Topic 2

Day 1

Advances and recent trends in Modeling and Analysis of Bridges

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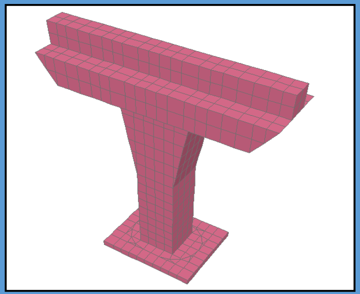
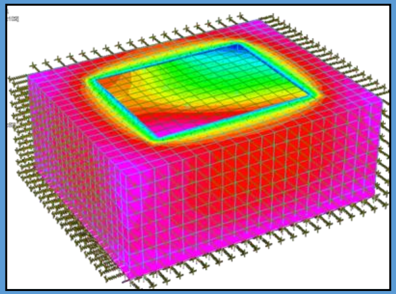
AIT Asian Institute of Technology 1959

AIT Solutions
Technology • Engineering • Environment • Development • Management
Formerly | AIT CONSULTING

1. Over view of Bridge Design Process and Bridge Types
2. Advances and recent trends in Modeling and Analysis of Bridges
3. Design of Bridge Super Structure and Sub Structure
4. International Bridge Design Standards and Approaches



The Structural Analysis Problem

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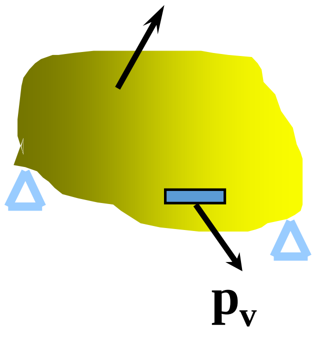
The Structural System

EXCITATION

Loads
Vibrations
Settlements
Thermal Changes

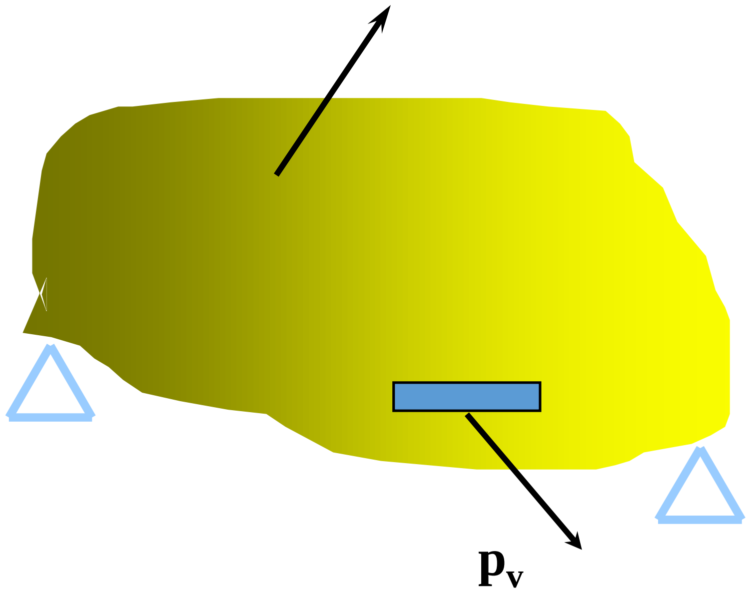
STRUCTURE



RESPONSES

Displacements
Strains
Stresses
Stress Resultants

Analysis of Continuums



Equilibrium Equation: The Sum of Body Forces and Surface Tractions is equal to Zero

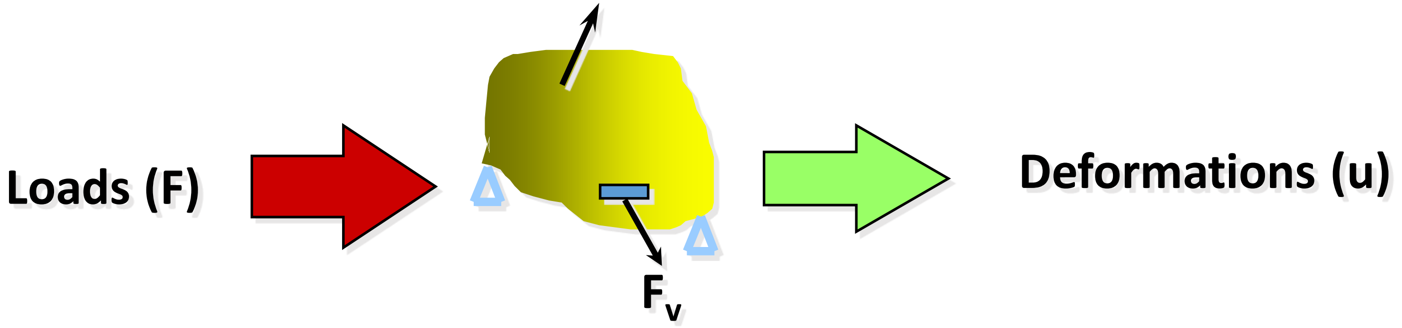
$$\frac{\partial \sigma_{xx}}{\partial x} + \frac{\partial \sigma_{yy}}{\partial y} + \frac{\partial \sigma_{zz}}{\partial z} + p_{vx} = 0$$

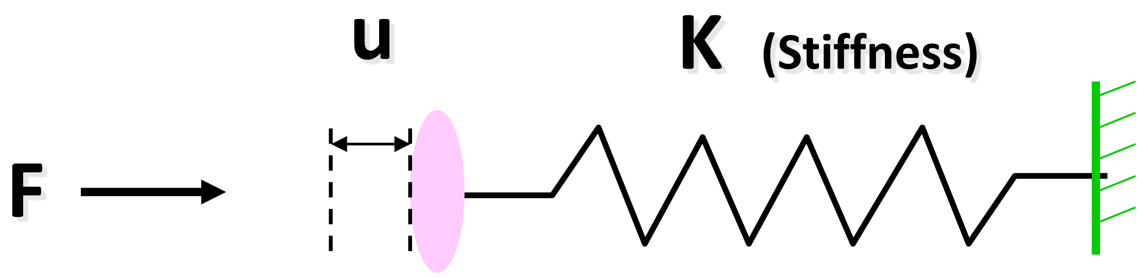
Real Structure is governed by "Partial Differential Equations" of various order

Direct solution is only possible for:

- Simple Geometry
- Simple Boundary
- Simple Loading

Simplified Structural System



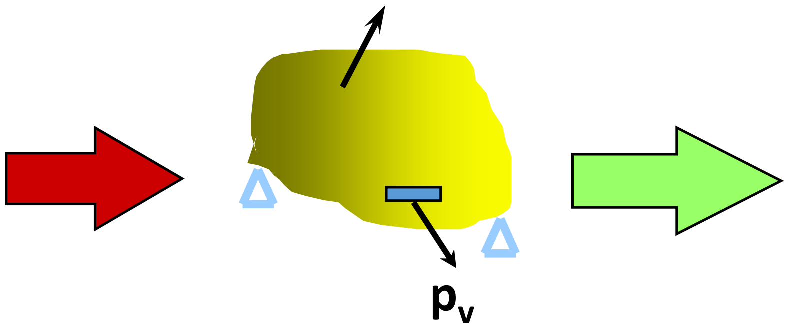


Equilibrium Equation → $$F = K u$$

The Total Structural System

STRUCTURE

EXCITATION



RESPONSES

- Static
- Dynamic

- Elastic
- Inelastic

- Linear
- Nonlinear

Eight types of equilibrium equations are possible!

Integrated Analysis Solution

Mass-Acceleration

Stiffness-Displacement

External Force

$$M\ddot{u} + C\dot{u} + Ku + F_{NL} = F$$

Damping-Velocity

Nonlinearity

$$M\ddot{u} + C\dot{u} + Ku$$

Specialized for every required analysis case

Linear and Nonlinear

- **Linear, Static and Dynamic**

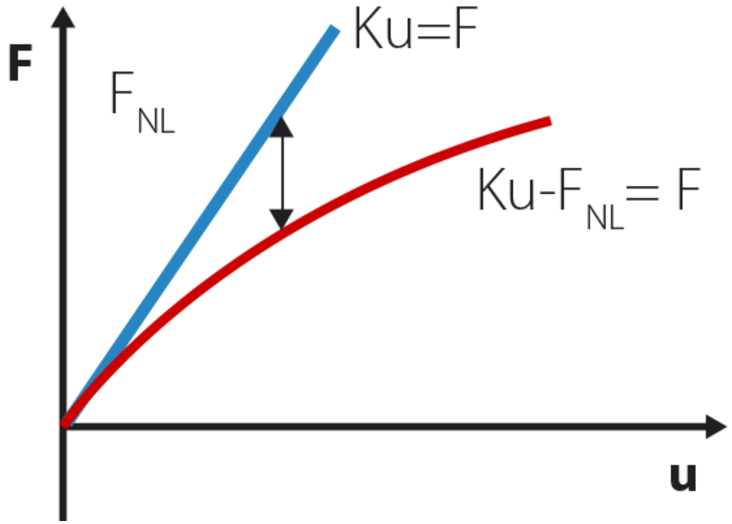
$$Ku = F$$

$$M\ddot{u}(t) + C\dot{u}(t) + Ku(t) = F(t)$$

- **Nonlinear, Static and Dynamic**

$$Ku + F_{NL} = F$$

$$M\ddot{u}(t) + C\dot{u}(t) + Ku(t) + F(t)_{NL} = F(t)$$



Non Linear Equilibrium

The Need For Analysis

- We need to determine the response of the structure to excitations

Analysis

so that

- We can ensure that the structure can sustain the excitation with an acceptable level of response

Design

Finite Element Method and FEA

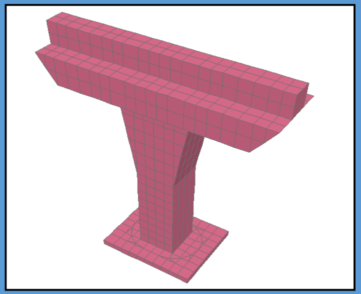
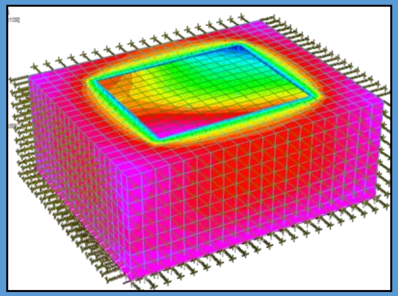
- Finite Element Analysis (FEA)

  "A discretized solution to a continuum problem using FEM"

- Finite Element Method (FEM)

  "A *numerical procedure for solving (partial) differential equations associated with field problems, with an accuracy acceptable to engineers"*



A quick overview of FEM and FEA

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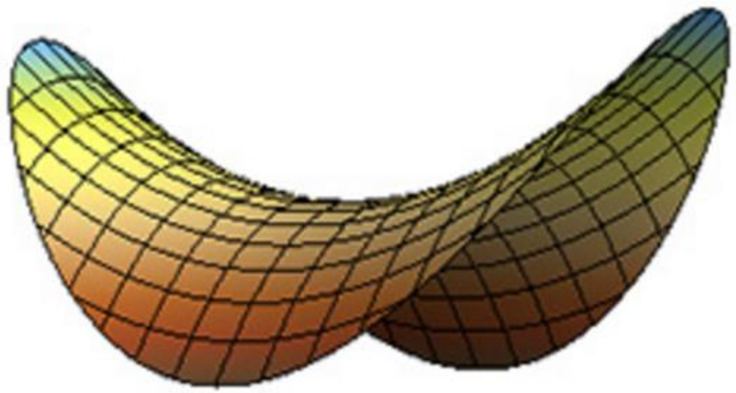
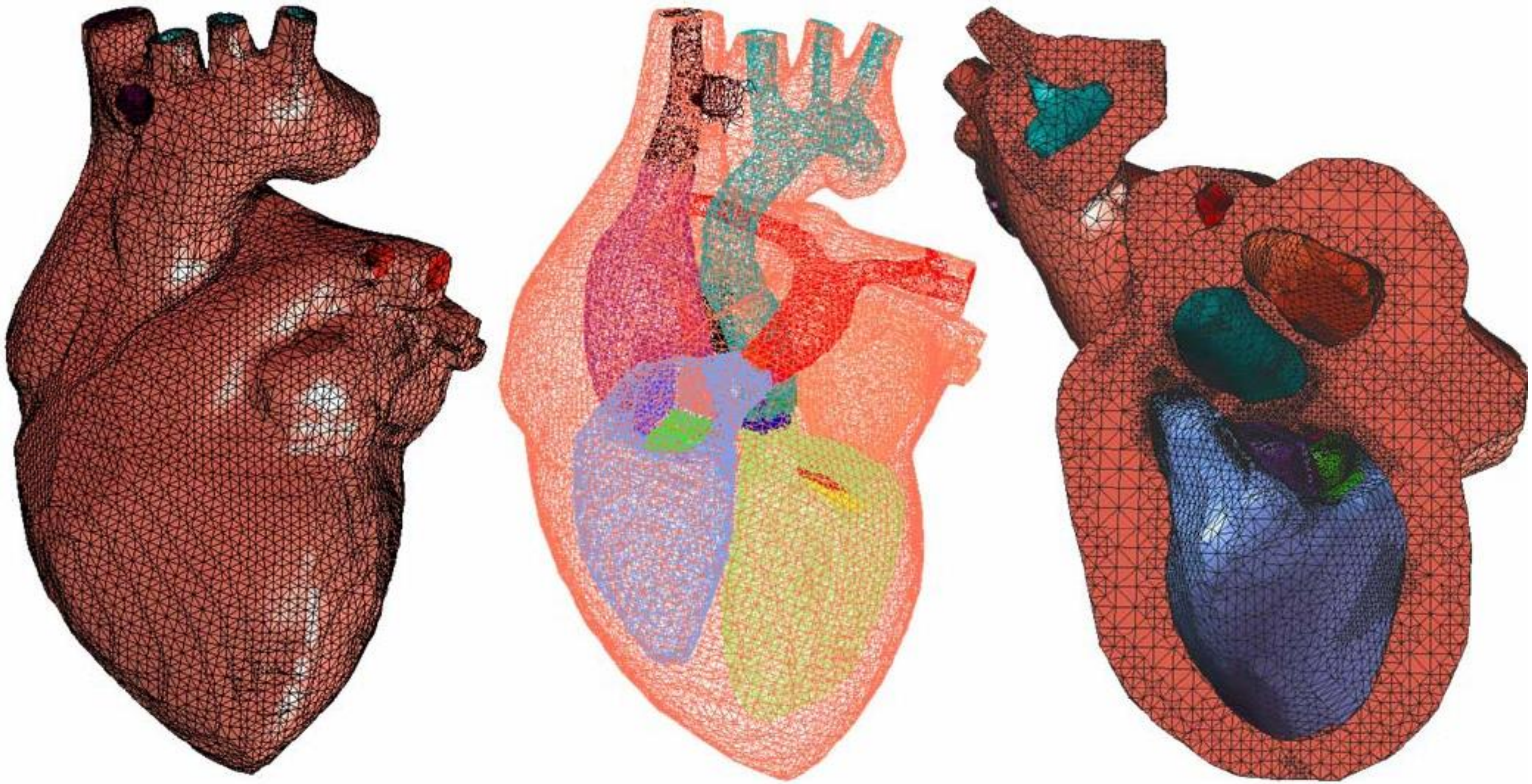
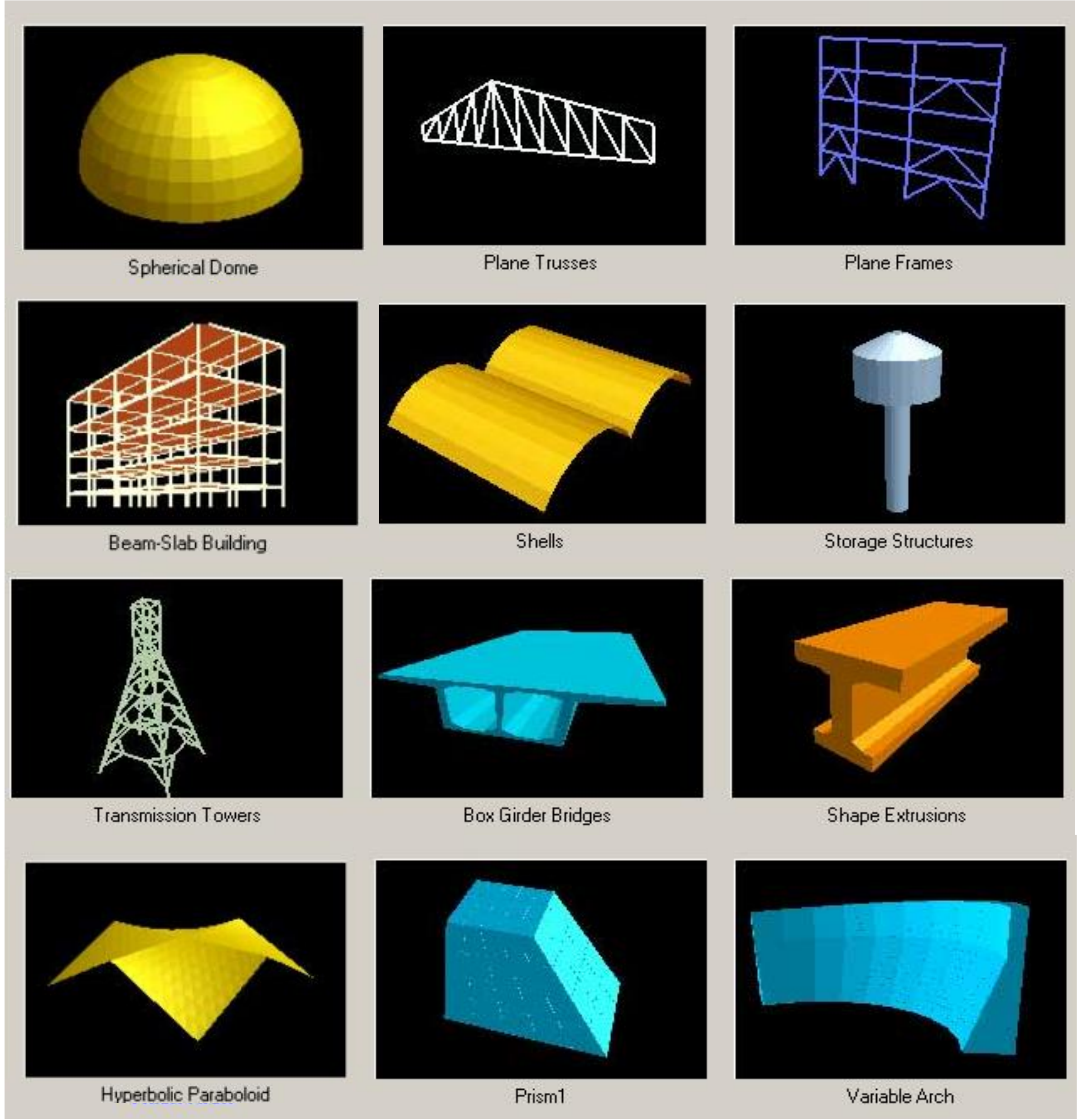
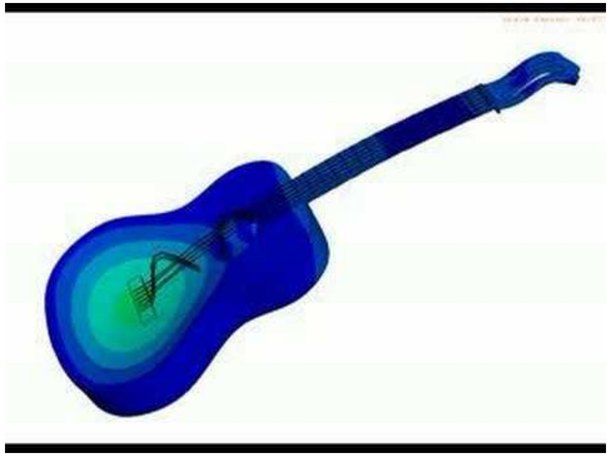
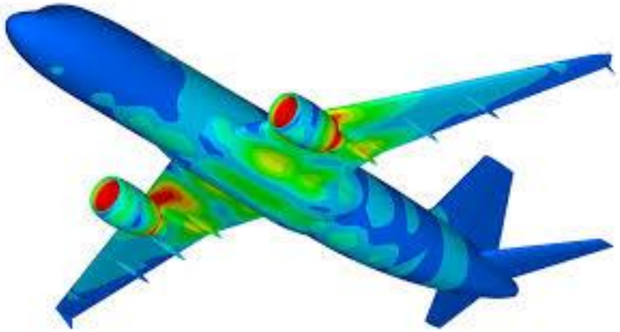
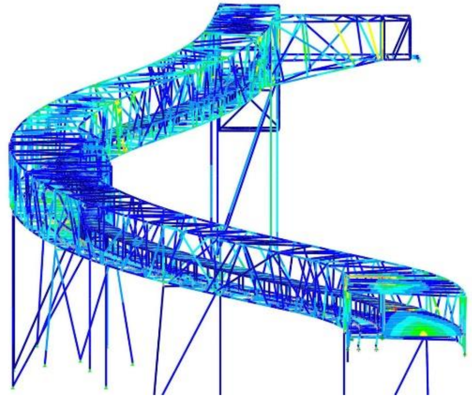
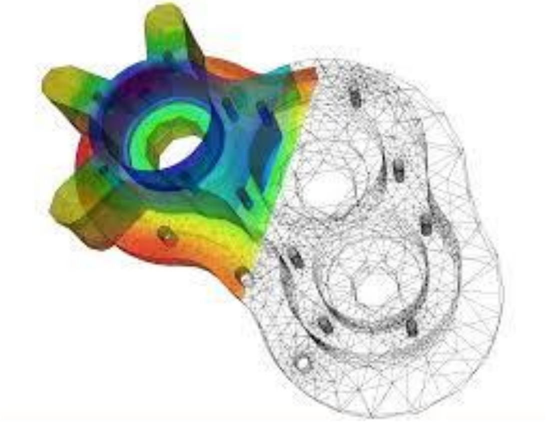
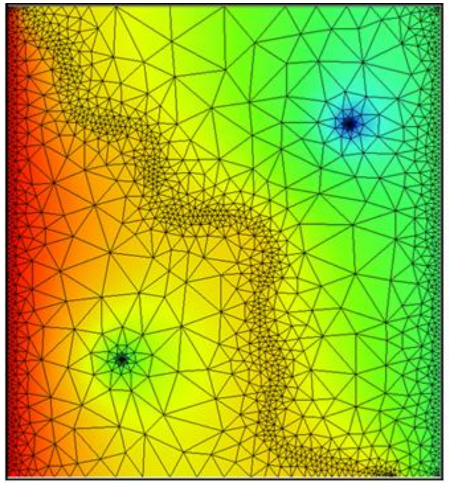
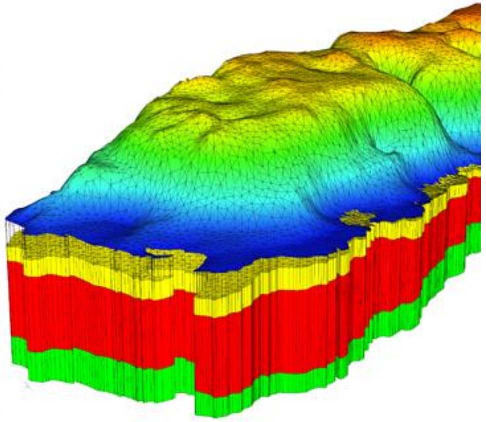


$$z = \frac{x^2}{a^2} - \frac{y^2}{b^2}, \quad \frac{x^2}{a^2} + \frac{y^2}{b^2} < 1$$




Spherical Dome
Plane Trusses
Plane Frames
Beam-Slab Building
Shells
Storage Structures
Transmission Towers
Box Girder Bridges
Shape Extrusions
Hyperbolic Paraboloid
Prism1
Variable Arch

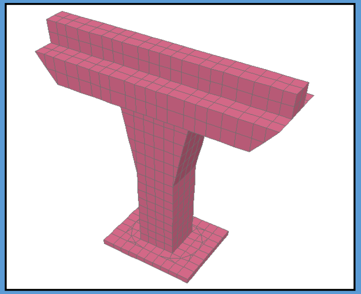
The Need for Modeling

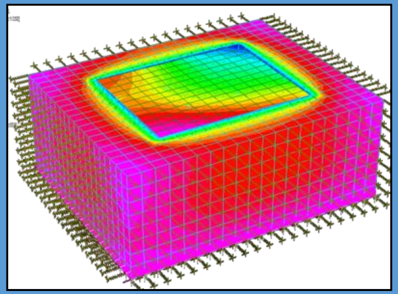
A - Real Structure cannot be Analyzed:
It can only be "Load Tested" to determine response

B - We can only analyze a "Model" of a Structure

C - We therefore need tools to Model the Structure and to Analyze the Model

We are analyzing a ***model*** of the structure, not the structure itself





Basic Modeling Principles

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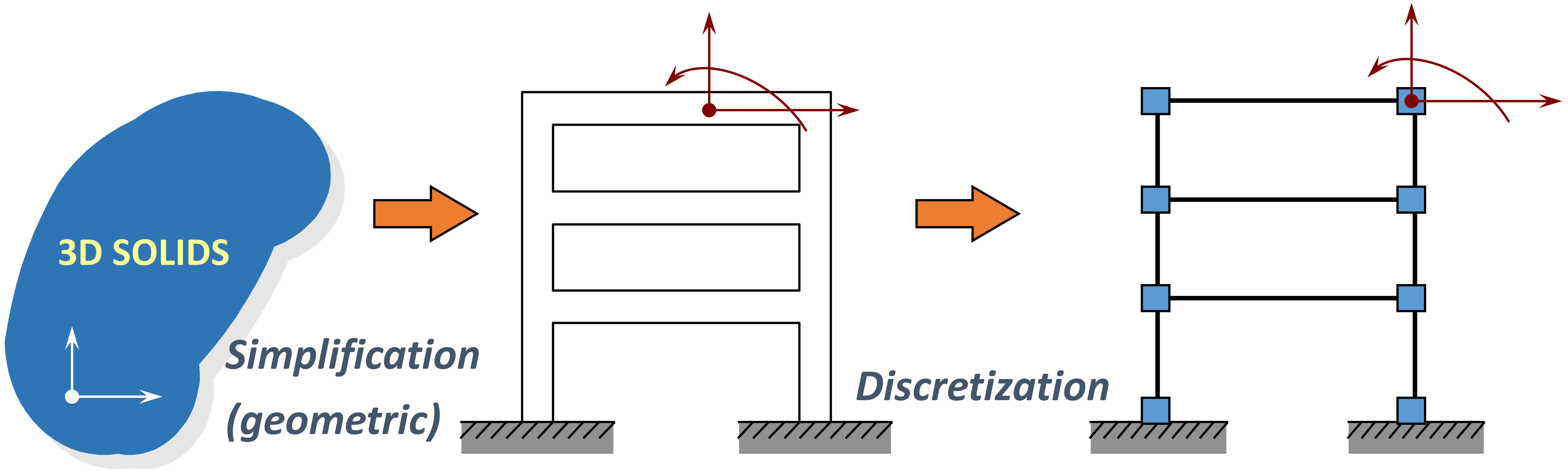
Solid – Structure Model



3D-CONTINUUM MODEL

(Governed by partial differential equations)

CONTINUOUS MODEL OF STRUCTURE

(Governed by either partial or total differential equations)

DISCRETE MODEL OF STRUCTURE

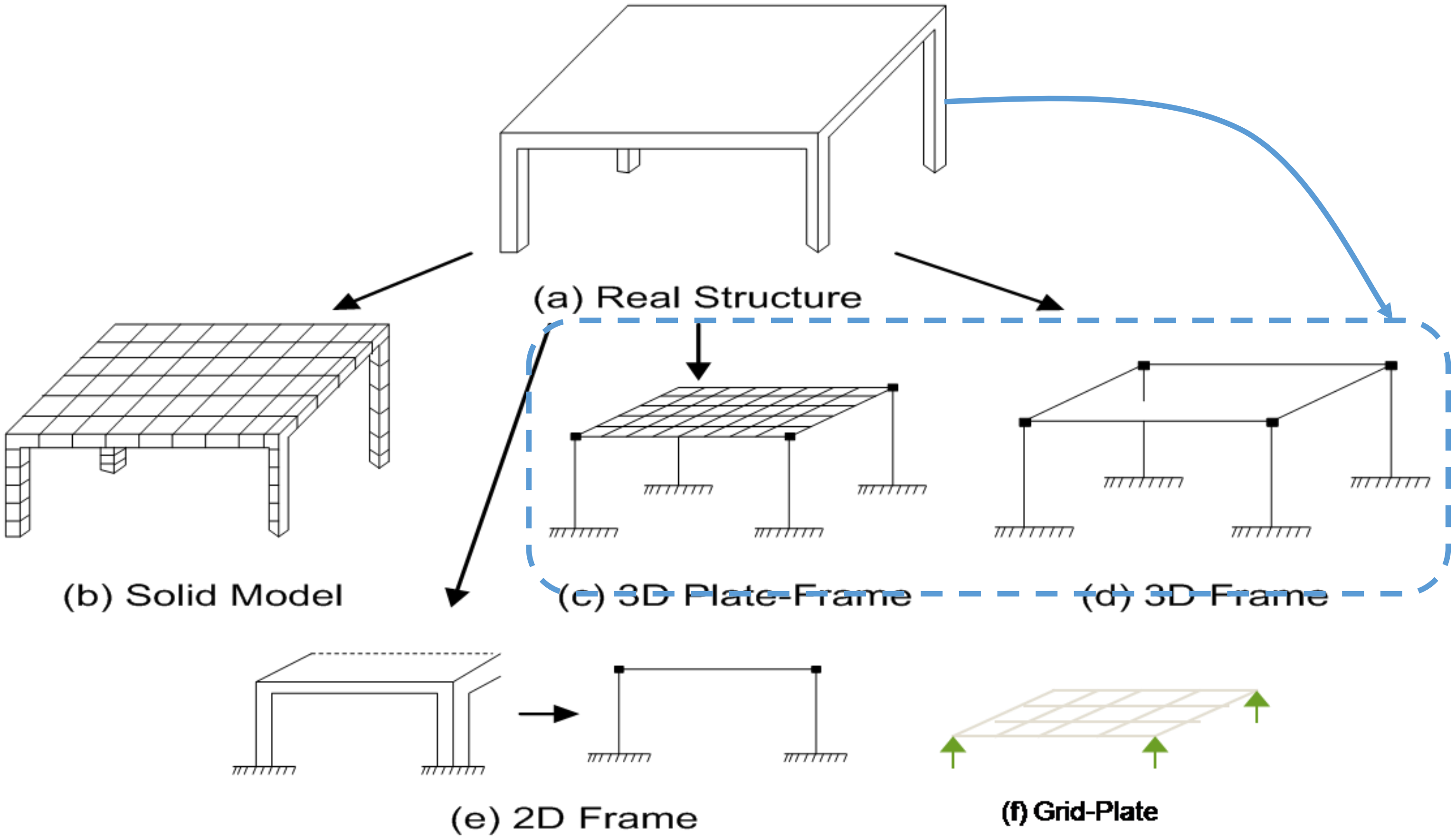
(Governed by algebraic equations)

Model what you will build

Or

Build what you modeled

Global Modeling of Structural Geometry

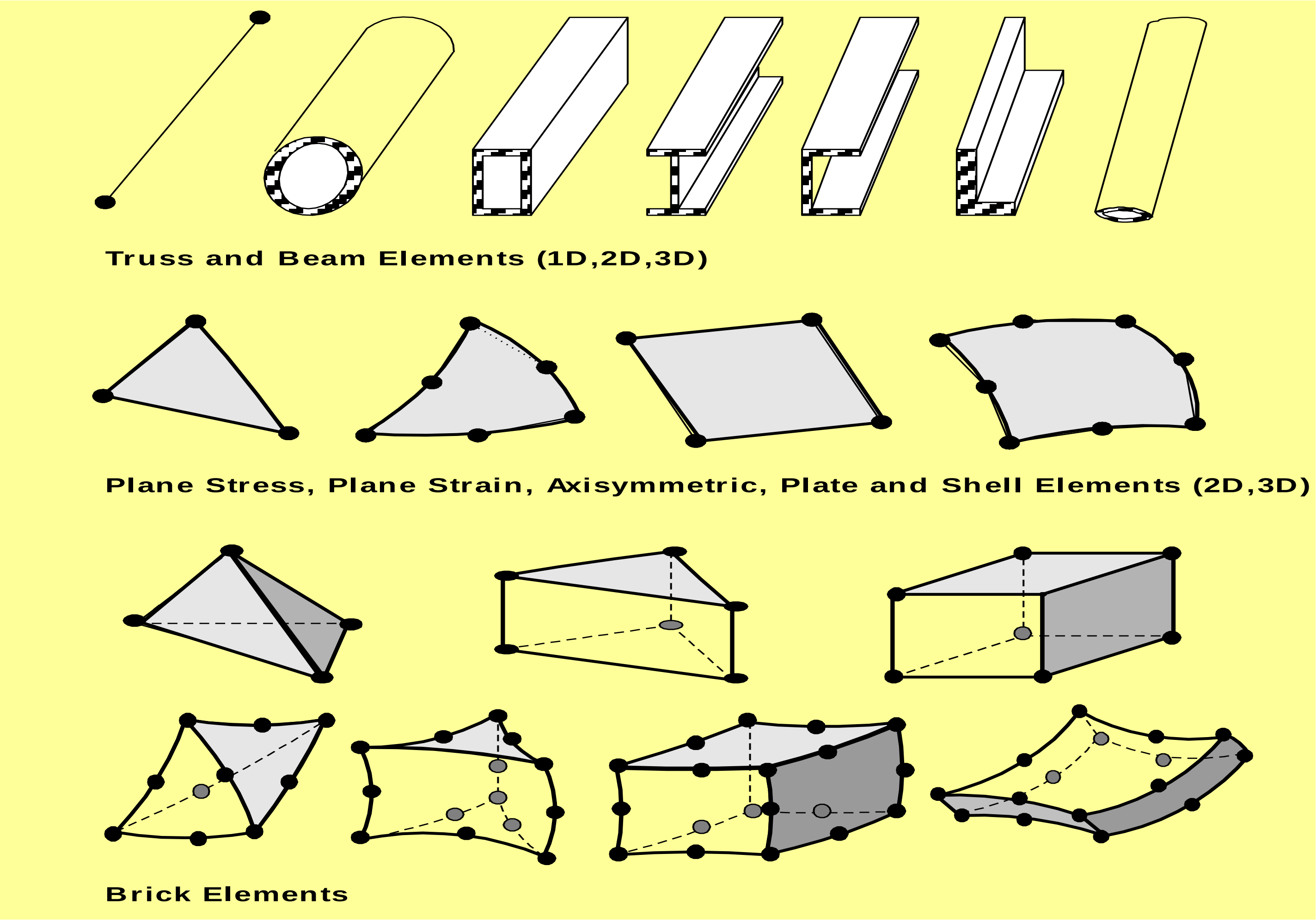


Various Ways to Model a Real Structure

Basic Categories of Finite Elements

- 0 D Elements (Joints)
- 1D Elements (Beam type)
  - Only one dimension modeled as a line, the other two dimensions are properties
  - Can be used in 1D, 2D and 2D
- 2D Elements (Plate type)
  - Only two dimensions are actually modeled as a surface, the third dimension is represented by stiffness properties
  - Can be used in 2D and 3D Model
- 3D Elements (Brick type)
  - All three dimensions are modeled as a solid
  - Can be used in 3D Model

