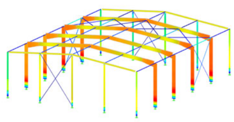
Chapter 17

Structural Modeling and Computer Analysis



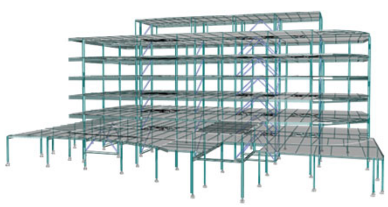
Chapter 17

Structural Modeling and Computer Analysis

Physical Model – represent the physical structural members. Physical model accurately display insertion points, member orientations, object intersections, and other geometric details.

Chapter 17

Structural Modeling and Computer Analysis



Analytical Model – uses finite element to model of the structure

Structural Modeling and Computer Analysis

General Structural Modeling

- In a general sense, a structural analysis using a computer is performed to determine the ***internal loadings*** within a structure.
- Also, to find the ***deflection*** of its components, when the structure is subjected to a variety of different loadings.
- Before we can do an analysis, it is first necessary to select a form for the structure, such as a ***truss*** or ***frame***, and then develop a model of this form that can be used for the analysis.
- The model must account for the ***geometry*** of each of the members, the types of ***connections***, the ***loadings***, and the ***material properties***.

Structural Modeling and Computer Analysis

General Structural Modeling

- The modeling process must be such that reasonable, yet conservative results are obtained.
- This is especially true for structures that are occupied by large groups of people, such as assembly halls, schools, and hospitals.
- Keep in mind that a computer analysis may be accurate when calculating a numerical answer, but the results can lead to ***disastrous consequences if the wrong model or input is involved***.

Structural Modeling and Computer Analysis

General Structural Modeling

- There are many different types of structural forms that may be used to support a loading.
- Choosing the correct form to fulfill a specific function is both a science and an art.
- Oftentimes, models for several different forms must be considered, and analyzed to find the one that is ***economically feasible***, and at the same time provides both ***safety*** and ***reliability***.

Structural Modeling and Computer Analysis

General Structural Modeling

- A typical example would be choosing a steel frame structure having light-gage metal walls and roof, versus one built from masonry and wood.
- The behavior of each of these structures is different under load, and the model for each depends upon the way it is constructed.
- In some cases, however, the selection of a structural form may be limited.
- For example, ***truss*** and ***girder bridges*** are preferred for short spans, and ***suspension or cable-stayed bridges*** are most efficient for longer spans.

Structural Modeling and Computer Analysis

General Structural Modeling

- Not only is it necessary to select a particular model for the form of a structure, but the elements that make it up may not have a unique pattern.
- For example, if a ***truss bridge*** is selected, then the form of the truss, such as a Pratt or Warren truss, must also be determined, as discussed in Sec. 3.1.
- ***Floor systems*** in buildings also vary in their details, as noted in Sec. 2.1, and models for each must be clearly specified.
- Proper selection for complex projects comes from experience, and normally requires a team effort, working in close contact with the architects who have conceived the project.

Structural Modeling and Computer Analysis

General Structural Modeling

- To ensure public safety, the building criteria for the design of some structures requires the structure to remain stable after some of its primary supporting members are ***removed***.
- This requirement follows in the aftermath of the tragic 1995 bombing of the Murrah Federal Building in Oklahoma City.



Structural Modeling and Computer Analysis

General Structural Modeling

- Investigators concluded that most deaths were the result, not of the blast, but of the progressive ***collapse*** of portions of all the floors in the front of the structure



Structural Modeling and Computer Analysis

General Structural Modeling

- As a result, the design of many federal buildings, and some high-rise commercial buildings, now requires the structure to remain in a ***stable position***, when possible, ***loss of its primary members*** occurs.



Structural Modeling and Computer Analysis

General Structural Modeling

- A complete structural analysis will therefore require a careful investigation of the ***load paths*** for several different cases of structural support, and a model of each case must be considered.



