civil

Title: 3D substructure analysis and design

NAME

Edgar De Los Santos / MIDAS IT – United States

2016

Content

- What is Substructure
- Parts of the substructure
- MIDAS Modeling
- Midas GSD
- Midas Design+

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What is the Substructure?

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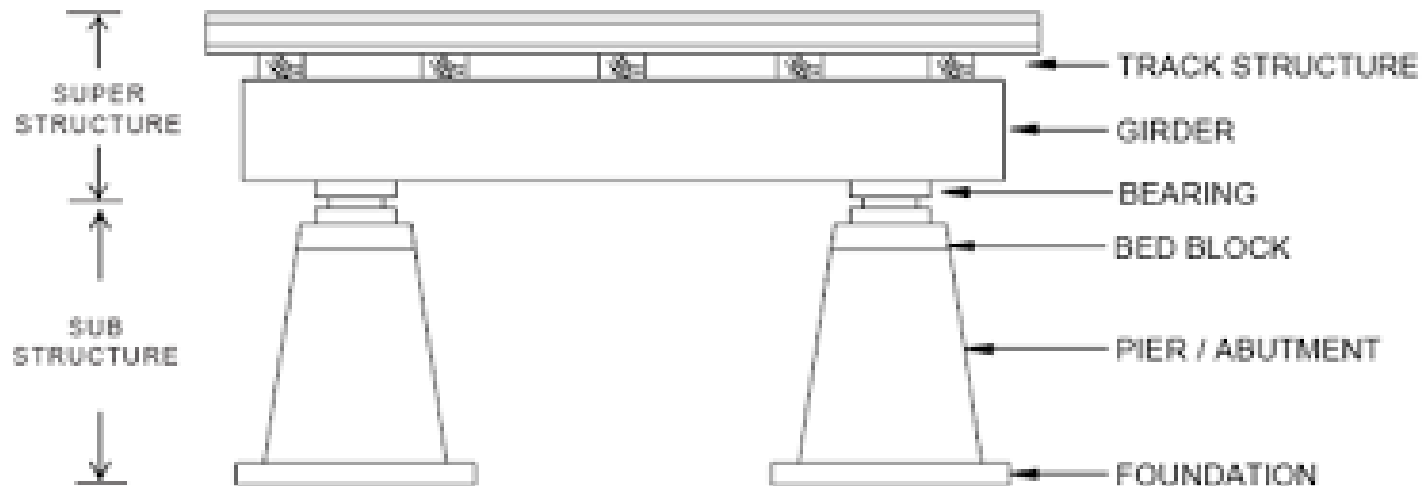
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What is Substructure?

Is the part of the structure that is in charge of transmitting the load to the ground.
It is composed of:

- Bearings
- Piers/Abutments
- Foundation



Parts of the Substructure

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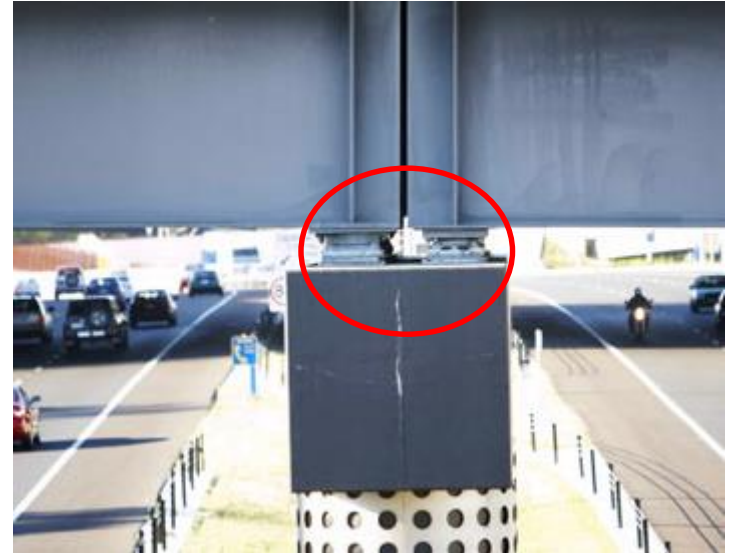
Bridge Bearings:

Functions of bridge bearings:

- Transfer forces from superstructure to Substructure
- Provide rotational &/or translational Restraints

To accommodate the deformations occurring due to:

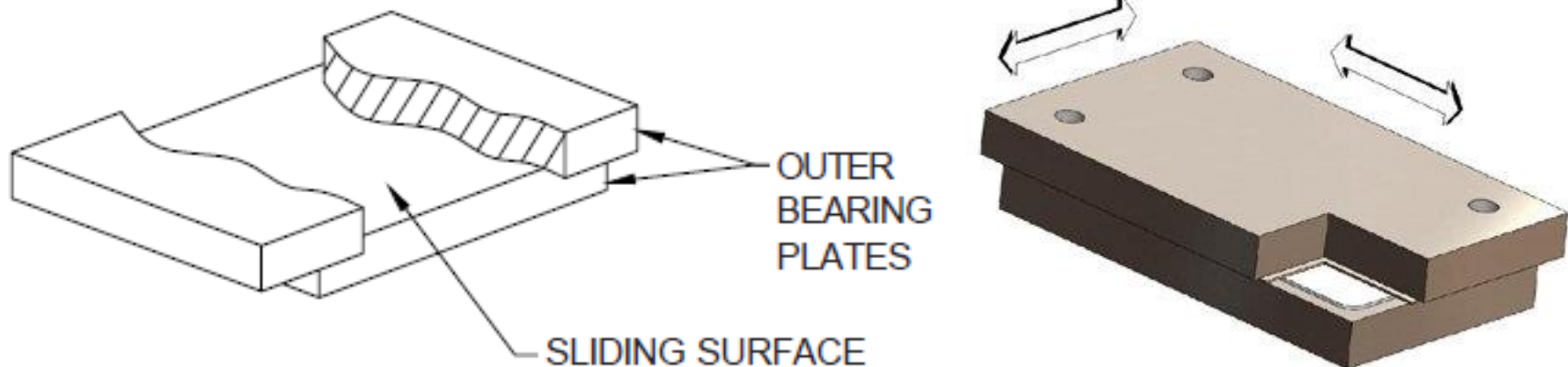
- Thermal expansion/contraction
- Elastic deformation under live load
- Seismic forces
- Creep and shrinkage of concrete
- Settlement of supports
- Longitudinal forces - tractive/ braking
- Wind loads



Bridge Bearing Types

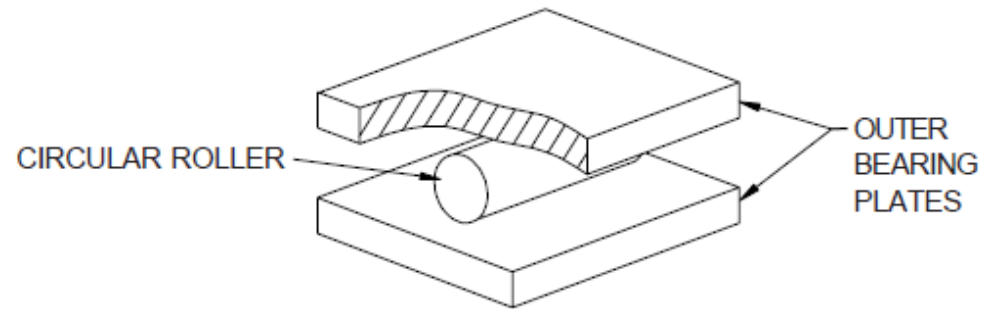
- Sliding Bearings
- Rocker & Roller Bearings
- Knuckle Bearings (Pinned, Cylindrical, Spherical & Leaf)
- Elastomeric Bearings (plain & laminated)
- POT PTFE Bearings