Some Finite Elements

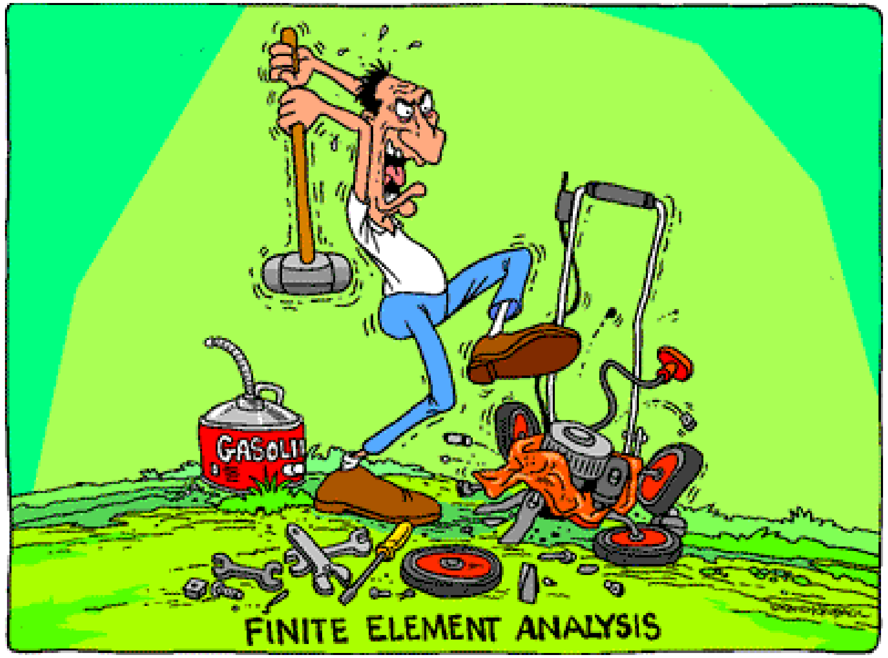


FEA Overall Process

- Prepare the FE Model
  - Discretize (mesh) the structure
  - Prescribe loads
  - Prescribe supports

- Perform calculations (solve)
  - Generate stiffness matric (k) for each element
  - Connect elements (assemble K)
  - Assemble loads (into load vector R)
  - Impose supports conditions
  - Solve equations (KD = R) for displacements

- Post-process



The Finite Element Analysis Process

Engineer

Evaluate Real Structure

Create Structural Model

Discretize Model in FE

Software

Solve FE Model

Interpret FEA Results

Engineer

Physical Significance of Results

FEA and **FEM** are the tools to get the answers,

but they do not provide the answers by themselves

Structural Modeling

Modeling of Geometry

- Materials
- Sections
- Members
- Connections

Modeling of Loads

- Mass based (Dead Load !)
- Usage Loads
- Environmental Loads

Moddeling of Boundary

- Simple
- Ground
- Other Structures

Modeling of Behavior

- Nonlinearity
- Damping
- Special

Basic Modeling Techniques

- Techniques to model Geometry
  - Direct physical representation of bridge components and parts by appropriate elements
  - Example: Frame Element, Shell Element

- Techniques to model Behavior
  - In-direct ways to model parts, components or behavior, otherwise too difficult or undesirable to model by geometry
  - Example: Restraint, Spring

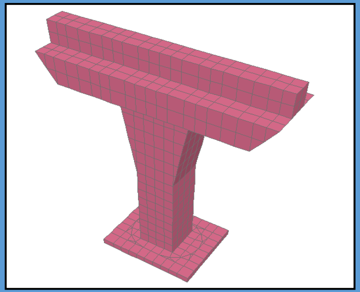
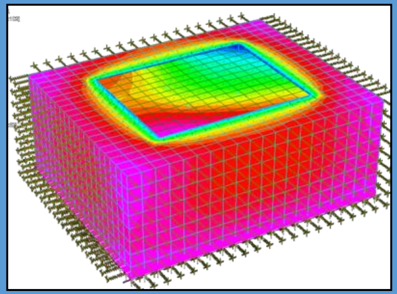
Developments in FE Modeling

- Level-1
  - Mostly developed and in use before the 1980s
  - The Nodes are defined first by coordinates and then Elements are defined that connect the nodes
- Level-2
  - Starting somewhere in the 1980s and 1990s
  - The Elements are defined directly, either numerically or graphically and the Nodes are created automatically
- Level-3
  - Current development stage
  - The structure is represented by generic Objects and the elements and Nodes are created automatically

Current Modeling Trend : Level-3

- In several software, the Graphic Objects representing the Structural Members are automatically divided into Finite Elements for analysis
- This involves
  - Object-based Modeling
  - Auto Meshing
  - Auto Load Computation
  - Auto Load Transfer
  - Converting FE results to Object results



Specific Issues in Bridge Modeling and Analysis

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Developments

- There were several specialized software for bridge modeling and analysis but they were typically developed and used by bridge designers and related departments
- These days, the developments in the core finite element solutions have almost been standardized and the focus has turned to development of software that works more closely and directly in the problem domain often hiding the underline solutions.
- These programs handle varying levels of the bridge design problem such as: modeling and analysis, integrated design, component design, substructure design, and some handles integrated geometric and structural design

Modeling Issues	Comments
The problem of the moving loads	Traditionally this problem has been handled by influence lines and influence surfaces. In computer aided analysis, this may be handled by automatic generation of multiple load cases representing moving loads. Many programs generate vehicles, traffic lanes following the road alignment; compute the corresponding post processing of results. Some programs also generate animated display of deformations and stresses.

Modeling Issues	**Comments**
The joints that must allow movement while transferring loads and forces	In bridges, the joints are often required to transfer heavy loads, while allowing movement. This presents special modeling issues for selecting appropriate connection elements and introduces non-linearity. Even a simple elastomeric bearing is difficult to model properly if right tools are not available.
The interaction between the post tensioning design and the basic behavior	Generally post tensioning is designed to counter the actions obtained from analysis. However, as many bridges are indeterminate structures, the secondary effects of pos-tensioning affect the basic response, hence complicating the analysis and design cycle.

Modeling Issues	Comments
The large proportion and scale of the structure and its components	In bridges often members are of massive proportions requiring more refined models using shell or solid elements. Also the assumptions of linear strain distribution may not hold true in many cases, especially at junctions and joints. Often several types of models may be needed to complete the analysis of some parts.
The inter dependency of construction methods, construction sequence, modeling and design	The construction sequence and construction methodology greatly affect the modeling as well as analysis, especially for segmental construction, cantilever construction, incremental launching and construction of cable stayed bridges. Not many software are equipped to handle the aspects

Modeling Issues	Comments
Large number of different load cases and combinations	Large number of load types and cases arising from environmental factors, construction sequence, vehicle movements, time dependent effects, post-tensioning etc. This also leads to a very large number of load combinations to be considered in member design.
Extensive nonlinearity inherently present in the structure itself	Several of the major bridge systems, such as cable stayed, suspension, tied arch, cantilever, stressed ribbon etc. possess high degree of non linearity due to the presence of cables, coupled effect of creep, differential movements, relaxation etc.
Complexities due to wind induced forces and motion	Many long span bridges with flexible decks are susceptible to flutter, vortex shedding and even hyper elasticity with significant interaction between structure and wind. Not many software are capable to handle wind analysis properly, and often wind tunnel tests are carried out to supplement the analysis.

Modeling Issues	Comments
Complexities in dynamic response	Due to large dimensions and often different types and scale of members, the local dynamic response of such model may affect the global dynamic response, specialty when determining primary time period, mass participation and mode extraction. Sometime multiple but independent support excitation may be needed for seismic analysis of long span bridges, with possibly different response spectrum or time history functions..
Special modeling needs for handling bearing, joints and connections	The proper modeling of joints, bearings and connections is very important for the determination of bridge response, especially for lateral; and longitudinal faces. The assumptions of simple, pin, roller or fixed supports are often insufficient. Most of the joints and bearings behave in a highly non linear manner. Only software that has the capability of handling non-linear links and connections can be used effectively.

Modeling Issues	Comments
Special problems involved in the modeling of abutments and foundation	Modeling of abutments can be significantly difficult. Active-passive response, the soil structure interaction combined with the non-linearity of the bearings, anchor blocks, restraining blocks etc. complicate the behavior and hence modeling and analysis.
Complexities in generating finite element models to account for geometric design.	The geometric design requirement such as curved decks, super elevation, vertical curves, skewed supports, merging and diverging bridge decks, very tall piers and towers, variable depth and wide multi-cell box girders, etc make the generation of models a very difficult problem. Special modeling techniques may be needed

Other Issues

- There may be other specialized issues to be considered in some bridges, such as:
  - The temperature effect caused by heat of hydration in hollow thin pier
  - Vibration of bridge due to vehicular high-speed movement as high speed train
  - High water level during construction period
  - Performance of bridge under blast loading

Cable Stayed and Suspension Bridges

- Modeling of Cables and Hangers
  - Consider the nonlinearity due to cable profile and material
  - Consider the pre-tensioning and multiple stressing cases
  - Consider the partial fixity at anchors and local anchor forces
  - Consider the dynamic response, flutter, resonance etc
  - Local modeling and design of saddles and anchors, including fatigue

- Modeling of Deck
  - The extent of deck model and level of detail. Several models may be needed
  - Composite action, transverse load transfer, tensional stiffness and modeling
  - Axial forces in the entire deck, stiffening and softening

Cable Stayed and Suspension Bridges

- Modeling of Pylons
  - Modeling the flexibility and stability
  - Partial construction loading and unbalanced conditions
  - Interaction of pylons and cables
  - Stability, P-Delta, Buckling, Verticality etc.

- Modeling of Expansion Joint systems
  - Accommodating Large movements (as much as 0.5 m or more)
  - Transfer of large forces

Cable Stayed and Suspension Bridges

- Modeling of Foundations
  - Very large loads and moments from pylons
  - Modeling of water waves, collision etc
  - Soil-structure-water interaction
  - Anchors and dead-man modeling and design

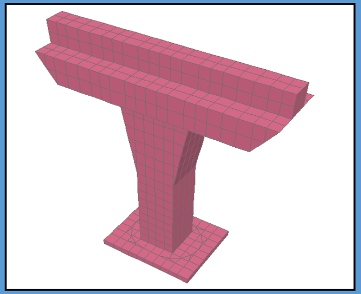
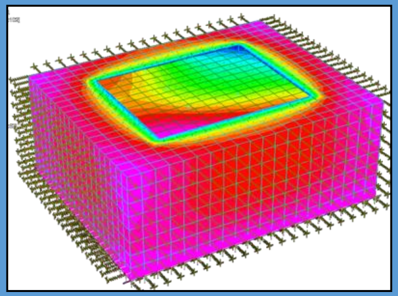
Computer Aided Solution

Design Step	Computer Application Type
Conceptual Design	Expert Systems, Artificial Analysis Systems, Value Engineering,
Preliminary Design	Standard Database and Libraries, Expert Systems
Geometric Design	Alignment and functional design programs
Modeling and Analysis	Finite Element Analysis
Component Design	RC Design, Steel Design, PSC Design, Special Design, Girder Design, Slab Design, Pier Design
Detailing	Automated Detailing, Computer Aided Drafting
Drafting	Computer Aided Drafting
Documentation	Analysis and Design Programs, Word Processing, Spread Sheets, Database

Computer Aided Solution

Design Step		Sample Software
Conceptual Design		ANSYS/Civil FEM Bridges
Preliminary Design		ANSYS/Civil FEM Bridges
Geometric Design		SAP 2000 Bridge Modular, ANSYS/Civil FEM Bridges, Bridgade, LEAP Bridge, QConBridge, SAM, MIDAS-WinBDS, RM2006
Modeling and Analysis		SAP 2000 Bridge Modular, ANSYS/Civil FEM Bridges, Bridgade, LUSAS Bridge, LEAP Bridge, RM2006, SAM, STRAP AutoBridge, ACES, MIDAS-WinBDS
Component Design		SAP 2000 Bridge Modular, ANSYS/Civil FEM Bridges, RM2006, LUSAS Bridge, LEAP Bridge, QConBridge, SAM, STRAP AutoBridge, ACES, MIDAS-WinBDS
Detailing		SAP 2000 Bridge Modular, ANSYS/Civil FEM Bridges, Bridgade, RM2006
Drafting		LEAP-Bridge, MIDAS-WinBDS
Documentation		MSWord. Excel, Access, SAP 2000 Bridge Modular, Bridgade, LEAP Bridge, QConBridge, ACES, MIDAS-WinBDS, RM2006



Geometric Modeling Techniques

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Generating Models

- Graphical Modeling Tools to Draw Elements
- Numerical Generation
- Mathematical Generation
- Copy and Replication
- Subdivision and Meshing
- Mesh Editing
- Geometric Extrusions
- Parametric Generation

Extrusions

- Sweep selected objects through space to create new objects of higher dimension.
- The process of extrusion increases the dimensional space of an existing object by one.
- Line objects are of one dimension that can be generated from a dimensionless point object.
- Two-dimensional area or plate/shell can be generated from a one-dimensional line object.
- This feature is especially suited to creating solid elements form plate/shells, plate/shell elements from beams and beams/columns from point/nodes.

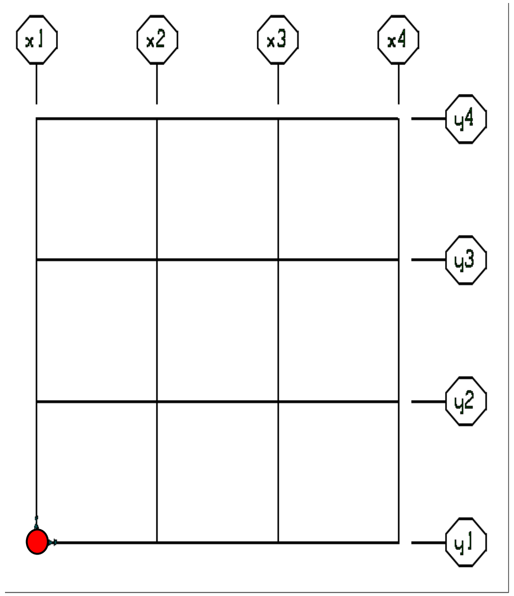
Extrusions

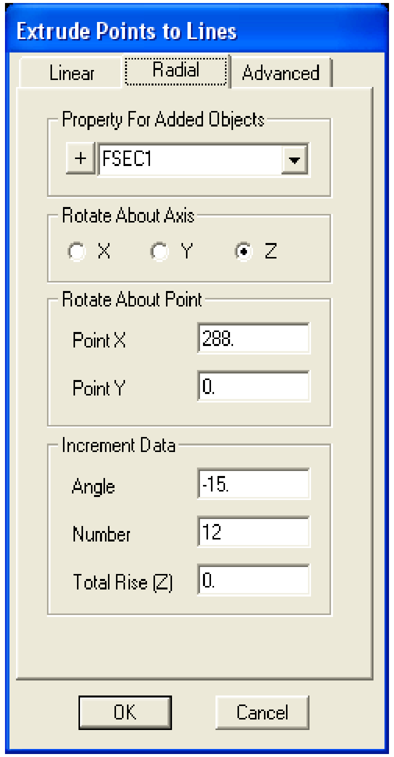
- Convert lower level object to higher level
  - Point to Line
  - Line to Area
  - Curve to Surface
  - Area To Solid
  - Surface to Volume

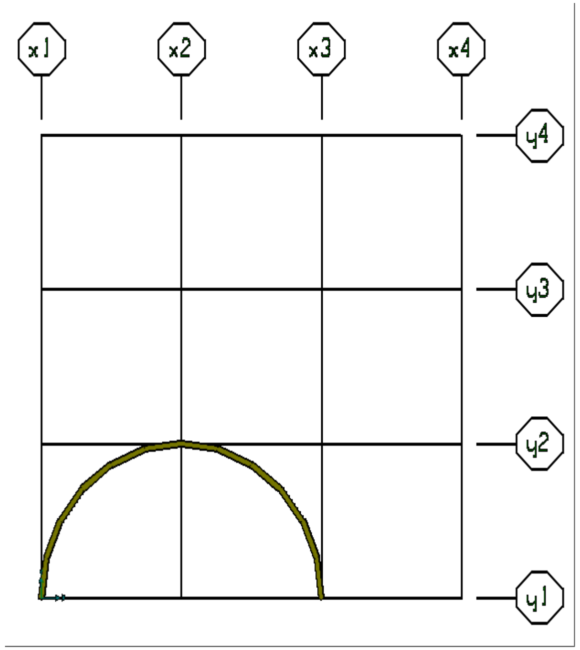
- Linear
  - Global
  - Along Path

- Radial
  - Global
  - About Axis

Extrude

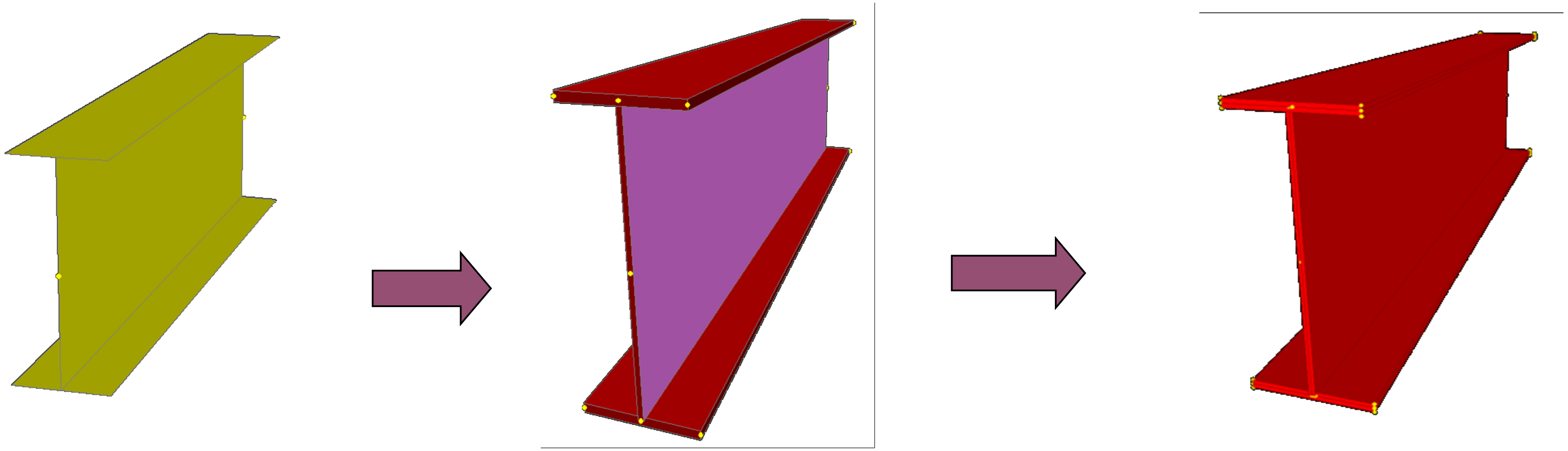






Model circular shaped beam by radial extrusion of point object

Extrude



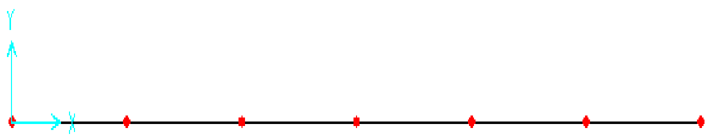
Comprised of one line object

Comprised of three area objects

Comprised of six solid objects

Convert line to area and area to solid

Extrude Line to Plate Objects



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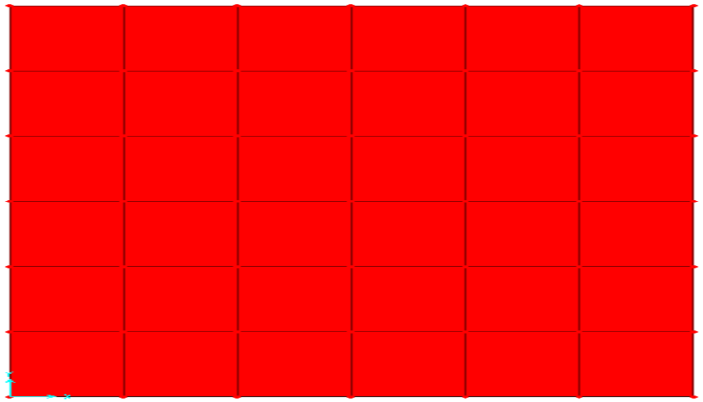
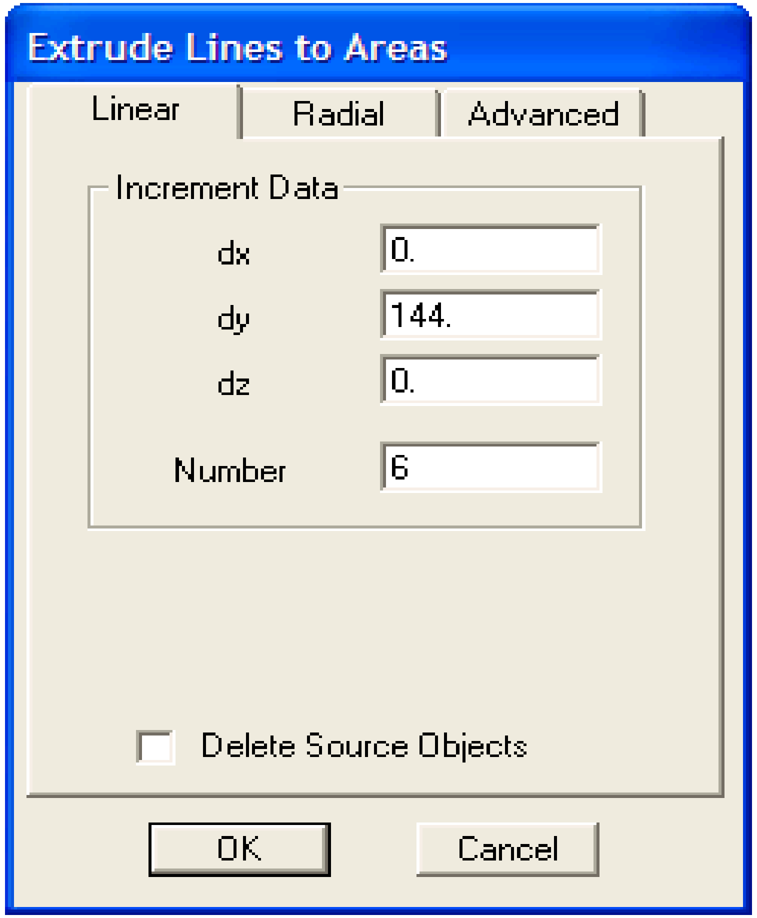
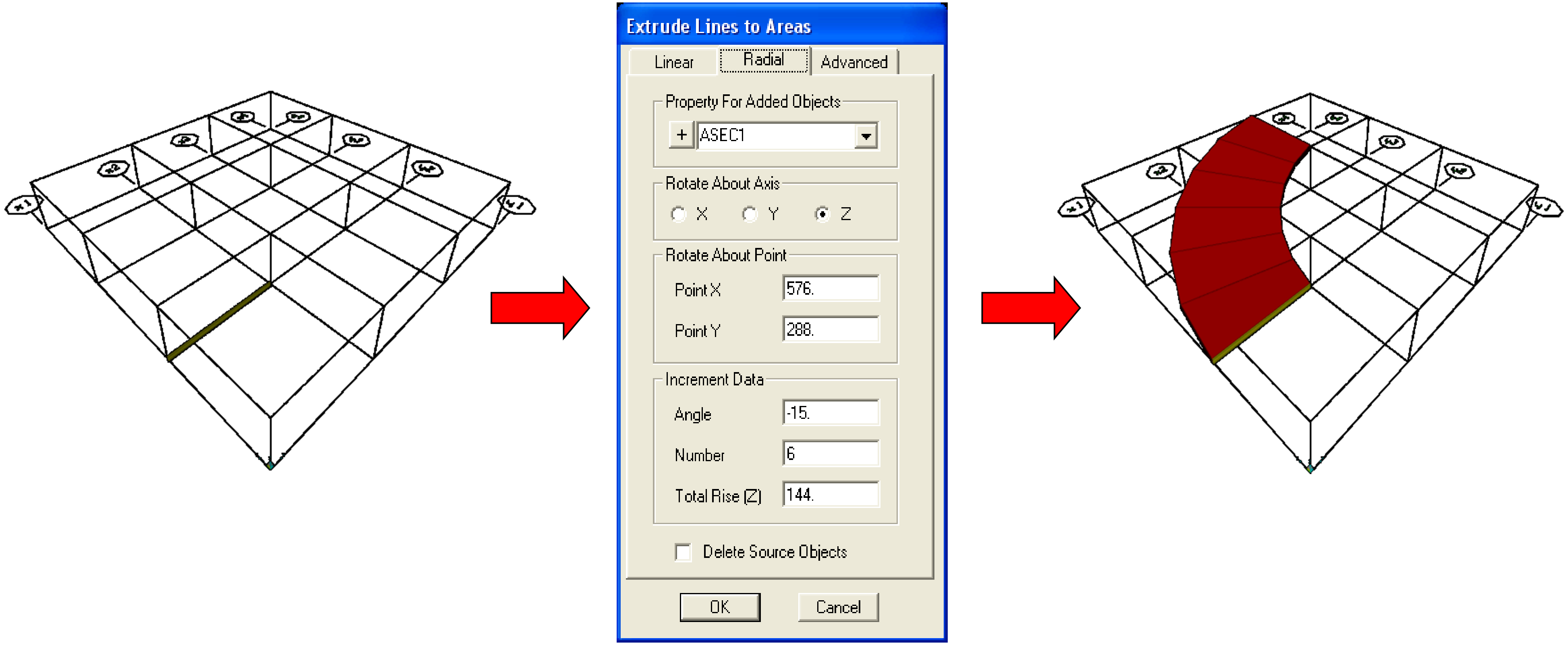


Result



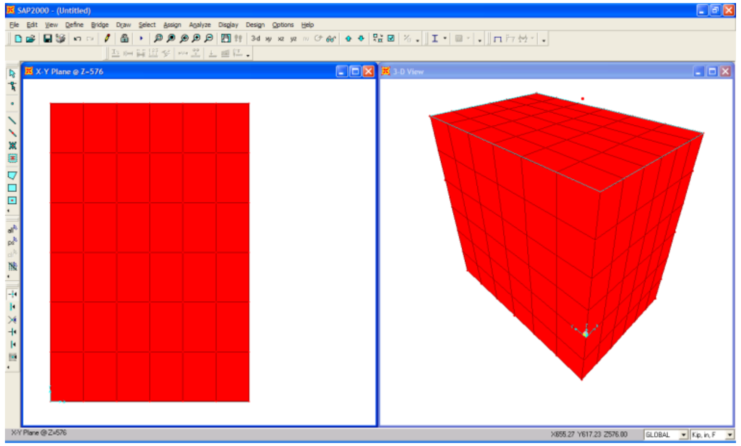
Input

Extrude



Model circular shaped ramp by radial extrusion of line object

Extrude Area to Solids



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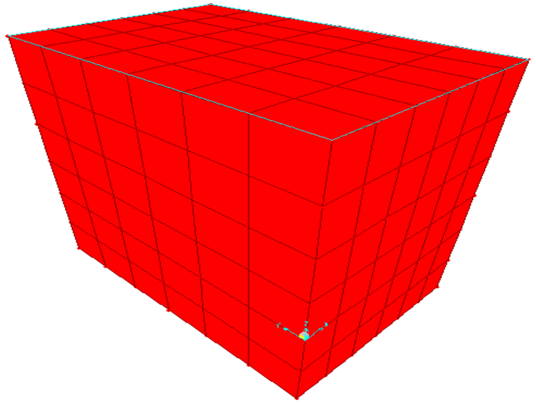
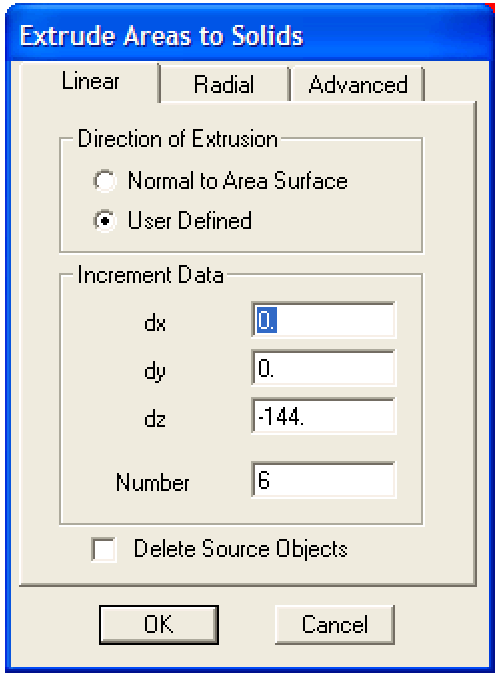
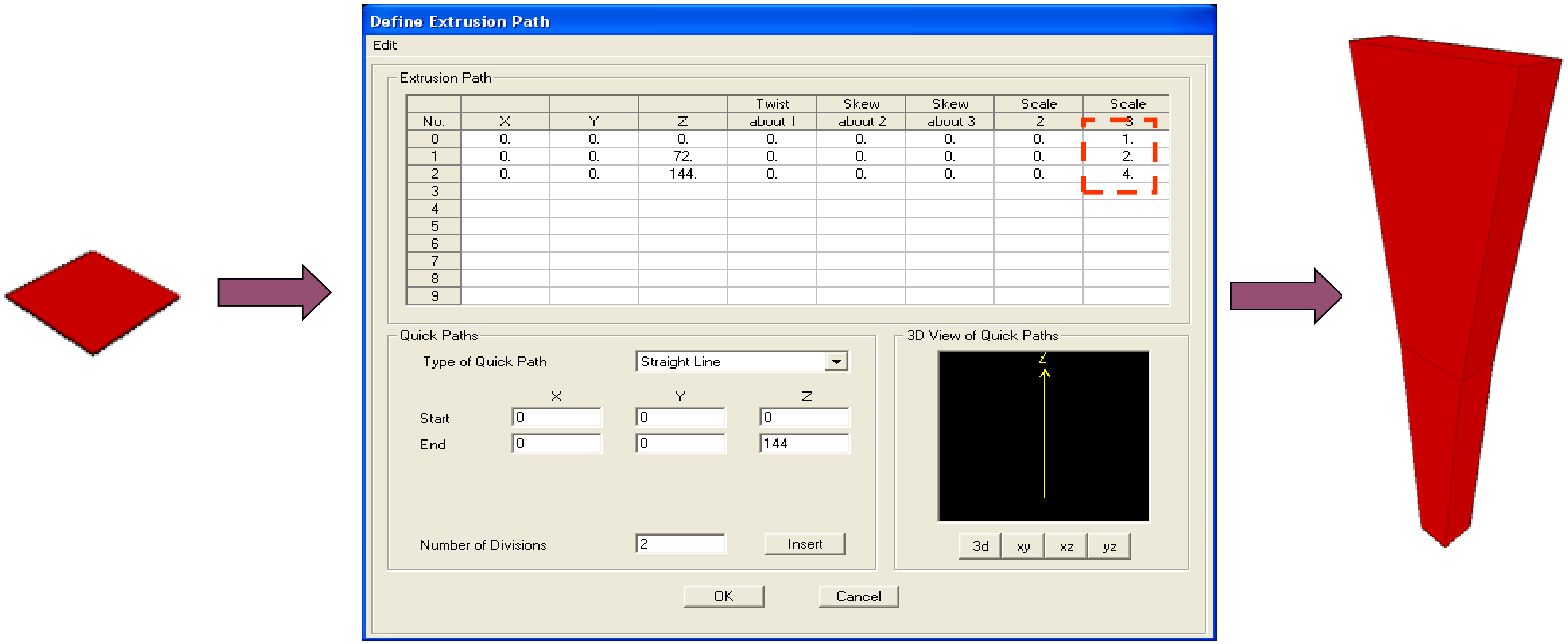