Structural Modeling and Computer Analysis

General Structural Modeling

- In the following sections, we will review this modeling process as it applies to basic structural ***elements***, various ***supports*** and ***connections***, ***loadings***, and ***materials***.
- Once the model is constructed, and a structural analysis performed, the ***computed results should be checked*** to be sure they parallel our intuition about the structural behavior.
- If this does not occur, then we may have to improve the modeling process, or justify the calculations based on professional judgment.

Structural Modeling and Computer Analysis

Modeling a Structure and its Members

- The various types of structural members have been described in Sec. 1.2.
- Here we will present a summary description of these members and illustrate how each can be modeled.

Structural Modeling and Computer Analysis

Tie Rods

- Sometimes called ***bracing struts***, these members are intended to only support a tensile force.
- They have many applications in structures, and an example, along with its support connection.
- Because they are slender, the supports for these members are always ***assumed*** to be pin connections.

Structural Modeling and Computer Analysis

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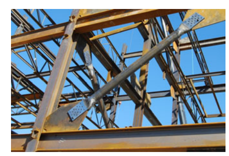

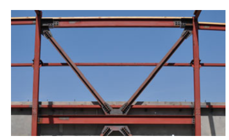

Structural Modeling and Computer Analysis

Beams and Girders

- ***Beams*** are normally prismatic members that ***support loadings applied perpendicular to their length***.
- A ***girder*** provides ***support for beams*** that are connected to it, as in the case of a building girder that supports a series of floor beams.

Structural Modeling and Computer Analysis

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Structural Modeling and Computer Analysis

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Structural Modeling and Computer Analysis

Beams and Girders

- One must be careful about selecting the proper support for these members
- If the support is a simple bolted connection, it should be modeled as a ***pin***.
- This is because codes generally ***restrict the elastic deflection of a beam***, and so the support rotation will generally be ***very small***.

Structural Modeling and Computer Analysis

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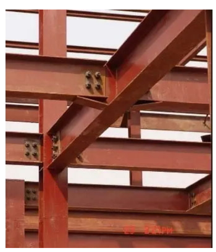
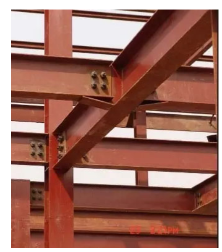


Structural Modeling and Computer Analysis

Beams and Girders

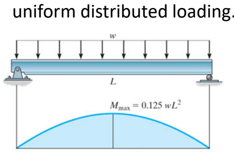
- One sometimes must be careful about selecting the proper support for these members
- If the support is a simple bolted connection, it should be modeled as a ***pin***.
- Also, choosing ***pin*** supports will lead to a more ***conservative*** approach to the design of the member.

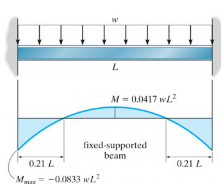


Structural Modeling and Computer Analysis

Beams and Girders

- To see this, consider the moment diagrams for the simply supported and fixed-supported beams that carry the same uniform distributed loading.



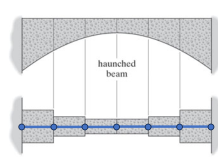


- The internal moment is ***largest*** in the simply supported case, and so this beam must have ***a higher strength and stiffness*** to resist the loading compared to the other two cases.

Structural Modeling and Computer Analysis

Beams and Girders

- Beams can also have cross sections that are tapered or haunched, or they can be built up by adding plates to their top and bottom.



- A model of the haunched beam to be used for a computer analysis can be represented by a series of fixed-connected prismatic segments, where “nodes” are placed at the joints of each segment.