1. Sliding Bearings

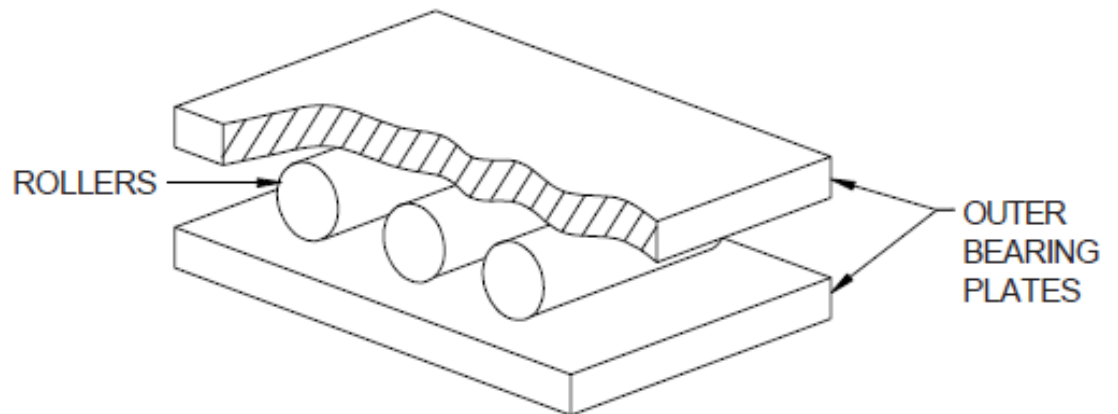


2.a. Roller Bearings

Single Roller Bearing

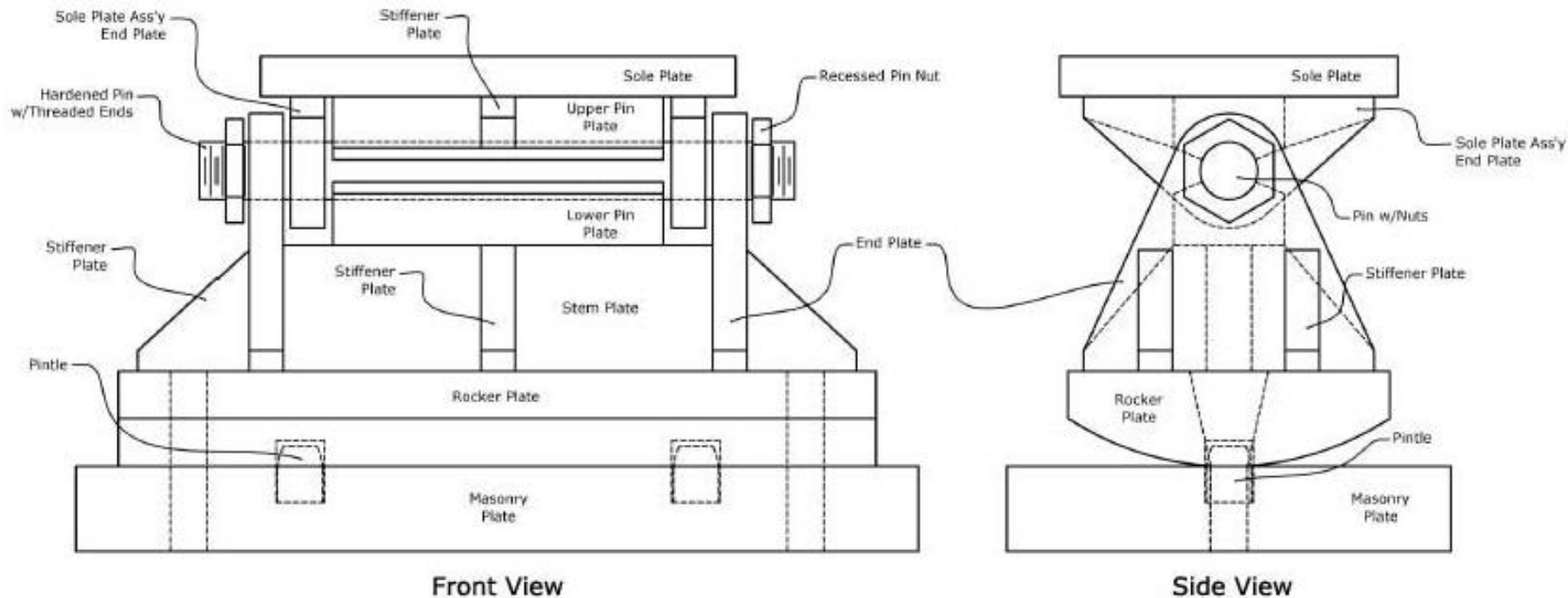


Multiple Roller Bearing



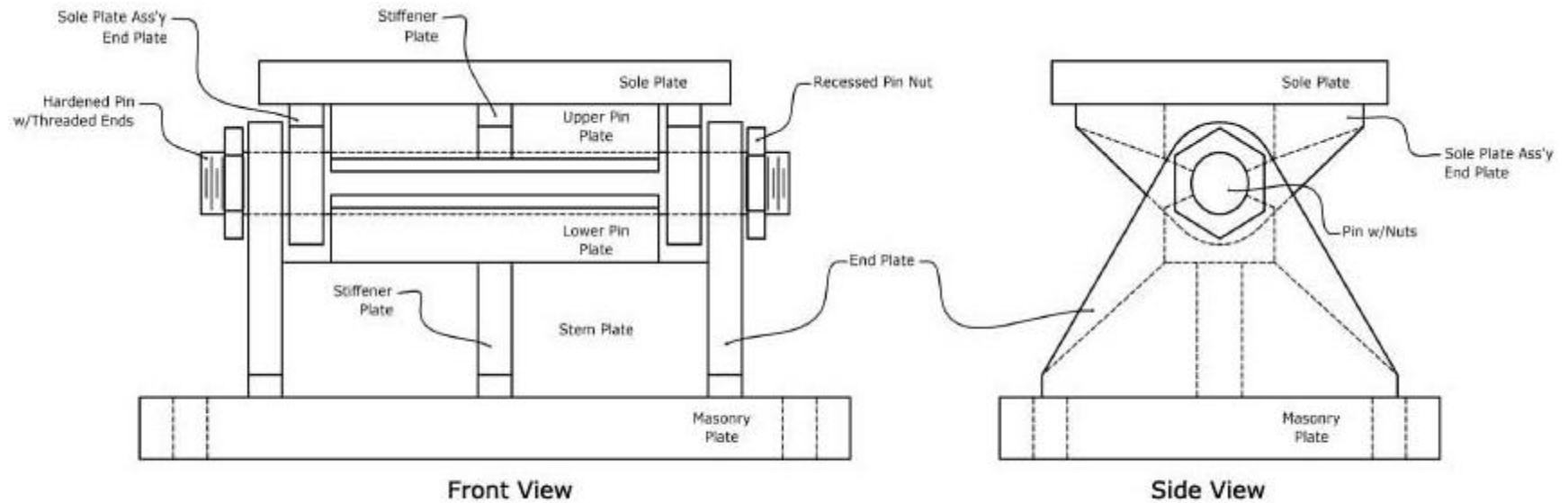
2.b. Rocker Bearings

Expansion Rocker Bearing (Pin Style)



2.b. Rocker Bearings

Fixed Rocker Bearing (Pin Style)



2.b. Rocker Bearings



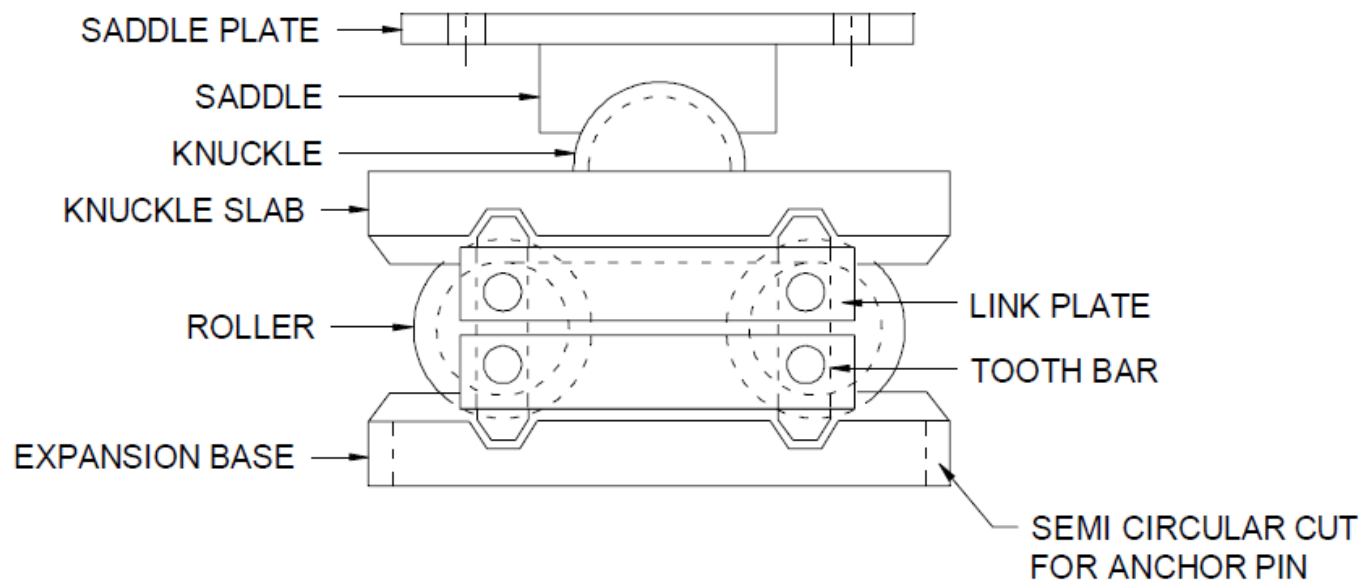
Free Rocker Bearing



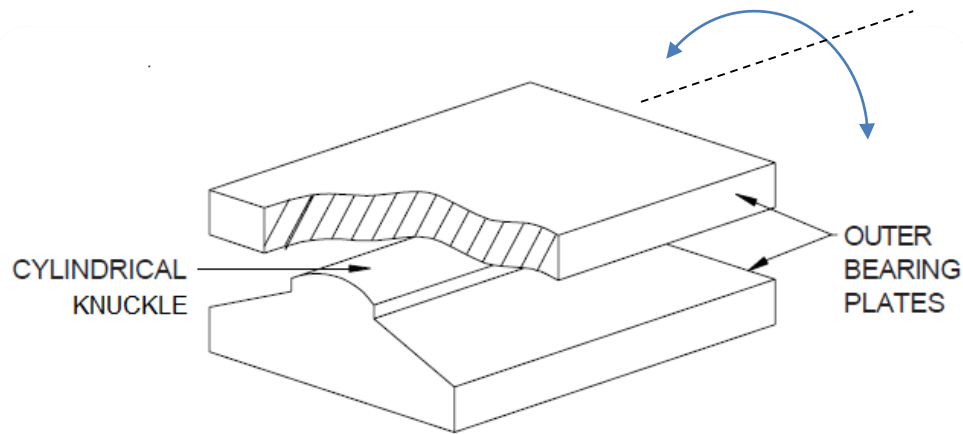
Fixed Rocker Bearing

3.a. Knuckle Pinned Bearing:

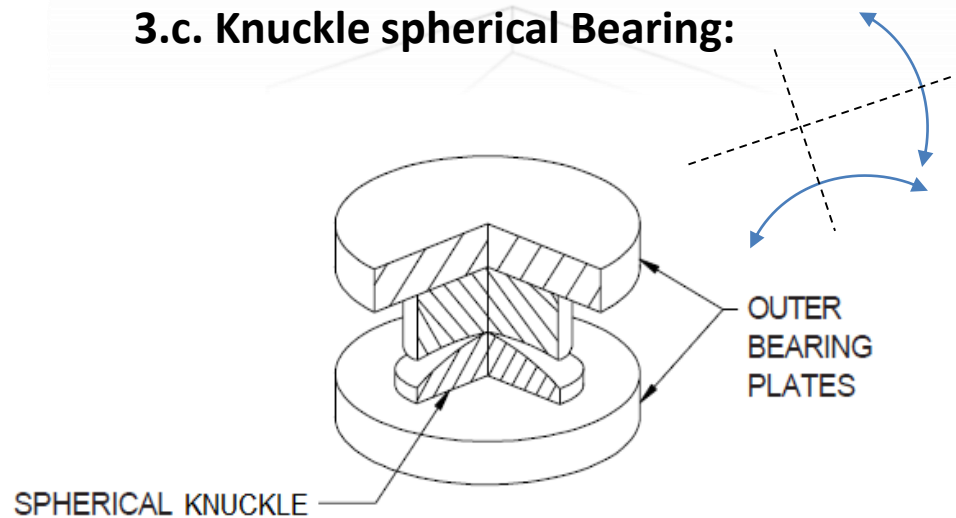
Combination of rocker and roller bearing



