CEE 151A
Spaghetti Bridge Contest
Loading Session: We, Th, Friday of Week 9 in SETH lab

Design Question:

Mr. Ali Morshedifard : morsheda@uci.edu

Dr. Abdolhosseini : mjaq@uci.edu

Fabrication and Loading Questions:

Mr. Sergio Carnalla : scarnall@uci.edu

Spaghetti Bridge Contest

- Why spaghetti? Why not toothpicks or balsa wood? Spaghetti is very unforgiving. Design is much more important in a spaghetti bridge than a toothpick one. Spaghetti is also available in a nice form for construction, long cylindrical rods. And, one can't complain about the cost . . .

- So, what's the project goal? To build a bridge out of only spaghetti and glue that spans a 50 cm, has a width of 25 cm, weighs no more than 1.0 kg and supports the heaviest load. We might do moving load this year. I keep you posted on our latest developments. The bridge is to be supported only by horizontal surfaces at each end.

Properties of Dry Spaghetti

- Youngs's Modulus (E) ~ 1000 Mpa
- Ultimate Tensile Strength (σ_y) ~ 10 MPa
- Buckling load ~ $\pi EI/l^2$ (I: moment of Inertia , l: length)
- Radius of Spaghetti Noodles (r) ~ 0.6, 1.25, 2.5 mm
- Length of Spaghetti Elements (l) : Depends on your design

Glue Materials:

- 1) White glue : Not good. Since it's water based, the spaghetti is softened by the glue. Glue joints take forever to dry. Once dry, joints are not very strong.
- 2) Model airplane glue : So so. Dries relatively quickly but is slightly flexible when dry. Glue joints should be rigid.
- 3) Hot-melt plastics (glue guns) : Easiest to use, but joints far too flexible.
- 4) Epoxy : Best solution -- especially the 5 minute kind. Creates rigid joints. Is messy. Requires careful mixing.
- 5) You are only allowed to apply glue in the joints, if you do otherwise your bridge will be disqualified from the competition.

Using 5-min Epoxy

- Purchase variety in two separate tubes with nozzle tips. (Double plunger varieties are too wasteful.)
- Mix epoxy and make glue joints on wax paper. Epoxy releases from wax paper fairly readily.
- Mix very small batches -- enough for maybe 5 glue joints.
- Proportions are very important – 50-50. Too far away from this ratio and epoxy will never harden. Many bridges fail because of unhardened joints.
- Squeeze same -size circular blobs of epoxy and hardener onto wax paper. Look to see that they’re of similar height. (You’re interested in equal volumes of epoxy and hardener). Mix together with a matchstick. Dime-size blobs yield enough epoxy for 6 or so joints.
- Lacquer thinner (nail polisher remover) is good for cleaning up uncured epoxy from surfaces and fingers.