Structural Modeling and Computer Analysis

Beams and Girders

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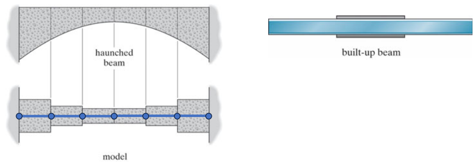
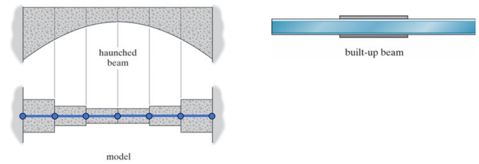


- Using good judgment, the number of segments selected for this division should be reasonable.

Structural Modeling and Computer Analysis

Beams and Girders

- Beams can also have cross sections that are tapered or haunched, or they can be built up by adding plates to their top and bottom.



- Here it would be conservative to select the ***smallest*** end of each tapered segment to represent the thickness of each prismatic segment.

Structural Modeling and Computer Analysis

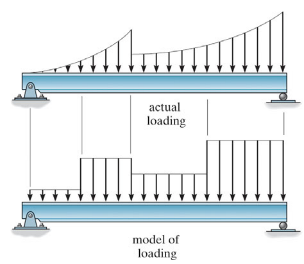
Beams and Girders

- Treatment of beams in this manner also applies to cases where an ***unusual distributed load*** is applied to the beam.
- Computer software usually accommodates ***uniform, triangular, and trapezoidal loadings***.
- If a unique loading is not incorporated into the computer program, then it can be approximated by a series of segmented uniform distributed loadings, acting on joined segments of the beam.

Structural Modeling and Computer Analysis

Beams and Girders

- Here a conservative approach would be to select the highest intensity of the distributed loading within each segment.



Structural Modeling and Computer Analysis

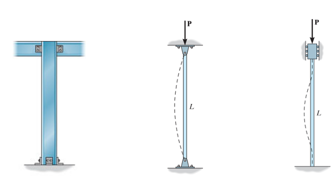
Columns

- As discussed in Sec. 1.2, a ***column*** should be designed to carry a compressive load in direct bearing, that is, the load should pass through the centroid of the cross section.
- As with beams, the ***end supports*** should be modeled so that the results will provide a ***conservative*** approach to the design.

Structural Modeling and Computer Analysis

Columns

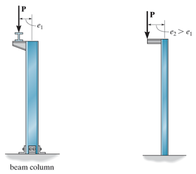
- For example, if a concentric load is applied to the column.
- Its supports are modeled as a ***pin***, then the cross section of the column will have to be ***larger to prevent buckling***, compared to the same column modeled as having ***fixed*** supports.



Structural Modeling and Computer Analysis

Columns

- As another example, if a ***corbel*** is attached to a column, it will carry an ***eccentric load***, thereby creating a ***beam column***.
- The model of the column should be dimensioned so that the load is applied at a ***conservative distance*** away from the bending axis of the column's cross section, thus ensuring further ***safety against buckling.***



Structural Modeling and Computer Analysis

General Structure

- Chapter 1 discusses the various ***dead and live loads*** that must be considered when designing a structure.
- These are all specified in codes, and as noted in Sec. 1.4, there is a trend to use probability theory to account for the uncertainty of the loads by using ***load factors*** and applying them in ***various combinations***.
- Once obtained, good engineering judgment is expected, so that the loading is applied to the model of the structure in a reasonably ***conservative manner***.

Structural Modeling and Computer Analysis

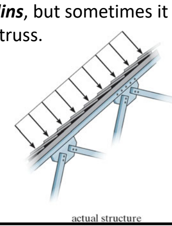
General Structure

- Not only must the ***magnitude*** of the loads be determined, but their ***locations*** on the model must also be specified.
- Generally, the dimensions for the model are reported ***centerline to centerline*** for each of the members.
- In case of uncertainty, always use ***larger dimensions***, so that larger internal loadings are calculated, thereby producing a safe design.