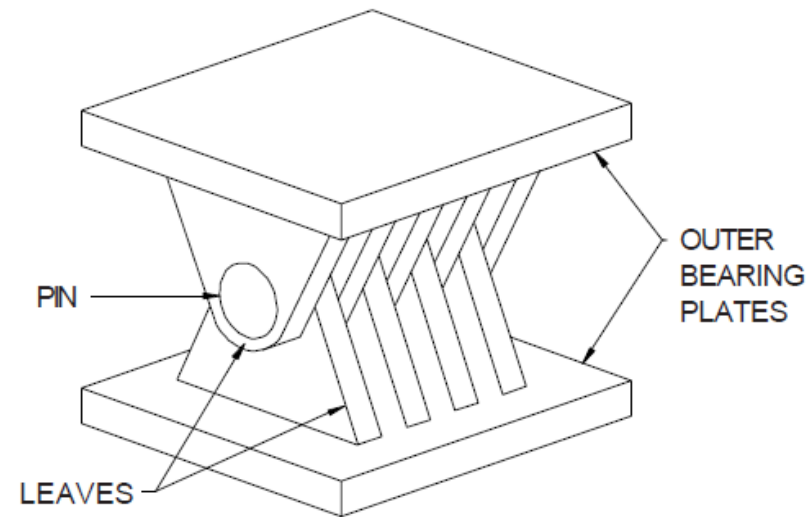
3.b. Knuckle cylindrical Bearing:



3.c. Knuckle spherical Bearing:



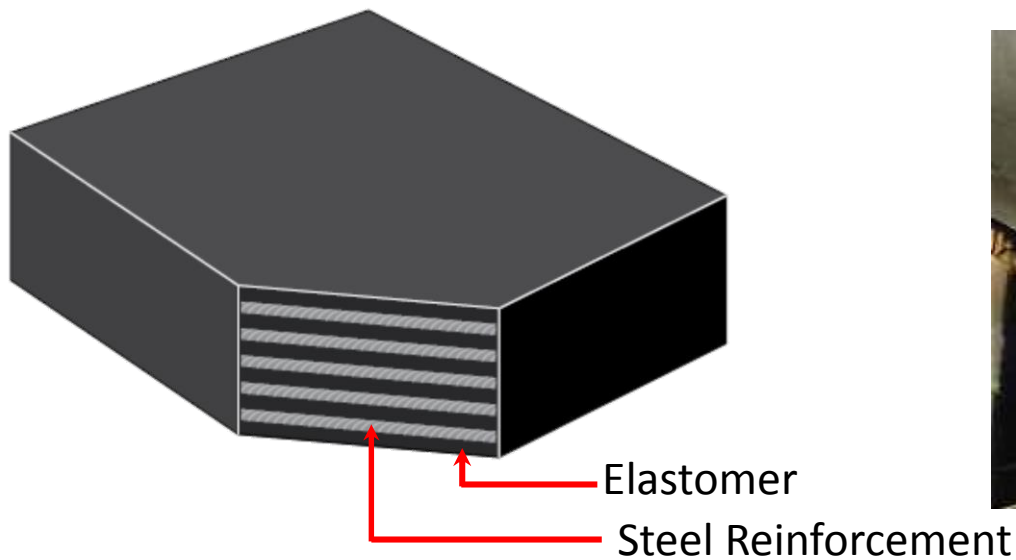
3.d. Knuckle leaf Bearing:



4. Elastomeric bearings:

- Plain elastomeric bearings
- Steel reinforced elastomeric bearings
- Fibre reinforced elastomeric bearings

Steel Reinforced Elastomeric Bearings



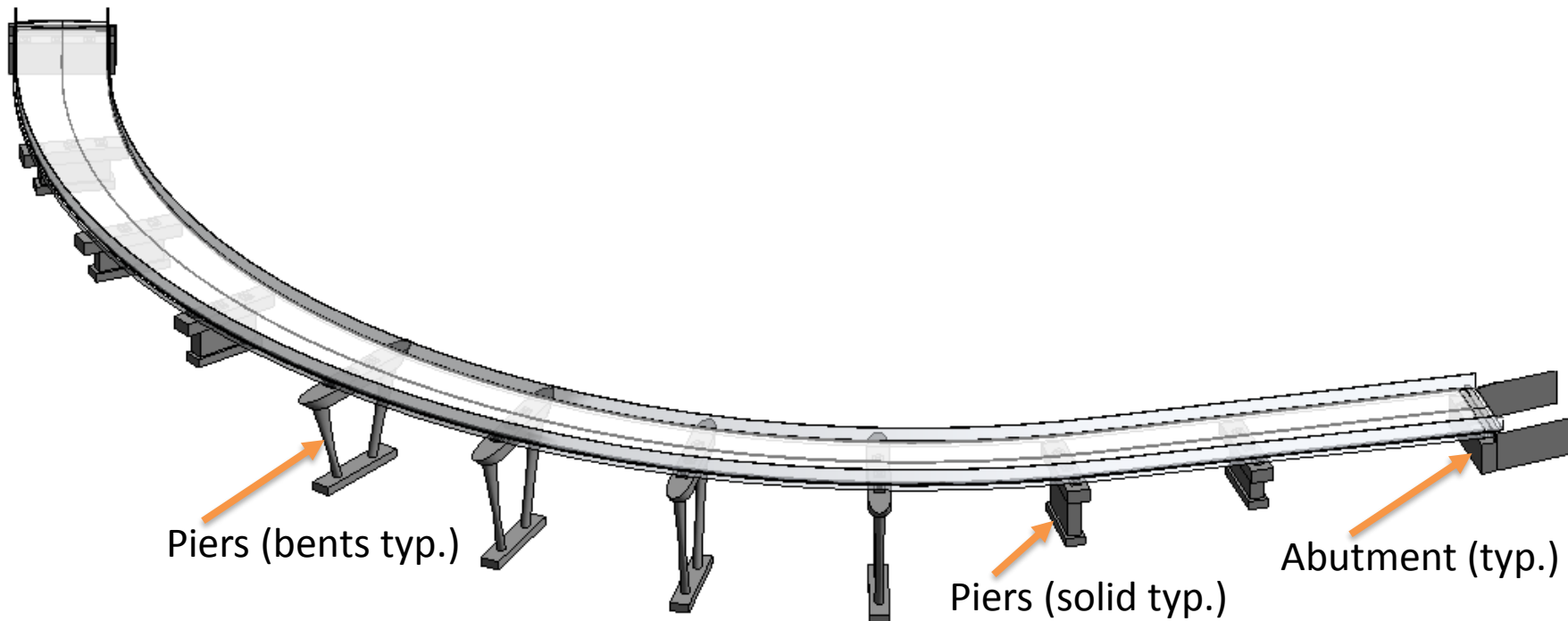
Piers & Abutments

an integral part of the load path between the superstructure and the foundation

Functions of Piers:

- To transfer the superstructure vertical loads to the foundation
- To resist all horizontal forces acting on the bridge

Abutments in addition to the above functions of piers are used at the ends of bridges to retain the embankment



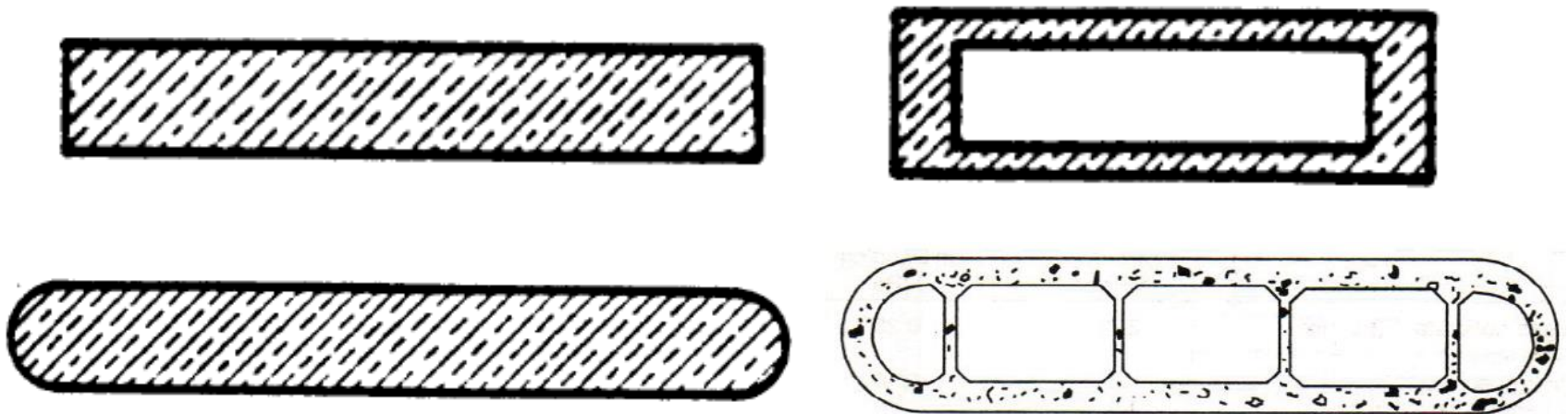
Piers

Classification based on connectivity with the superstructure

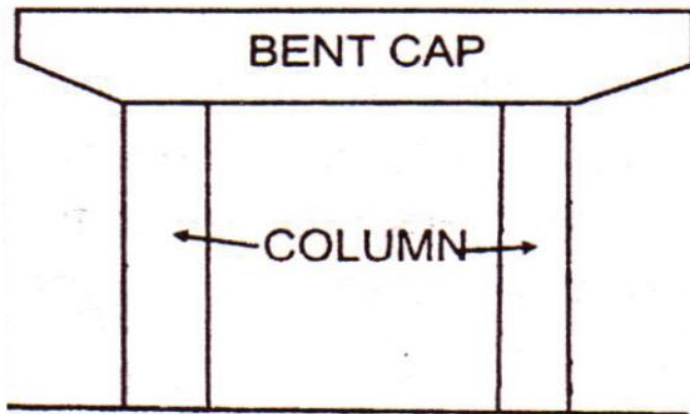
- Monolithic (integral)
- Cantilever

Classification based on sectional shape and framing configuration

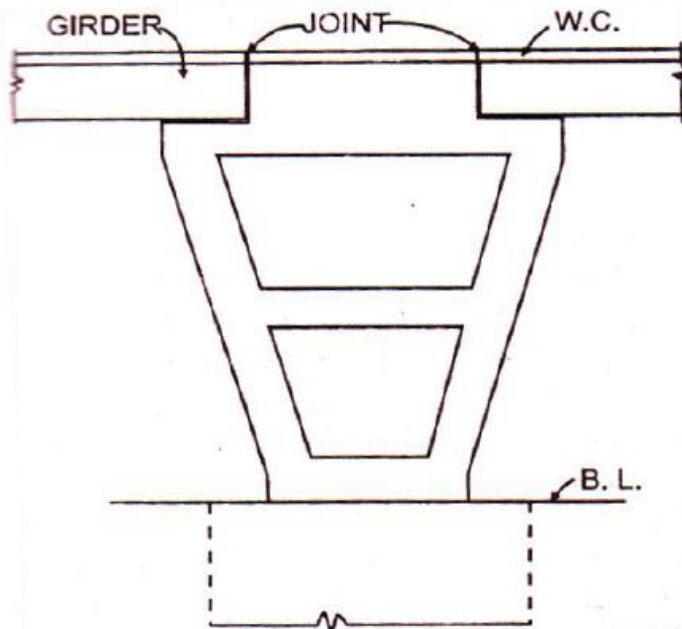
- Solid , Solid-hollow & Cellular type piers
- Trestle type pier (two or multiple column bent)
- Hammer-head type pier
- Framed type pier