Result



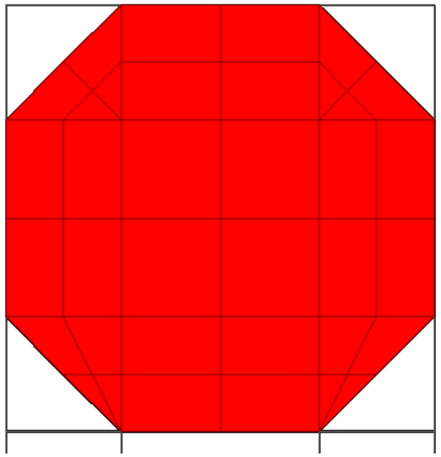
Input

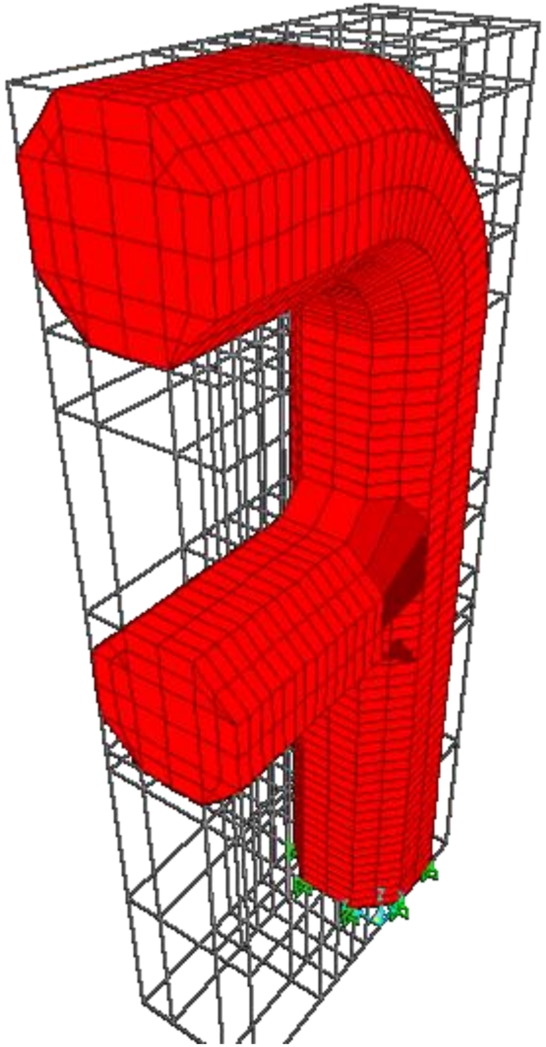
Extrude



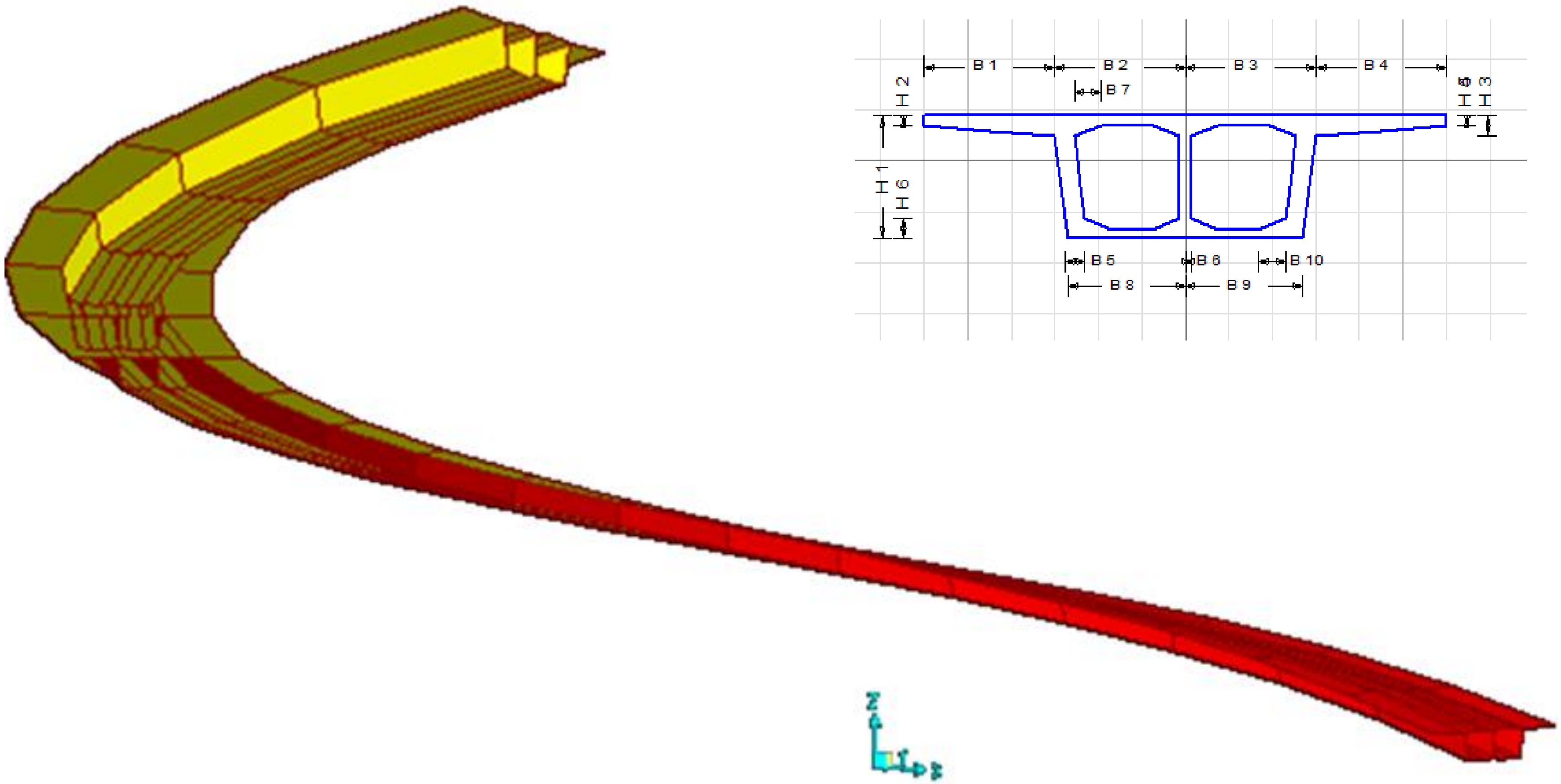
Model the member with varying cross section by advanced extrusion of area object

Other Examples of Extrusions





Other Examples of Extrusions



Automated Meshing

- Object Based model would require that the Object is converted to Elements Automatically
- Automated meshing bridges the gap between Modeling Objects and Finite Elements
- Automated meshing also helps in Automated Load Calculation and Application

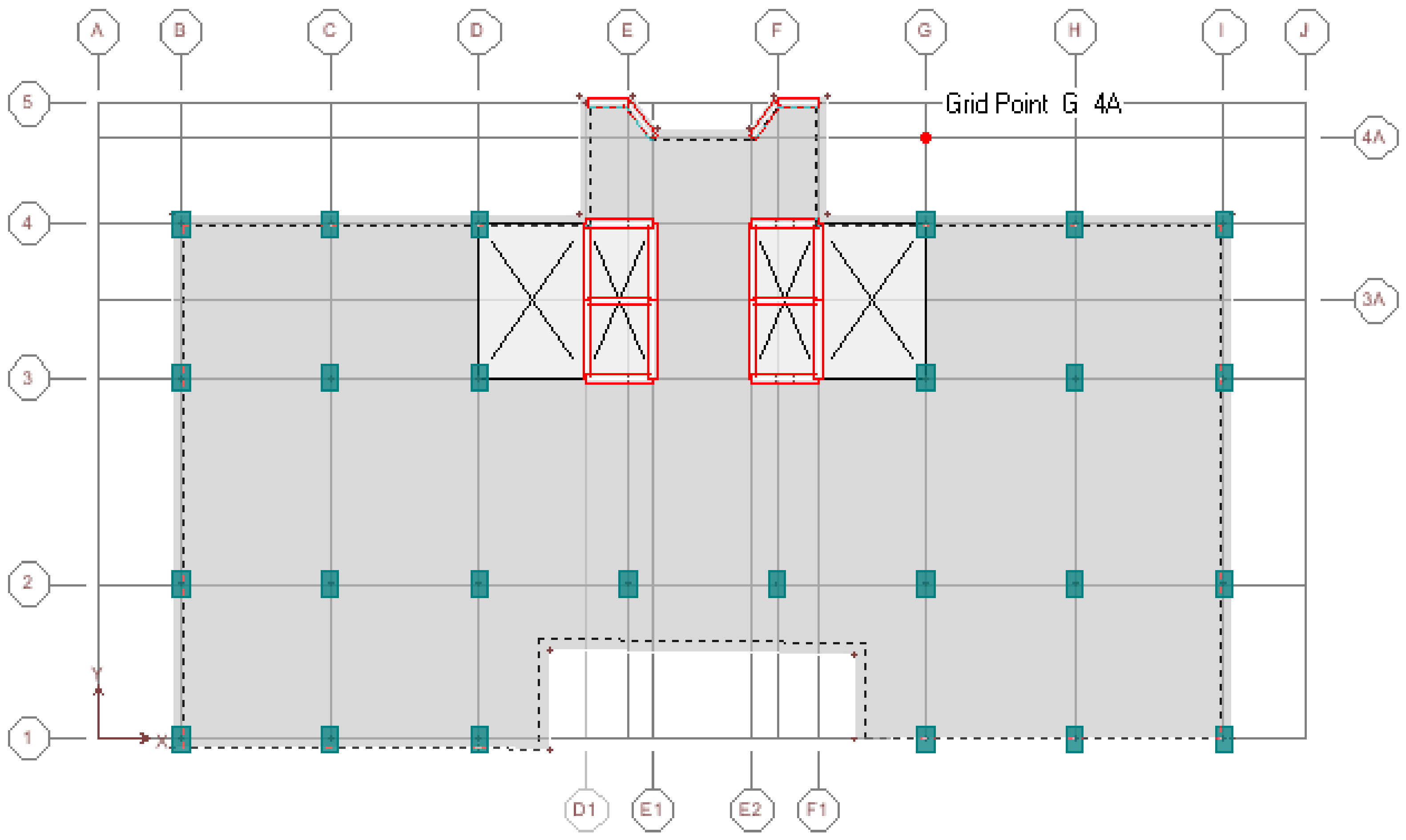
Automated Meshing

- Draw or define overall structure geometry in terms of Physical Objects
- The program uses specified rules to convert Objects to valid Finite Element Mesh
- Analysis is carried out using Elements and results presented in terns of Objects
- Meshing does not change the number of objects in the model

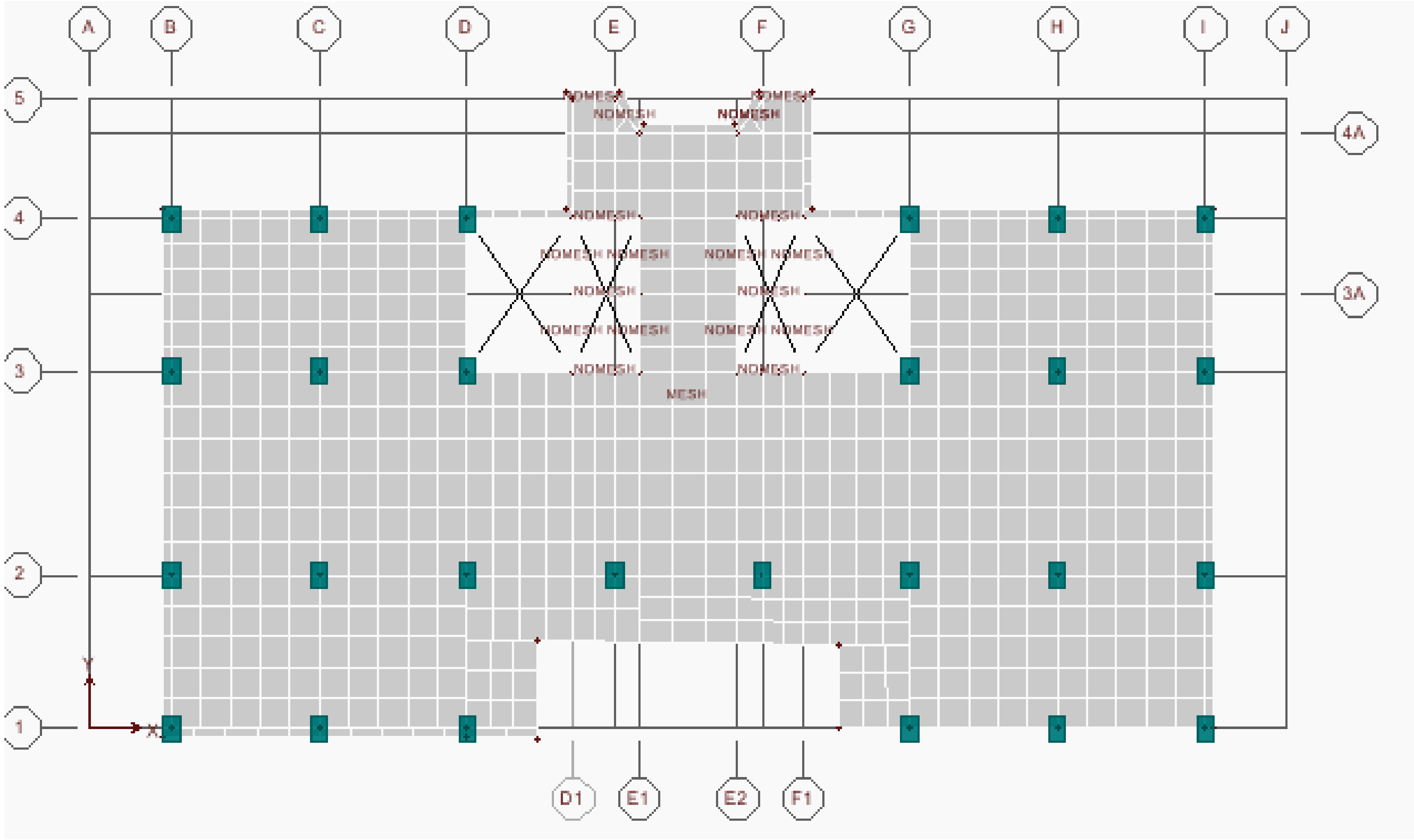
Automated Meshing

- Automatic Meshing of Line Objects
  - Where other Line Objects attach to or cross them
  - Locations where Point Objects lie on them.
  - Locations where Area objects cross them
- Automatic Meshing of Area Objects
  - Auto Meshing of area objects is much more complex than Line Objects
  - Area objects are meshed using several criteria and is often software dependent

Single Slab Object



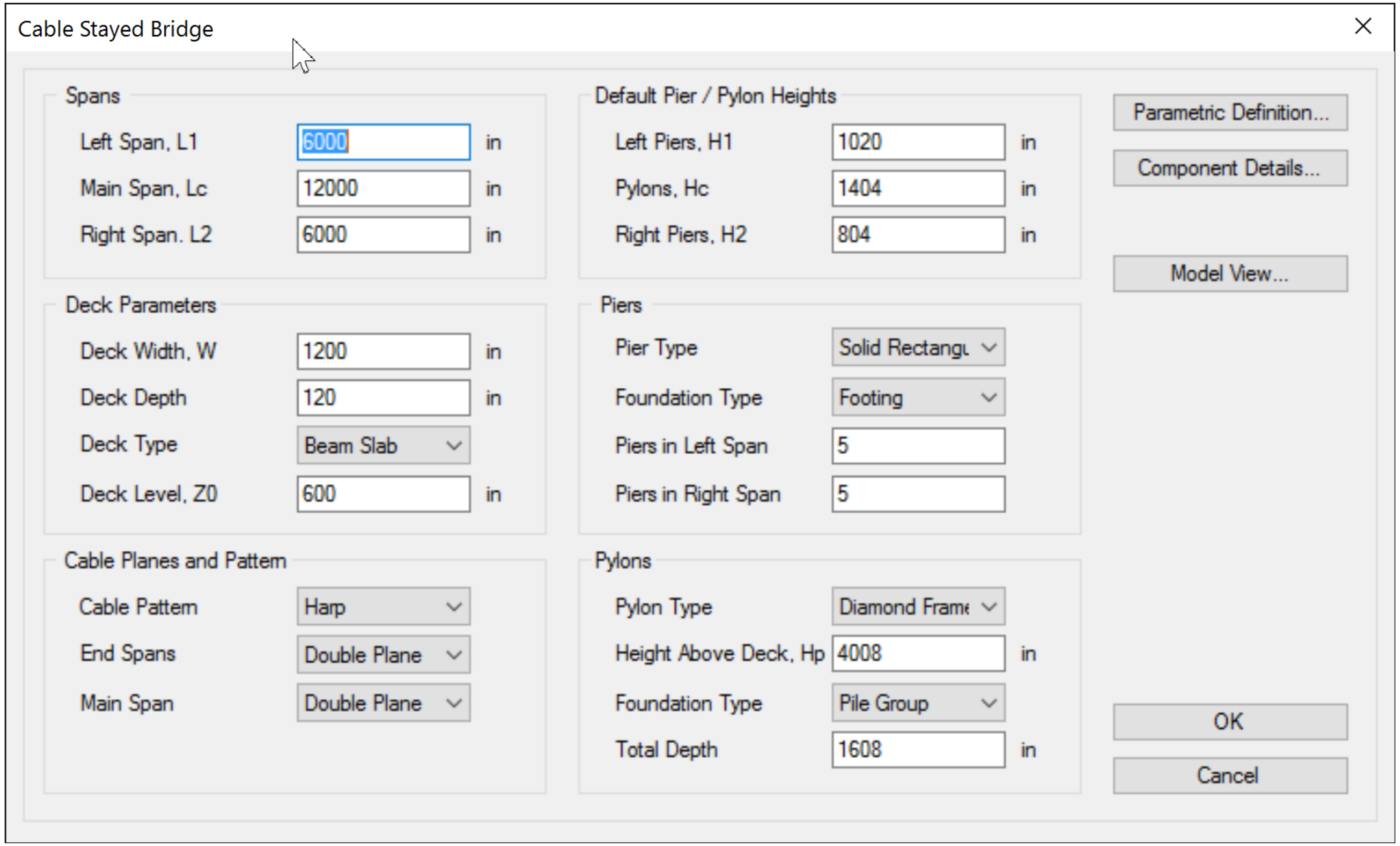
Auto Meshed Slab

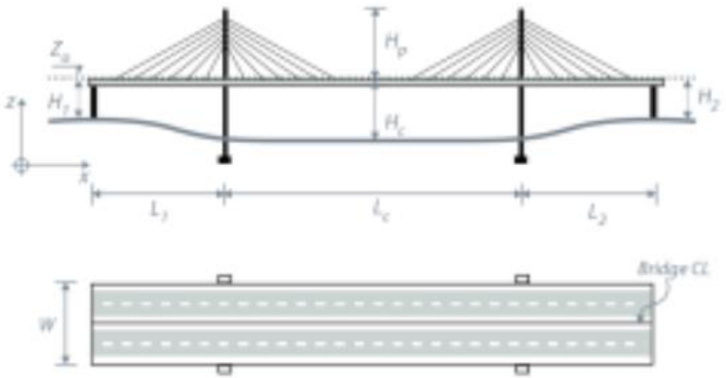


Parametric Structures

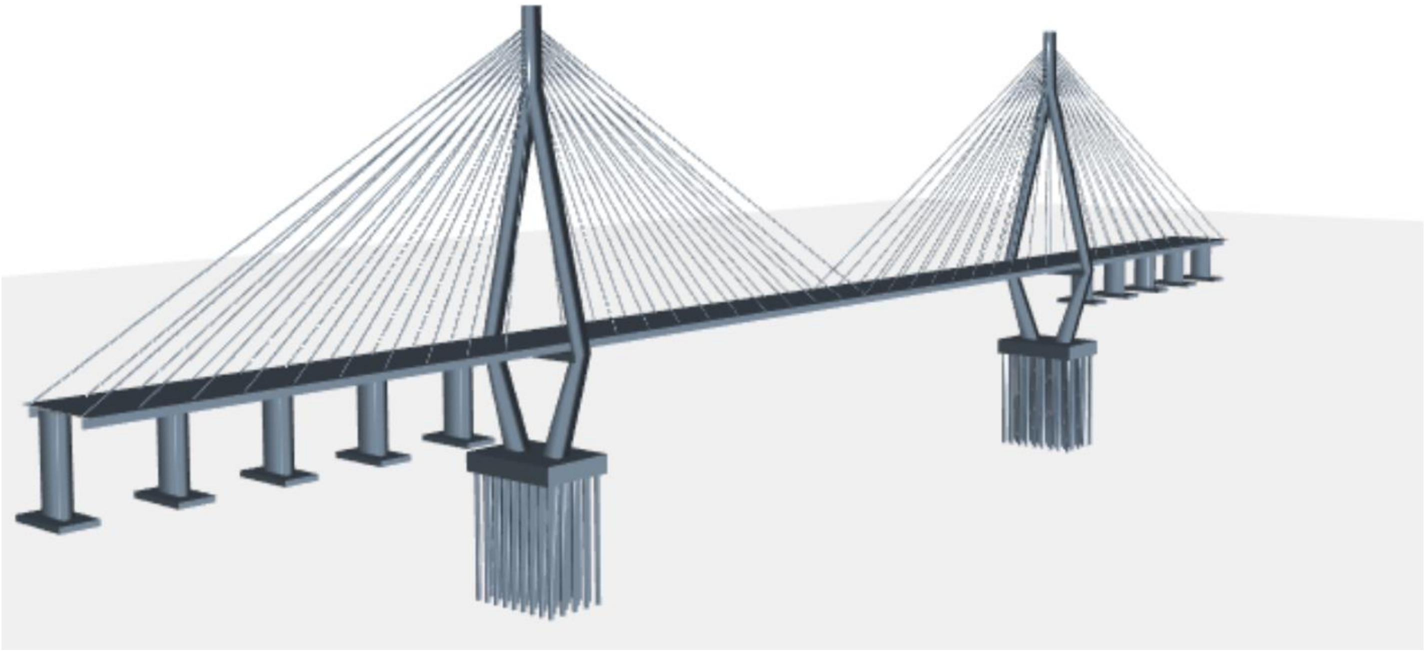
- Add objects or structures from template files or parametrically defined entities
- Easy to construct models
- Saves Time
- Capable of generating complex structural models

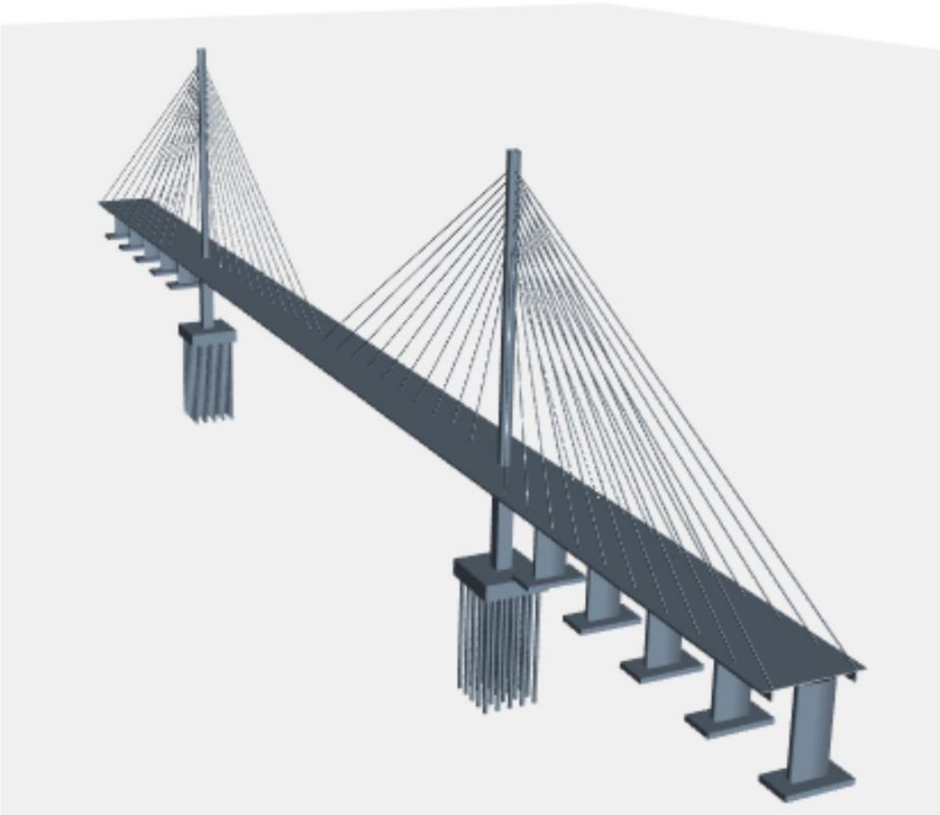
Parametric Cable Stayed Bridge



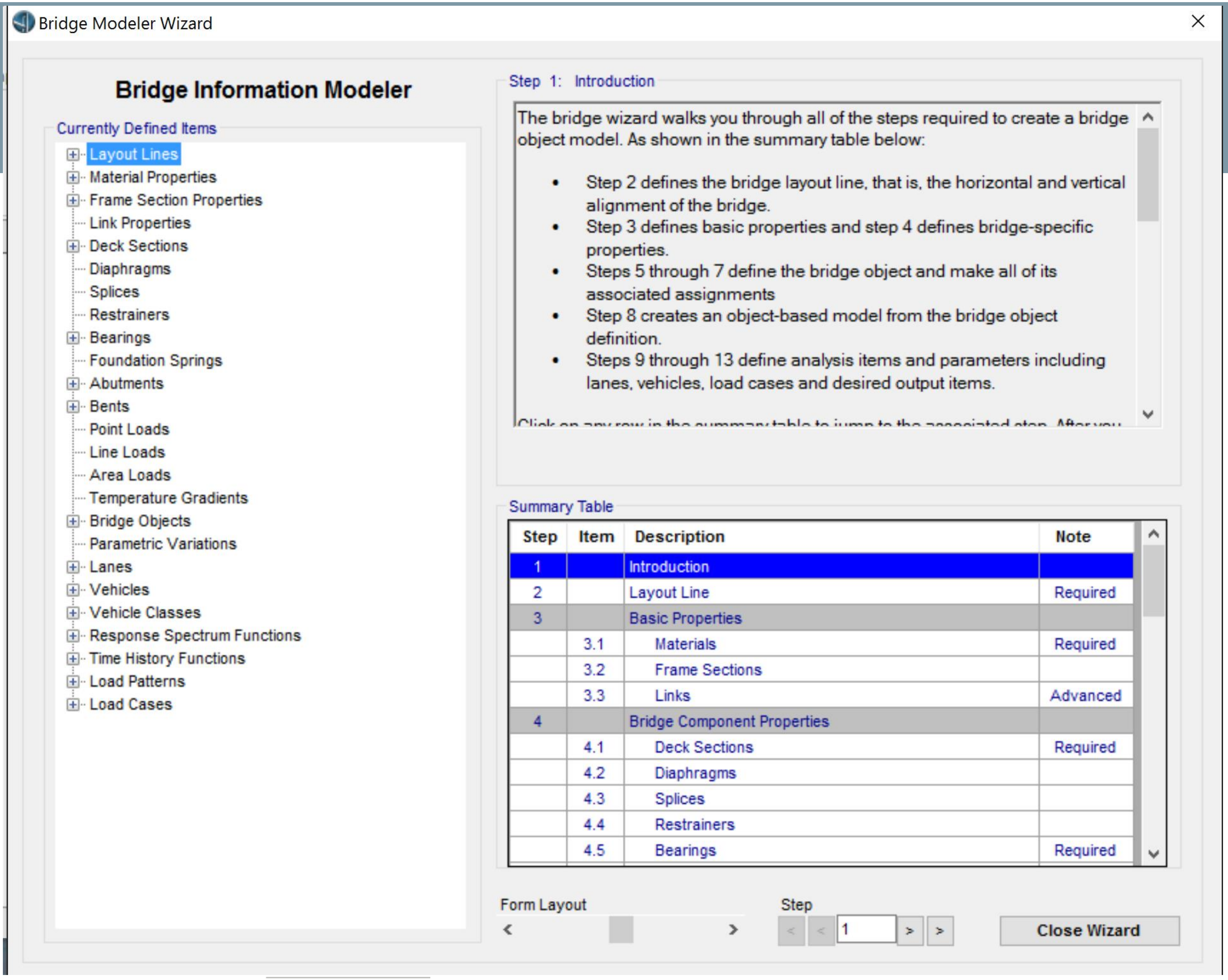


Parametric Bridge Models

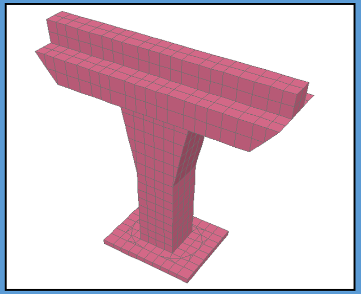
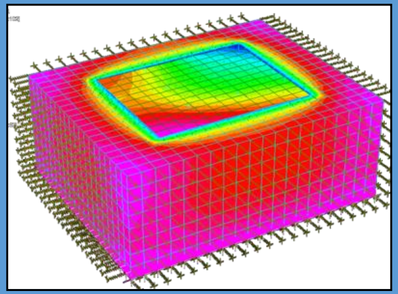




Wizards


Bridge Modeler Wizard
Bridge Information Modeler
Currently Defined Items
Layout Lines
Material Properties
Frame Section Properties
Link Properties
Deck Sections
Diaphragms
Splices
Restrainers
Bearings
Foundation Springs
Abutments
Bents
Point Loads
Line Loads
Area Loads
Temperature Gradients
Bridge Objects
Parametric Variations
Lanes
Vehicles
Vehicle Classes
Response Spectrum Functions
Time History Functions
Load Patterns
Load Cases
Step 1: Introduction
The bridge wizard walks you through all of the steps required to create a bridge object model. As shown in the summary table below:
Step 2 defines the bridge layout line, that is, the horizontal and vertical alignment of the bridge.
Step 3 defines basic properties and step 4 defines bridge-specific properties.
Steps 5 through 7 define the bridge object and make all of its associated assignments
Step 8 creates an object-based model from the bridge object definition.
Steps 9 through 13 define analysis items and parameters including lanes, vehicles, load cases and desired output items.
Summary Table
Step Item Description Note
1 Introduction
2 Layout Line Required
3 Basic Properties
3.1 Materials Required
3.2 Frame Sections
3.3 Links Advanced
4 Bridge Component Properties
4.1 Deck Sections Required
4.2 Diaphragms
4.3 Splices
4.4 Restrainers
4.5 Bearings Required
Form Layout
Step
1
Close Wizard



Modeling of Connections and Behavior

Dr. Naveed Anwar

AIT Solutions

Basic Modelling Techniques-Behaviour

- Constraints
- Restraints
- Springs
- Nonlinear Links
- Nonlinear Hinges
- Element End Conditions
- Dummy elements

Restrained Degrees of Freedom

- If the displacement of a joint along any one of its available degrees of freedom is known, such as at a support point, that degree of freedom is restrained.

- The known value of the displacement may be zero or non-zero, and may be different in different Load Cases.

- The restraint reaction is determined by the analysis.

- Unavailable degrees of freedom are essentially restrained.

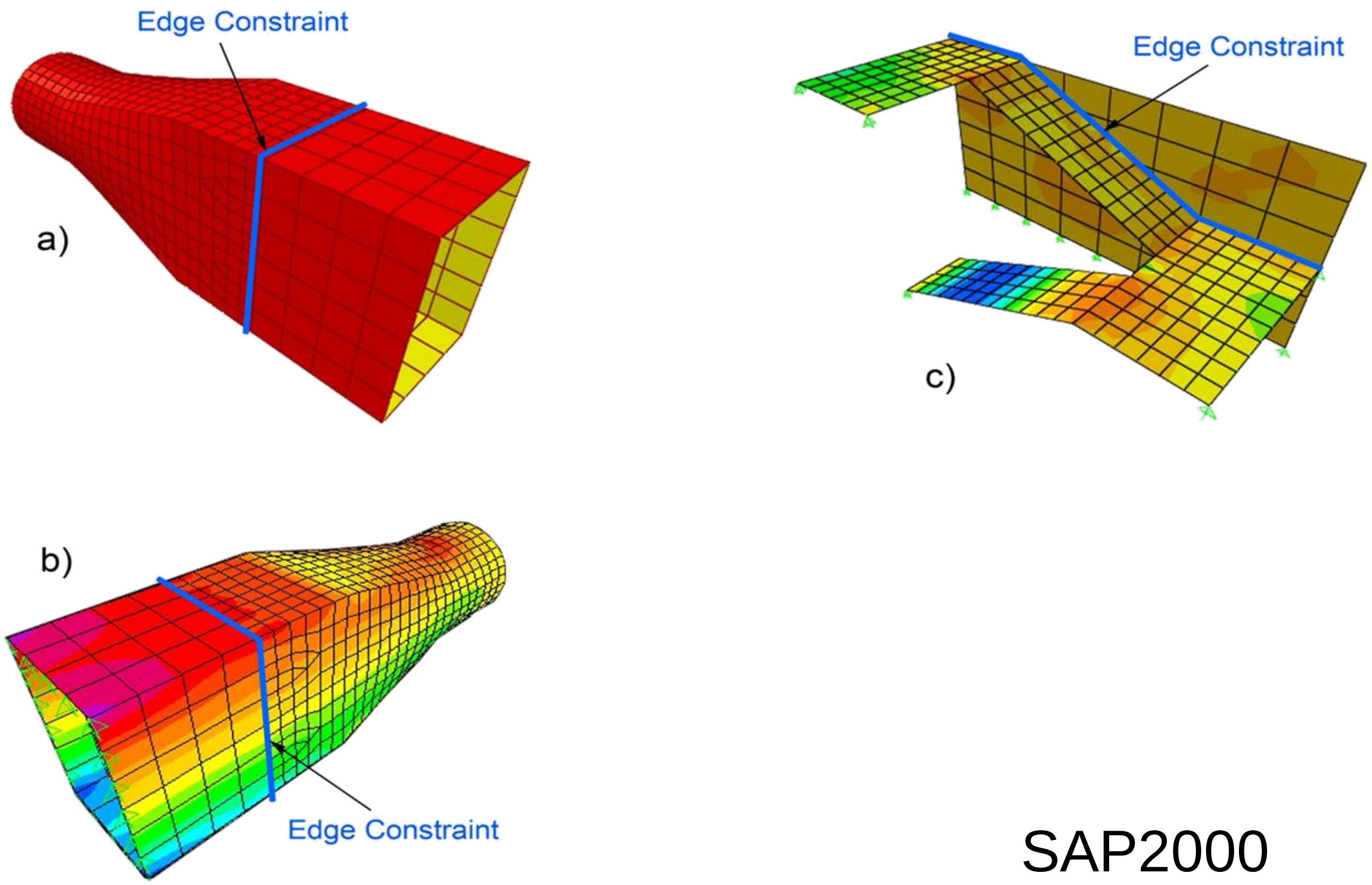
Constraints

- A constraint consists of a set of two or more constrained joints.
- The displacements of each pair of joints in the constraint are related by constraint equations.
- The types of behavior that can be enforced by constraints are:
  - Rigid-body behavior
    - Rigid Body: fully rigid for all displacements
    - Rigid Diaphragm: rigid for membrane behavior in a plane
    - Rigid Plate: rigid for plate bending in a plane
    - Rigid Rod: rigid for extension along an axis
    - Rigid Beam: rigid for beam bending on an axis
  - Equal-displacement behavior
  - Symmetry and anti-symmetry conditions

Constraints – Direct Links

- A constraint consists of a set of two or more constrained joints whose displacement is linked
- Rigid-body behavior
  - Rigid Body: fully rigid for all displacements
  - Rigid Diaphragm: rigid for membrane behavior
  - Rigid Plate: rigid for plate bending in a plane
  - Rigid Rod: rigid for extension along an axis
  - Rigid Beam: rigid for beam bending on an axis
- Equal-displacement behavior
- Symmetry and anti-symmetry conditions