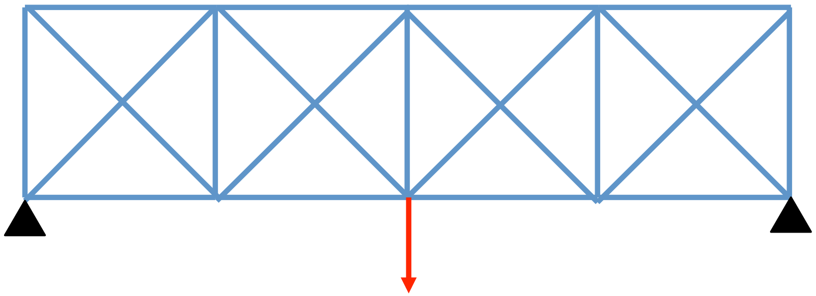
Design and Fabrication Procedure

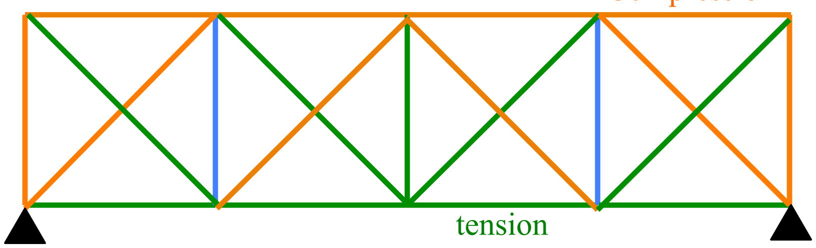
- Conceptual Design: At this stage, we simply come up with the form of the structure. We might be inspired by nature, by other designs or other resources. A good structural form makes a huge difference.
- Calculation of internal forces: We can calculate the internal forces in truss members either by hand calculations (method of joints or sections) or via computer analysis of structure using finite element method. You Should do this either by hand or via UCI-Structural Analysis Program.
- Checking Strength and Stability of members: When the analysis is done and all internal forces are derived we have to check that the internal forces are less than the admissible yield force for tensile and less than buckling load limit for compressive members. If members fail, we have to change the design and re-run our calculation and check the strength criterion.
- Construction: when the design is finalized, we embark on construction phase. Remember that any fabrication error adds unwanted forces in your members…

Conceptual Design

- At this stage we focus on the shape of the bridge by considering the loads that are acting on it.
- There are infinite ways to connect point A to B. There are a few of them that are more efficient than the others.
- The efficiency is the maximum load that the bridge can carry divided by its dead weight.
- Without any analysis, try to find how loads will be moving in your structure. Determine which elements are in compression and which ones are in tension.
- Determine all the nodal positions (the geometry of your structure).

www.mnn.com





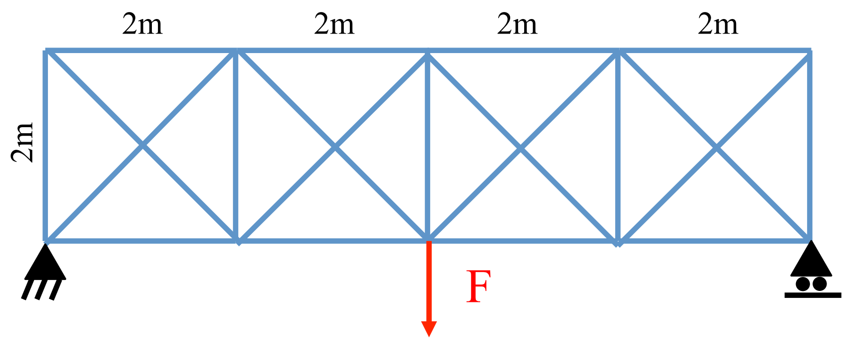
Calculation of Internal Forces: Manual

- If you think you cannot manage working with the software, you are more than welcome to use a <u>simple determinate structure</u> of your choice, Maybe a structure from Hibler book, and analyze it via the method of sections or method of joint.
- In this way, you should be able to calculate the internal forces in your structure with minimum effort.