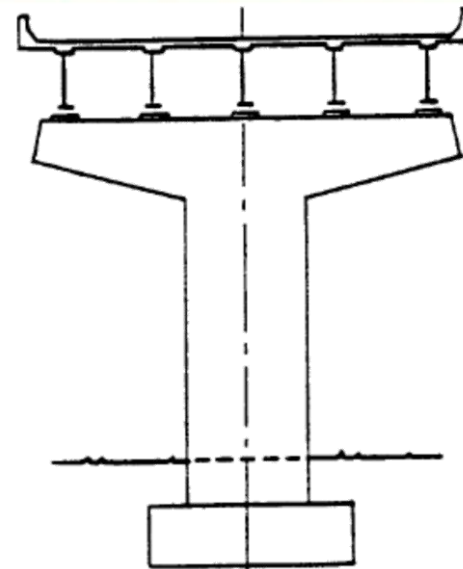
Solid , Solid-hollow & Cellular type piers



Trestle type pier



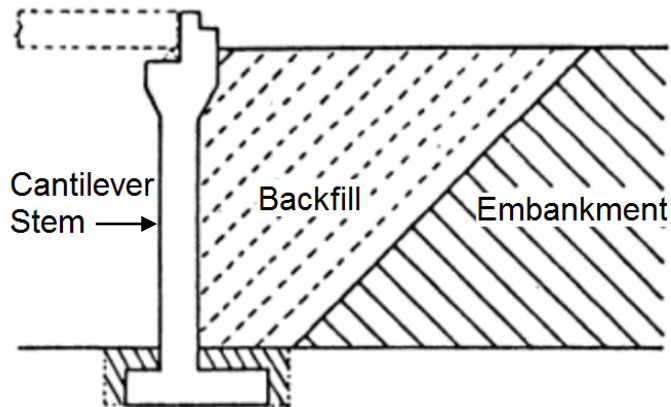
Framed type pier



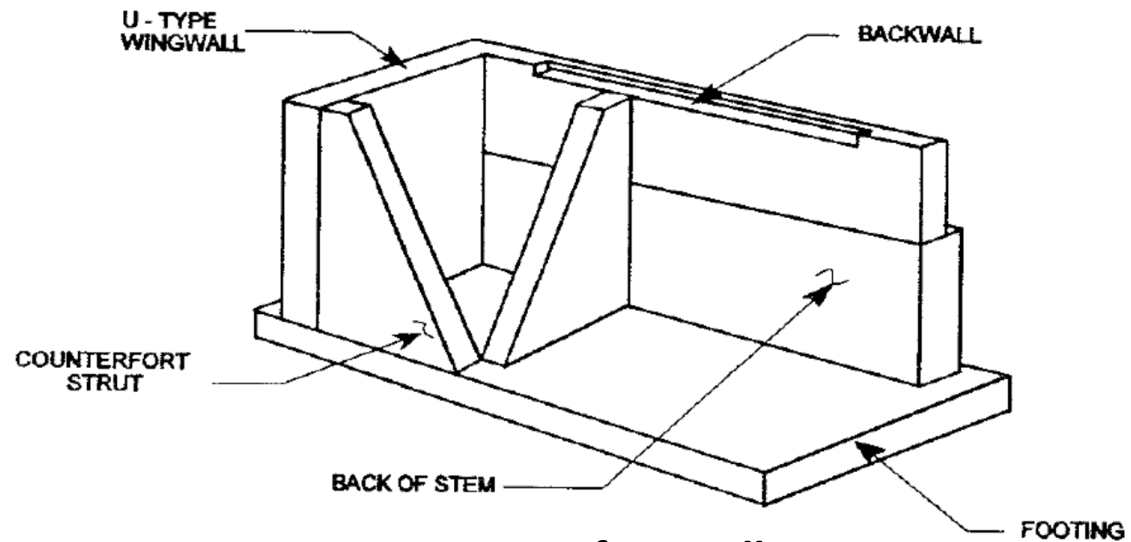
Hammer-head type pier

Abutment Types

- Closed Cantilever (high) abutments
 - Wall type
 - Counterfort type
- Stub or perched abutments
- Pedestal or spill through abutments
- Integral abutments
 - With Piles
 - With open foundation