Structural Modeling and Computer Analysis

General Structure

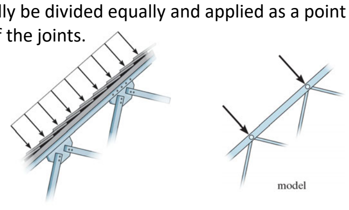
- By establishing the ***load path*** for a structure, one can then make reasonable assumptions for load transference from one member to another (See Sec. 2.2).
- For example, a roof that is supported by trusses is often attached to ***purlins***, but sometimes it is directly fixed to the entire top cord of the truss.



Structural Modeling and Computer Analysis

General Structure

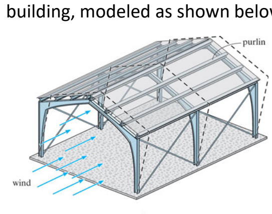
- By establishing the ***load path*** for a structure, one can then make reasonable assumptions for load transference from one member to another (See Sec. 2.2).
- The resultant of the distribution of load between the joints can generally be divided equally and applied as a point loading on each of the joints.



Structural Modeling and Computer Analysis

General Structure

- As a second example, consider the effect of the ***wind*** on the front of a metal building, modeled as shown below:



- Cross bracing, using ***tie rods*** between each bay, prevents the building from ***racking*** or leaning, as shown by the dashed lines.

Structural Modeling and Computer Analysis

General Structure

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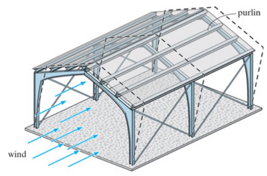


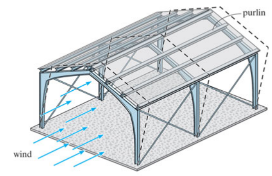
actual structure

- Being conservative, we will neglect the additional restraint provided by the ***purlins*** and assume the rods ***do not support a compressive force*** since their cross section is small.

Structural Modeling and Computer Analysis

General Structure

- As a second example, consider the effect of the wind on the front of a metal building, modeled as shown below:



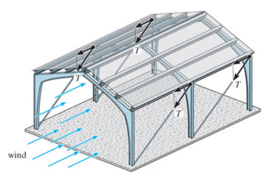
actual structure

- Instead, ***only the rods in tension*** provide the necessary resistance against collapse.

Structural Modeling and Computer Analysis

General Structure

- In other words, only the four rods shown on the model below are assumed to resist the wind loading.



model

- The other four rods provide support if the wind loading acts on the opposite side.

Structural Modeling and Computer Analysis

Materials

- Consideration should also be given to the ***material strength*** and ***stiffness*** of the structure.

- Strength properties include choosing ***allowable stresses*** that ensure the elastic limit or the ultimate stress is not exceeded

- Also, possibly a ***stress limit*** that prevents fatigue or fracture in the case of cyclic loadings or temperature variations.

Structural Modeling and Computer Analysis

Materials

- The ***material properties*** that are relevant for an elastic analysis include:
  1. the modulus of elasticity ***E***,
  2. the shear modulus ***G***,
  3. Poisson's ratio ν,
  4. the coefficient of thermal expansion α, and
  5. the specific weight or the density of the material γ.

- In particular, the ***stiffness*** of the structure is dependent upon its modulus of elasticity ***E***.

Structural Modeling and Computer Analysis

Materials

- For ***steel***, this property remains fairly constant from one specimen of steel to another, unless the steel undergoes drastic changes in temperature.

- Care must be given to the selection of ***E*** for ***concrete*** and ***wood***, because of the variability that can occur within these materials.

- As time passes, all material properties can be affected by ***atmospheric corrosion***, as in the case of steel and concrete, and ***decay***, in the case of wood.