Special Edge Constraints

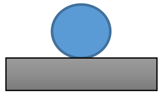


SAP2000

Link/Support Element

- 1 Joint Link Element

- 2 Joint Link Element



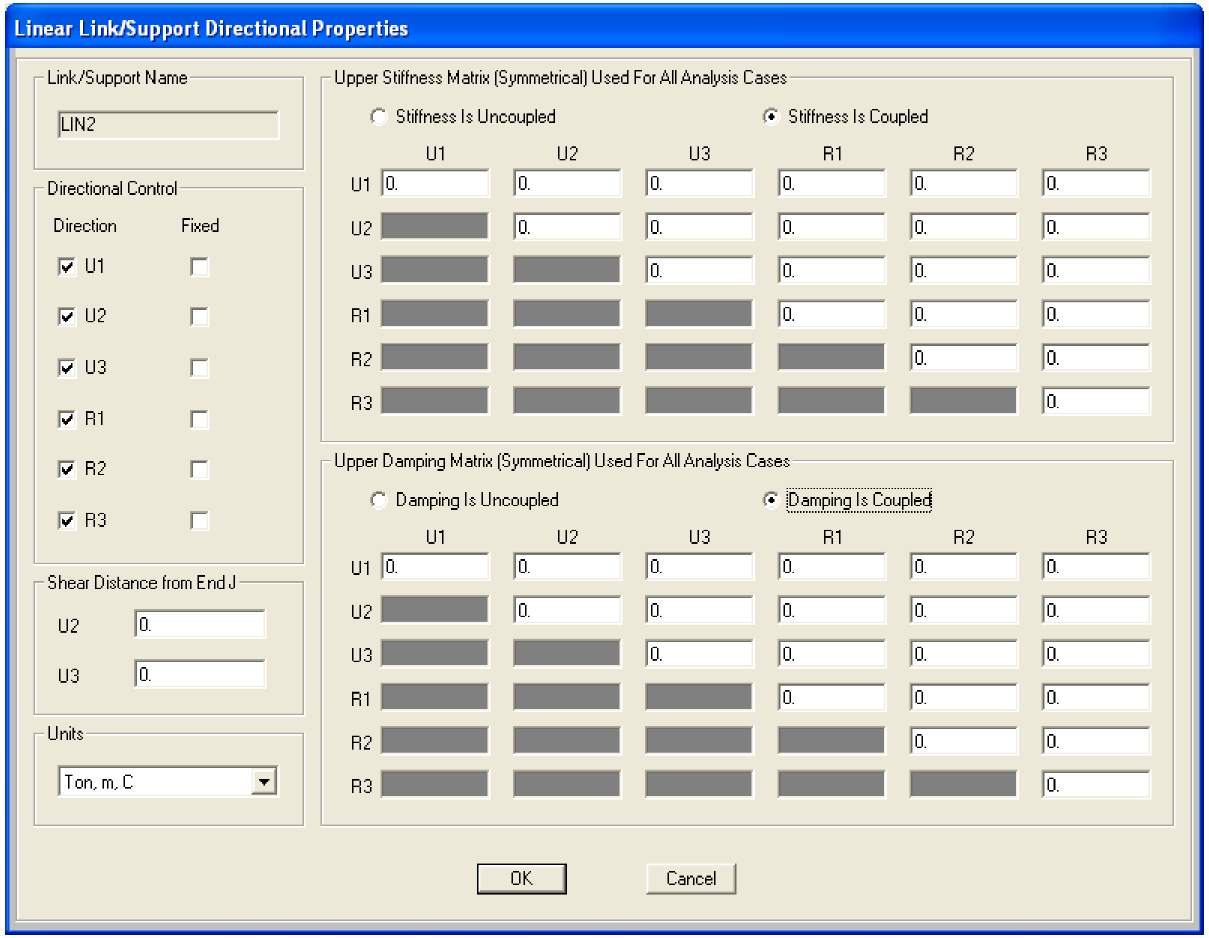
Link/Support Element

- Linear
- Multilinear Elastic
- Multilinear Plastic
- Damper
- Gap
- Hook
- Plastic (Wen)
- Rubber Isolator
- Friction Isolator
- T/C Friction Isolator
- Frequency-Dependent Link/Support Properties

Link/Support Element

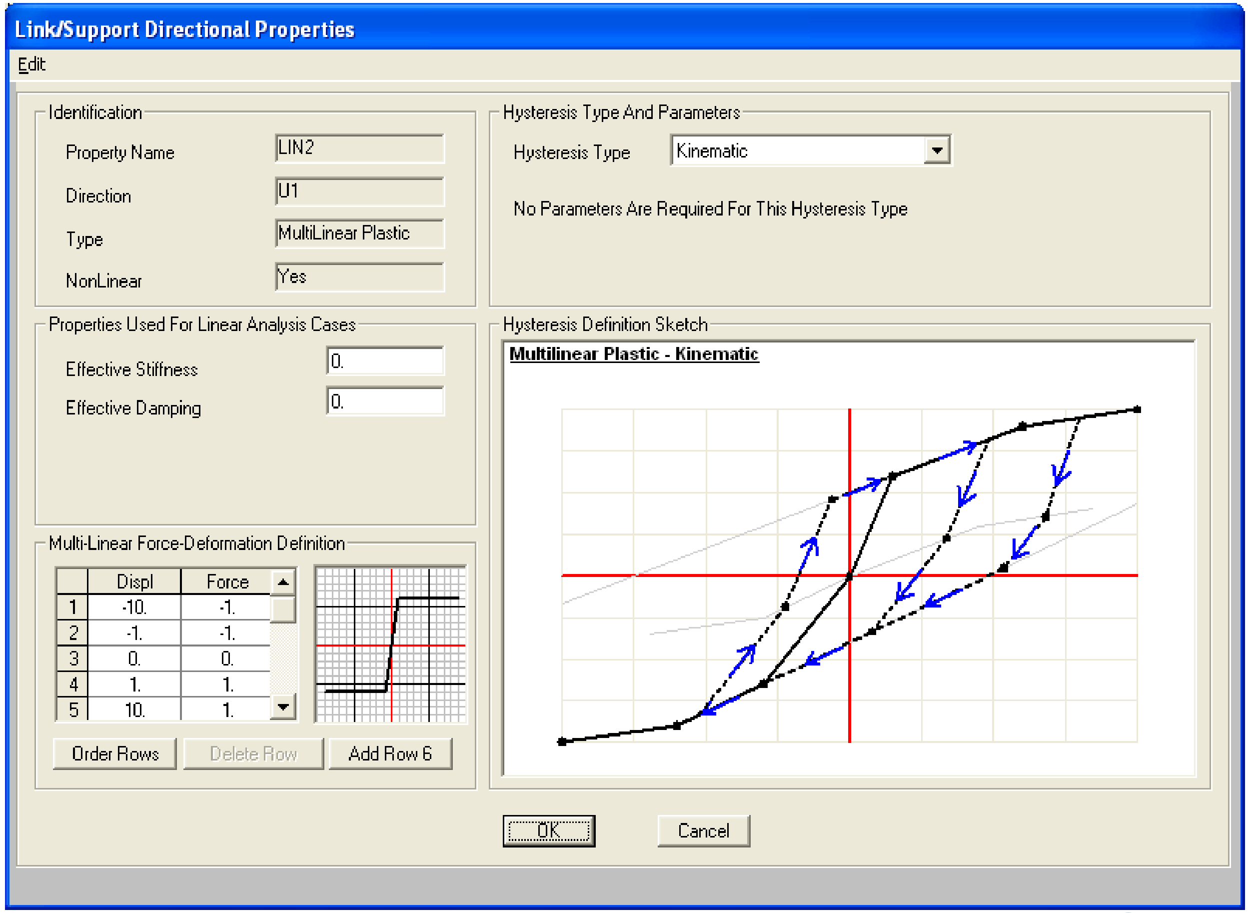
Linear Link Element

- Linear stiffness and damping in every degree of freedom



Link/Support Element

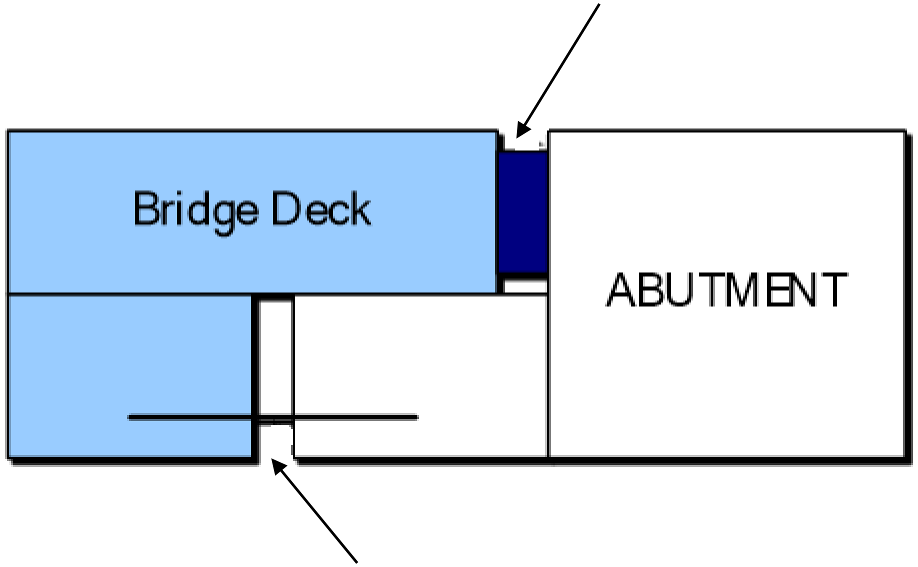
- Multilinear Elastic Element)
- Multilinear Plastic Element



Gap and Hook Connections

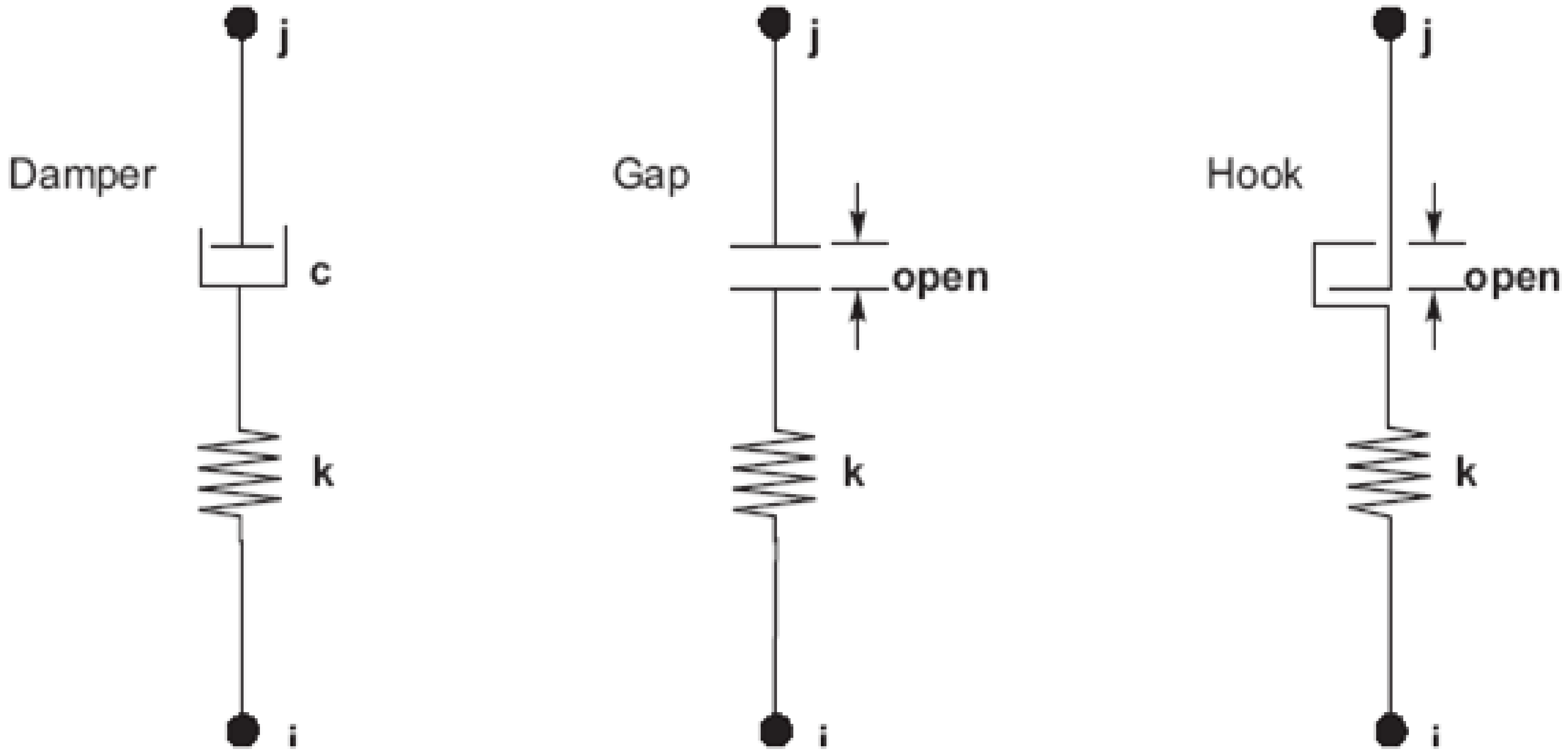
- Gap and Hook Elements are used to model contact type problems
- Gaps are compression only elements while Hooks are Tension only elements

Gap Element



Tension Only Element

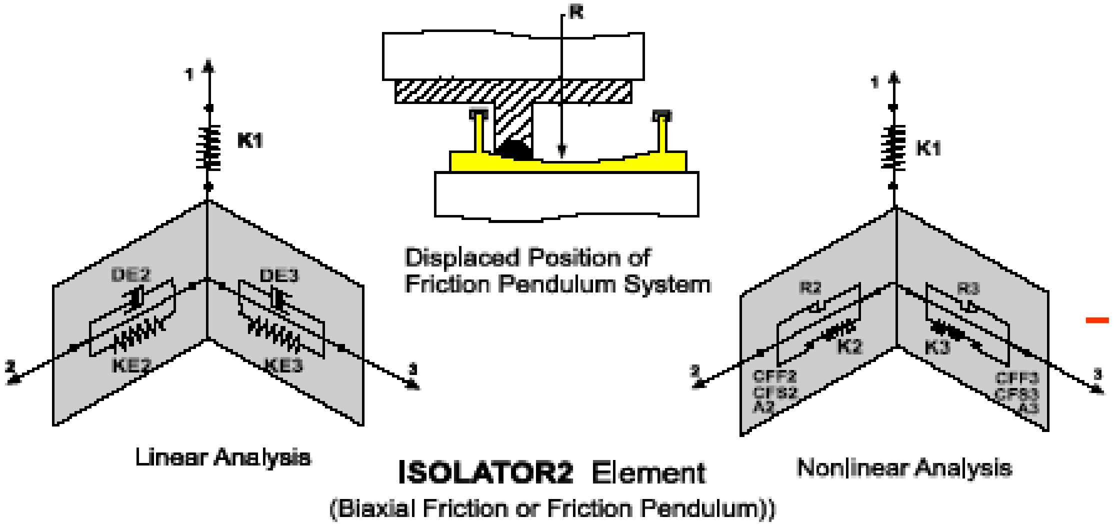
Link/Support Element

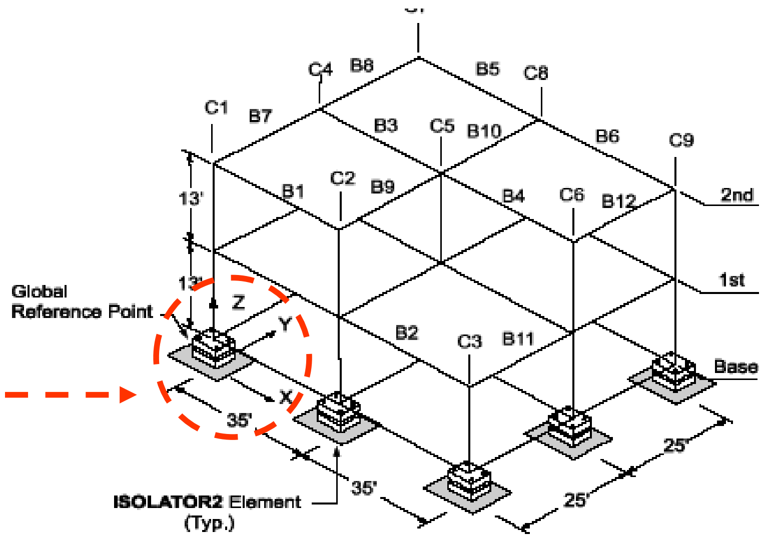


Link/Support Element

- Friction Isolator
  - Biaxial friction-pendulum isolator that has coupled friction
  - properties for the two shear deformation, post-slip stiffness
  - in the shear direction due to the pendulum radii of the
  - slipping surfaces, gap behavior in the axial direction, and
  - linear effective-stiffness properties for the three moment deformations

Link/Support Element

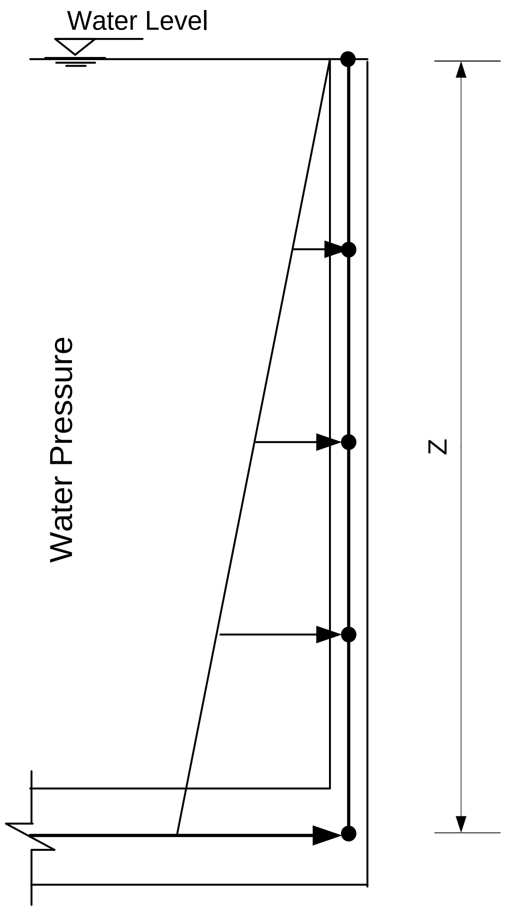


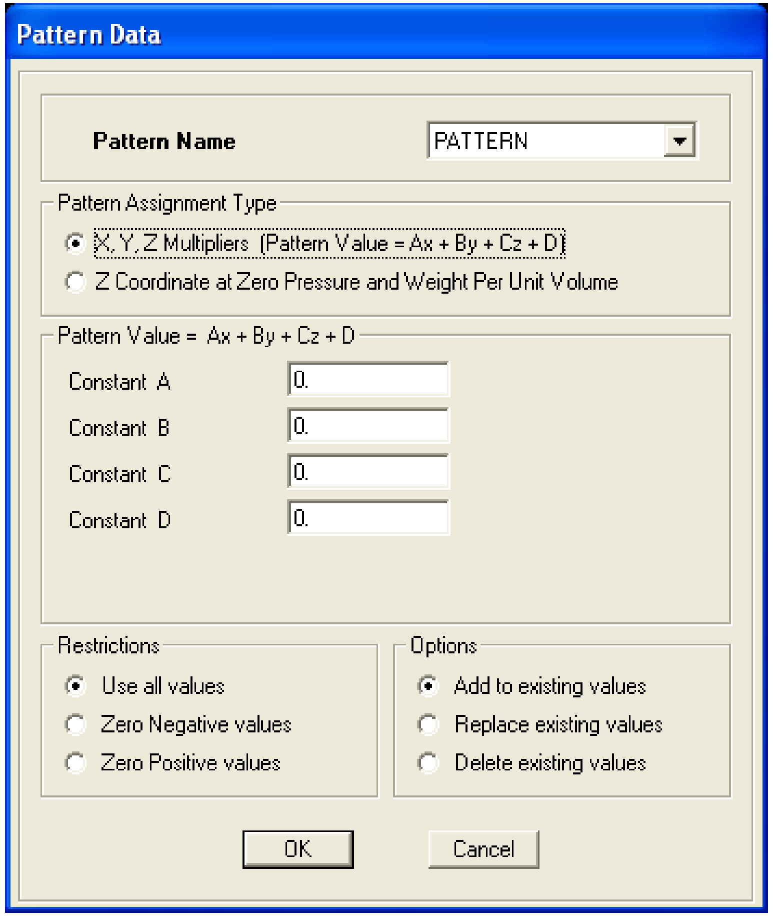


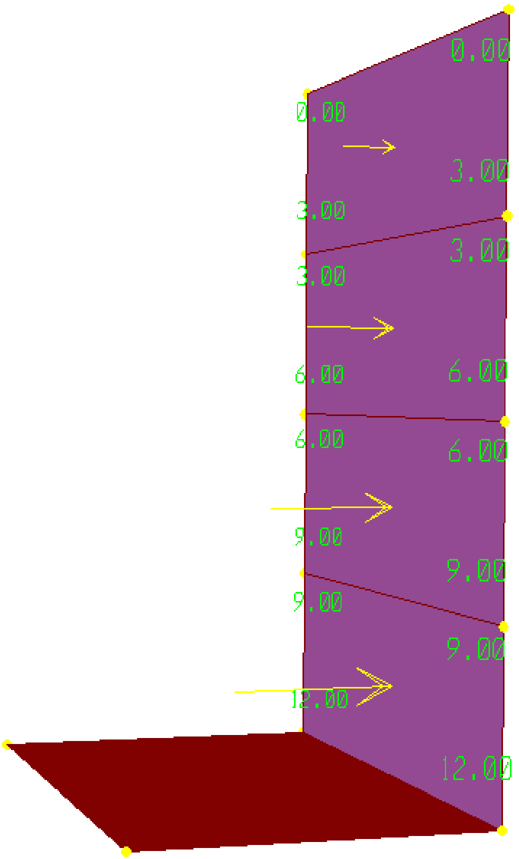
Joint Pattern

- A joint pattern is simply a set of scalar values defined at the joints for assigning more complex distributions of temperature and pressure over the structure.
- Joint patterns by themselves create no loads on the structure.
- For example, joint patterns are used to define triangular load for water pressure at water tank wall

Joint Pattern

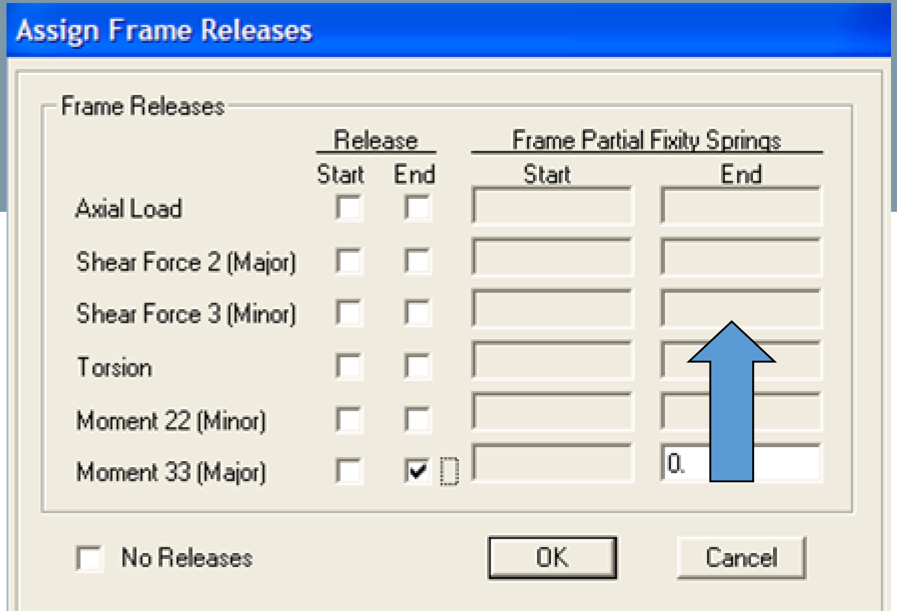


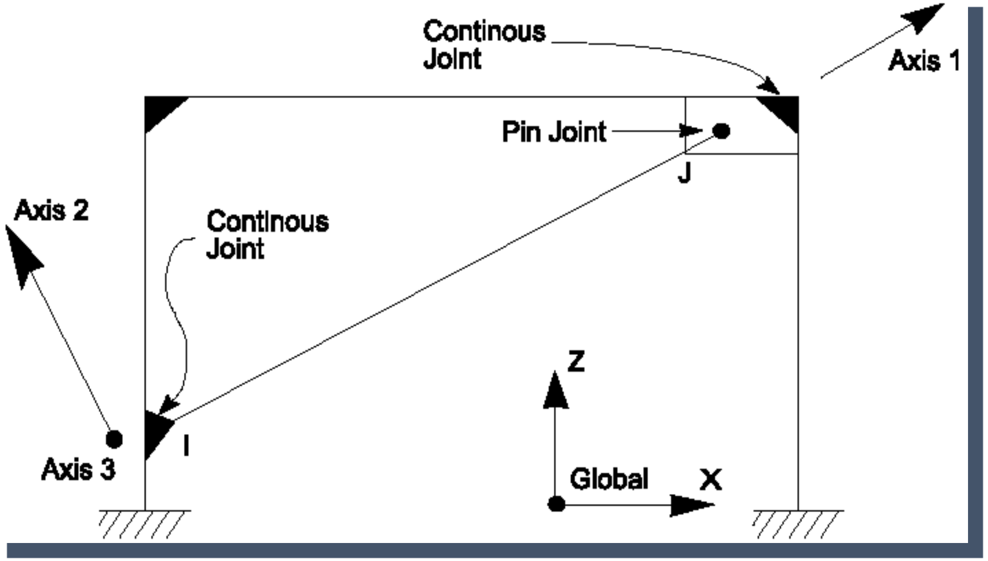




End Releases

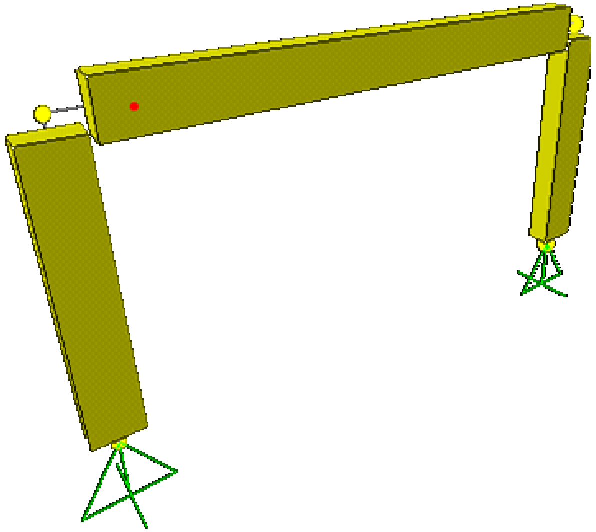
- Easily model non-fixed connections by general “End-Release”
  - Axial
  - Shear
  - Torsion
  - Moment

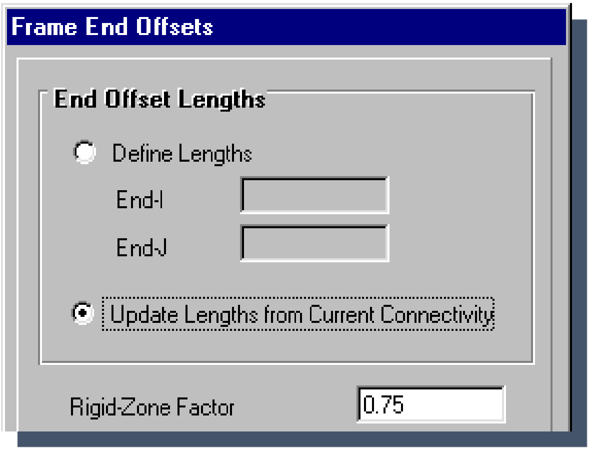


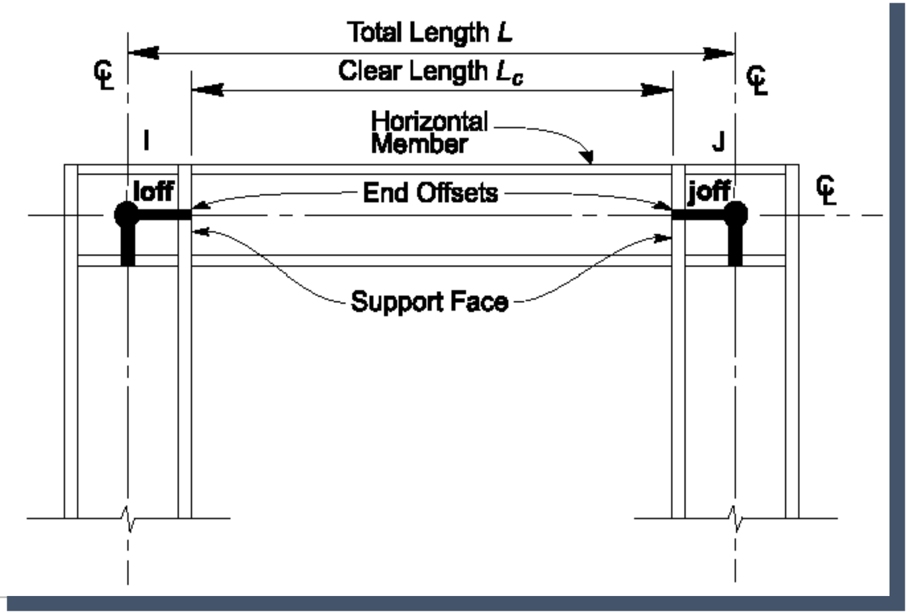


Rigid End Offsets

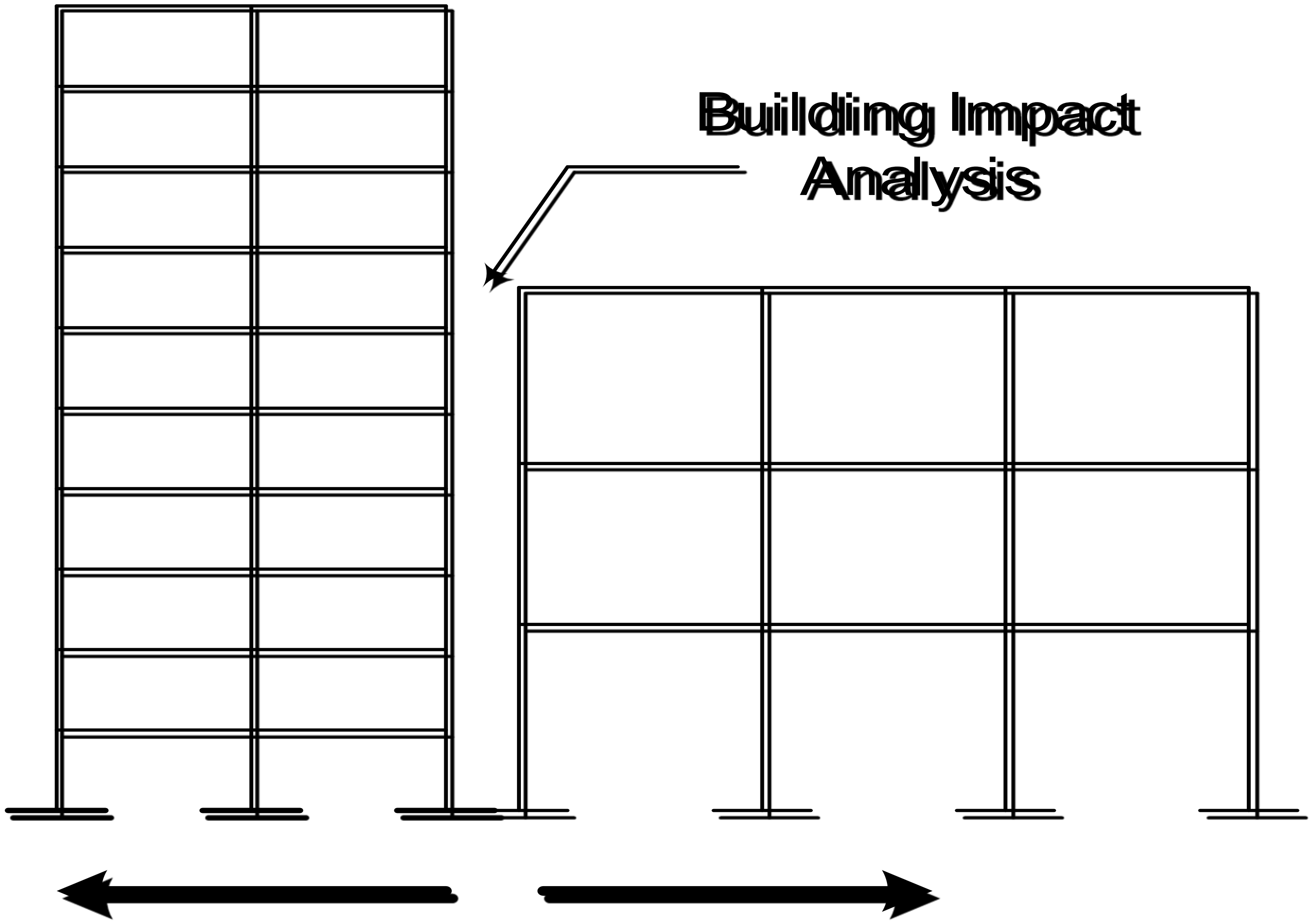
- Rigid End connections to model large joints
- Automated end offset evaluation and assignment





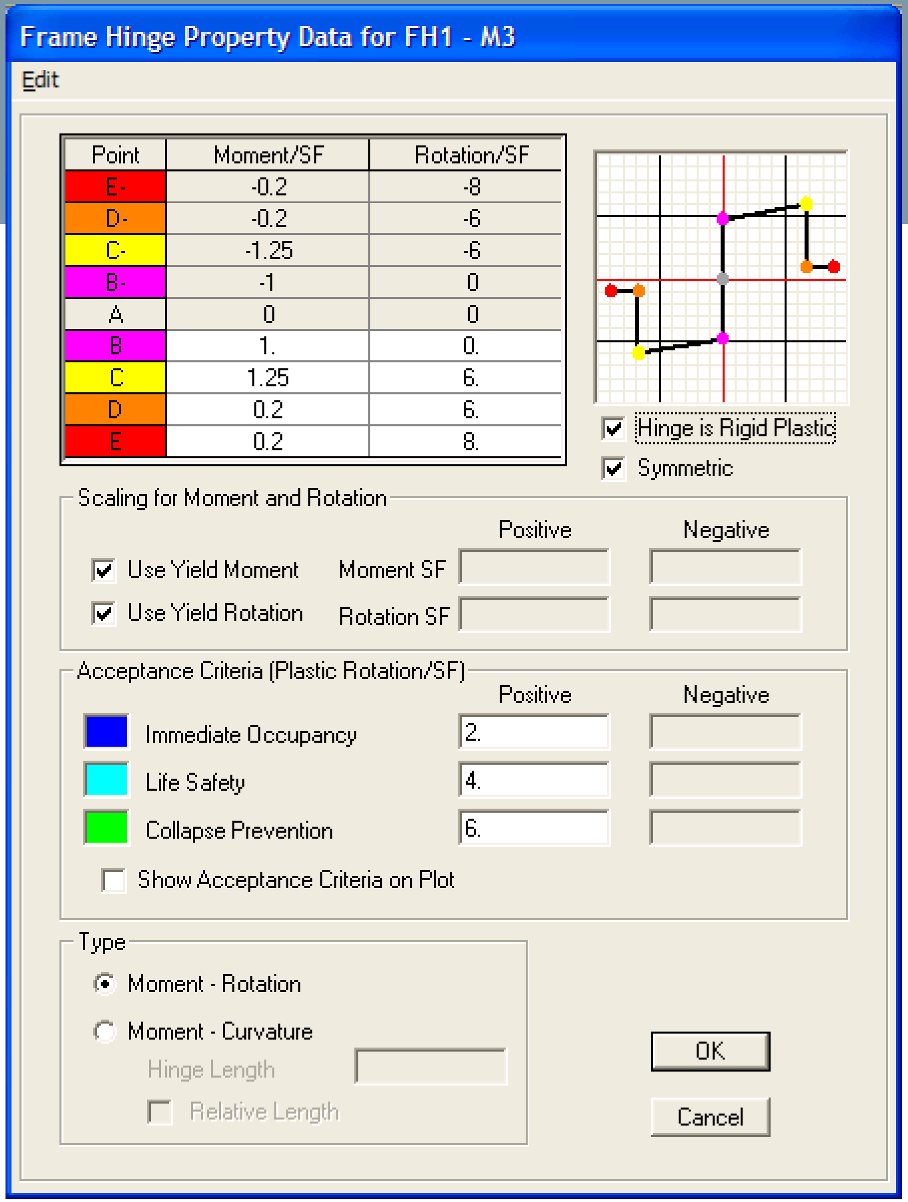


Modeling Building Impact

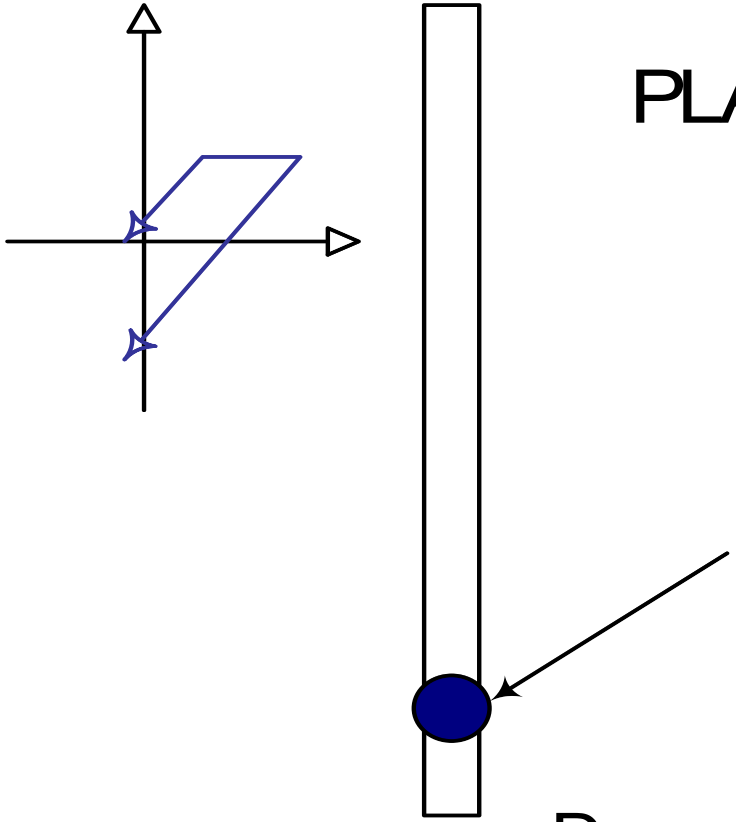


Plastic Hinges

- Hinge properties are used to define nonlinear force-displacement or moment-rotation behavior that can be assigned to discrete locations along the length of frame (line) elements