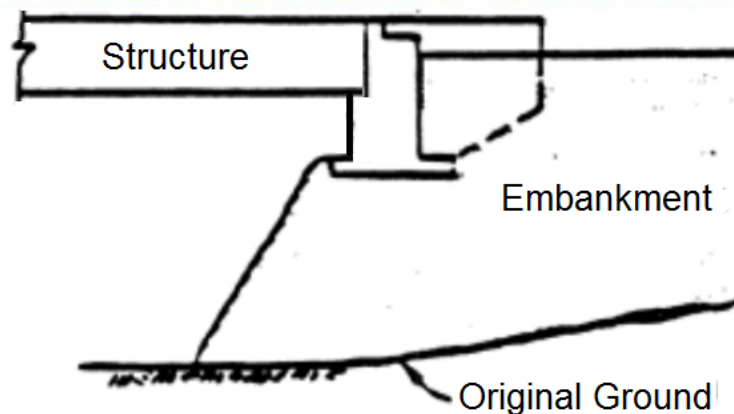


Wall type

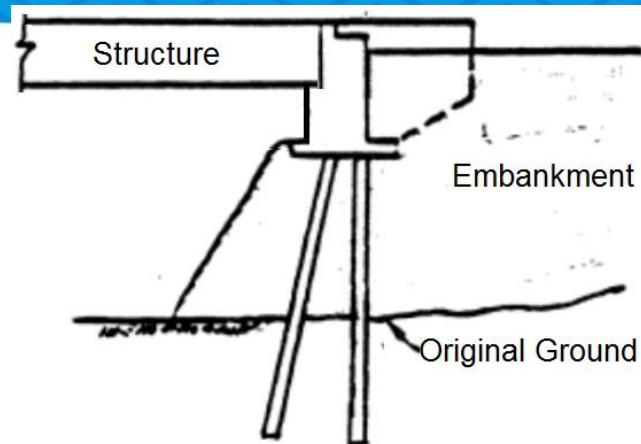


Counterfort Wall type

Cantilever Closed Abutments

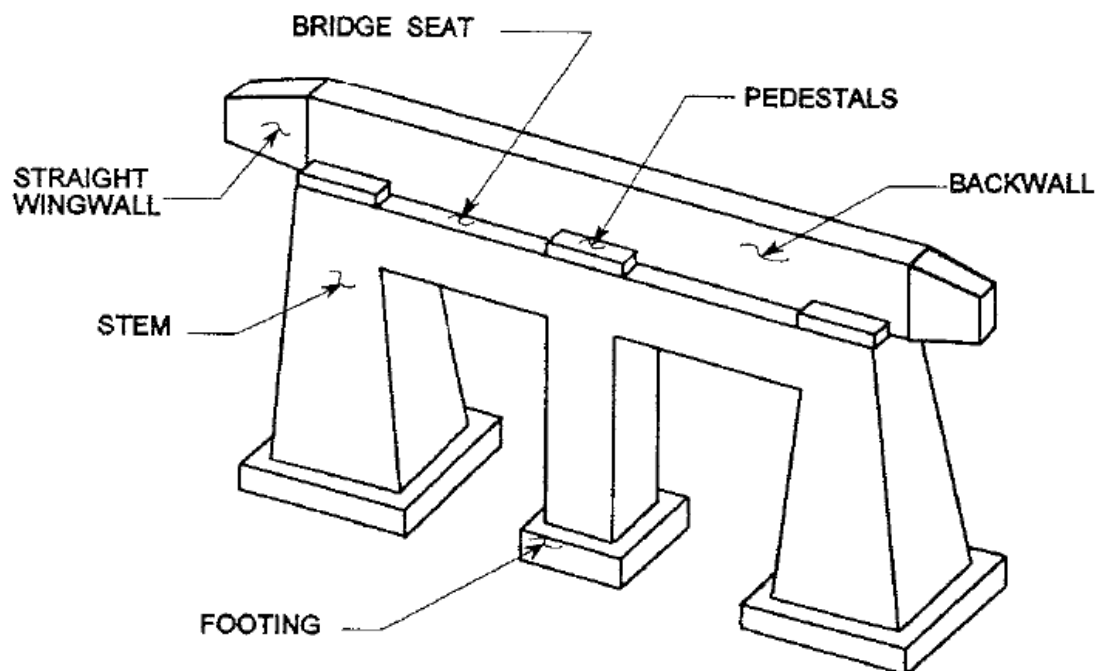


With Spread Footing

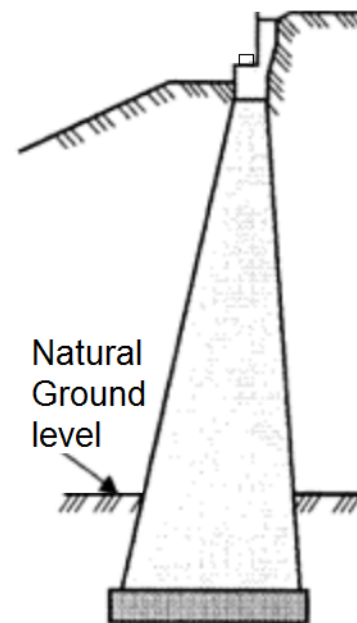


With Piles

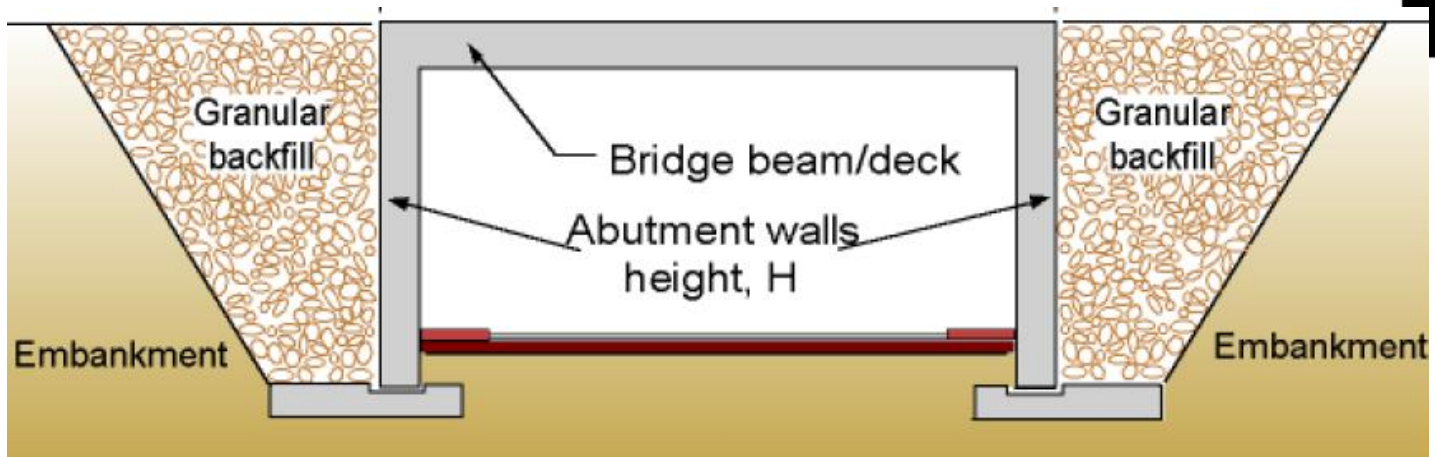
Stub Abutments



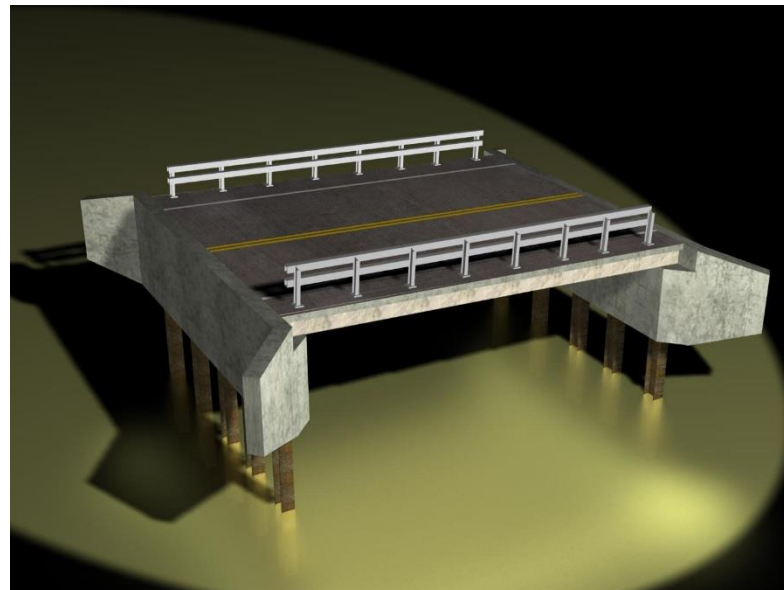
Spill Through Abutment



Cross section



Integral Abutment with Shallow Foundation



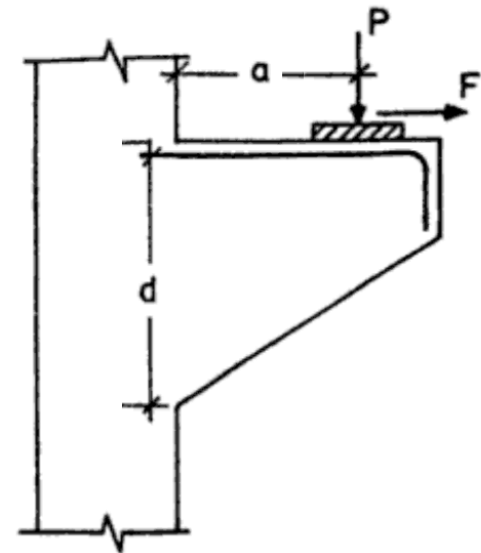
Integral Abutment with Pile foundation

Design of Piers

1. Design loads

- Dead loads
- Live loads and impact from the superstructure
- Wind loads on the structure and the live loads
- Centrifugal force from the superstructure
- Longitudinal force from live loads (braking and traction)
- Drag forces due to the friction at bearings
- Ice pressure
- Earthquake forces
- Thermal and shrinkage forces
- Forces due to settlement of foundations
- Vehicle Collision Loads

Pier-Cap Design → a/d Ratio $\begin{cases} < 1 \rightarrow \text{Corbel} \\ > 1 \rightarrow \text{Cantilever} \end{cases}$



Design of Piers

2. Combined Axial and Bending Strength

Interaction Diagrams

For Pure Compression, the factored axial resistance is computed as

$$P = \Phi P_n = \Phi 0.85 P_o = \Phi 0.85 [0.85 f'_c (A_g - A_{st}) + A_{st} f_y] \rightarrow \text{for piers with spiral reinforcement}$$

$$P = \Phi P_n = \Phi 0.8 P_o = \Phi 0.8 [0.8 f'_c (A_g - A_{st}) + A_{st} f_y] \rightarrow \text{for piers with tie reinforcement}$$

For Pure Flexure, the factored flexural resistance is computed as

$$M_r = \Phi M_n = \Phi (A_s f_y d (1 - 0.6 \rho \frac{f_y}{f'_c}))$$

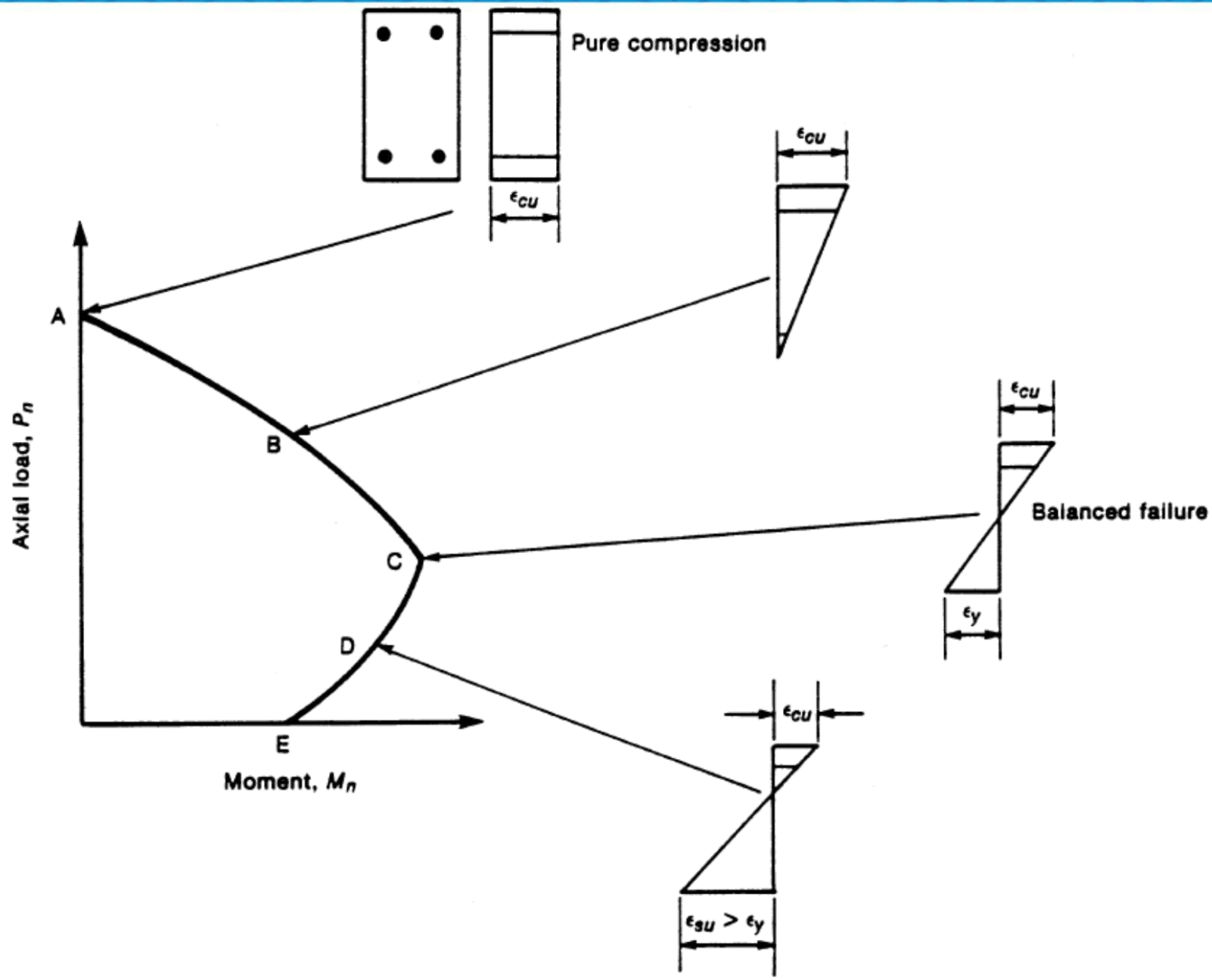
For Biaxial bending, interaction check is carried out as

$$\frac{M_{ux}}{M_{rx}} + \frac{M_{uy}}{M_{ry}} \leq 1$$

Where,

M_{ux}, \tilde{M}_{uy} = factored applied moment about the x-axis, y-axis

M_{rx}, M_{ry} = uniaxial factored flexural resistance of a section about the x-axis and y-axis corresponding to the eccentricity produced by the applied factored axial load and moment, and



Design of Piers

3. Shear Strength

The nominal shear strength provided by concrete subjected to flexure and axial compression should be computed by

$$V_n = V_c + V_s + V_p \leq 0.25 f_c' b_v d_v + V_p$$

where f_c' = concrete compressive strength

b_v = effective web width

d_v = effective shear depth taken as the distance, between tensile and compressive forces due to flexure, it should not be taken less than the greater of $0.9d_e$ or $0.72D$

Here V_c = shear resistance due to concrete = $0.0316 \beta \sqrt{f_c} b_v d_v$

β = factor indicating ability of diagonally cracked concrete to transmit tension as specified in S5.8.3.4, taken as 2 for non-prestressed members

And V_s = shear resistance due to steel = $[A_v f_y d_v (\cot \theta + \cot \alpha) \sin \alpha] / s$

where:

s = spacing of stirrups

θ = angle of inclination of diagonal compressive stresses as determined in S5.8.3.4 (deg) = 45 deg for nonprestressed members