Calculation of Internal Forces: UCI-SAP

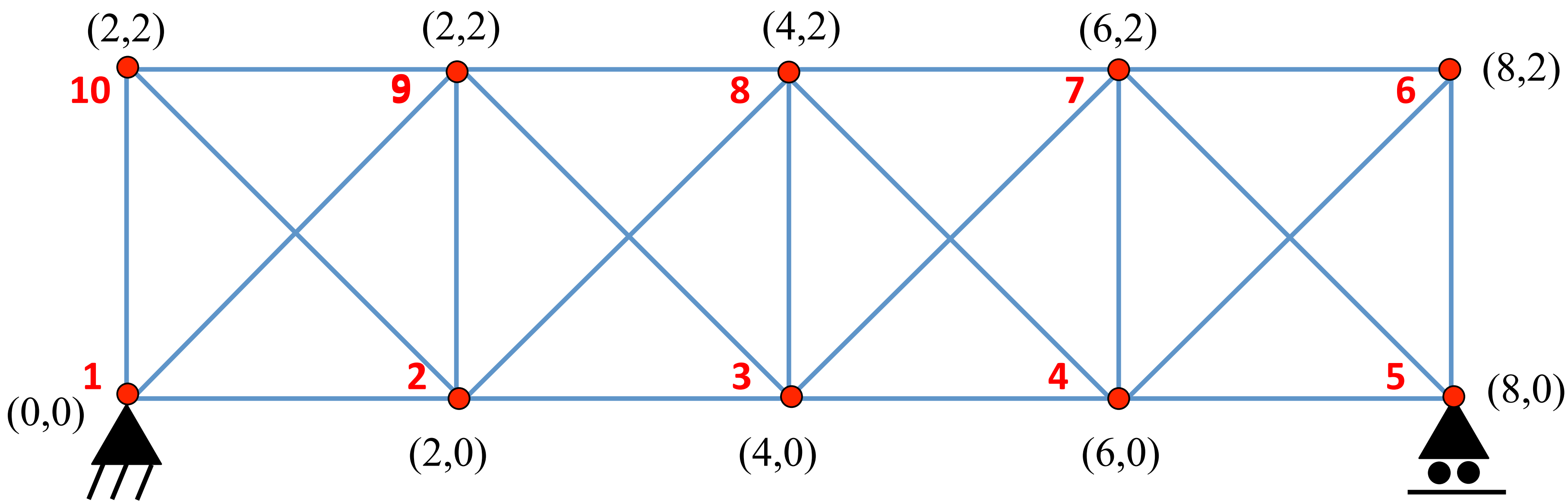
- In this class, we use UCI-SAP which is an open-source matlab software developed by the instructor based on the idea of matrix analysis of structures.
- The code is consisted of 4 files:
  - Analyze_Truss.m (The main code (engine) that is responsible for the entire analysis.)
  - TrussElement2D.m (It produces the stiffness matrix for each element.)
  - TrussForce2D.m (It calculates the internal force for each element at the end of analysis.)
  - Input_Truss.m (The input file that contains geometry, A, E, BCs and Loading.)
- UCI-SAP Calculates:
  - Nodal displacements
  - Support forces
  - Internal forces

- Let's Solve our first truss together we, UCI-SAP:
- A=10^(-2) m^2
- E=10^(11) Pa
- F=10^(4) N



Defining Nodes in UCI-SAP

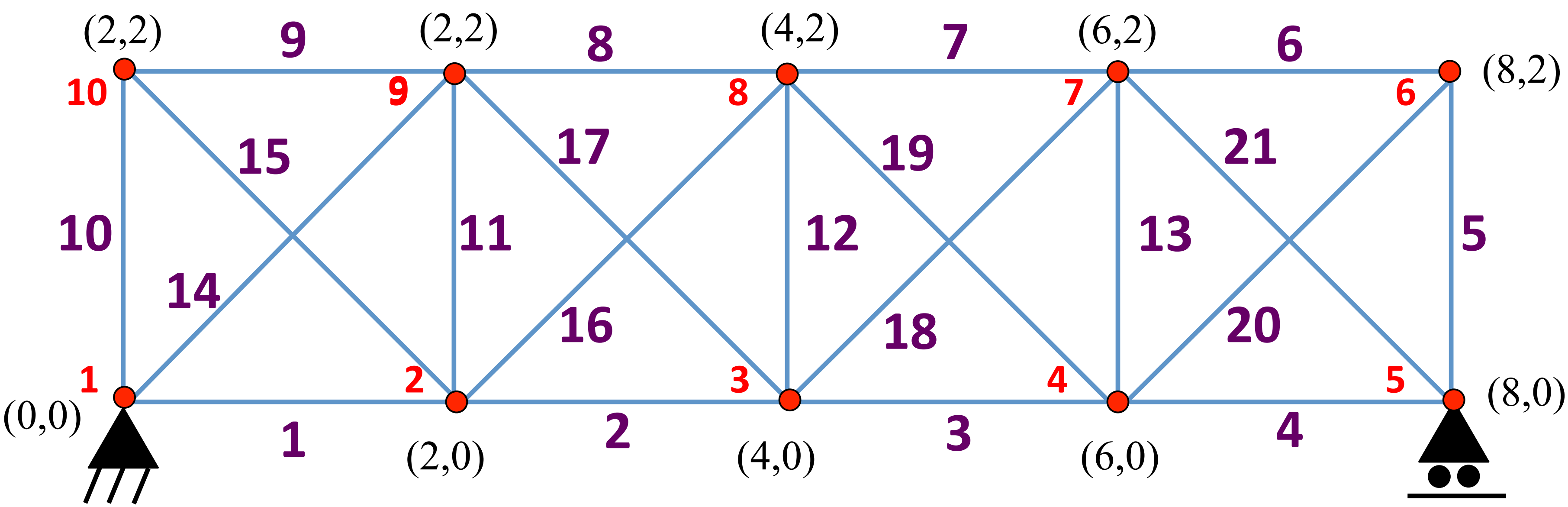
- The First step is to define the nodal points in Input_Truss.m
- The “nodes” matrix contains the X and Y of all nodes in the truss.
- Each red circle in the truss below indicate a node.
- Please note that supports are also considered as nodes.