Hinges

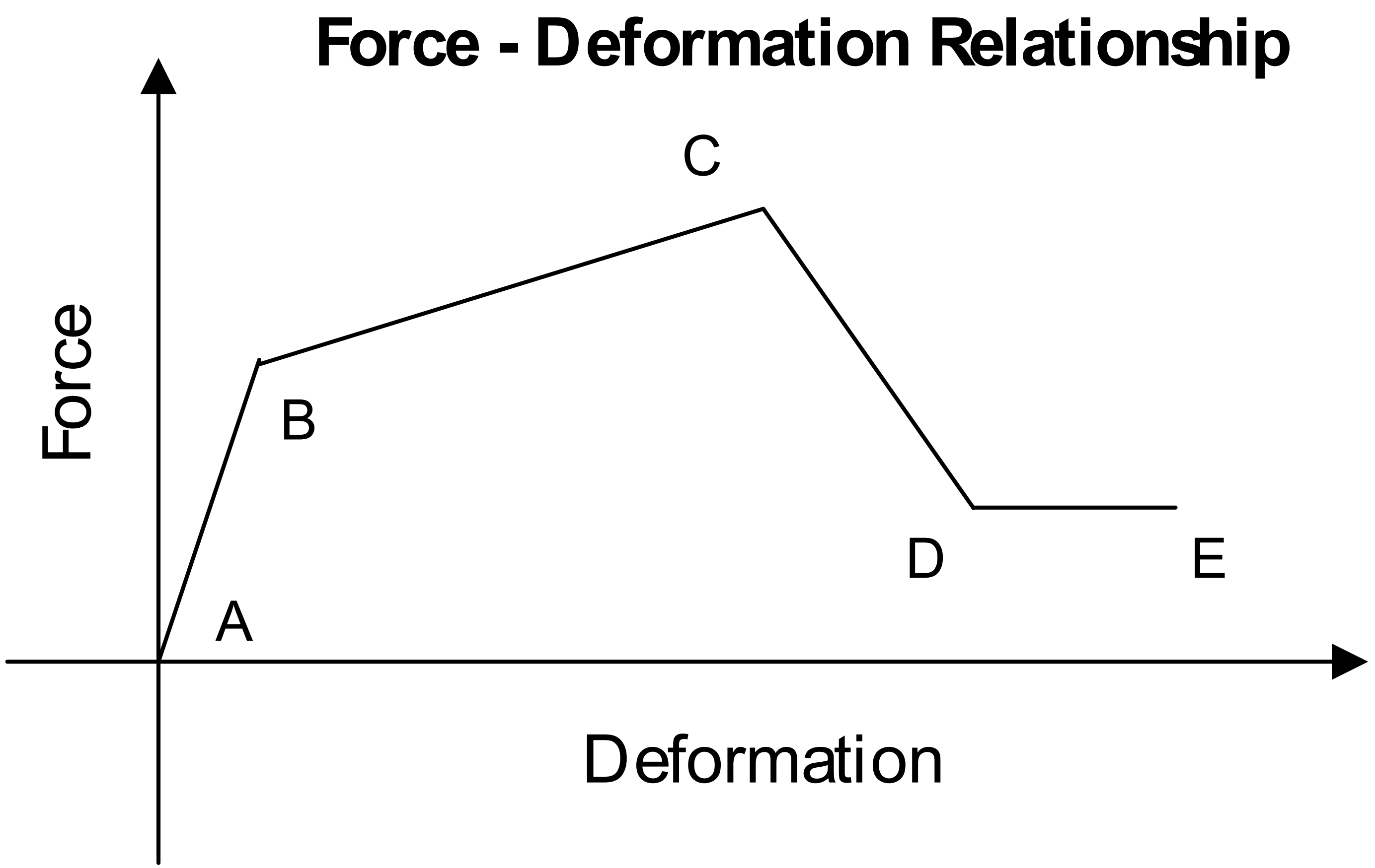


PLASTIC HINGES

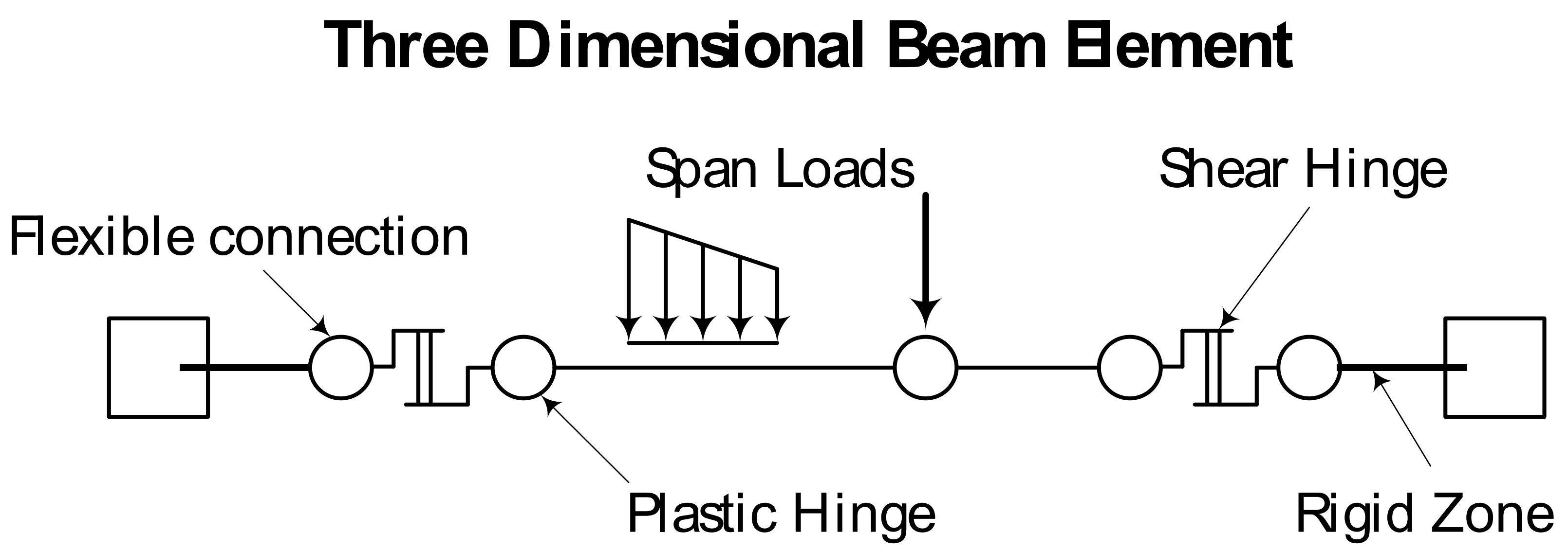
2 Rotational DOF

Degrading Stiffness?

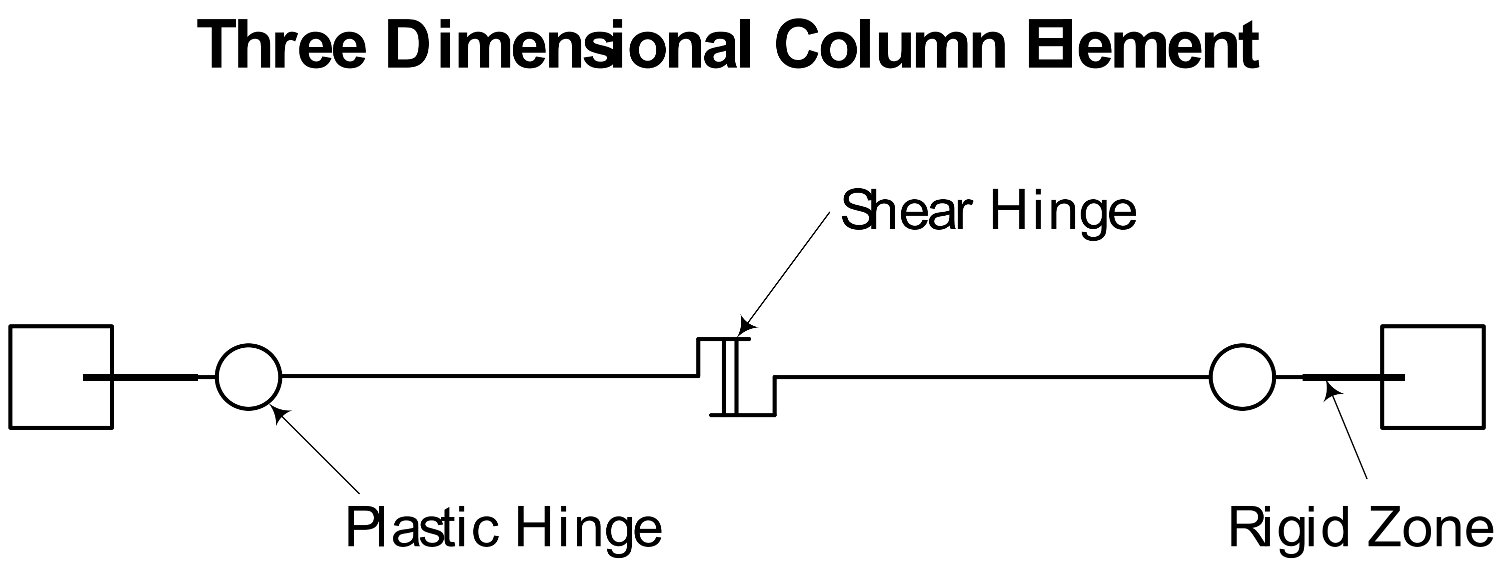
Pushover Modeling (Properties)



Pushover Modeling (Beam Element)



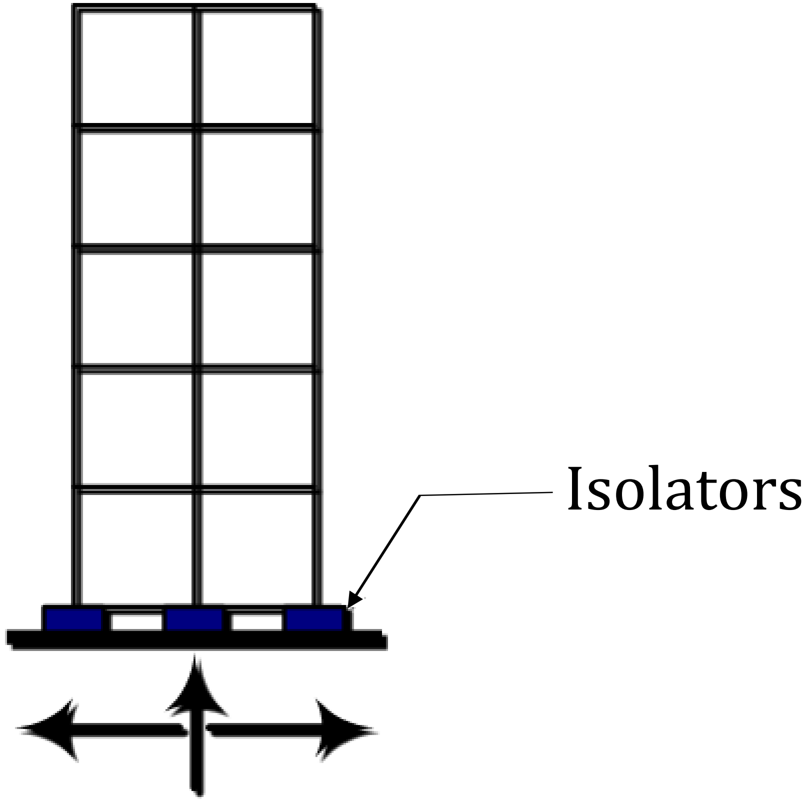
Pushover Modeling (Column Element)



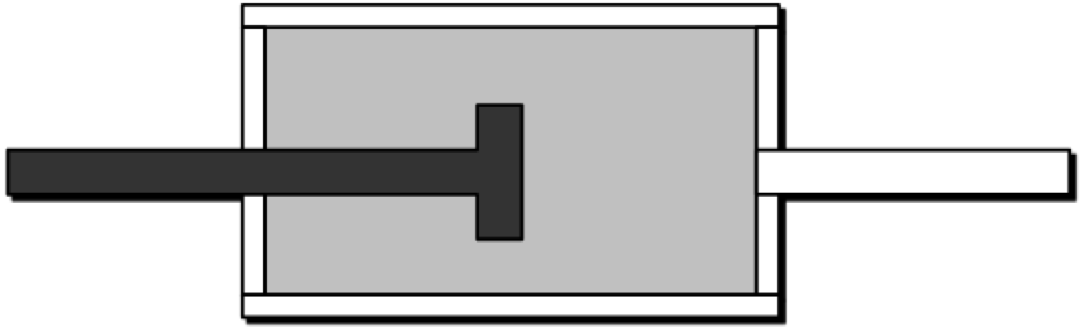
Base Isolation

- Base Isolators are important to restrict the ground motion transfer to structure during earthquake

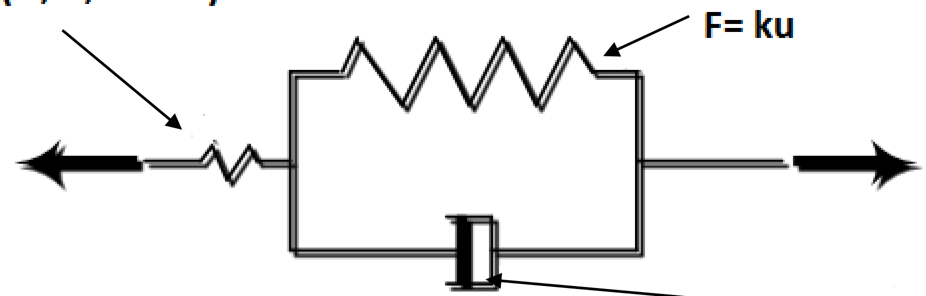
- General Isolators can be used to separate vibrating loads or parts of structure from rest of structure



Dampers

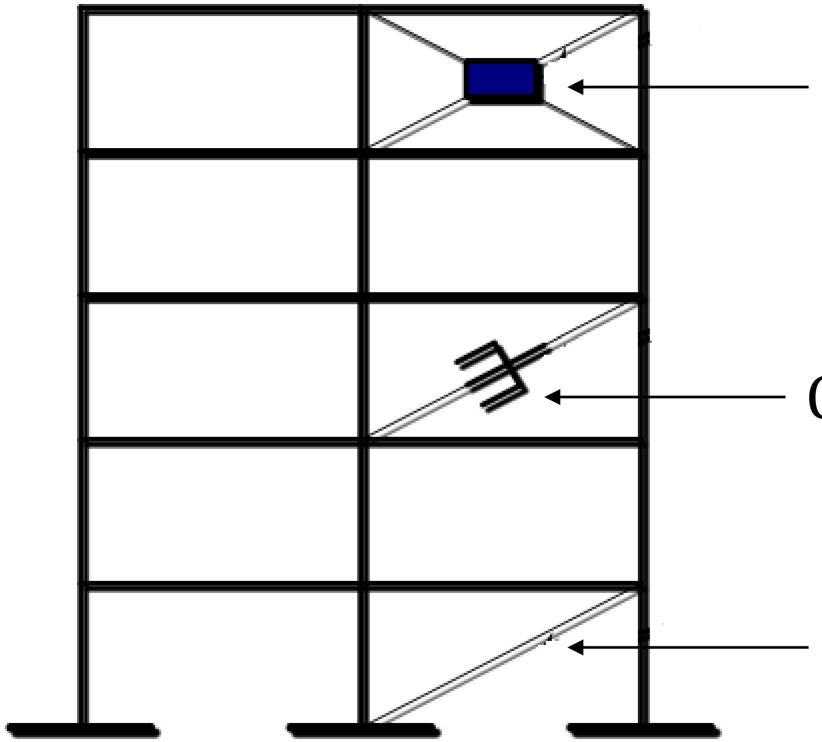


Mechanical Damper

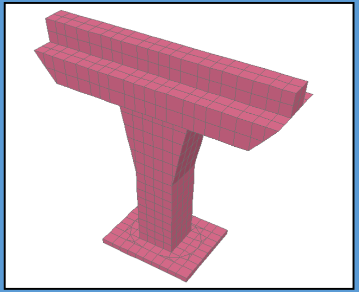
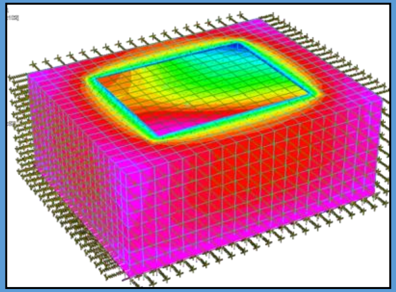


Mathematical Model

Dampers





Modeling of Loads

Dr. Naveed Anwar

AIT Solutions

Bride Load Classification

- Externally Applied , Internally Applied
- Primary, Secondary, Extraordinary
- Static, Dynamic
- Permanent, Transient
- Deterministic, Non-Deterministic
- Environmental, Man-made
- Short term, Long Term

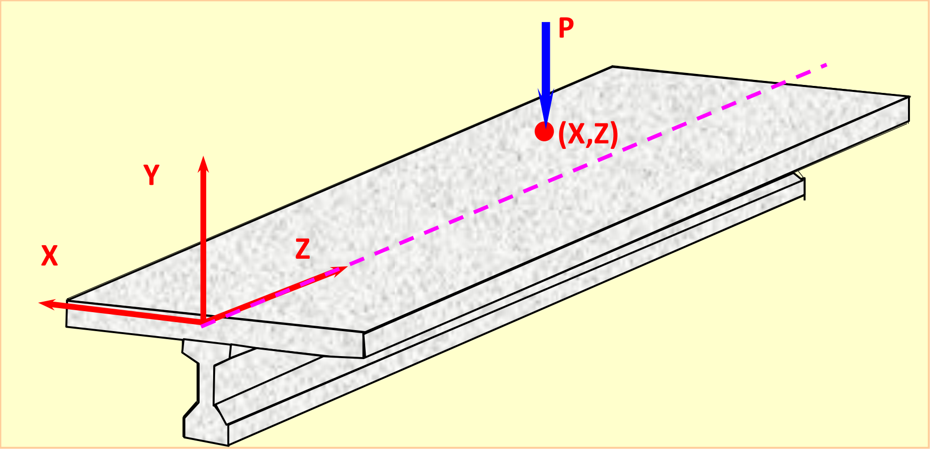
Loads on Bridge Deck

- Gravity Loads
- Traffic and Highway Loads
- Pre-stressing Loads
- Temperature Loads
- Shrinkage and Creep
- Wind Load
- Seismic Load

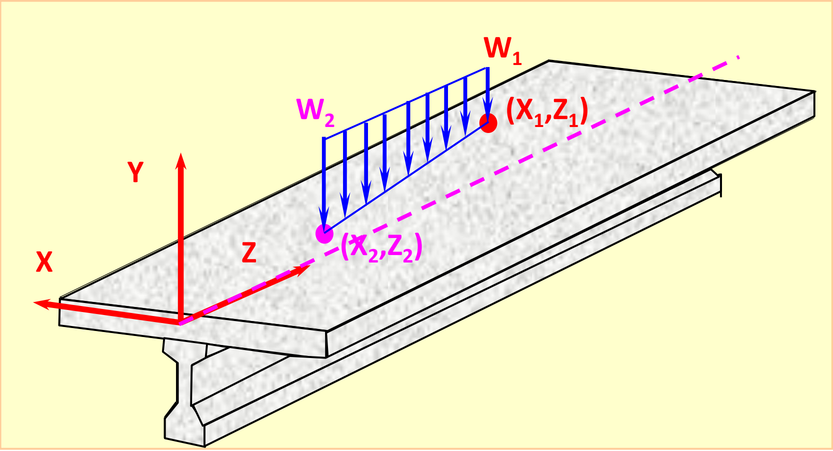
Modeling Loads

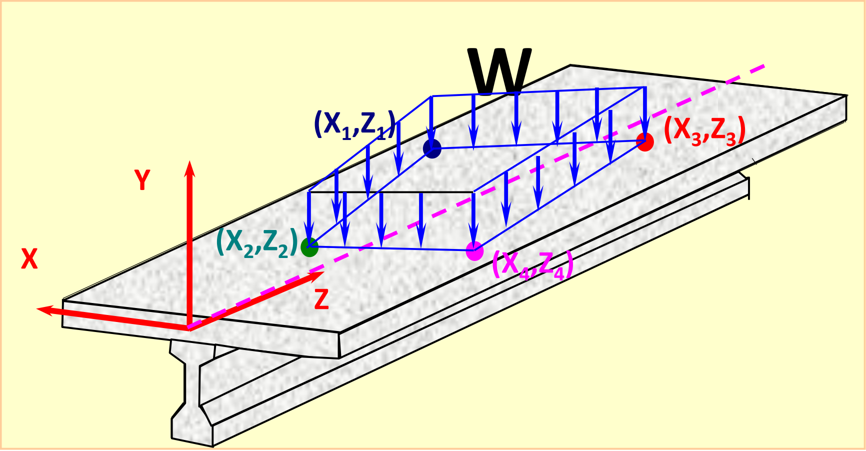
- For Level-1 FE models where elemenst are defined directly, the loads may be applied or defined for the elements
- For Level-3, Object based FE models, loads may be defined independently of the Finite elements using geometric representation
- Most loads can be computed/ applied from geometry and mass distribution automatically

Geometric Modeling of Loads



- Point Load
- Line Load
- Area Load
- Volume Load





Gravity Loads

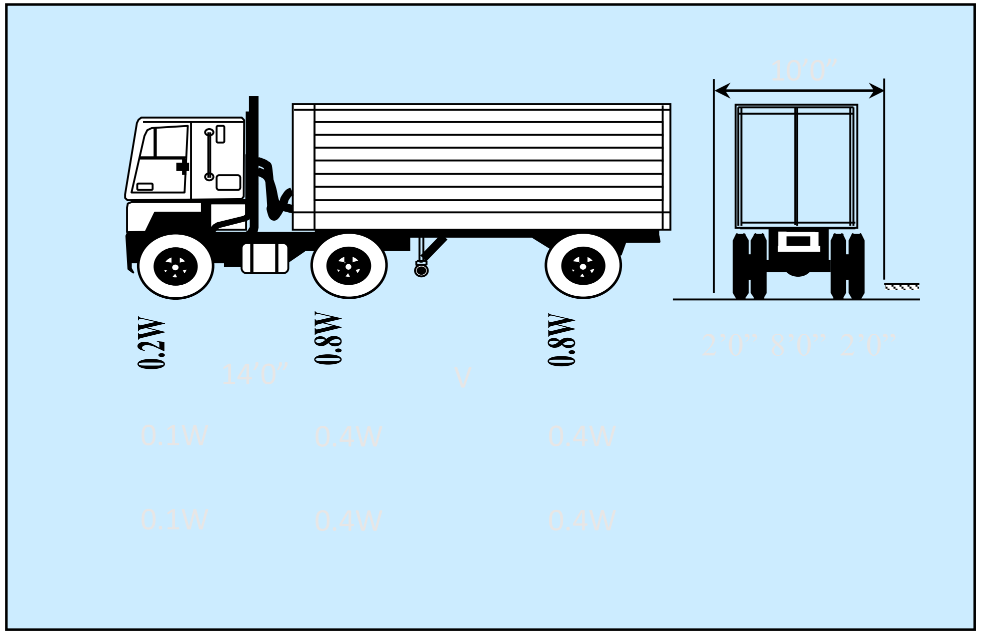
- These are the vertical loads due to the gravity. It consists of the dead weight of the structures. These loads can be applied as the element loads or as nodal loads.

  - For Beam Model applied as UDL over the length
  - For Shell Model applied as UDL over the area
  - Special loads applied as Point Loads
  - Applied as Lumped Mass

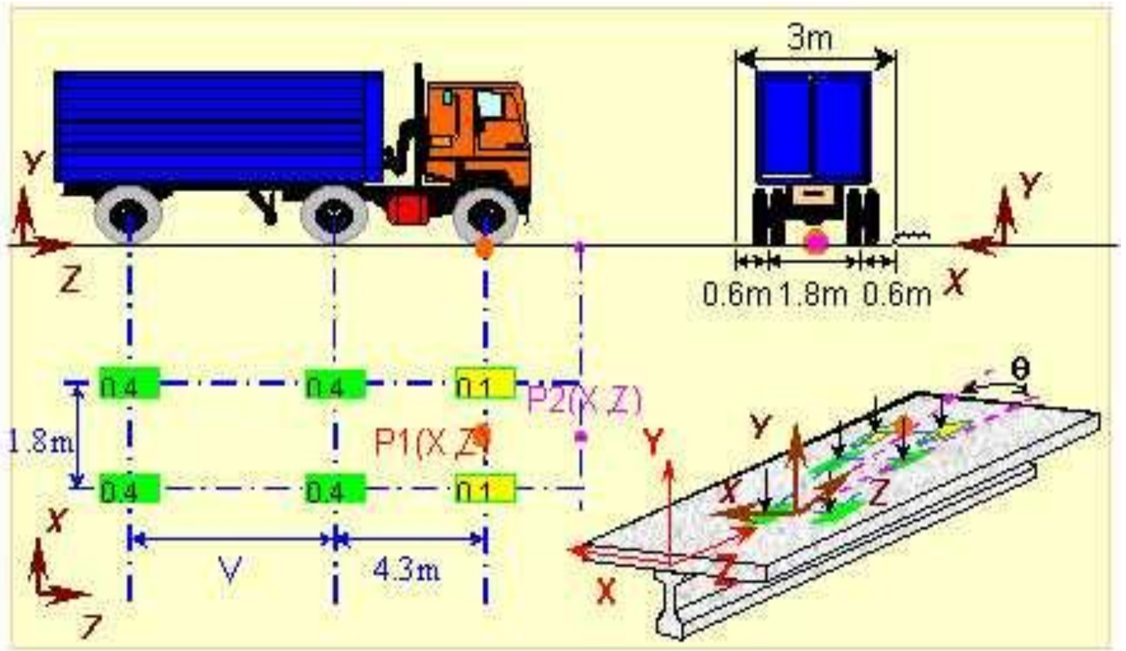
Traffic and Highway Loads

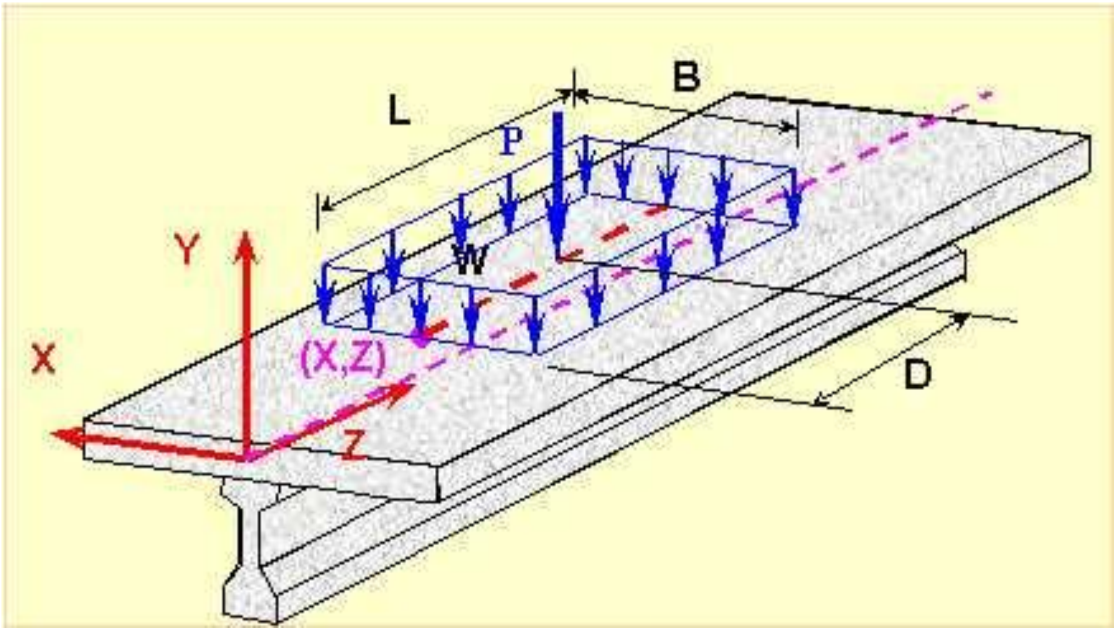
- Moving load handled as a special problem
  - Vehicles
  - Vehicle Classes
  - Traffic Lanes

  - Additional Point Loads



The Truck Load





Temperature Loads

- Both local temperature variation across section and global changes may need to be considered
- In case of Beam model
  - The temperature loads to any member can be applied as a form of fixed end moment caused by the temperature changes.
- For the cases of Thin-wall and Plate model
  - The temperature loads can be applied as the initial strains caused by the temperature changes to each element.

Shrinkage and Creep

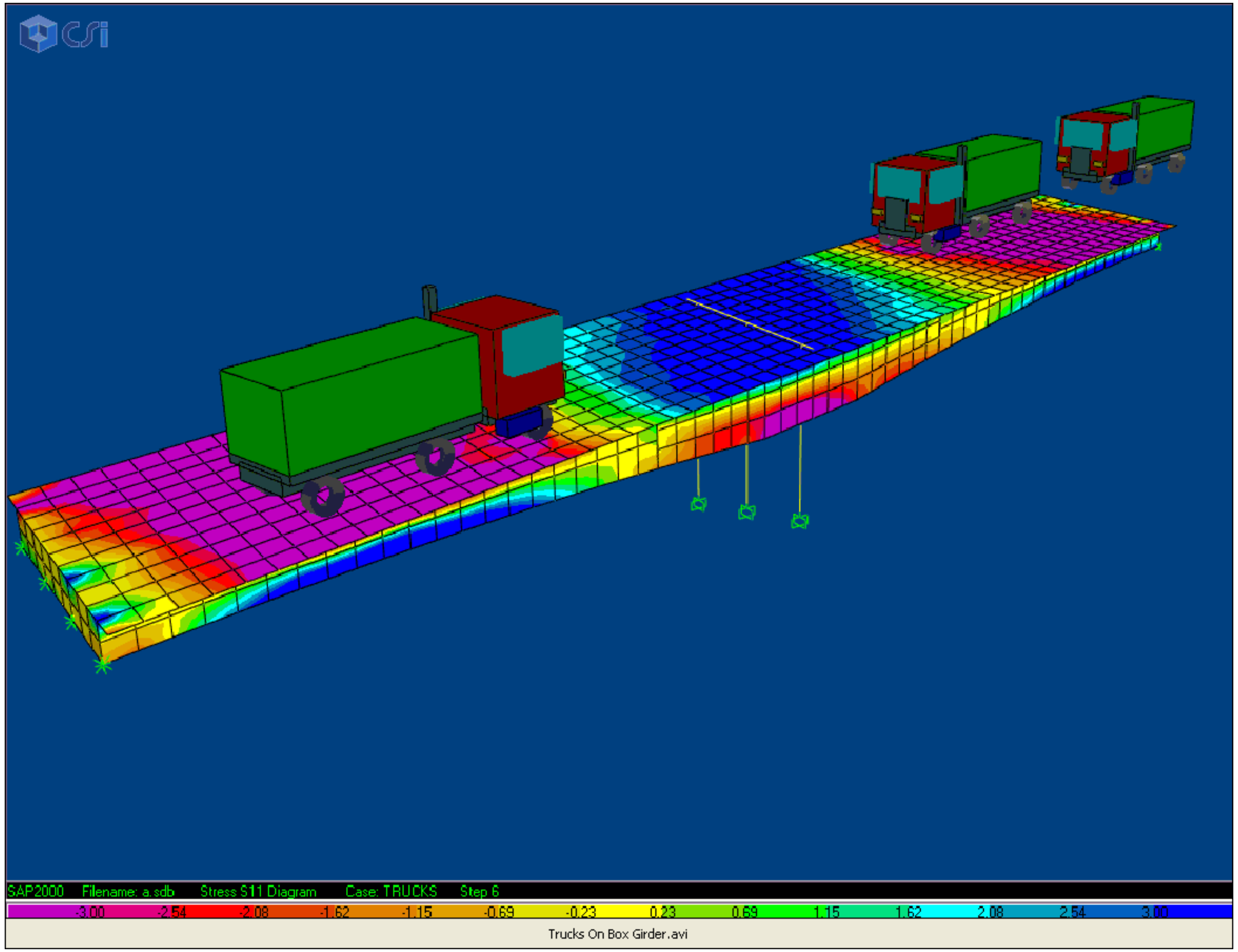
- The effect of Shrinkage and Creep of concrete can also be applied as the load by converting the expected creep and shrinkage strain in to an equivalent temperature strain.
- Many programs now handle creep, shrinkage and relaxation etc. directly and internally convert them to loads

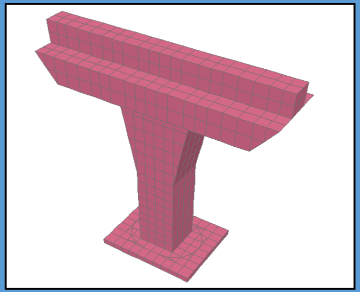
Shrinkage and Creep

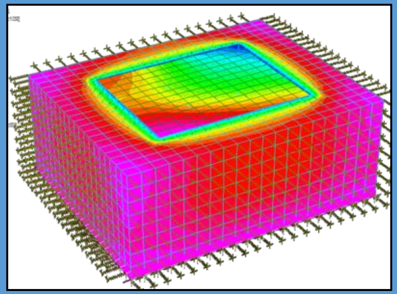
- Determine strains due to shrinkage and creep separately
- Using the coefficient of thermal expansion for the material and the determined strain calculate the equivalent temperature change
- Apply this temperature to the model

$$Creep/Shrinkage(strain) = \alpha.\Delta T$$

Animations


SAP2000 Filename: a.sdb Stress S11 Diagram Case: TRUCKS Step 6
-3.00 -2.54 -2.08 -1.62 -1.15 -0.69 -0.23 0.23 0.69 1.15 1.62 2.08 2.54 3.00
Trucks On Box Girder.avi





Analysis and Results

Dr. Naveed Anwar

AIT Solutions

The purpose of modeling and analysis is to try to get the “**correct response**”, not necessarily the “accurate one”

Analysis Case

- Static
  - Linear Static
  - Nonlinear Static (Included Push Over)
  - Staged Construction
- Multi-Step Static (SAP2000 only)
- Response Spectrum
- Time History
  - Linear Time History
  - Nonlinear Time History
- Moving Load (SAP2000 only)
- Buckling (SAP2000 only)
- Steady State (SAP2000 only)
- Power Spectral Density (SAP2000 only)

Analysis Case

- Static

  - Linear: The most common type of analysis. Loads are applied without dynamical effects.