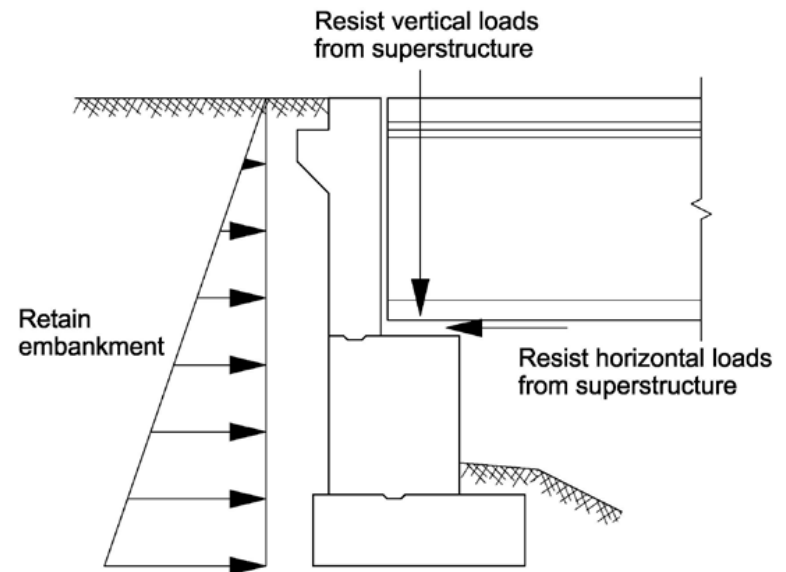
α = angle of inclination of transverse reinforcement to longitudinal axis (deg) = 90 deg for vertical stirrups

A_v = area of shear reinforcement

Design of Abutment

Design loads

- Dead loads
- Live loads and impact from the superstructure
- Wind loads on the structure and the live loads
- Centrifugal force from the superstructure
- Longitudinal force from live loads (braking and traction)
- Drag forces due to the friction at bearings
- Ice pressure
- Earthquake forces
- Thermal and shrinkage forces
- Forces due to settlement of foundations
- Vehicle Collision Loads

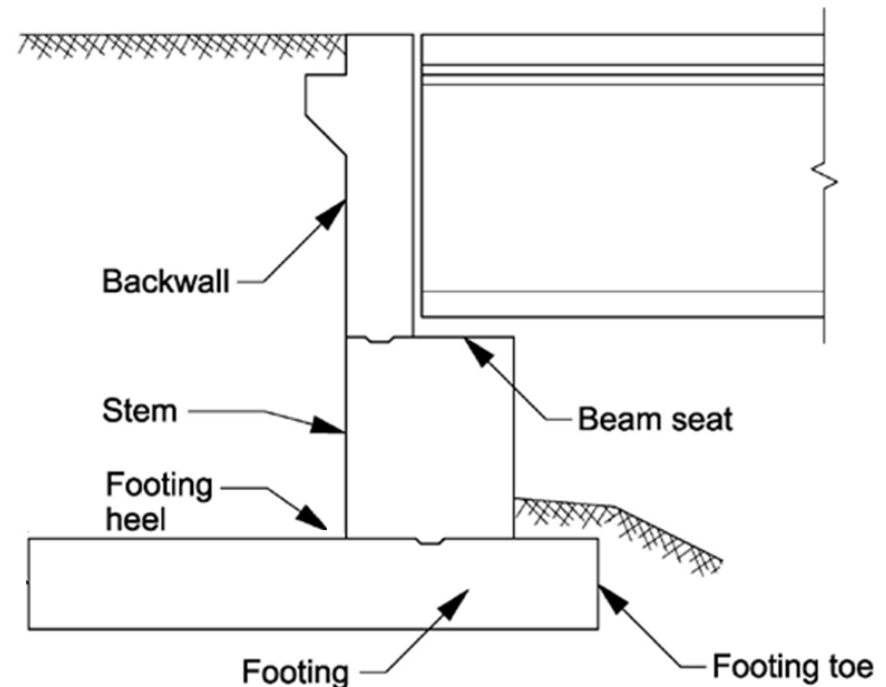


Design of a Cantilever Abutment with Shallow Footing

- The Abutment comprises of 3 components, heel, stem and toe.
- The dimensions of the footing are based on the base pressure check :
 - Forces due to lateral earth pressure.
 - Vertical and horizontal reactions from the superstructure.

$$\frac{P}{A} \pm \frac{M_L}{Z_L} \pm \frac{M_T}{Z_T}$$

- In order to assure no tension at the bottom, the dimensions of footing are fixed based on the base pressure.



Stability Checks:



Sliding Failure

FOS > 1.5



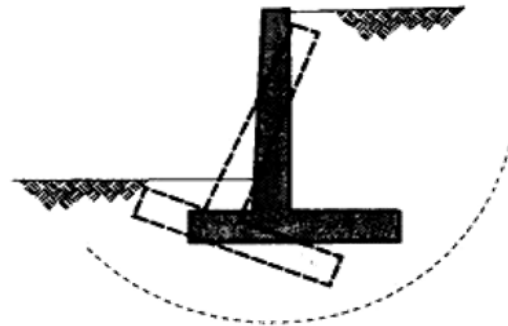
Overturning Failure

FOS > 2

Bearing Failure

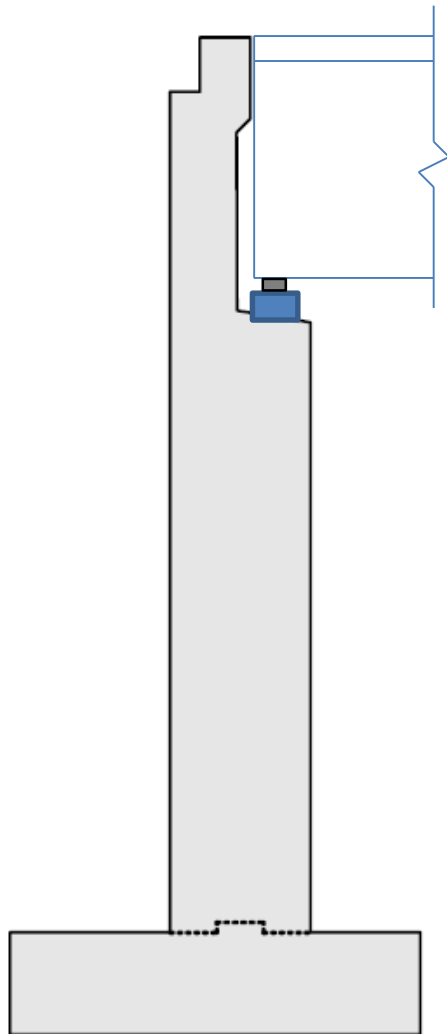


**Deep-Seated
Sliding Failure**



Stem Design → As a flexure member with shear check similar to piers

Design Loads Calculation for Abutment design



First, Preliminary dimensions of stem, toe and heel are selected and design loads are calculated.

1 : Computation of Dead Load Effects

- a) Dead Load from Superstructure per unit length:

$$\frac{\text{Summation of Dead Load bearing Reactions from all bearings}}{\text{Length of Abutment}}$$
- b) Dead load of backwall and Stem per unit length
- c) Footing dead load of per unit length
- d) Backfill Earth dead load of per unit length
- e) Live Load effects
- f) Temperature effects

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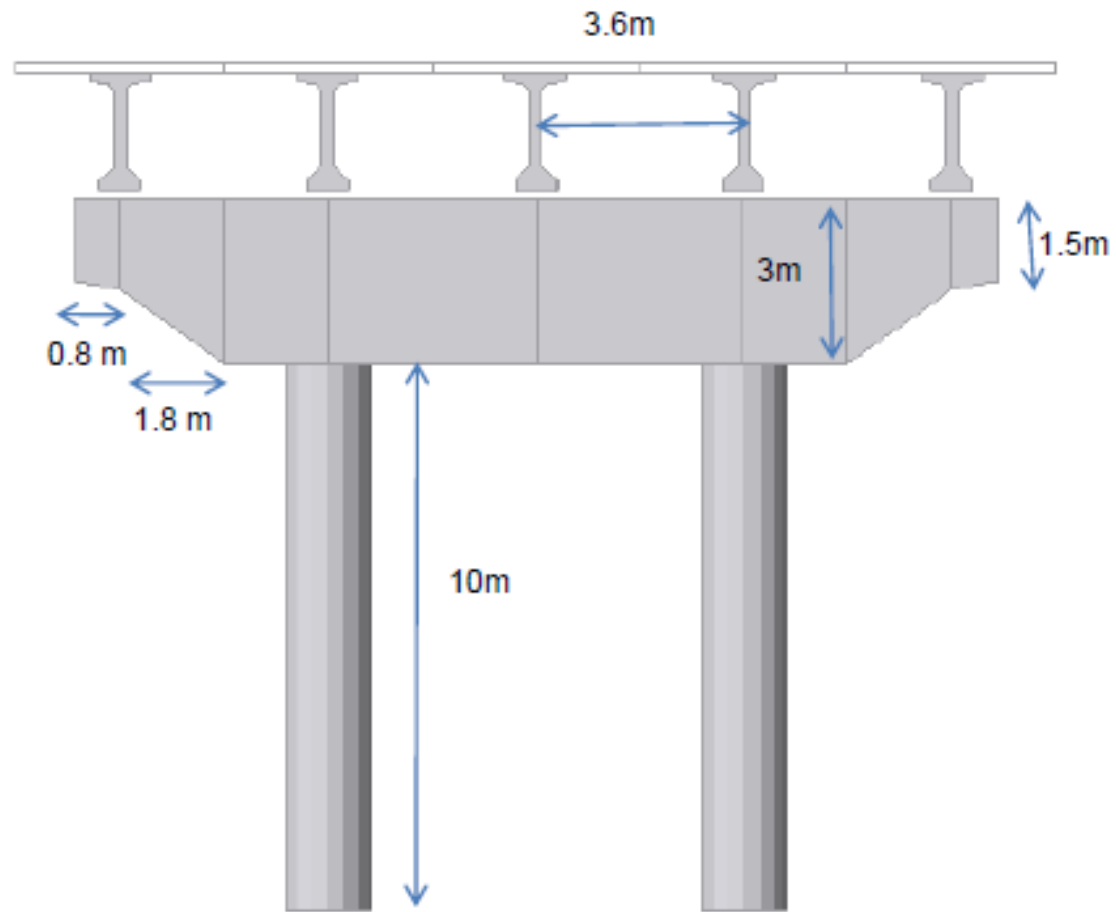
Pier Modeling

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Pier modeling



Front View

Pier Design Midas GSD

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Pier modeling – Midas GSD

- Fiber Section for refined Dynamic Analysis
- Obtain PMM curve for Pier Design
- Check Pier Section for Cracking
- Obtain Moment Curvature Diagram

Section View : Section 1 | **Interaction Curve** | Moment-Curvature Curve | Stress Contour

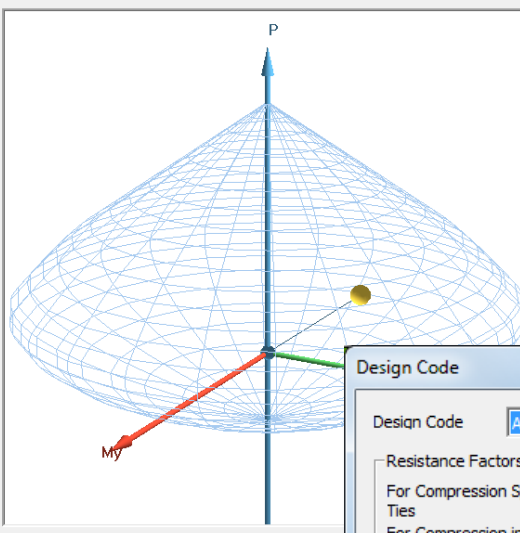
P-M | My-Mz | 3D

View Option

P-M Curve
☒ Show All
☐ Select Angle : 0 Deg.

