Preliminary Design Report

EK301 Section C1

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4/8/13

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Abstract

In this report, there are two different truss designs, designed under certain limitations of span and cost. These two designs will be well evaluated and analyzed. By using MATLAB, the force that acting on each member of the truss can be determined. Together with the results from the Straw Test, it can be determined that which member will buckle first when the whole truss fails in loading.

Introduction:

A truss will be considered as a good one if it is economic but efficient. The purpose of this report is to evaluate a truss design before it has been built. By using MATLAB, the force acting on each member will be determined; in addition, it will tell the possible maximum load of the truss. By comparing the load-to-cost ratios between different trusses, a better design can be determined for the remainder of the project as intended.

Considering the fact that triangle appears to be the most stable geometry shape, the motivation for the design is to put different triangles together to form a strong truss. Meanwhile, a few standards have to be met, such as the span will be 55±1cm, length of each member will between 8cm and 15cm, and the cost will be less than \$335 where cost would be determined by

Cost = \$10·Joints+\$1·Length.

The rationale for using MATLAB is to write down the static analysis while assuming every member experiences a tension force, and convert all the equations into several matrixes so that the computer can help solving.

Procedure:

For Design No.1, considering the span should be between 54cm and 56cm, and each straw should be between 8cm and 15cm, 6*9=54 first came to mind. For simplicity, symmetry is considered, and the general shape of the truss can be flat. Thus, a decision was made that there will be 6 pieces and 9cm each for the bottom line. After the first sketched was made, the cost calculation turned to be less than \$335 (See Appendix A).

For Design No.2, difference became the priority, because different types of truss can bring more analysis, which can benefit the final project in the future. Since Design No.1 is a flat shaped, Design No.2 then is decided to be non-flat shape. By thinking of the roof of houses, a sketch of a roof-like truss was made. Due to the cost limitation, the sides of triangles are carefully selected. Since the span should be 55±1cm, one side of the triangle then is determined to be 13.5cm. For the rest of two sides, one of these has to be greater than 8cm, so the other one has to be 15.9cm (It doesn't violate the limitation because 15.69cm indicates joint-to-joint distance). And the cost turned to be valid. Therefore, a final sketched is made (See appendix A).

Analysis

(a) By Hand (Original hand written paper is on Appendix B)

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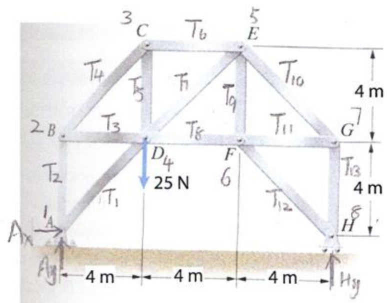
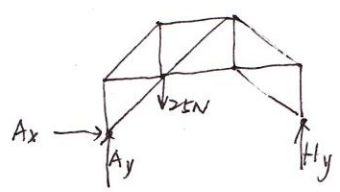
EK 301 Engineering Mechanics I

Truss project computational method validation problem

Determine the loads in each of the members and whether they are in tension or compression. Analyze the loads yourselves using standard equilibrium analysis, and MATLAB (results should match!).





$$\Rightarrow \begin{cases} \Sigma F_x = 0 = A_x \\ \Sigma F_y = 0 = A_y + H_y - 25\text{ N} \\ \Sigma M_A = 0 = 25 \times 4 + H_y \times 12 \end{cases} \Rightarrow \begin{cases} A_x = 0\text{ N} \\ A_y = \frac{50}{3} = 16.7\text{ N} \\ H_y = \frac{25}{3} = 8.33\text{ N} \end{cases}$$

A: T_2, T_1, A_x, A_y

$$\Rightarrow \begin{cases} \Sigma F_x = 0 = A_x + T_1 \times \cos 45^\circ \\ \Sigma F_y = 0 = T_2 + A_y + T_1 \times \sin 45^\circ \end{cases} \Rightarrow \begin{cases} T_1 = 0\text{ N} \\ T_2 = -16.7\text{ N (C)} \end{cases}$$