  - Nonlinear: Loads are applied without dynamical effects. May be used for cable analysis, pushover analysis, and other types of nonlinear problems. (Pushover + P-Delta)

  - Nonlinear Staged Construction: The definition of a nonlinear direct-integration time-history analysis case for staged construction.

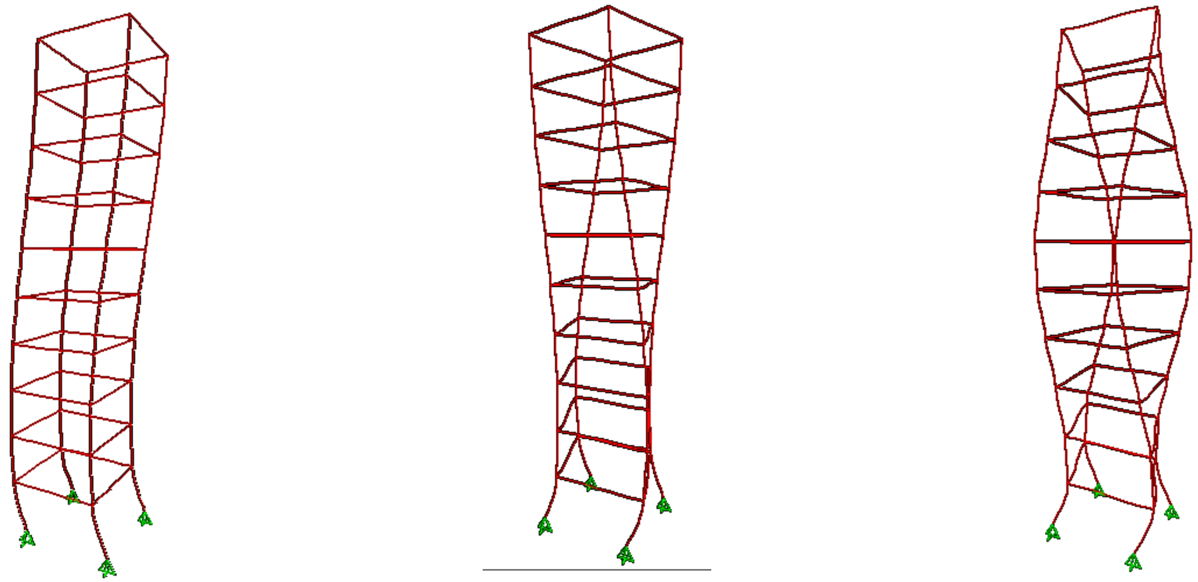
Analysis Case

- Multi-Step Static (SAP2000 only)

- Linear static analysis for multi-stepped load cases, such as moving loads and wave loads. A separate output step is produced for each step of the given loads

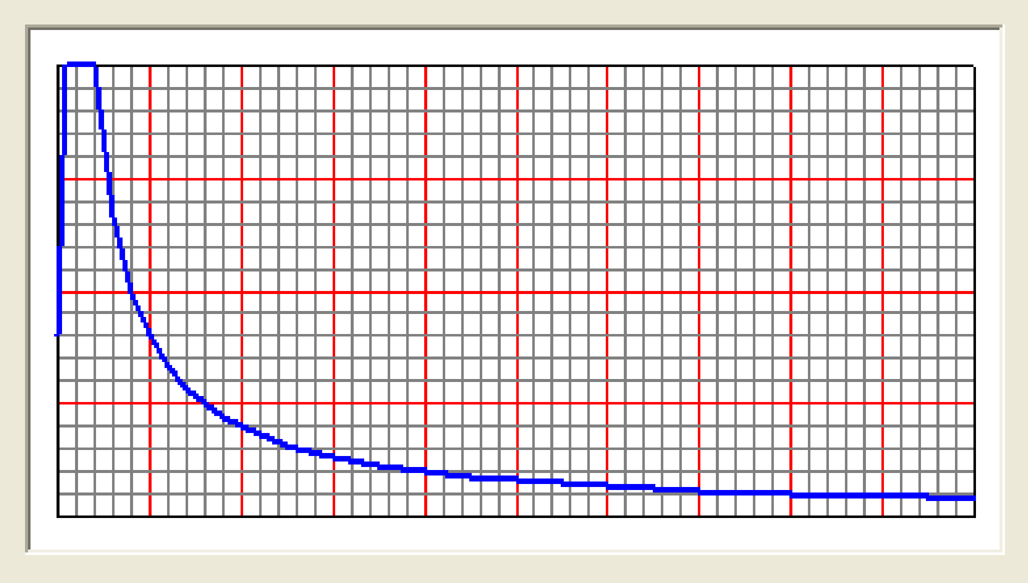
Analysis Case

- Modal
  Calculation of dynamic modes of the structure using the Eigenvector or Ritz-vector method. Loads are not actually applied, although they can be used to generate Ritz vectors.



Analysis Case

- Response Spectrum
- Statistical calculation of the response caused by acceleration loads. Requires response-spectrum functions.



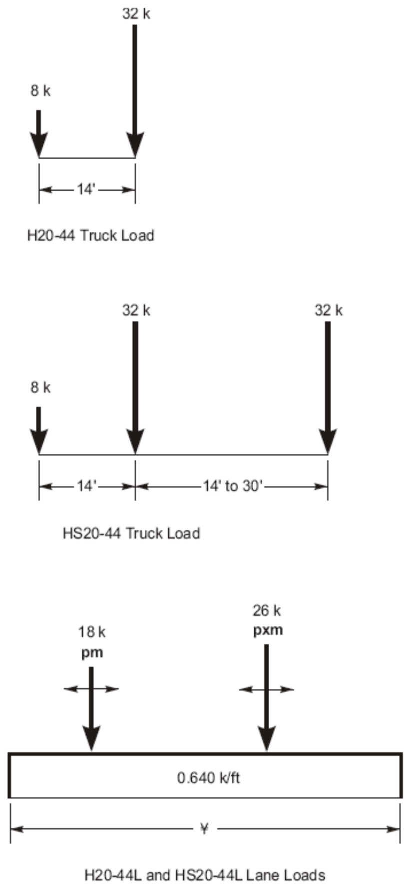
Response Spectrum Function

Analysis Case

- Time History
  - Time History. Time-varying loads are applied. Requires time-history functions. The solution may be by modal superposition or direct integration methods.
    - Linear Modal
    - Linear Direct Integration
  - Nonlinear Time History. Time-varying loads are applied. Requires time-history functions. The solution may be by modal superposition or direct integration methods.
    - Nonlinear Modal
    - Nonlinear Direct Integration

Analysis Case

- Moving Load
  - Calculation of the most severe response resulting from vehicle live loads moving along lanes on the structure. Uses defined vehicle loads and defined lanes rather than the load cases that are used by other analysis types.



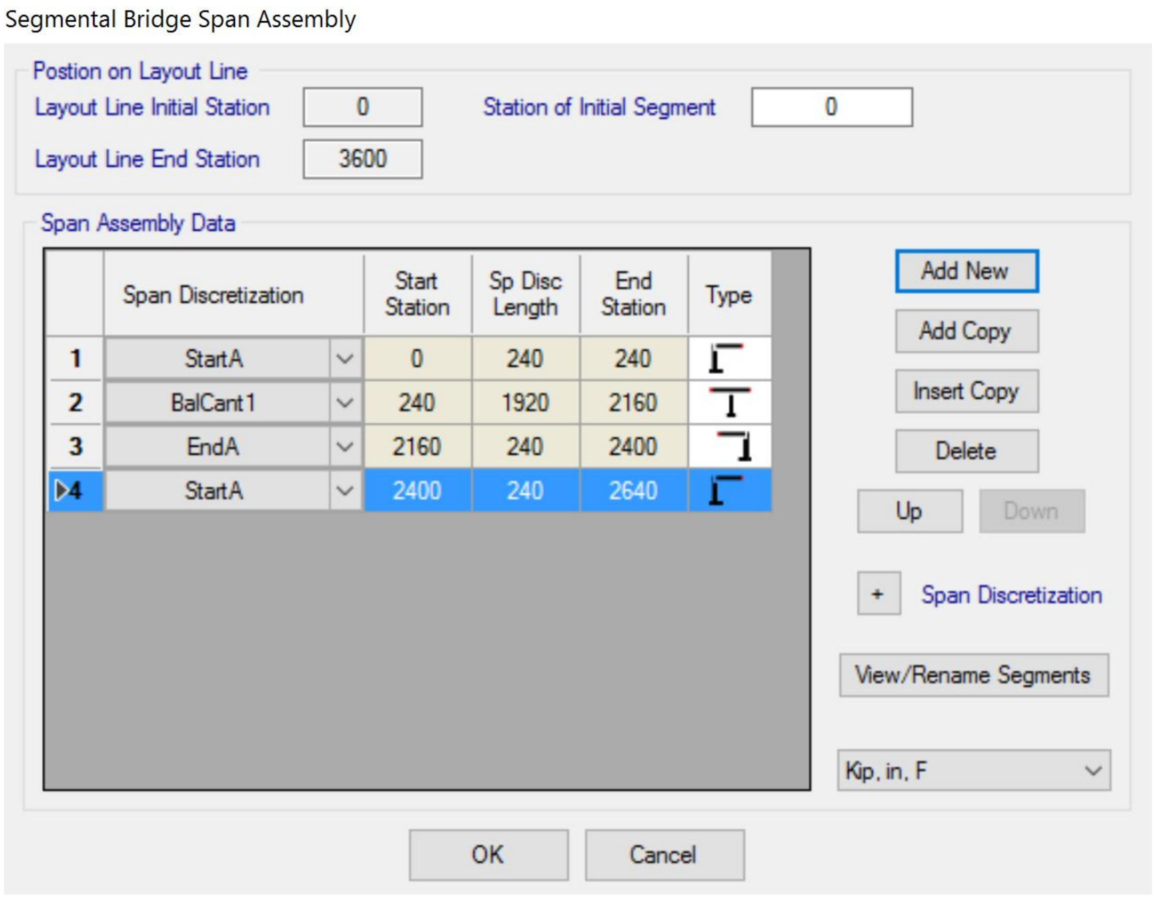
Vehicle Load

Analysis Case

- Buckling
  - Calculation of buckling modes under the application of loads.

- Steady State
- A steady-state analysis case solves for the response of the structure due to cyclic (harmonic, sinusoidal) loading at one or more frequencies of interest.

Analysis Case – Construction Sequence



Staged Construction Analysis

Main Stage 1: Super Structure

Step 1: Add Pylon

Step 2: Add Deck01

Step 3: Add Deck02

Step 4: Add Deck03

Step 5: Add Deck04

Step 6: Add Deck05

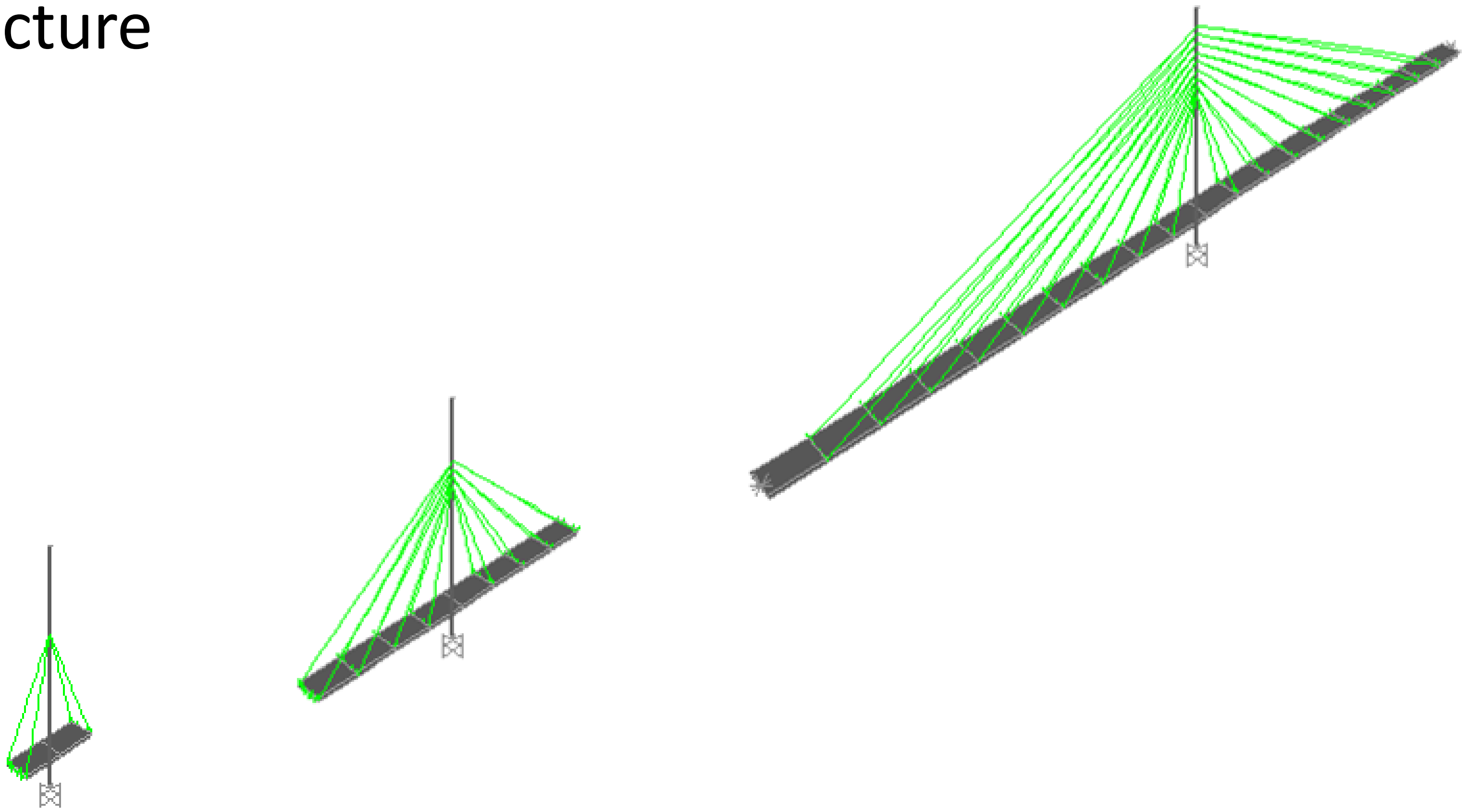
Step 7: Add Deck06

Step 8: Add Deck07

Step 9: Add Deck08

Step 10: Add Deck09

Step 11: Add Deck10



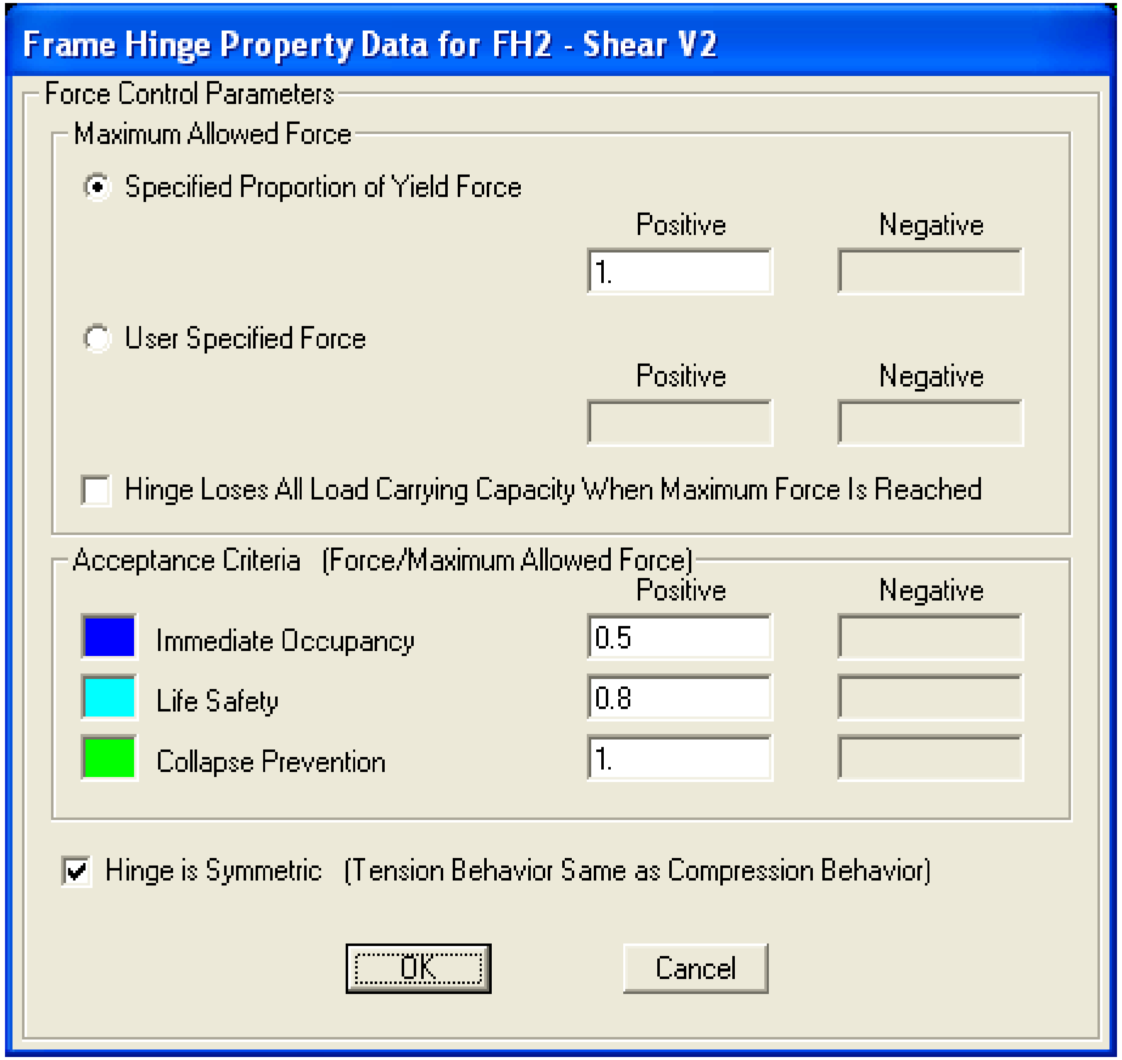
Staged Construction Analysis

- Main Stage 2: Post Build
- Step 1: Time01 at 3 days
- Step 2: Time02 at 3 days
- Step 3: Time03 at 10 days
- Step 4: Time04 at 30 days
- Step 5: Time05 at 100 days
- Step 6: Time06 at 300 days
- Step 7: Time07 at 1,000 days
- Step 8: Time08 at 3,000 days

Pushover Analysis

Hinge Property Data

Force Controlled



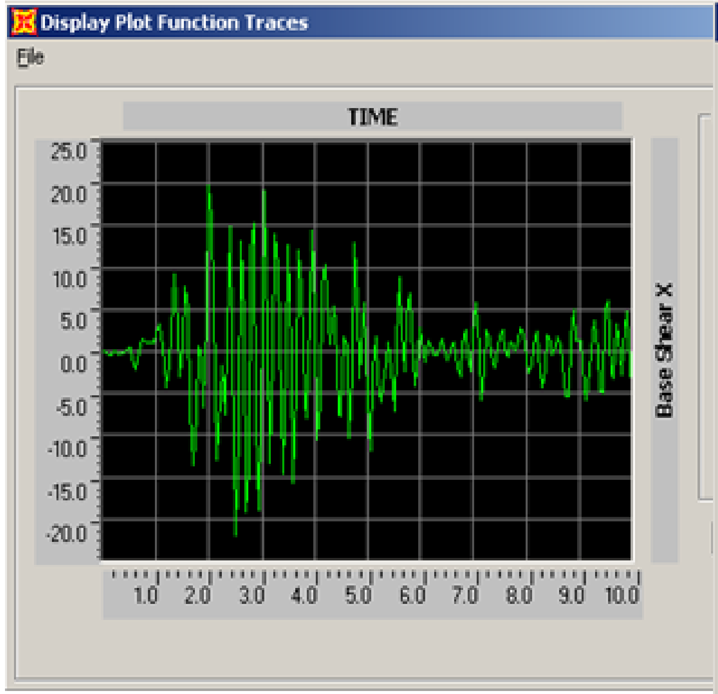
Response Curve

- Create from Time History Case at Particular Joint
- Frequency or Period
- Versus
  - Spectral Displacement
  - Spectral Velocity
  - Pseudo Spectral Velocity
  - Spectral Acceleration
  - Pseudo Spectral Acceleration

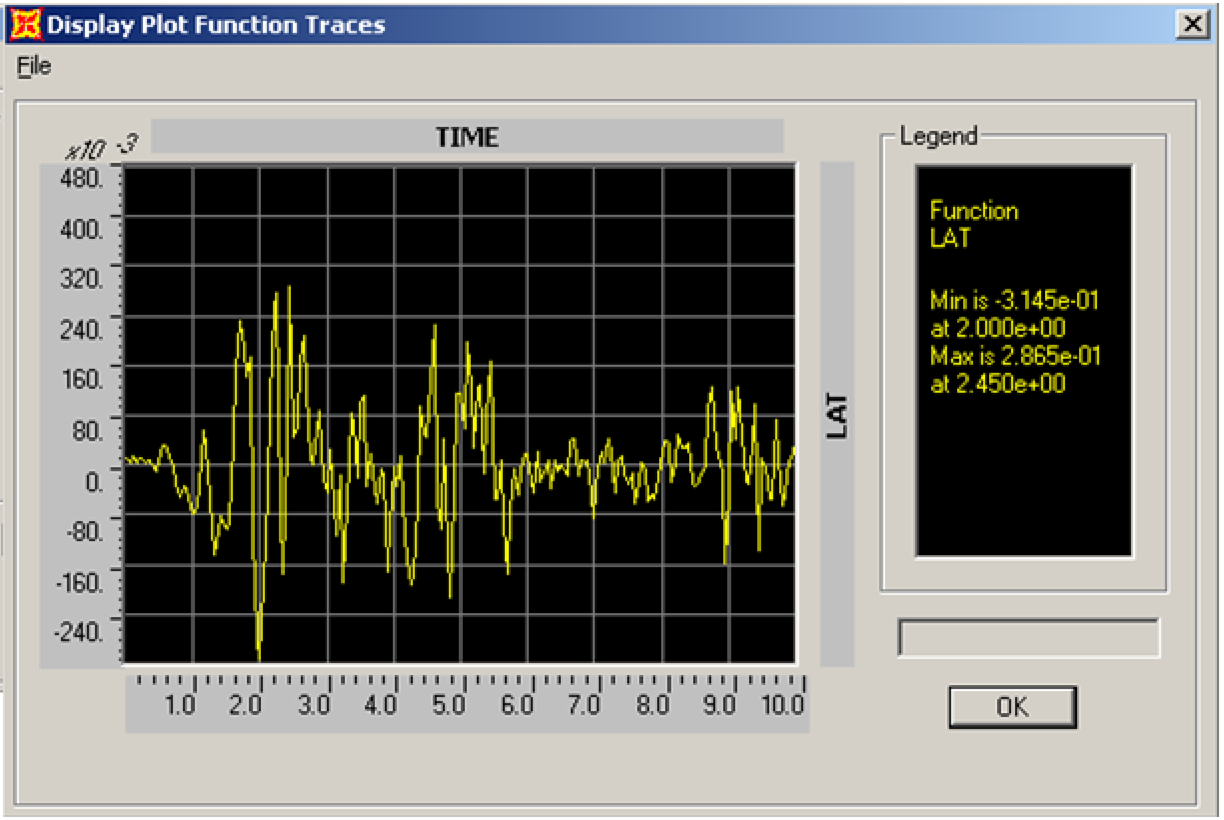
Show Plot Function

- For Multi-stepped Case
- Such as Time History Case
- Load Function
- Energy Function
- Input, Kinetic, Potential Modal Damping
- Link Damper, Link Hysteretic or Energy Error
- Base Function
- Joint Displacement/Forces
- Frame Forces

Show Plot Function



Base Function



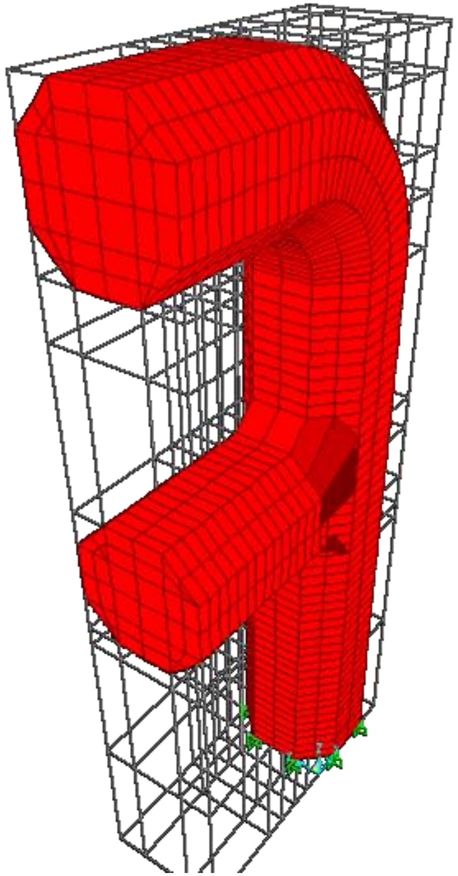
Load Function

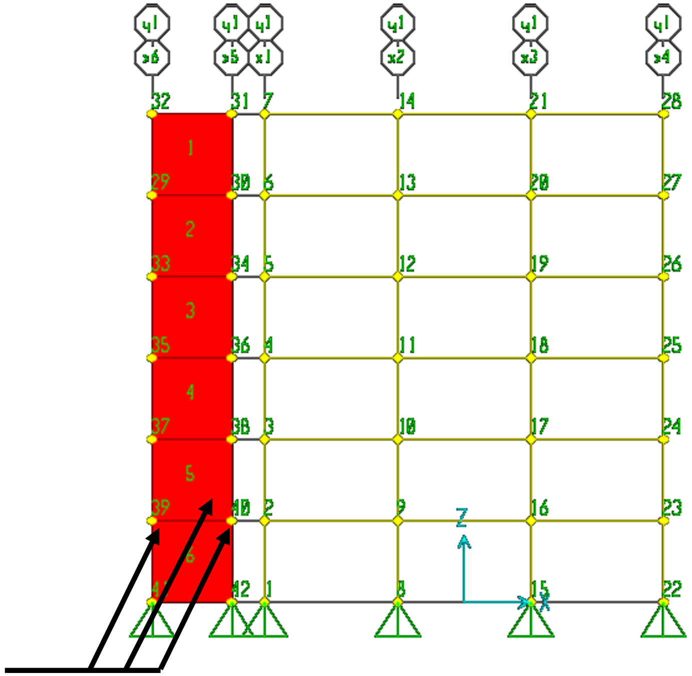
Section Cuts

- To obtain resultant forces acting at section cuts through a model.
- Defined before or after an analysis has been run.
- First select the objects that are to be part of the section cut and assign to group.

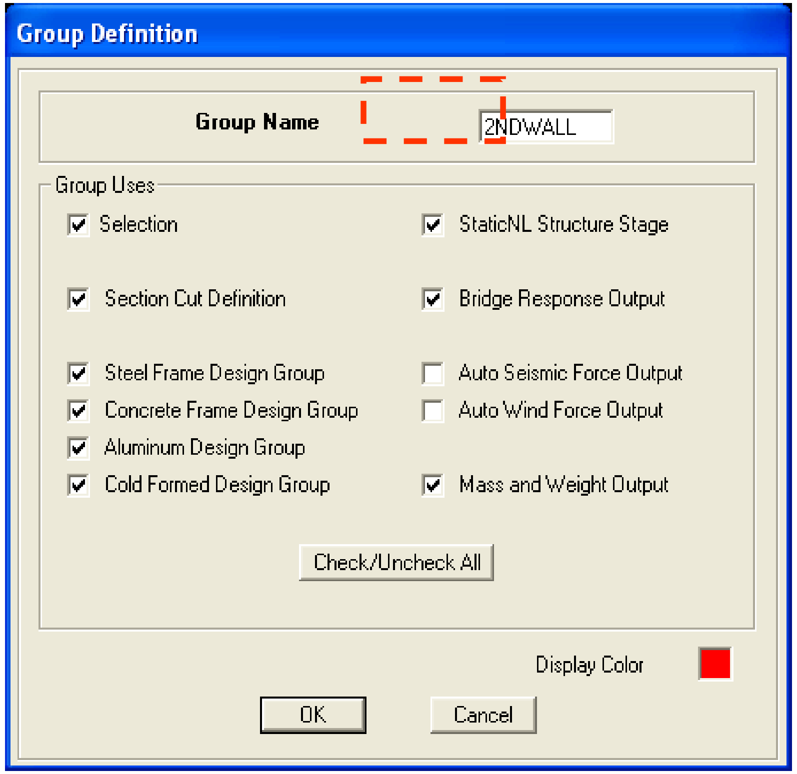
  - Section cut defined by group
  - Section cut defined by quadrilateral cutting planes

Section Cuts





Select Point 39, 40 and Area 5.