M-M Curve
☒ Show All
☐ Select Axial Force : 73528.9 kN

Load Combination
☐ Show All
☒ Select Load Combination : Load



Load Combination Name	Ratio P-My/Mz
Load	0.003

Unconfined Area
Confined Area

Design Code

Design Code: AASHTO-LRFD 12

Resistance Factors

For Compression Spirals or Ties: 0.75

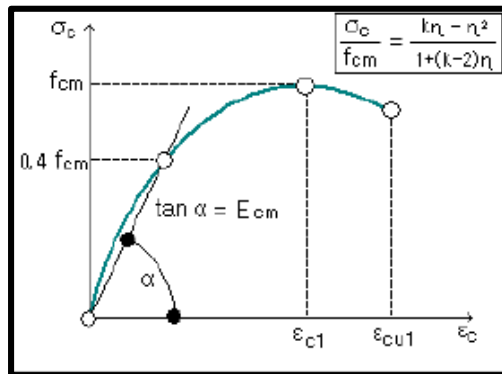
For Compression in Strut and Tie models: 0.7

OK Cancel

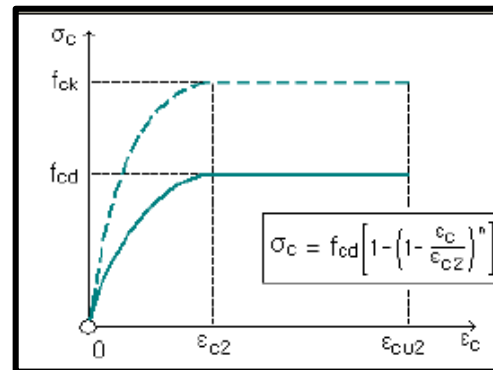
Eurocode2:04
 GB50010-02
 GB50010-10
 KSCE-USD10
 KSCE-USD05
 KSCE-RAIL-USD11
 KCI-USD07
 AASHTO-LRFD 12
 ACI318-11
 ACI318-08
 CSA-S6-10
 JTG-D62-2004

Pier modeling – Midas GSD

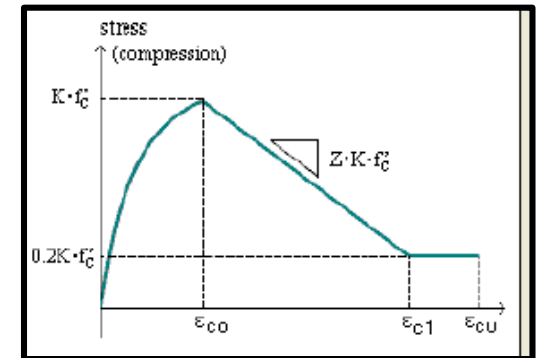
Concrete Nonlinear Properties



Parabolic stress-strain curve

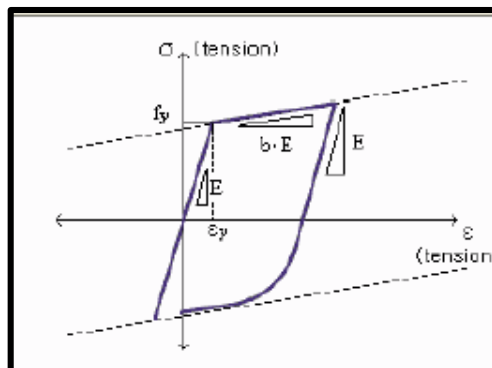


Parabola-rectangle

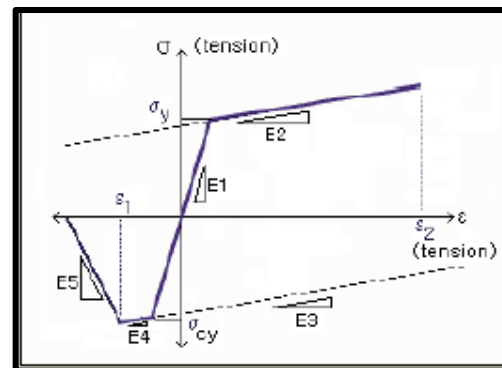


Kent & Park model

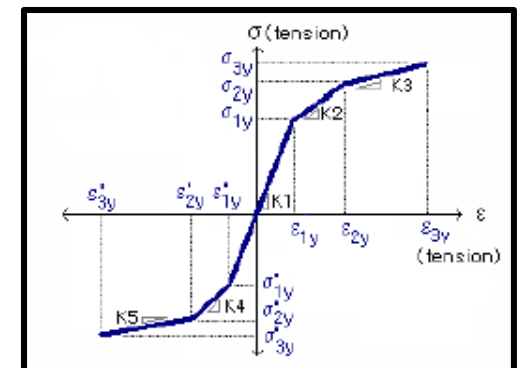
Steel Nonlinear Properties



Menegotto -Pinto



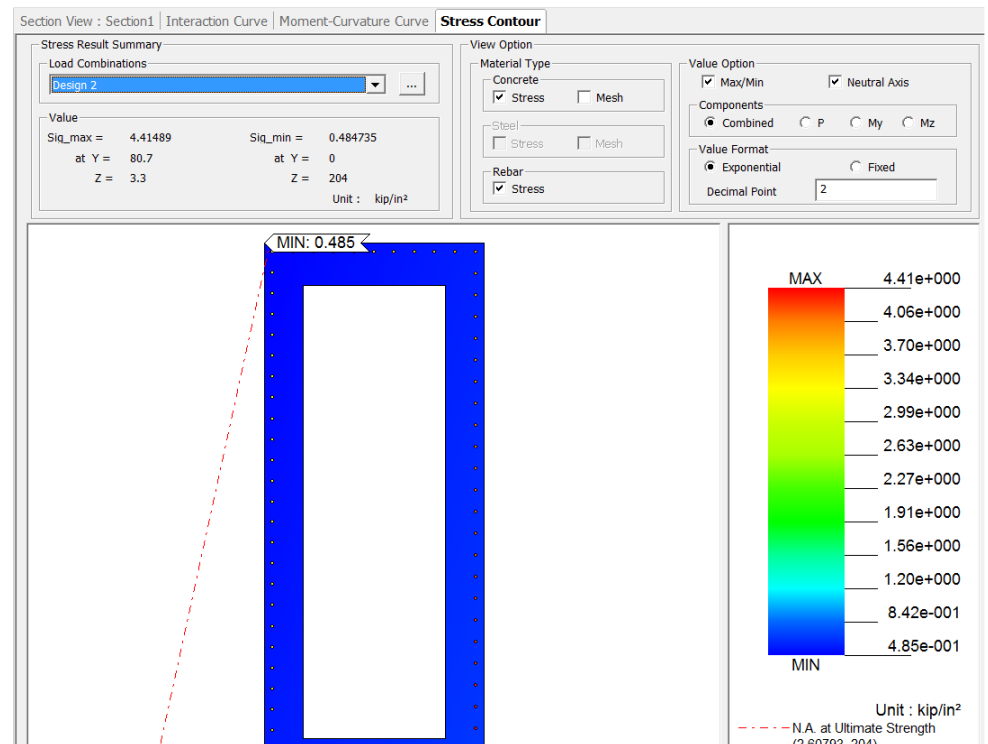
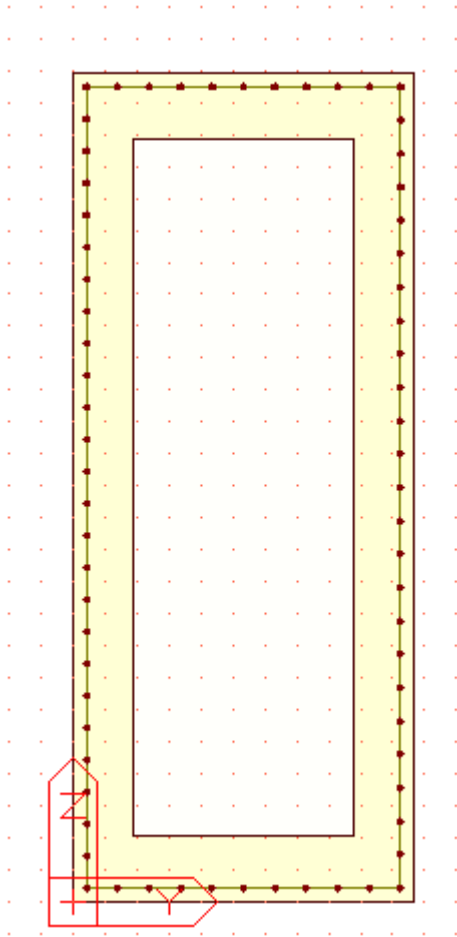
Asymmetric Bi-linear