nodes=[0 0; 2 0; 4 0; 6 0; 8 0; 8 2; 6 2; 4 2; 2 2; 0 2];

Defining Elements in UCI-SAP

- The Second step is to define the Elements in Input_Truss.m
- The “element” matrix contains the two nodes that are connected via elements.
- There are 21 elements in the structure below. These elements are numbered as follows:




```
elems=[1 2;2 3;3 4;4 5;5 6  ;6 7;7 8;8 9;9 10;10 1;...
        2 9;3 8;4 7;1 9;10 2;8 2;3 9;3 7;4 8  ;4 6  ;5 7];
```

Defining Boundary Conditions in UCI-SAP

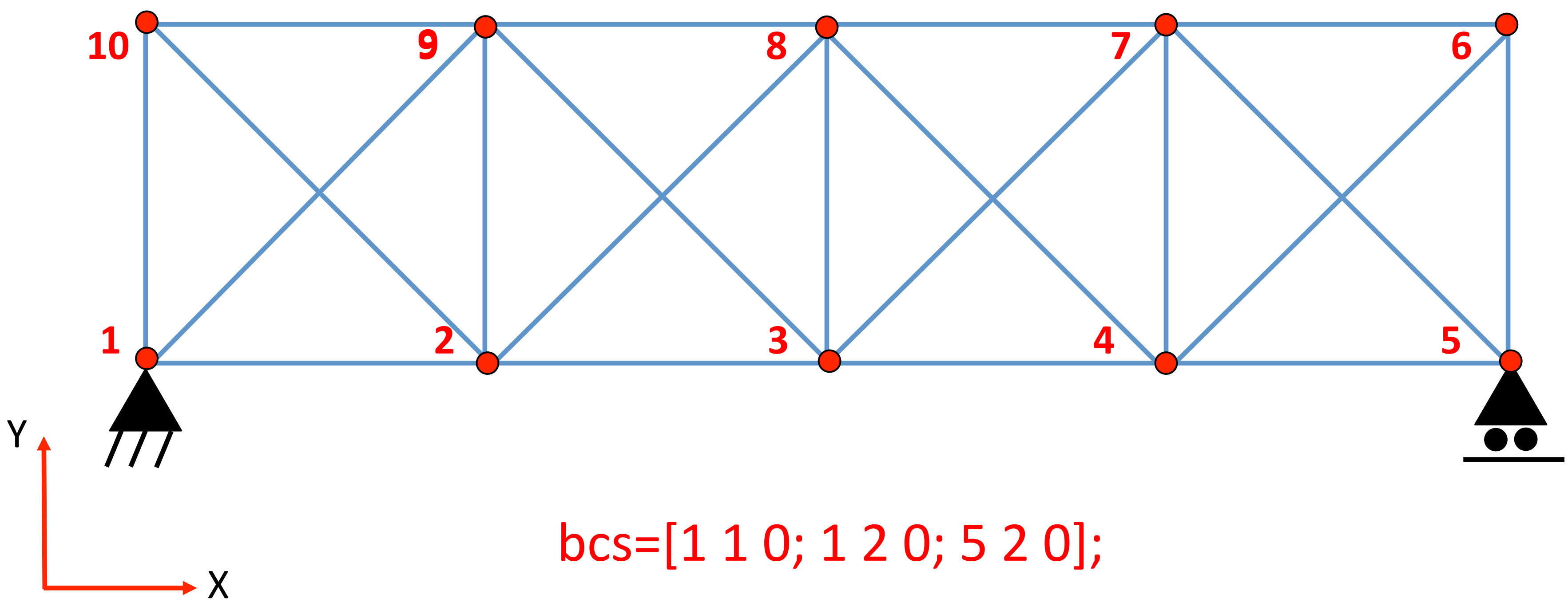
- The Third step is to define the Boundary Conditions in Input_Truss.m
- The "bcs" matrix contains three entries for each boundary condition:

  1- the node number at which the boundary condition is applied.

  2- The degree of freedom (dof) which is constrained (X:1 and Y:2).

  3- The amount that this dof moves in the specified direction.
- There are BCs in the following structure: (node 1 does not move in X and Y

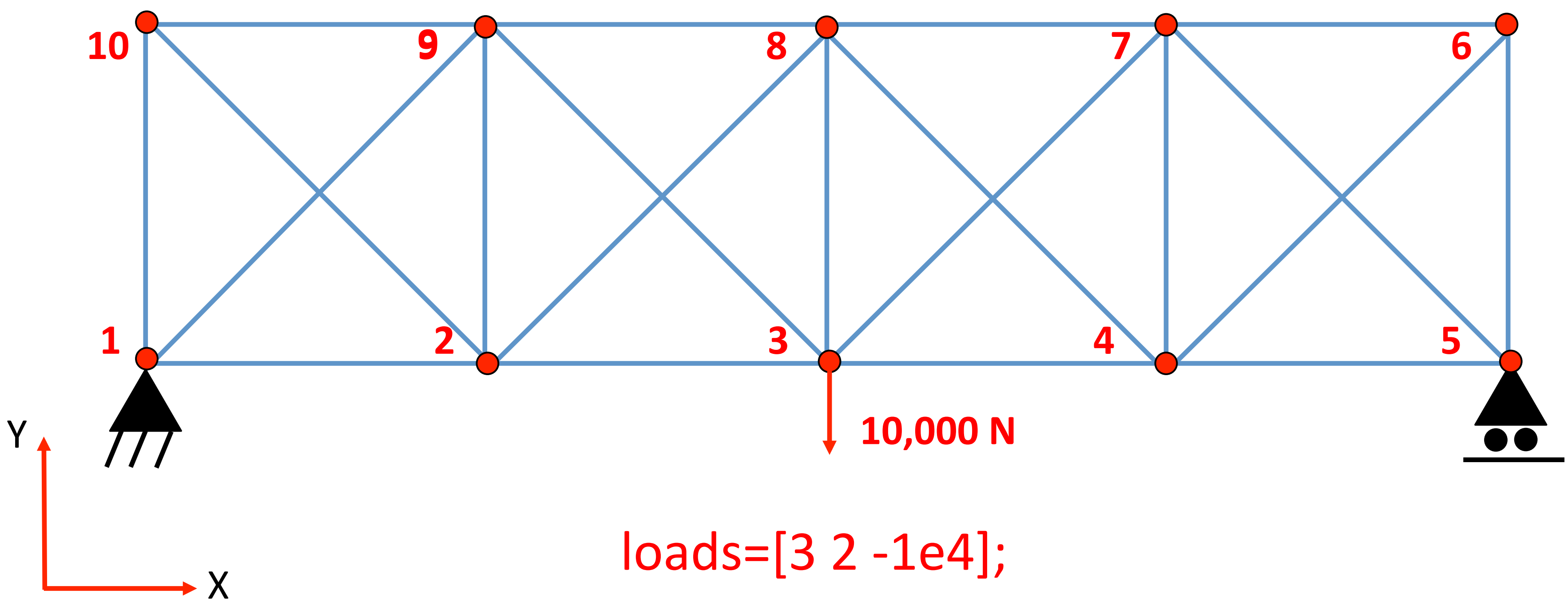
  node 5 does not move in Y)



bcs=[1 1 0; 1 2 0; 5 2 0];