Structural Modeling and Computer Analysis

General Application of a Structural Analysis Computer Program

- Once the model of the structure is established and the load and material properties are specified, then all this data should be tabulated for use in an available computer program.
- The most popular structural analysis programs currently available, such as STAAD, RISA, and ***SAP2000***, are all based on the stiffness method of matrix analysis, described in Chapters 14 through 16.
- Although each of these programs has a slightly different interface, they all require the engineer to input the data using a specified format.

Structural Modeling and Computer Analysis

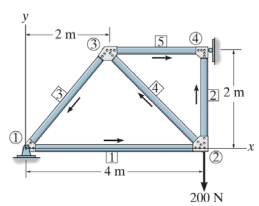
Preliminary Steps

- Before using any program, it is first necessary to numerically identify the members and joints or ***nodes*** of the structure.
- Also, to establish both ***global*** and ***local coordinate systems*** to specify the structure's geometry and loading.
- To do this, make a ***sketch*** of the structure and specify each member with a number enclosed within a square □, and use a number enclosed within a circle ○ to identify the nodes.

Structural Modeling and Computer Analysis

Preliminary Steps

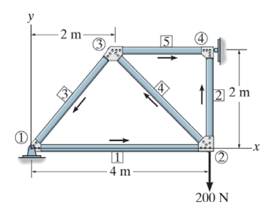
- In some programs, the "***near***" and "***far***" ends of the member must be identified.
- This is done using an arrow written along the member, with the head of the arrow directed toward the far end.

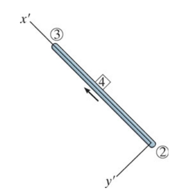


Structural Modeling and Computer Analysis

Preliminary Steps

- In truss model, node ② is at the "near end" of member 4 and node ③ is at its "far end."
- These assignments can all be done arbitrarily.

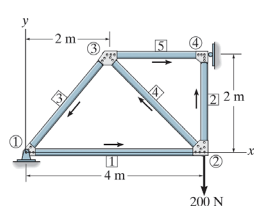


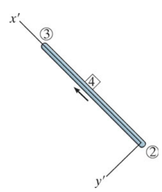


Structural Modeling and Computer Analysis

Preliminary Steps

- The nodes on the ***truss*** are always at the joints, since this is where the loads are assumed to be applied and the displacements and member forces are to be determined.

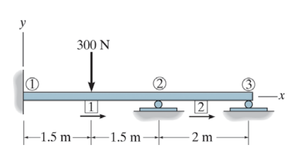




Structural Modeling and Computer Analysis

Preliminary Steps

- For ***beams*** and ***frames***, the nodes are at the supports, at a corner or joint, at an internal pin, or at a point where the linear or rotational displacement is to be determined.



Structural Modeling and Computer Analysis

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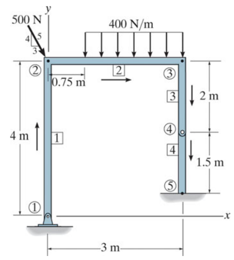
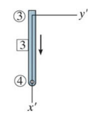




Structural Modeling and Computer Analysis

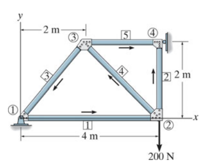
Coordinate systems

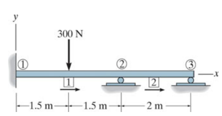
- Since loads and displacements are vector quantities, it is necessary to establish a coordinate system to specify their correct sense of direction.
- Here we must use two types of coordinate systems.

Structural Modeling and Computer Analysis

Global Coordinates

- A single ***global*** *or* ***structure coordinate system***, using right-handed *x*, *y*, *z* axes, is used to specify the location of each node relative to the origin, and to identify the sense of each of the external load and displacement components at the nodes.
- It is convenient to locate the origin at a node so that all the other nodes have ***positive coordinates***.