Tri-linear

Pier modeling – Midas GSD

Hollow Section



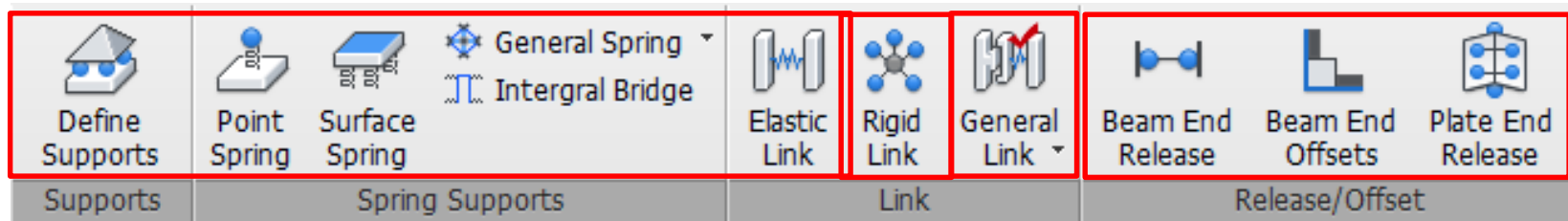
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Bearing Modeling

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Boundary Conditions



Nodal boundary conditions

- Constraint for degree of freedom (Supports)
- Elastic boundary element (Spring supports)
 - Point Spring Supports
 - Surface Spring Supports
 - General Spring Supports
- Elastic link element (Elastic Link)
- General Link element (General Link)
 - Element Type
 - Force Type

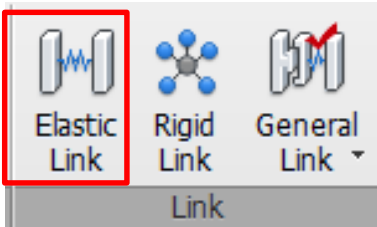
Element boundary conditions

- Element End Release
 - Beam End Release
 - Plate End Release
- Rigid End Offset distance (Beam End Offset)
- Rigid Link

Boundary Conditions

Usage

- Elastic bearings of a bridge structure, which separate the bridge deck from the piers.
- Compression-only Elastic link : the soil boundary conditions.
- Rigid Link : Connects two nodes with an "infinite" stiffness



Elastic Link Data

Type: **General**

SDx: 0 kips/ft
SDy: 0 kips/ft
SDz: 0 kips/ft
SRx: 0 ft·kips/[rad]
SRy: 0 ft·kips/[rad]
SRz: 0 ft·kips/[rad]

☒ Shear Spring Location
Distance Ratio From End I
SDy: 0.5 SDz: 0.5

Beta Angle: 0 [deg]

2 Nodes:

☐ Copy Elastic Link
Node Inc. Distance
Axis: x y z
Distances: ft
(Example: 5, 3, 4.5, 3@5.0)

Elastic Link Data

Type: **Rigid**

SDx: 0 kips/ft
SDy: 0 kips/ft
SDz: 0 kips/ft
SRx: 0 ft·kips/[rad]
SRy: 0 ft·kips/[rad]
SRz: 0 ft·kips/[rad]

☒ Shear Spring Location
Distance Ratio From End I
SDy: 0.5 SDz: 0.5

Beta Angle: 0 [deg]

2 Nodes:

☐ Copy Elastic Link
Node Inc. Distance
Axis: x y z
Distances: ft
(Example: 5, 3, 4.5, 3@5.0)

Elastic Link Data

Type: **Tension Only**

SDx: 0 kips/ft
SDy: 0 kips/ft
SDz: 0 kips/ft
SRx: 0 ft·kips/[rad]
SRy: 0 ft·kips/[rad]
SRz: 0 ft·kips/[rad]

☒ Shear Spring Location
Distance Ratio From End I
SDy: 0.5 SDz: 0.5

Beta Angle: 0 [deg]

2 Nodes:

☐ Copy Elastic Link
Node Inc. Distance
Axis: x y z
Distances: ft
(Example: 5, 3, 4.5, 3@5.0)

Elastic Link Data

Type: **Compression Only**

SDx: 0 kips/ft
SDy: 0 kips/ft
SDz: 0 kips/ft
SRx: 0 ft·kips/[rad]
SRy: 0 ft·kips/[rad]
SRz: 0 ft·kips/[rad]

☒ Shear Spring Location
Distance Ratio From End I
SDy: 0.5 SDz: 0.5

Beta Angle: 0 [deg]

2 Nodes:

☐ Copy Elastic Link
Node Inc. Distance
Axis: x y z
Distances: ft
(Example: 5, 3, 4.5, 3@5.0)

Elastic Link Data

Type: **Multi-Linear**

Symmetric: 3

	d(x) (ft)	F(y) (kips)
1	0	0
2	0	0
3	0	0

Direction: Dx

☒ Shear Spring Location
Dist. Ratio From End I: 0.5

Beta Angle: 0 [deg]

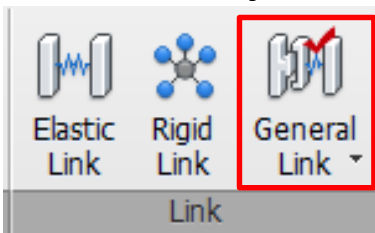
2 Nodes:

☒ Copy Elastic Link
Node Inc. Distance
Axis: x y z
Distances: ft
(Example: 5, 3, 4.5, 3@5.0)

Boundary Conditions

Usage

- Dampers, base isolators, compression-only element, tension-only element, plastic hinges, soil springs
- Used as linear and nonlinear elements
- Element type: Spring, Dashpot, Spring and Dashpot
- Force type: Viscoelastic Damper, Hysteretic System, Seismic isolators (Lead Rubber Bearing Isolator, Friction Pendulum System Isolator)



General Link Data

General Link Property

Name : ...

Type :

☐ Inelastic Hinge Property

Name : ...

Reference Coordinate System

☒ Element ☐ Global

Input Method

☒ Beta Angle

☐ Ref. Point

☐ Ref. Vector

[deg]

2 Nodes :

☒ Copy General Link

☐ Node Inc. ☒ Distance

Axis : ☒ x ☐ y ☐ z

Distances : in

(Example : 5, 3, 4.5, 3@5.0)

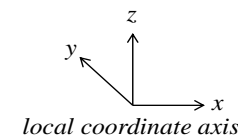
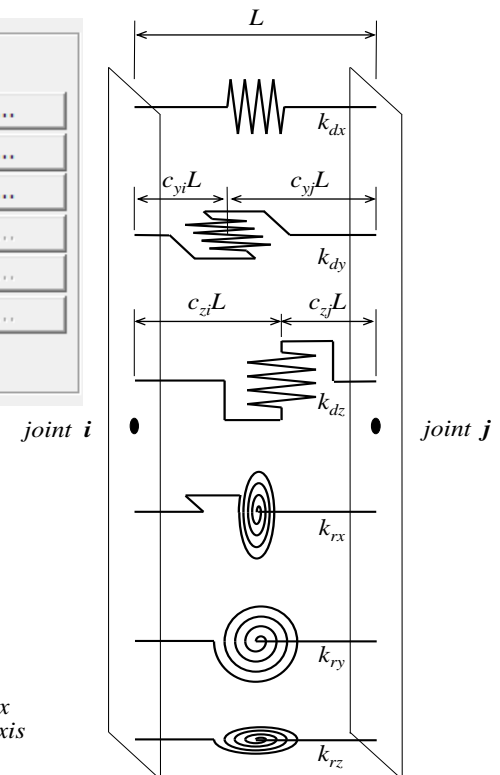
Linear Properties

DOF	Effective Stiffness	Effective Damping
<input checked="" type="checkbox"/> Dx	55997397 kips/in	0 kips*sec/in
<input checked="" type="checkbox"/> Dy	21.5 kips/in	0 kips*sec/in
<input checked="" type="checkbox"/> Dz	21.5 kips/in	0 kips*sec/in
<input type="checkbox"/> Rx	0 in*kips/[rad]	0 in*kips*sec/[rad]
<input type="checkbox"/> Ry	0 in*kips/[rad]	0 in*kips*sec/[rad]
<input type="checkbox"/> Rz	0 in*kips/[rad]	0 in*kips*sec/[rad]

Coupled

Nonlinear Properties

DOF	Properties...
<input checked="" type="checkbox"/> Dx	Properties...
<input checked="" type="checkbox"/> Dy	Properties...
<input checked="" type="checkbox"/> Dz	Properties...
<input type="checkbox"/> Rx	Properties...
<input type="checkbox"/> Ry	Properties...
<input type="checkbox"/> Rz	Properties...



Isolated Footing

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Midas Design+ - Isolated Footing



Midas Design+ - Isolated Footing

File Edit View RC Steel SRC Aluminum Load Option Mode Tool Link Window Help

WorkBar: Start Page Member Member List Drawing Quantity

Add new member
System: RC
Type: Footing
Name:
Option... Add
☐ Keep Sect. & Bar Data

RC Steel SRC Aluminum

RC Design Procedure
Design Option
RC: ACI318-11
Rebar Code: ASTM
Preference
Slab
Beam
Column
Column (General)
Shear Wall
Shear Wall (Combined)
Footing (1)
F01
Footing (Combined)
Footing (Strip)
Basement Wall
Buttress
Stair
Corbel/Bracket
Retaining Wall
Beam Table
Slab Table
Batch Wall
Smart Design Option
Building Data Setting
Run Smart Design (All)

Concrete: 24 MPa
Main Bar: 400 MPa
☐ Light Weight Concrete
Factor: 1

Design Load
Ps: 2000.00 kN
M_{sx}: 0.00 kN.m
M_{sy}: 50.00 kN.m
Load Combinations (1) ...
Pu: 1000.00 kN
M_{ux}: 50.00 kN.m
M_{uy}: 0.00 kN.m
Load Combinations (1) ...
☒ Include Self-Weight Mx <-> My

Surcharge Load
Surface Load: 0.00 kN/m²
Weight Density: 18.00 kN/m³
Height: 0.00 m

Footing
Type: Isolated (Mat)
Depth: 700.00 mm
Cover: 80.00 mm

Column Section
☒ Rectangle ☐ Circle
Size: 500.00 mm

3,000
1,500 1,500
3,000
1,500 1,500
700
Y1
X1

Rebar
Moment (kN.m) Y-Direction (M_{ux}) X-Direction (M_{uy})
28.37 26.46

Calculation Result

Check Items	Result
Soil Bearing (kPa)	249 NG(2.493)
1Way Shear-X (kN)	250 OK(0.233)
1Way Shear-Y (kN)	259 OK(0.232)
2Way Shear (kN)	863 OK(0.262)
Min. Bar Ratio (mm ²)	0.180% 384
Max. Bar Space (mm)	#7 @457

Footing Size

FOOTING SIZE		
Lx	3.00	m
Ly	3.00	m
SOIL BEARING		
Capacity(fe)	100.00	KPa

MIDAS Technical Support
<http://globalsupport.midasuser.com/>

Thank you