Defining Nodal Forces in UCI-SAP

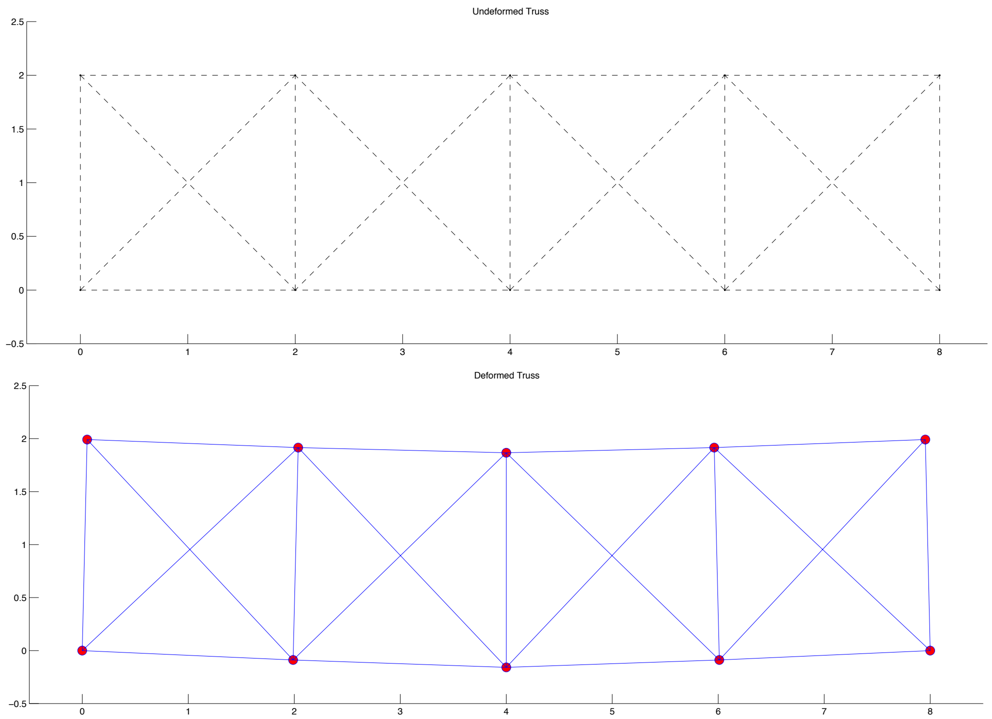
- The Forth step is to define the Nodal Forces in Input_Truss.m
- The "loads" matrix contains three entries for each nodal force:
  1- the node number at which the force is applied.
  2- The degree of freedom (dof) for the direction of force (X:1 and Y:2).
  3- The magnitude of the load.
- There is one point load in the following structure: (at node 3 in -Y direction with the magnitude of 10,000 N).



loads=[3 2 -1e4];

Running UCI-SAP

- When input preparation is done, simply type Analyze_Truss in matlab terminal.
- The code analyzes your structure and gives you the following results:
  - Undeformed Truss Shape
  - Deformed Truss Shape
  - Nodal Displacements
  - Nodal Forces (including Reactions)
  - Internal Forces