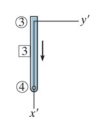


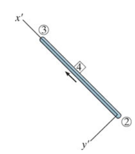


Structural Modeling and Computer Analysis

Local Coordinates

- A ***local*** *or* ***member coordinate system*** is used to specify the location and direction of external loadings acting on beam and frame members and for any structure.
- This system can be identified using right-handed *x*′, *y*′, *z*′ axes with the origin at the “near” node and the axis extending along the member toward the “far” node.





Structural Modeling and Computer Analysis

Program Operation

- When any computer program is executed, a menu will appear which allows various selections for inputting the data and getting the results.
- The following explains the items used for input data.
- For any problem, be sure to use a ***consistent set of units*** for numerical quantities.

Structural Modeling and Computer Analysis

Program Operation

General Structure Information

- Assign a problem title and identify the type of structure to be analyzed—***truss***, ***beam***, or ***frame***.

Node Data

- Enter each ***node*** number and its ***global coordinates***.

Structural Modeling and Computer Analysis

Program Operation

Member Data

- Each member number, the near and far node numbers, and the member properties, ***E*** (modulus of elasticity), ***A*** (cross-sectional area), and/or ***I*** (moment of inertia).
- If these member properties are unknown then provided the structure is ***statically determinate***, these values can be set equal to one.

Structural Modeling and Computer Analysis

Program Operation

Member Data

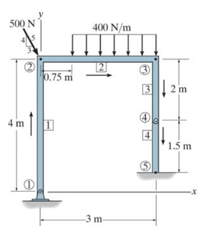
- Each member number, the near and far node numbers, and the member properties, ***E*** (modulus of elasticity), ***A*** (cross-sectional area), and/or ***I*** (moment of inertia).
- This can also be done if the structure is ***statically indeterminate***, provided there is no ***support settlement***, and the members all have the ***same cross section and are made from the same material.***
- In both these cases, the computed results will then give the correct reactions and internal forces, but ***not the correct displacements.***

Structural Modeling and Computer Analysis

Program Operation

Support Data

- Each node located at a support, specify the global coordinate directions in which restraint occurs.
- For example, since node ⑤ of the frame is a ***fixed*** support, a zero is entered for the *x*, *y*, and *z* (rotational) directions
- However, if this support settles downward 0.003 m, then the value entered for *y* would be -0.003.

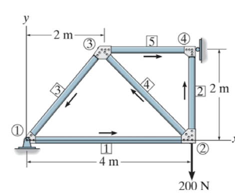


Structural Modeling and Computer Analysis

Program Operation

Load Data

- Loads are specified either at ***nodes***, or on ***members***.
- Enter the algebraic values of ***nodal loadings*** relative to the ***global coordinates***.
- For example, for the truss the loading at node ② is in the *y* direction and has a value of -200 N.

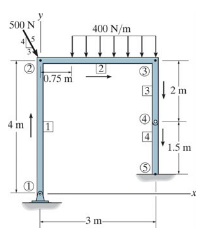


Structural Modeling and Computer Analysis

Program Operation

Load Data

- For beam and frame ***members*** the loadings and their location are generally referenced using the ***local coordinates***.
- For example, the distributed loading on member 2 of the frame is specified with an intensity of -400 N/m starting 0.75 m from the near node ② and -400 N/m ending 3 m from this node.



Structural Modeling and Computer Analysis

Program Operation

Results

- Once all the data is entered, then the problem can be solved.
- One obtains the ***external reactions*** on the structure and the ***displacements*** and internal loadings at each node, along with a graphic of the deflected structure.
- As a partial check of the results a statics check is often given at each of the nodes.

Structural Modeling and Computer Analysis

Program Operation

Results

- ***It is very important that you never blindly trust the results obtained.***
- Instead, it would be wise to perform an intuitive structural analysis using one of the many classical methods discussed in the text to further check the output.
- *After all, the structural engineer must take full **responsibility** for both the **modeling** and interpreting of **final results**.*

Structural Modeling and Computer Analysis

Let's work some problems

Displacement method of analysis: **slope-defection method**

Any questions?