CSI Bridge

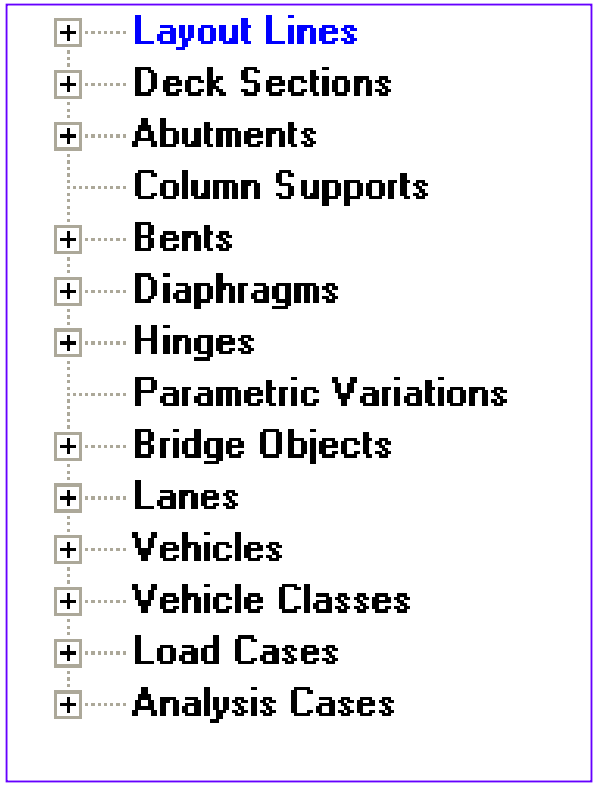
- Basic Bridge related functions
  - Moving Loads: Lanes, Vehicles..
  - Sequential Construction

- Special CALTRANS bridge modeler
  - Step-by-step Modeler

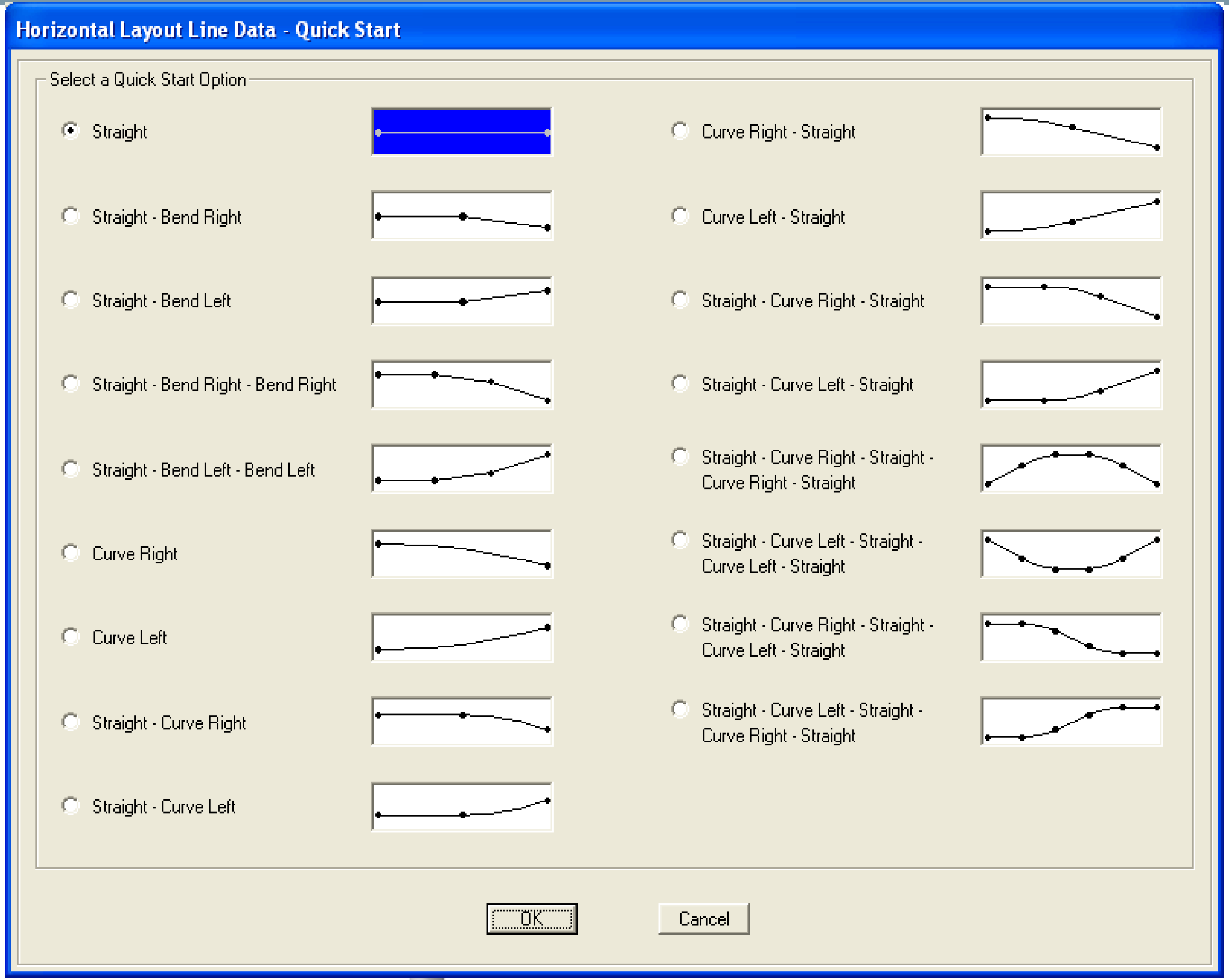
- The full Object Based Bridge Modeler
  - Step-by-step Modeler
  - General Parametric Modeler

CSI Bridge -Object Based Bridge Modeler

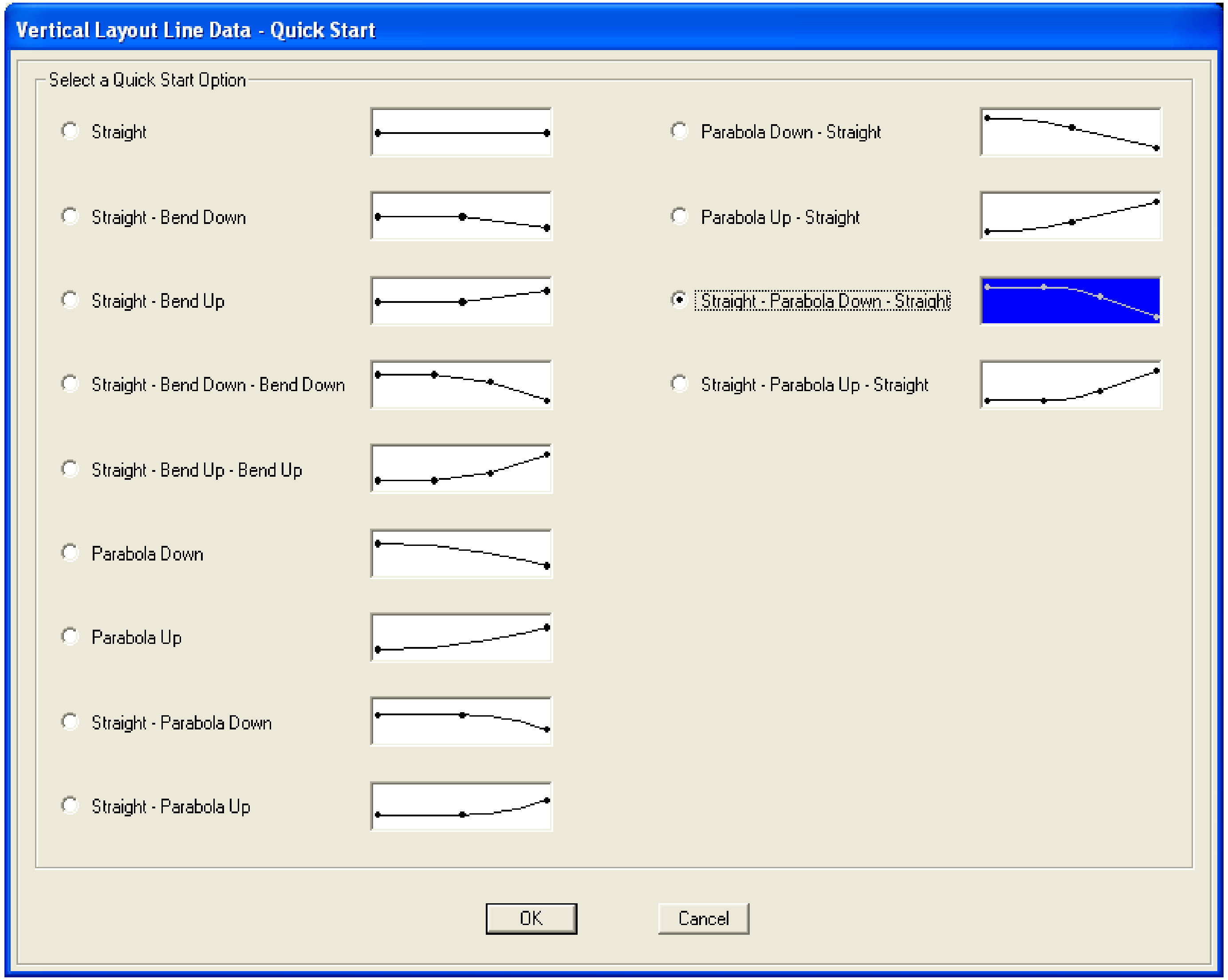
- Useful for staring any bridge model
- Applicable to most typical and Category-1 bridge projects
- Especially useful for preliminary and comparative studies of various options



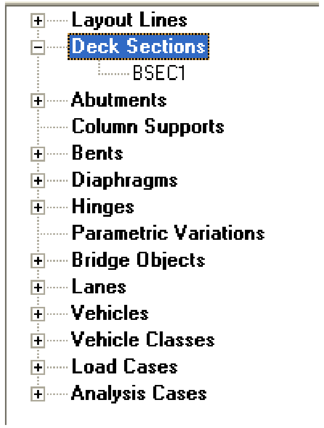
Horizontal Layout – Quick Options

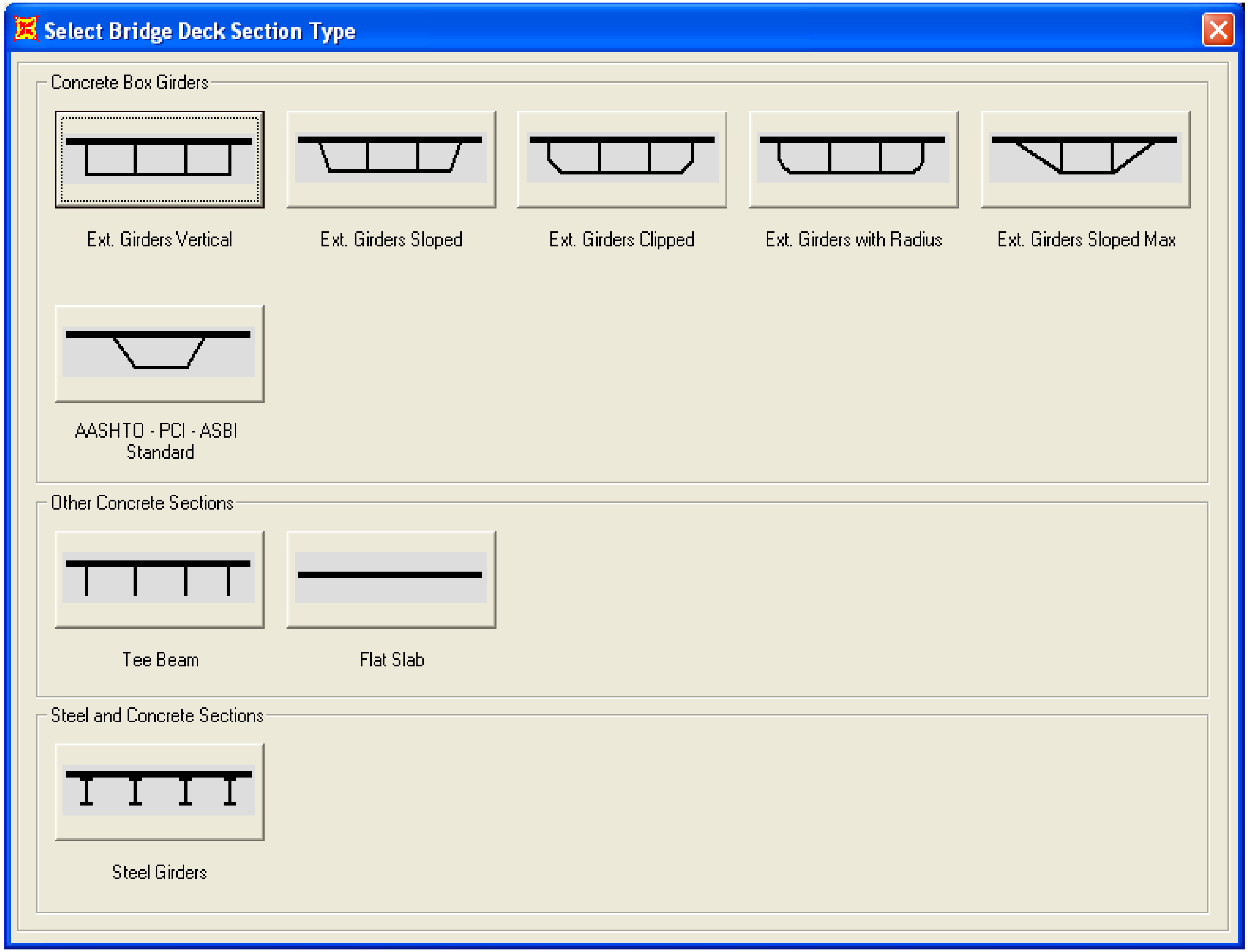


Vertical Layout – Quick Options

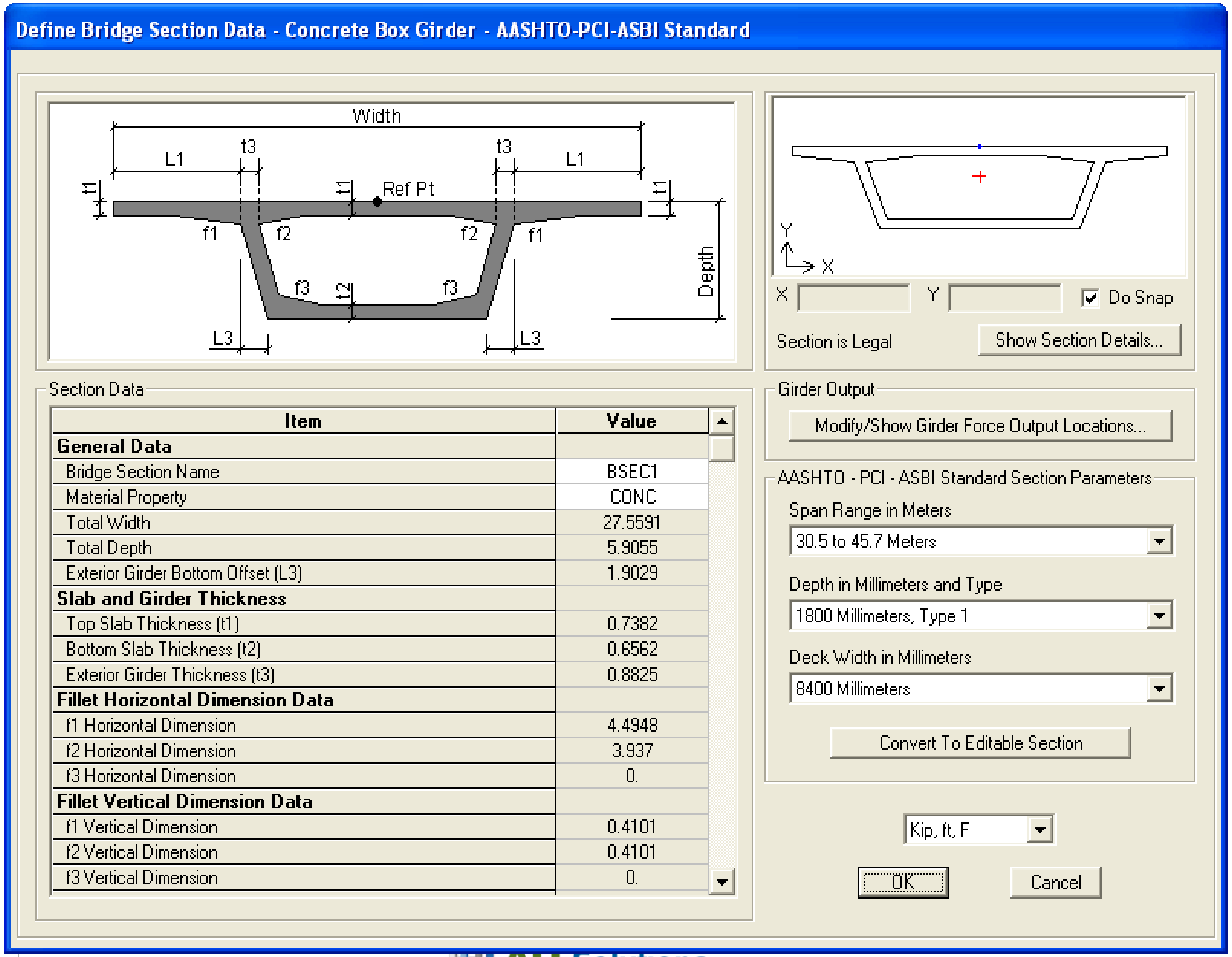


Parametric Deck Sections

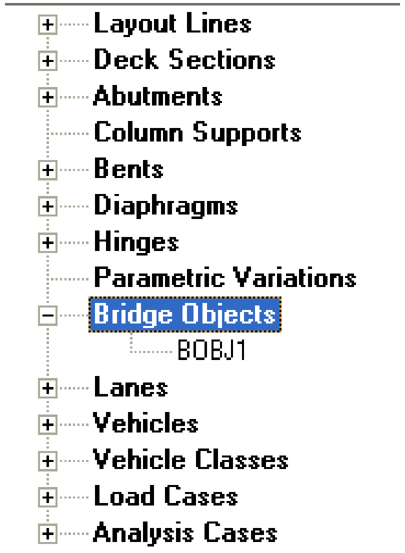


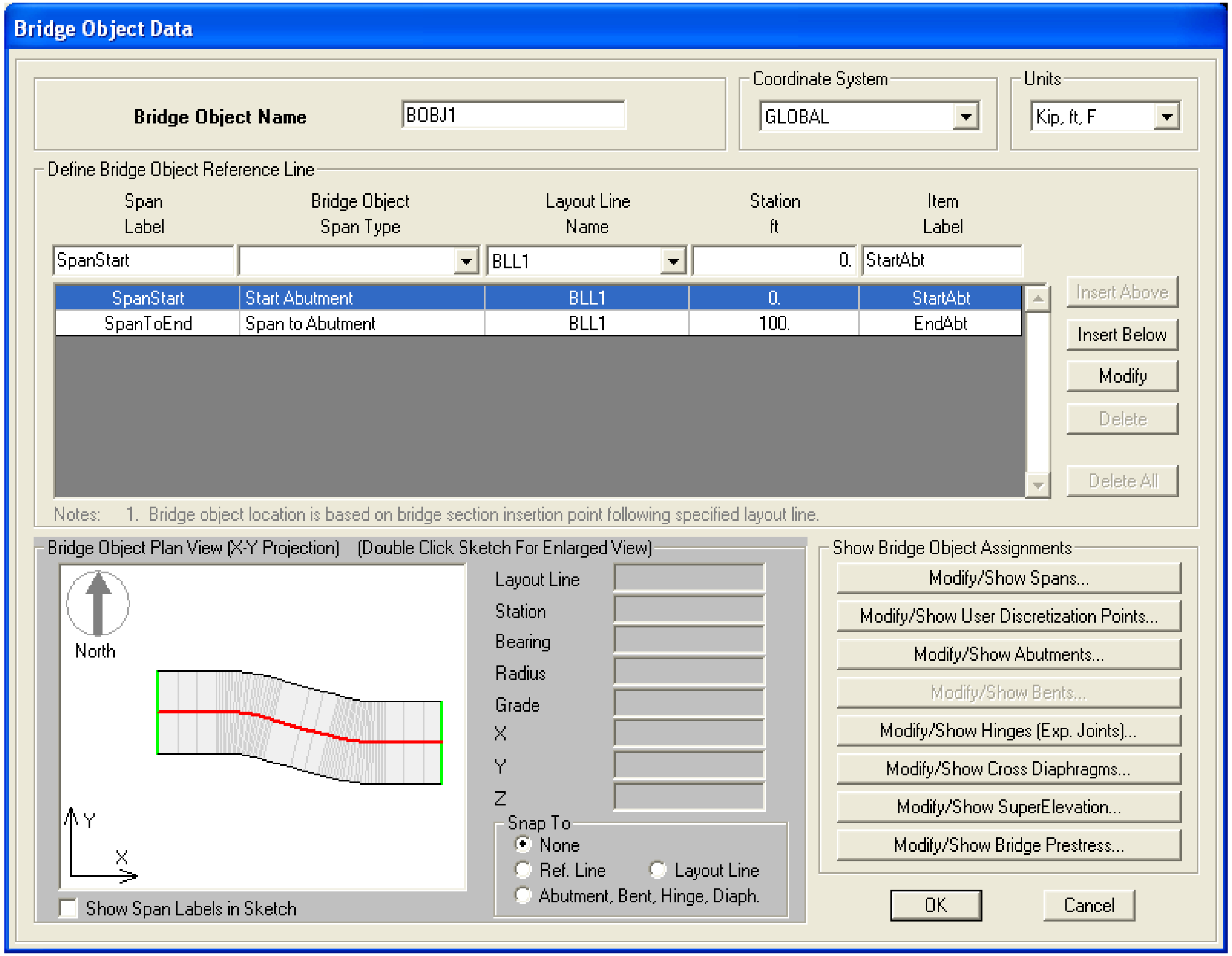


Parametric Deck Section

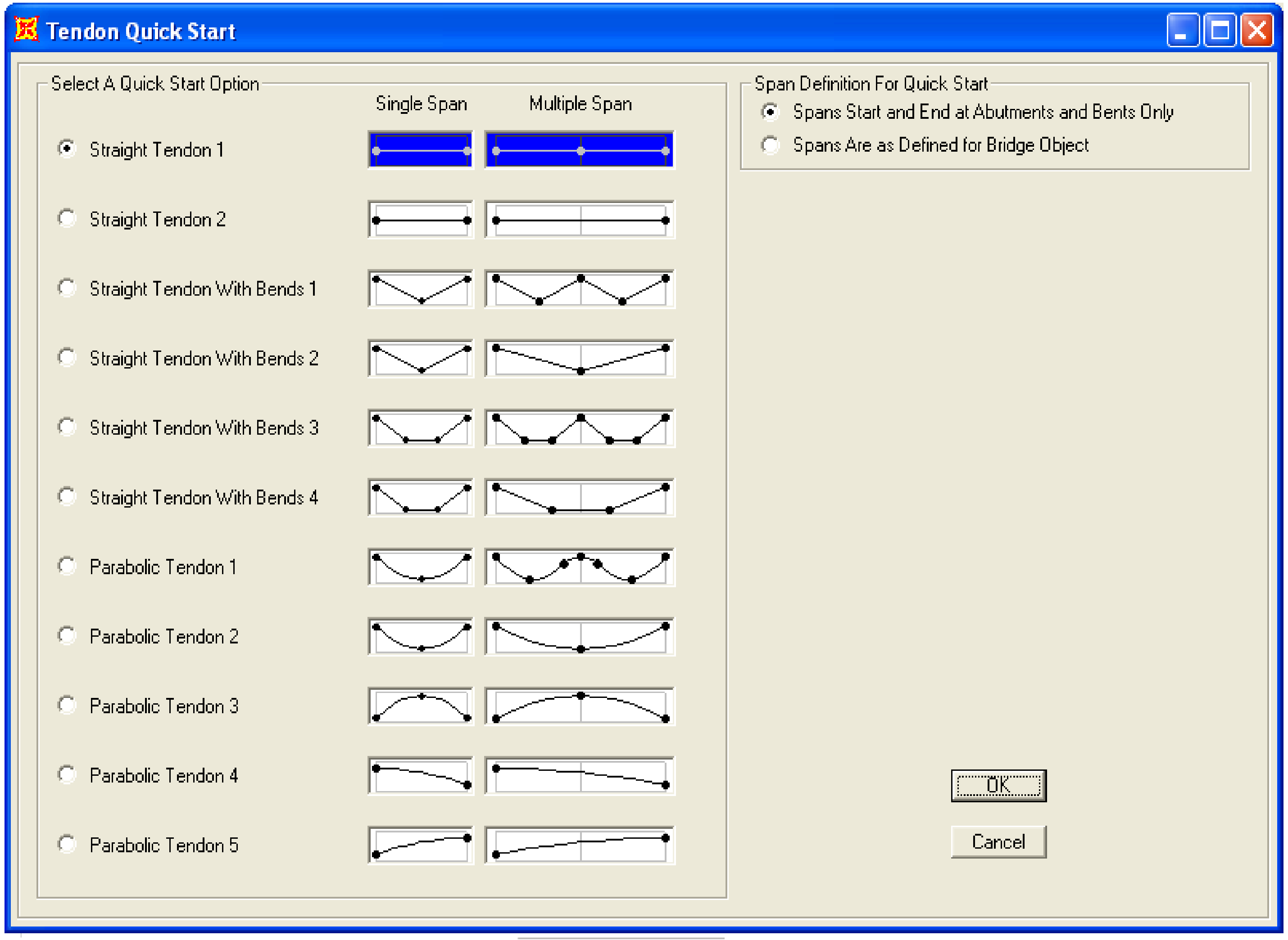


Bridge Objects

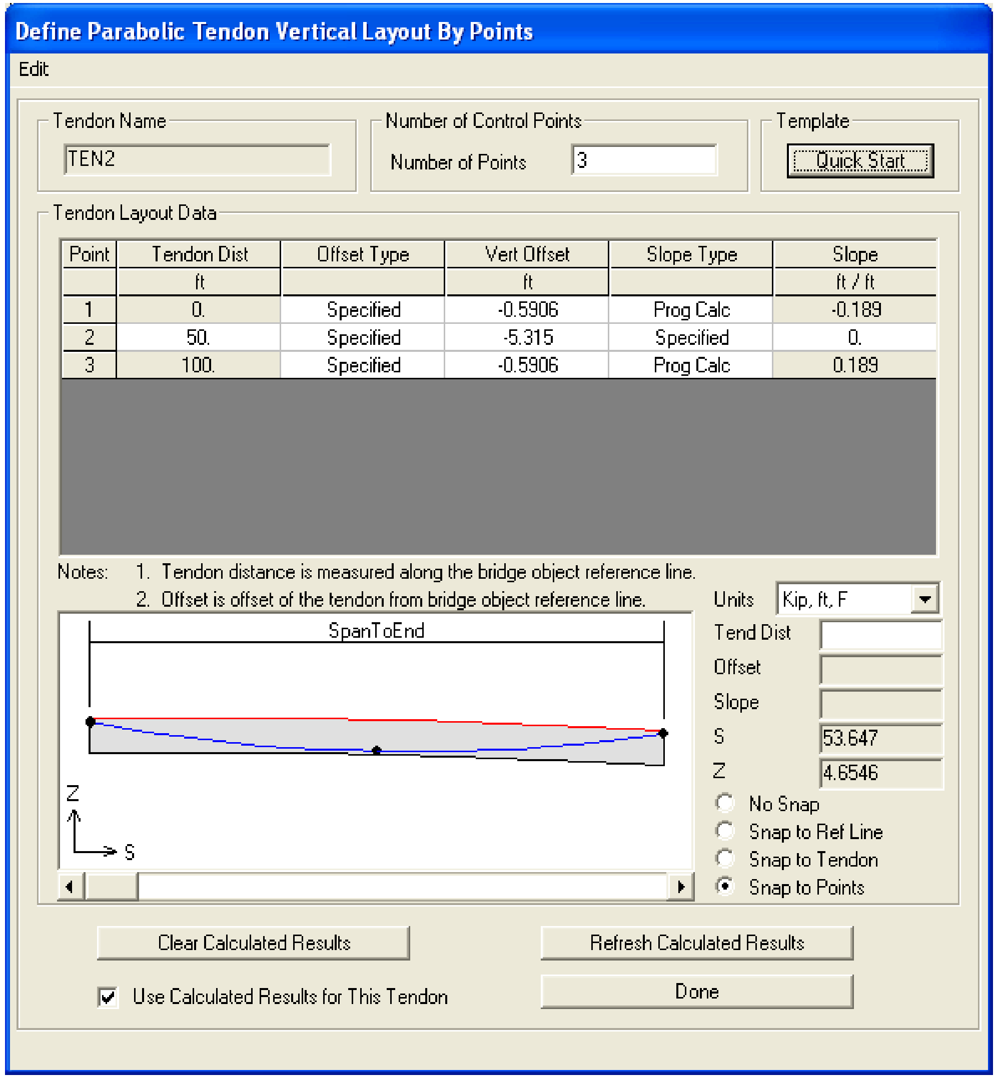




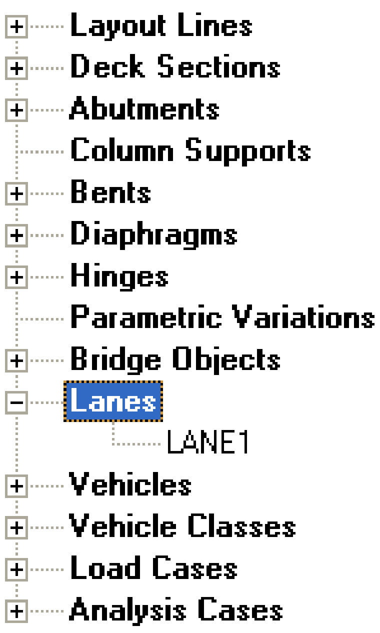
Pre-stressing Tendons – Quick Options

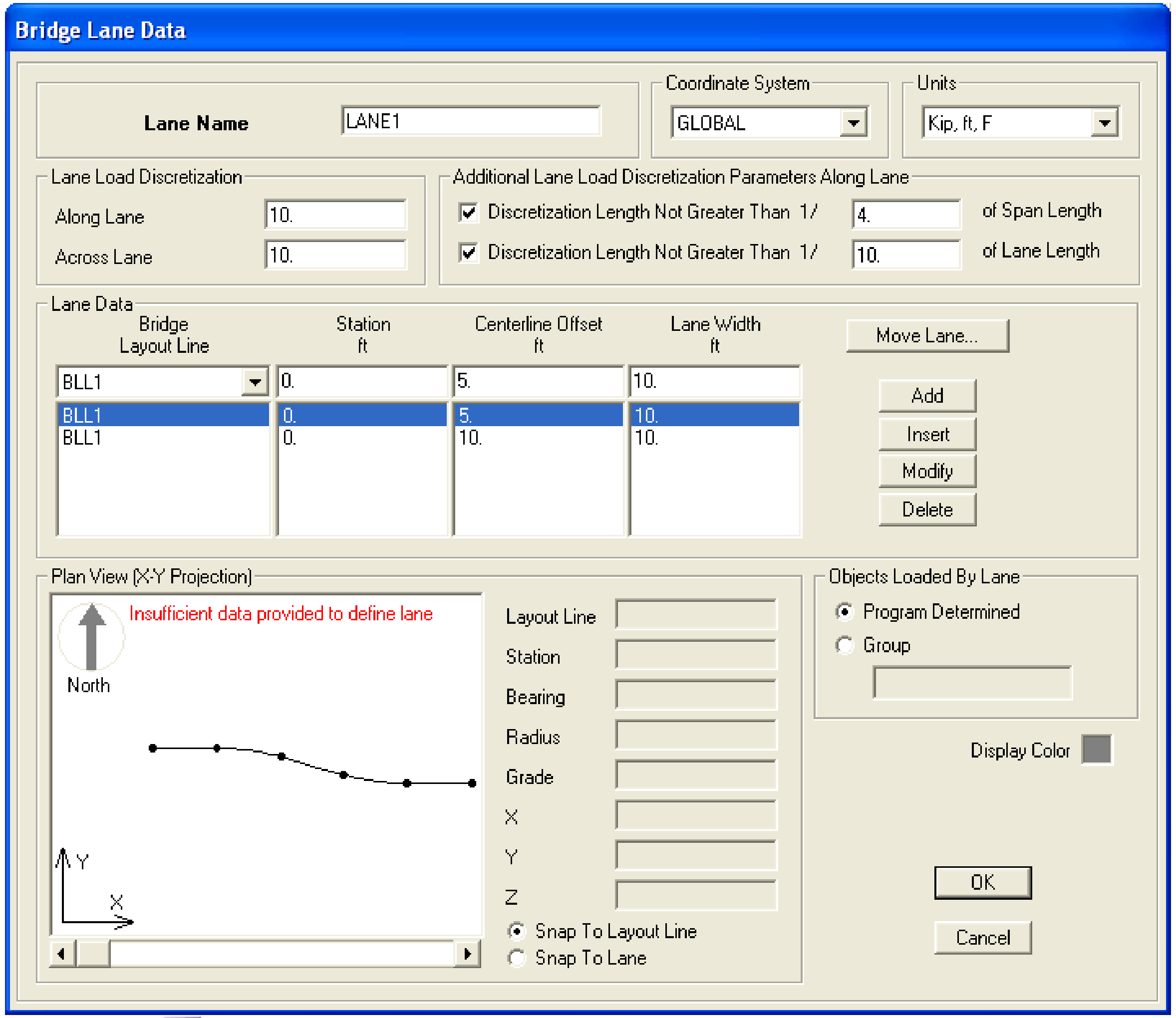


Pre-stressing Tendons - Parabolic

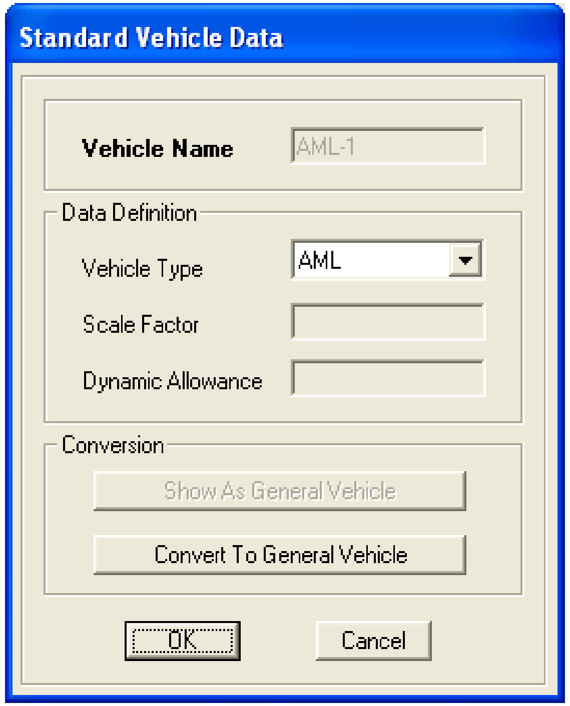


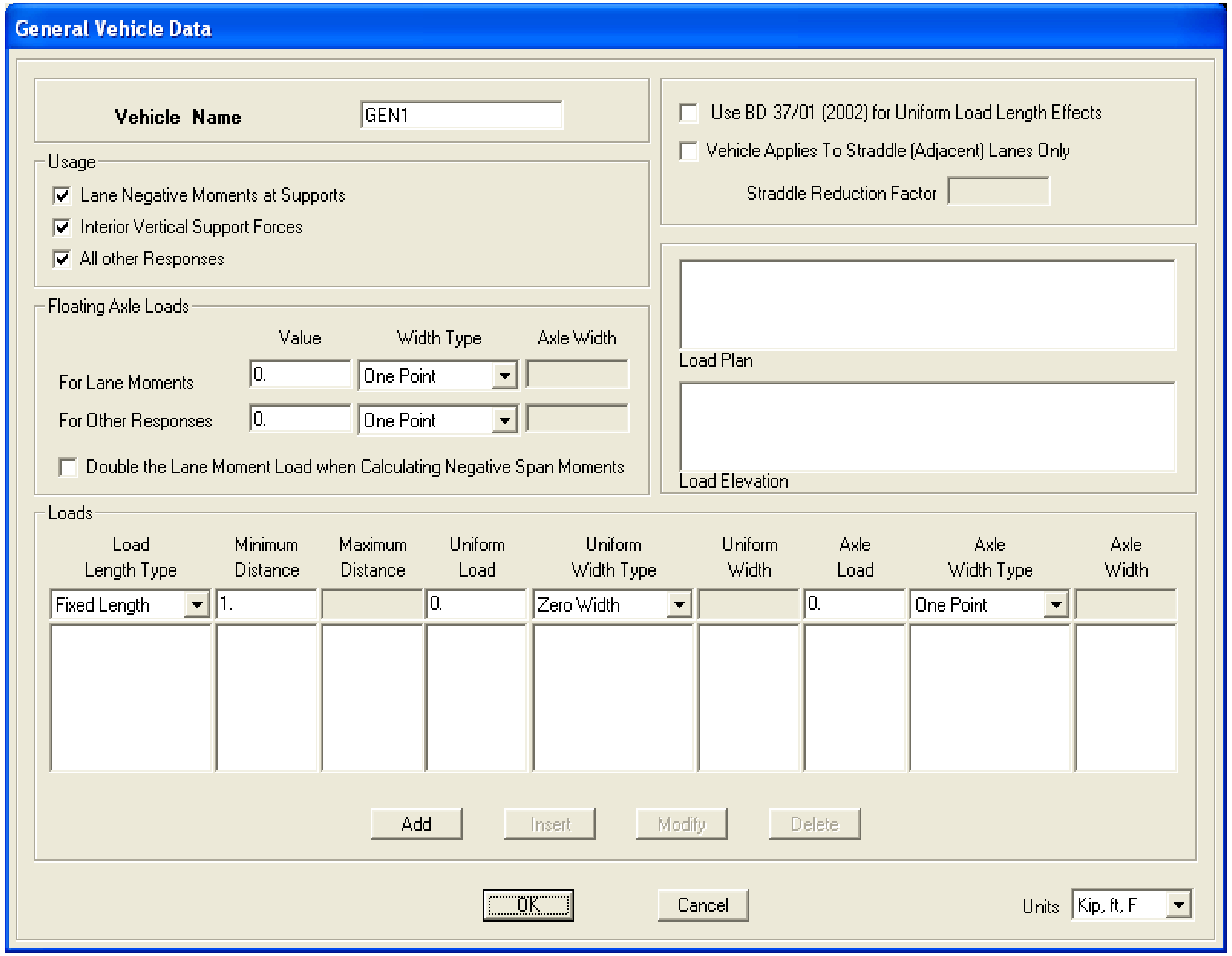
Traffic Loads – Lanes and Vehicles





Vehicle Data – Standard and General





PULAU MUARA BESAR BRIDGE

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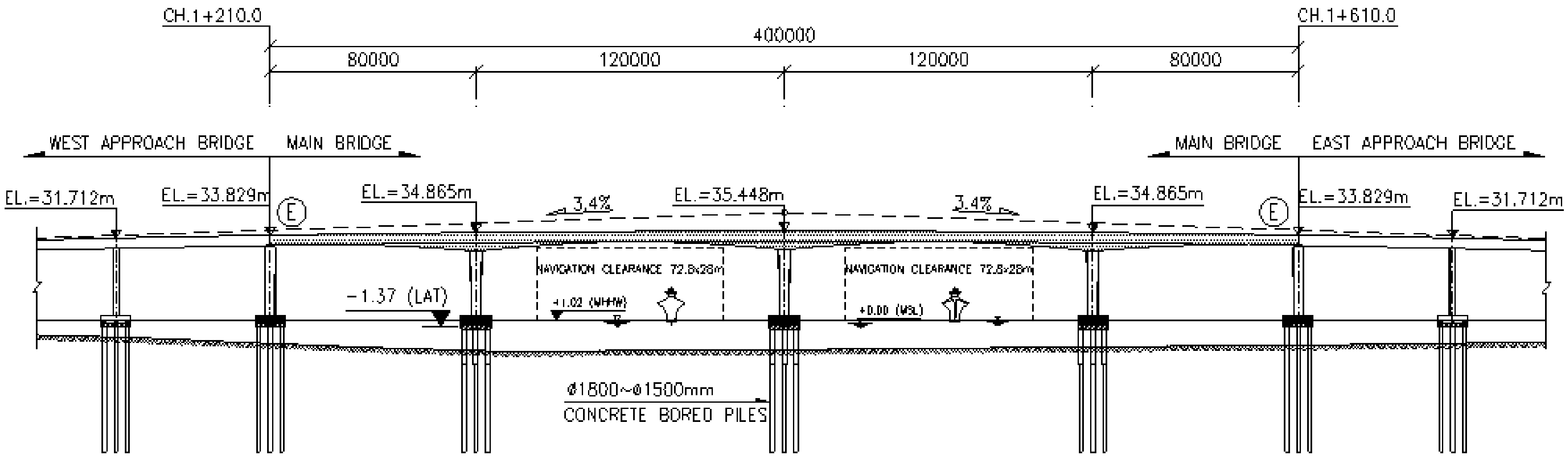
Bridge Locations