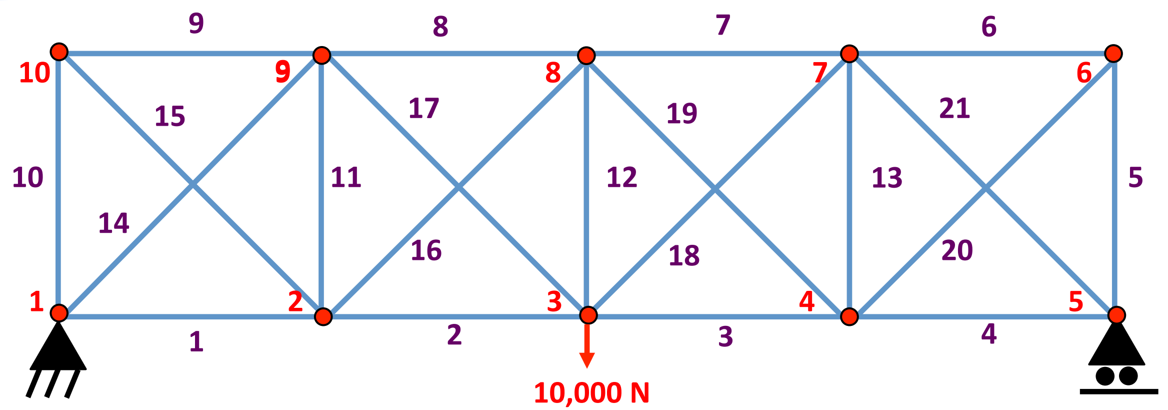


- Common Mistakes that causes Matrix Singularity and matlab error:
  - Please refrain from defining repetitive nodal points. It causes singularity.
  - The connectivity (elems) matrix of your structure. Please triple check it.
  - The boundary conditions are convergent so makes the entire structure unstable.

Interpreting the Results of UCI-SAP

- UCI-SAP outputs three columns:
  - u : nodal displacements (a column of size 2*number of nodes). The order is as follows:
    - u=[u1_x; u1_y; u2_x; u2_y; …, un_x; un_y];
  - f : Nodal forces (a column of size 2*number of nodes). The order is as follows:
    - $f=[f_1\_x; f_1\_y; f_2\_x; f_2\_y; \ldots, f_n\_x; f_n\_y];$
  - F_int : Internal forces (a column of size number of elements). The order is as follows:
    - $F\_int=[F\_int_1; \ldots F\_int_n];$

The Results of UCI-SAP



u =	f =	F_int =
1.0e-04 *	1.0e+04 *	1.0e+03 *
0	-0.0000	2.8105
0	0.5000	7.0017
0.0281	0	7.0017
-0.2557	0	2.8105
0.0981	0	-2.1895
-0.4224	-1.0000	-2.1895
0.1681	0	-7.9983
-0.2557	0	-7.9983
0.1962	0	-2.1895
0	0.5000	-2.1895
-0.0038	0	-0.1878
-0.0219	0	4.0034
0.0181	0	-0.1878
-0.2576	0	-3.9746
0.0981	0	3.0964
-0.3824	0	-2.8308
0.1781	0	4.2403
-0.2576	0	4.2403
0.2000	0	-2.8308
-0.0219	0	3.0964
		-3.9746

Checking Stability and Strength of Members

- Check the stress limit and buckling stability in each member of your truss for the maximum design load.
  - If you are doing manual analysis, you should do this stage by hand.
  - If you use UCI-SAP, please write a small code that does this automatically in matlab.
    - $|F\_int_i|/Ai < \sigma_y$
    - If compressive member : $|F\_int_i| < \pi EI/l^2$

How to increase the Load Limit

- If a member is failing the strength criterion, you can increase the cross-section of the beam in your calculations and add extra spaghetti noodles in that particular beam in your bridge.
- If a member is failing in buckling mode, you can either increase the cross-section or decrease the buckling length by adding extra supporting elements.

What is the Competition about then?

- Remember that you have a Maximum Weight of 1.0 kg.
- This means that you cannot make your elements as thick as you might want to.
- The winning team is the one with the best design and construction which enables their bridge to endure the highest load.

Project Outcome and Prize

- A spaghetti bridge at the competition
- One report describing the 4 phases of your design and construction. Maximum 5 pages.

I'll take the winning team out for dinner right after the contest and it will be my treat.