Project Scope

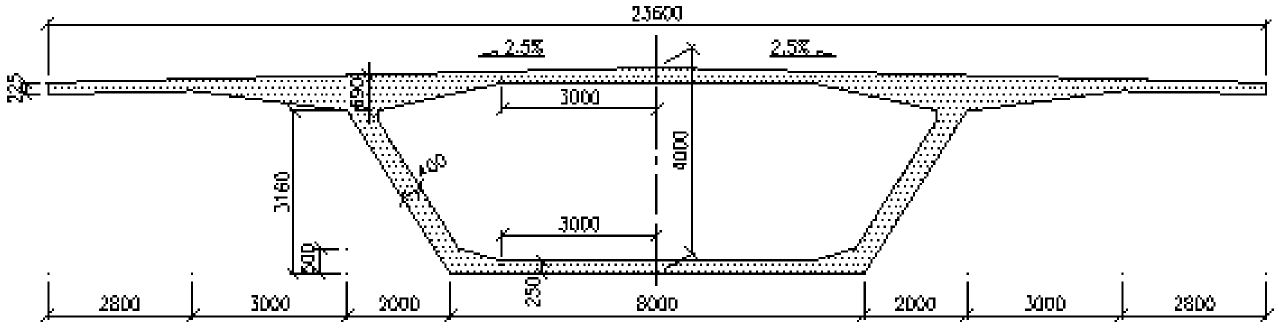
West Approach Road	The west approach road on the Mainland consists of all earthworks and roadworks
West Approach Bridge Section	A prestressed concrete box girder bridge with a span length of 60m.
Main Bridge Section	A prestressed concrete box girder bridge with a minimum soffit clearance of 28m and a main span length of 120m
East Approach Bridge Section	A prestressed concrete box girder bridge with a span length of 60m.
East Approach Road	The east approach road on PMB consists of all earthworks and roadworks

Main Bridge Span Configurations

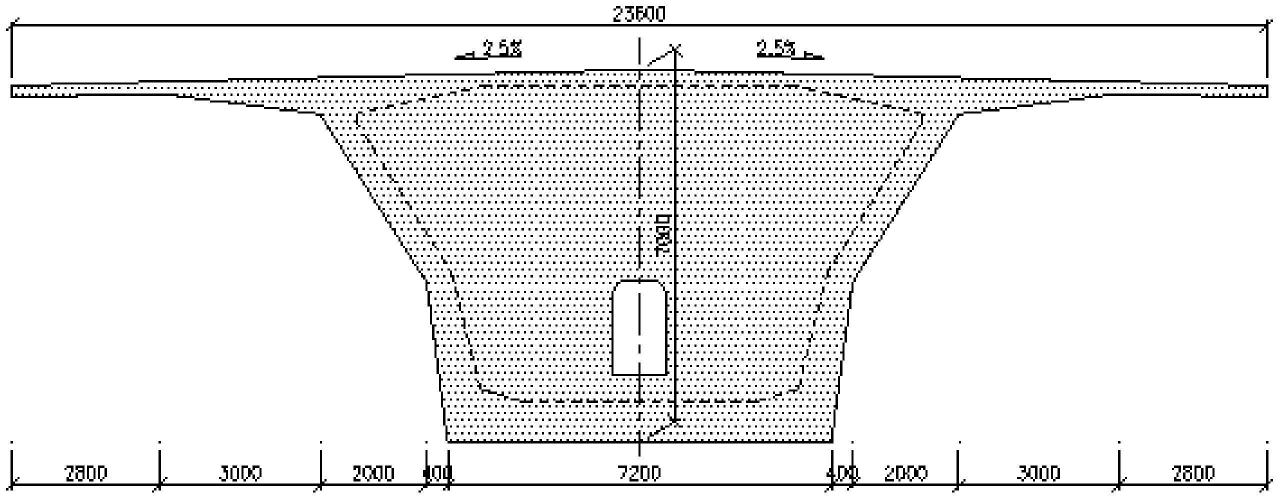
The Main Bridge has a total length 400 m and has a span configuration of 80m+120m+120m+80m in continuous rigid frame structure



Main Bridge Superstructure Arrangement



Typical Cross Section of Main Bridge Deck at Mid Span

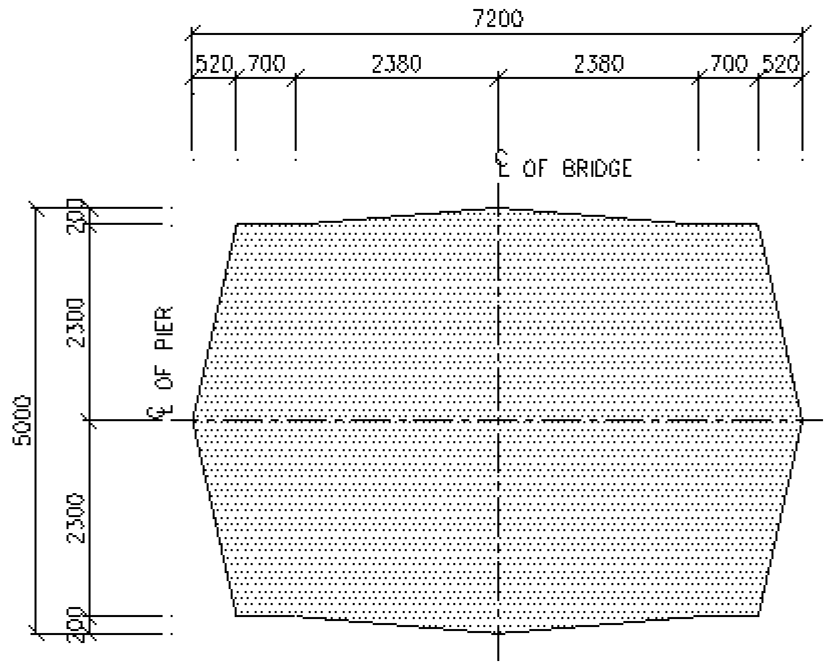


Typical Cross Section of Main Bridge Deck at Pier Position

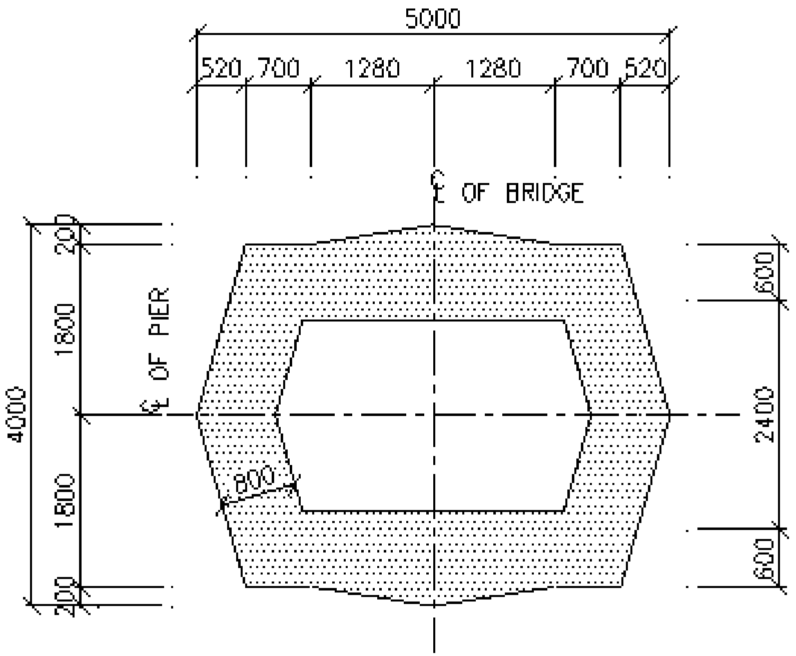
Main Bridge Pier Arrangement

The intermediate piers are numbered as MP2 to MP4 and the movement joint piers are numbered as MP1 and MP5

Main Bridge MP2 to MP4 Pier Dimensions



Pier Head



Pier Shaft

TELISAI HIGHWAY PROJECT

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General Information

- British Code BS 5400 or relevant version are followed for this project.

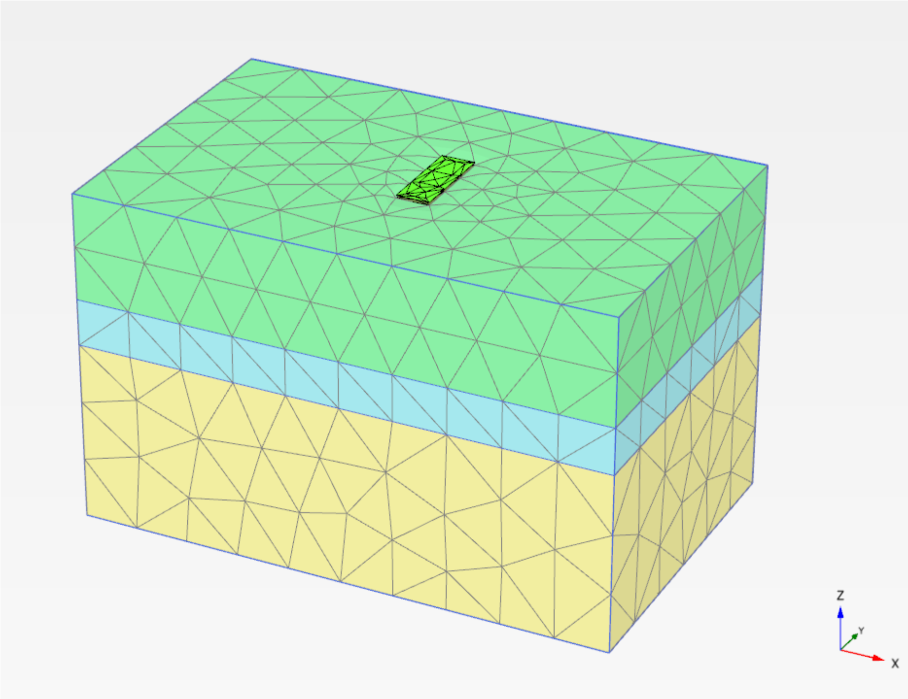
- Concrete Strength:

Member	Nominal Strength (MPa)
Blinding concrete	10
Mass concrete	15
RC where live load stresses are low	20
General rc, insitu bored piles, rc pavement	40
Concrete bridge decks, columns, footing & approach structure	40
Insitu prestressed concrete	60
Precast prestressed concrete	60

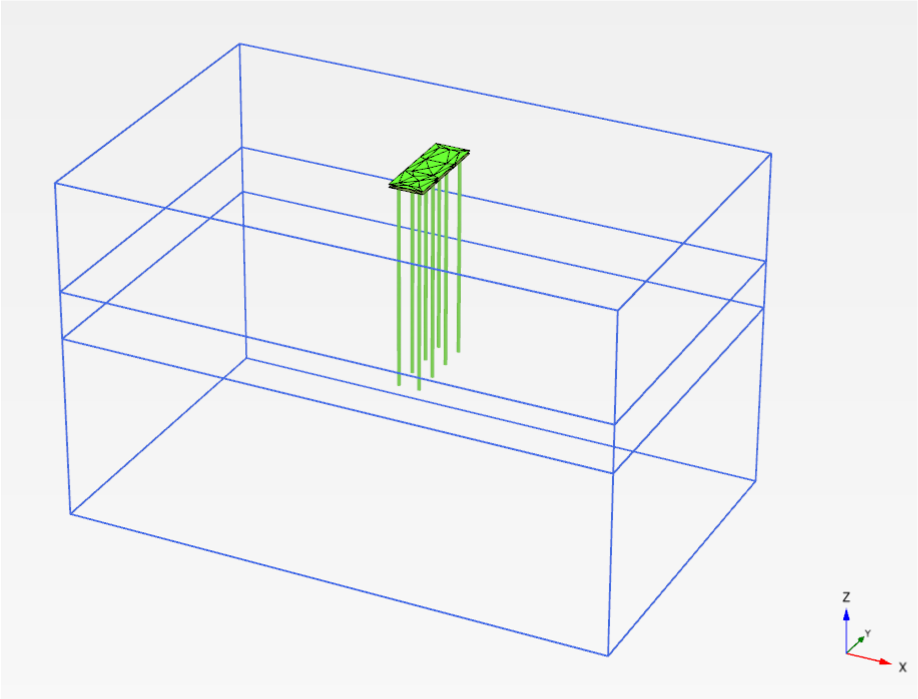
- Minimum yield strength of reinforcement (f_y) to be used shall be 460 (MPa)

Design of Pile and Pile Cap

Pile and pile cap are designed using Finite Element Analysis.



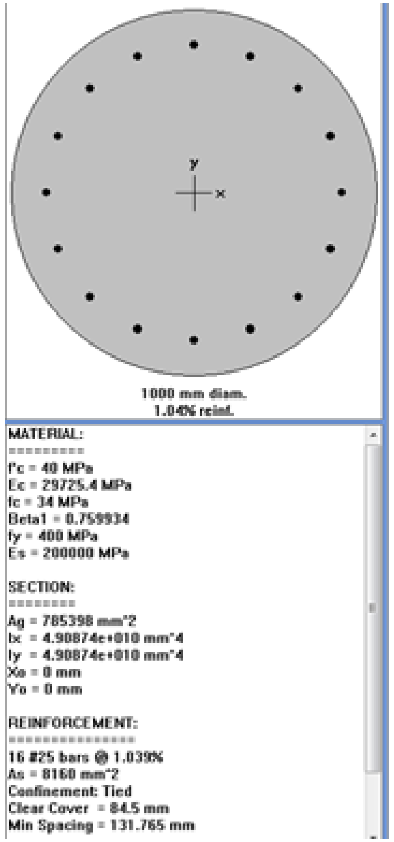
FEM for Pile Design

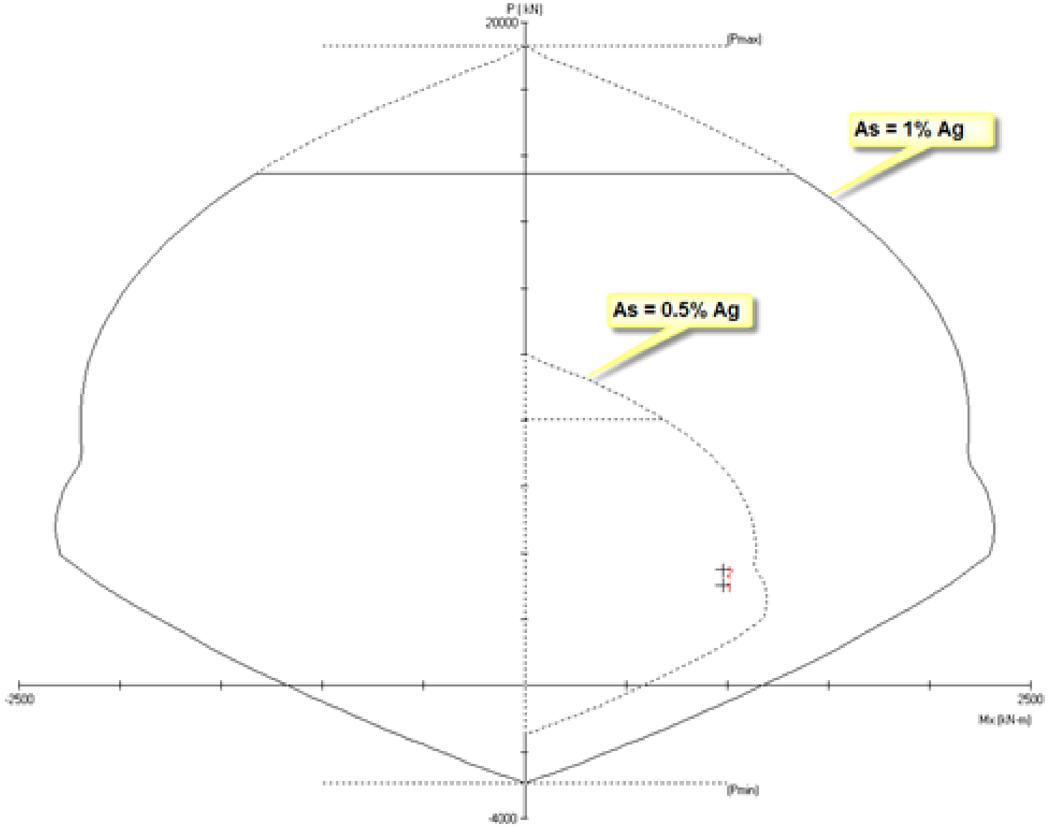


FEM for Pile Cap Design

Pile Capacity

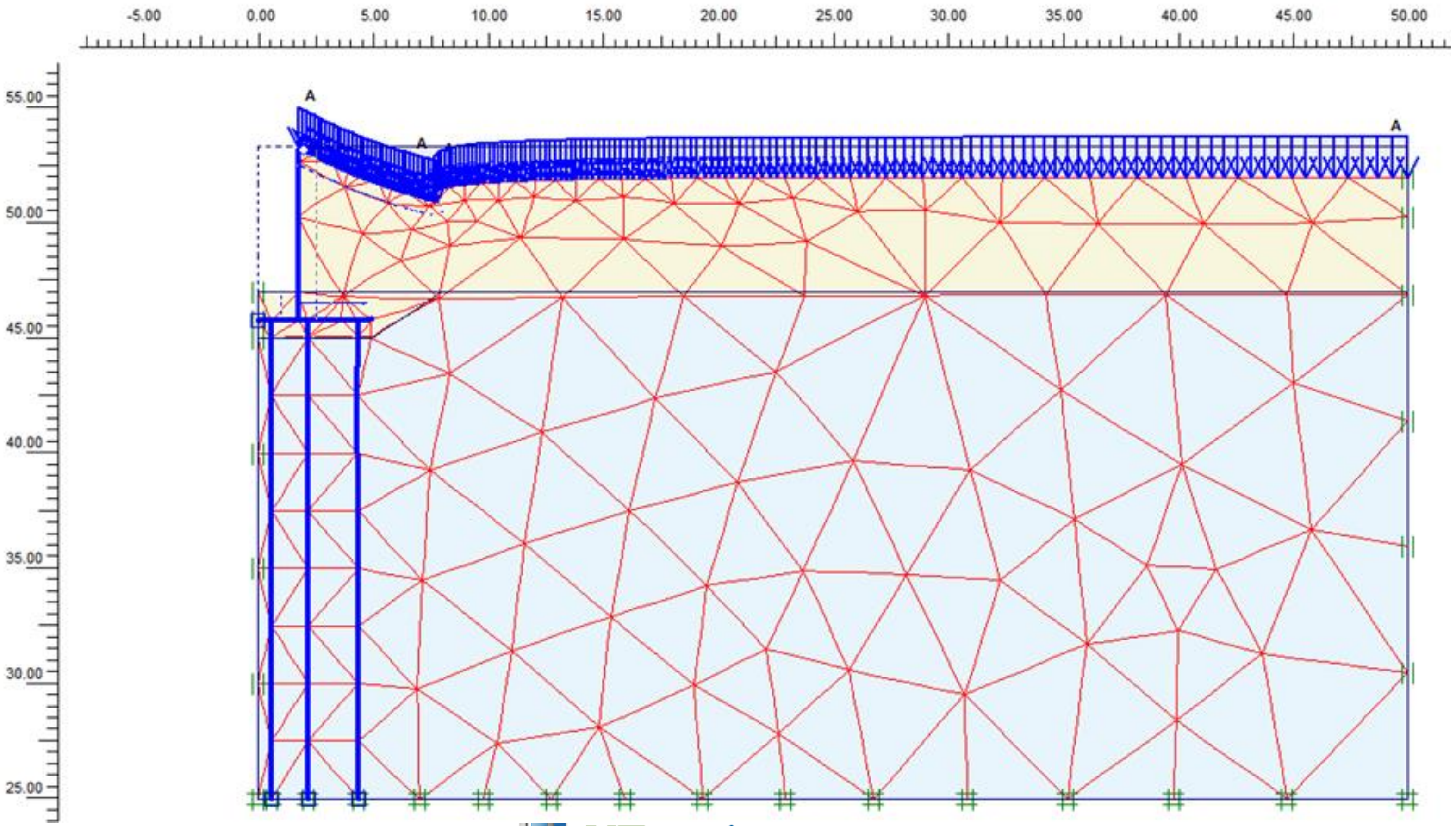
Capacity of section versus extreme load in pile





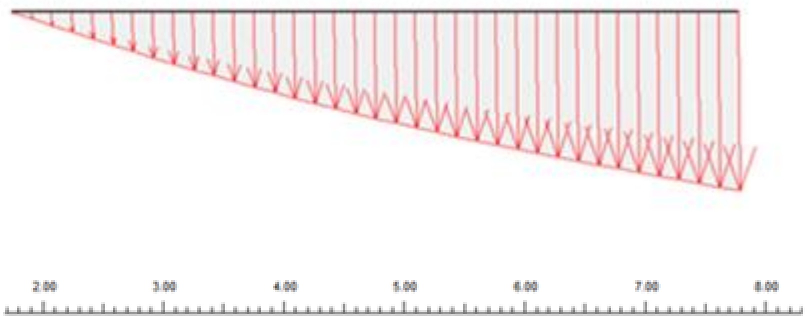
Bridge Approach Slab Design

Deformed FEM Mesh

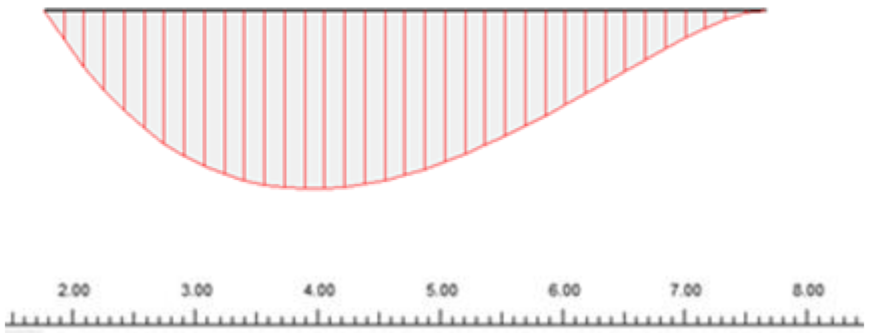


Bridge Slab Design

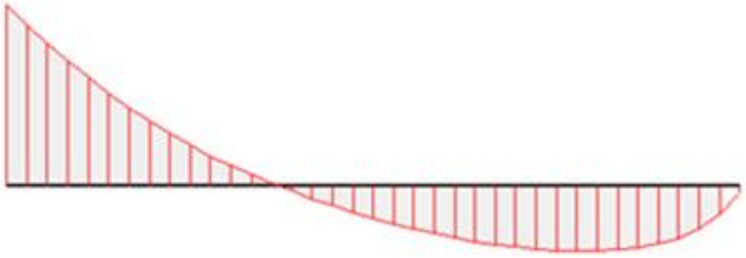
Total Displacement
Extreme Value = 23.53 x 10^{-3} m



Bending Moment
Extreme Value = 22.59 kN/mm^3



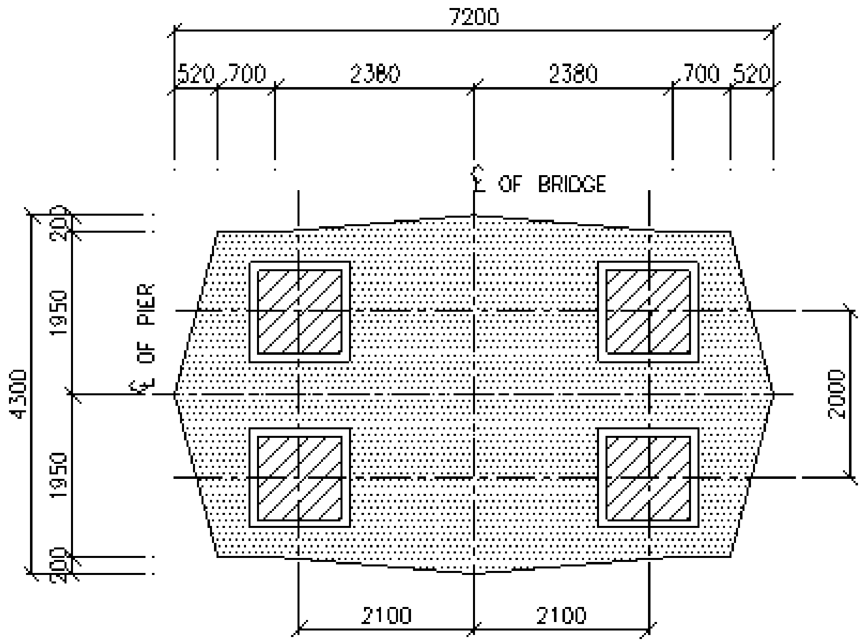
Shear Force
Extreme Value = -23.93 kN



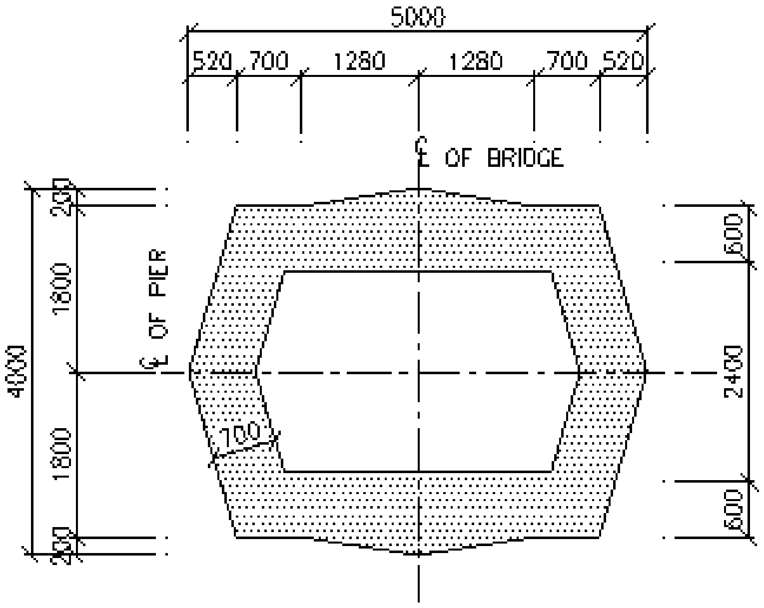
Main Bridge Pier Arrangement

The intermediate piers are numbered as MP2 to MP4 and the movement joint piers are numbered as MP1 and MP5

Main Bridge MP1 & MP5 Pier Dimensions



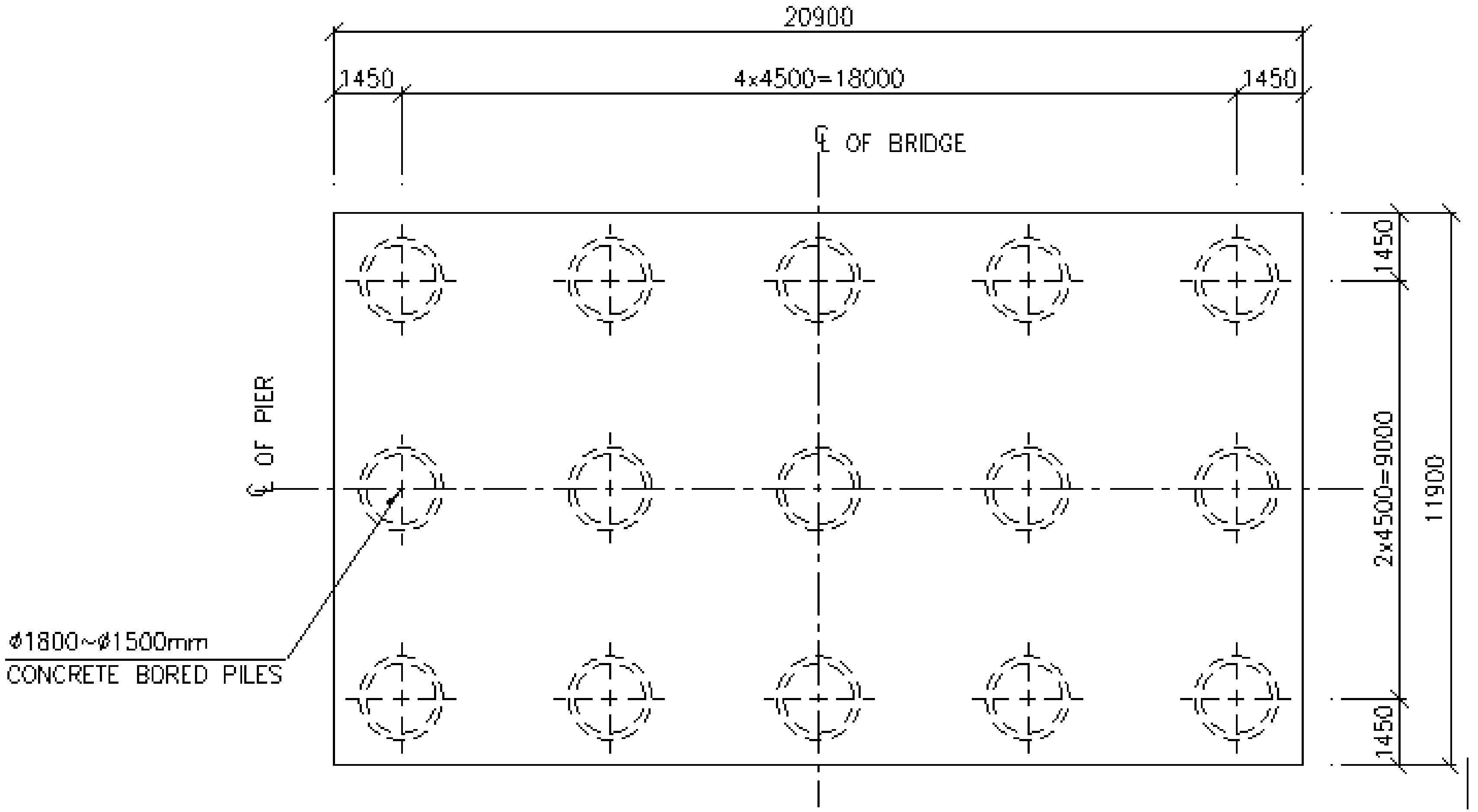
Pier Head



Pier Shaft

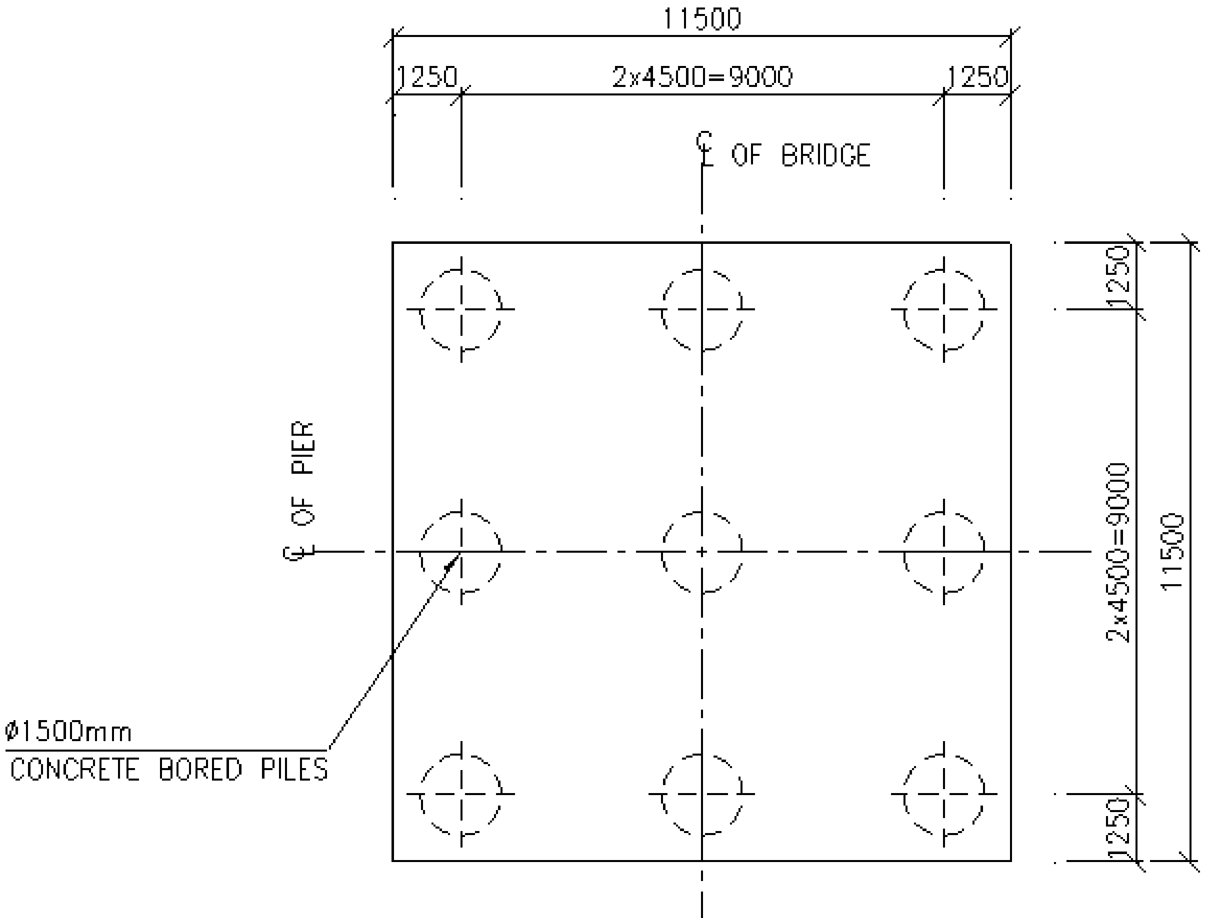
Main Bridge Pile Cap & Piling Arrangement

Pier MP2 & MP4 Foundation



Main Bridge Pile Cap & Piling Arrangement

Pier MP1 & MP5 Foundation



Questions and discussion!