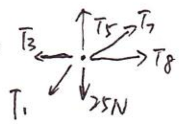
B: T_4, T_3, T_2

$$\Rightarrow \begin{cases} \Sigma F_x = T_4 \cdot \cos 45^\circ + T_3 = \\ \Sigma F_y = 0 = T_4 \cdot \sin 45^\circ + (-T_2) \end{cases} \Rightarrow \begin{cases} T_3 = 16.7\text{ N (T)} \\ T_4 = -23.6\text{ N (C)} \end{cases}$$

C: T_4, T_6, T_5

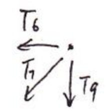
$$\Rightarrow \begin{cases} \Sigma F_x = T_4 \cdot \cos 45^\circ + T_6 = 0 \\ \Sigma F_y = 0 = T_4 \cdot \sin 45^\circ + T_5 \end{cases} \Rightarrow \begin{cases} T_5 = 16.7 \text{ (T)} \\ T_6 = -16.7 \text{ (C)} \end{cases}$$

D:



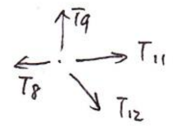
$$\Rightarrow \begin{cases} \sum F_x = 0 = T_3 + T_1 \cdot \cos 45^\circ - T_7 \cdot \cos 45^\circ - T_8 \\ \sum F_y = 0 = T_5 + T_7 \cdot \sin 45^\circ - T_1 \cdot \cos 45^\circ - 25 \end{cases} \Rightarrow \begin{cases} T_7 = 11.8N \ (T) \\ T_8 = 8.33N \ (T) \end{cases}$$

E:



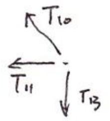
$$\Rightarrow \begin{cases} \cancel{T_6}\ \sum F_x = 0 = T_6 + T_7 \cdot \cos 45^\circ \\ \sum F_y = 0 = T_7 \cdot \sin 45^\circ + T_9 \end{cases} \Rightarrow \begin{cases} T_9 = 0 \ N. \end{cases}$$

F:



$$\Rightarrow \begin{cases} \sum F_x = 0 = T_8 - T_{11} - T_{12} \cdot \cos 45^\circ \\ \sum F_y = 0 = T_9 - T_{12} \cdot \sin 45^\circ \end{cases} \Rightarrow \begin{cases} T_{12} = 0N \\ T_{11} = 8.33N \ (T) \end{cases}$$

G:



$$\Rightarrow \begin{cases} \sum F_x = 0 = T_{11} + \cos 45^\circ \cdot T_{10} \\ \sum F_y = 0 = T_{13} - T_{10} \cdot \sin 45^\circ \end{cases} \Rightarrow \begin{cases} T_{13} = -8.33 \ N \ (C). \\ T_{10} = \cancel{11.8 \ N \ (} \\ -11.8 \ N \ (C) \end{cases}$$

(b) By MATLAB

Computational approach:

1. Set up parameters for joint locations, member-joint connections, reaction forces locations, and the load.
2. Assume all members are under tension. Using FDB to analyze the static equilibrium and construct a system of equations.

```
%Paste everything on a script and run it, then get the solution.
% The definition of the connection marix C
C=[1,1,0,0,0,0,0,0,0,0,0,0,0,0;
   0,1,1,1,0,0,0,0,0,0,0,0,0,0;
   0,0,0,1,1,1,0,0,0,0,0,0,0,0;
   1,0,1,0,1,0,1,1,0,0,0,0,0,0;
   0,0,0,0,0,1,1,0,1,1,0,0,0,0;
   0,0,0,0,0,0,0,1,1,0,1,1,0;
   0,0,0,0,0,0,0,0,0,1,1,0,1;
   0,0,0,0,0,0,0,0,0,0,0,1,1];

%The definition of the reaction forces in the x-dirextion
Sx=[1,0,0;0,0,0;0,0,0;0,0,0;0,0,0;0,0,0;0,0,0;0,0,0];

%The definition of the reaction forces in the y-dirextion
Sy=[0,1,0;0,0,0;0,0,0;0,0,0;0,0,0;0,0,0;0,0,0;0,0,1];

% The definition of the vectors X and Y joint locations
X = [0 0 4 4 8 8 12 12];
Y = [0 4 8 4 8 4 4 0];

% The definiton of the vector of applied external loads L
L=zeros(16,1);
L(12)=25;

%One to get matrix A
[r,cl]=size(C);
A_x=zeros(r,cl);
length=zeros(1,cl);
for j=1:cl
    p=C(:,j)';
    l=find(p==1);
    a=l(1);
    b=l(2);
    R=norm([X(a),Y(a)]-[X(b),Y(b)]);
    A_x(a,j)=(X(b)-X(a))/R;
    A_x(b,j)=(X(a)-X(b))/R;
    length(j)=R;
end

A_y=zeros(r,cl);
for j=1:cl
    p=C(:,j)';
    l=find(p==1);
    a=l(1);
```

```
    b=l(2);
    R=norm([X(a),Y(a)]-[X(b),Y(b)]);
    A_y(a,j)=(Y(b)-Y(a))/R;
    A_y(b,j)=(Y(a)-Y(b))/R;
end
A=[A_x,Sx;A_y,Sy];

%Find the forces on each member and reaction force on pin and roller
T=A\L;

for i=1:numel(T)
T(i)=str2double(sprintf('%.3f',T(i)));
end

%disp('EK301, Section C1, Group Bear, 4/7/2013')
%disp('Cong Liu, ID 75856171')
%disp('Zeming Wu, ID 61003163')
%fprintf('DATE: %s\n',date)
disp('This is the solution for the problem assigned on the web site')
Load=L(L~=0);
fprintf('Load: %.2f N\n',Load)
disp('Member forces in Newtons')
[r,c]=size(A);
for i=1:(c-3)
    if  T(i)==0
        fprintf('T%d: %.3f \n',i,T(i))
    elseif T(i)>0
        fprintf('T%d: %.3f (T)\n',i,T(i))
    elseif T(i)<0
        fprintf('T%d: %.3f (C)\n',i,-T(i))
    end
end

disp('Reaction forces in Newtons:')
fprintf('Ax1: %.2f\nAy1: %.2f\nHy2: %.2f\n',T(end-2),T(end-1),T(end))

%totallen=sum(length);
%fee=10*r/2+totallen;
%fprintf('Cost of truss: $%.0f\n',fee)
%fprintf('Theoretical max load/cost ratio in N/$: %.4f\n',Load/fee)
```

The result of (a) and (b) agrees to each other.

Data

From the result of Straw Test, a relationship between the buckling strength and length of the straw was found:

$F(L) = A/L^2$ Where $A = 1215.75\ N*cm^2$

And the uncertainty of this result is:

$U\_force(L) = 600/L^3\ (N)$

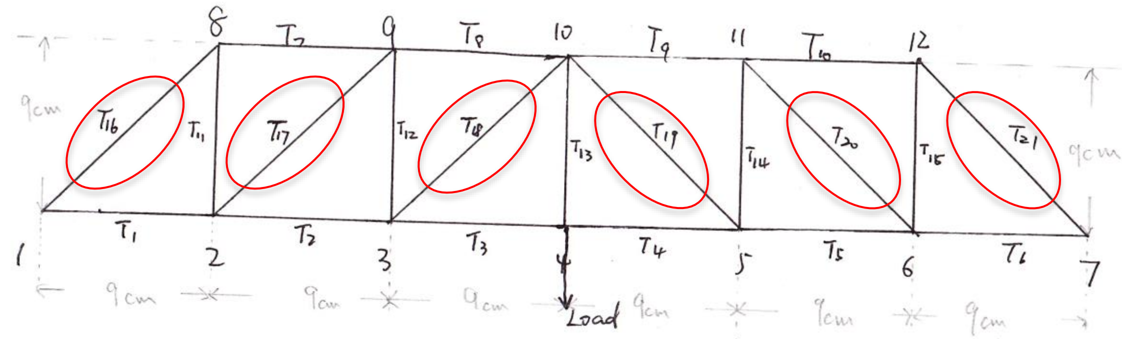
Thus, the theoretical maximum load and uncertainty of buckling strength can be calculated from the equations above. As for the uncertainty for the maximum load, the following equation can be applied:

$$\frac{test\ \ load}{compression} = \frac{maximum\ \ load}{buckling\ \ strength \pm uncertainty}$$

Where the test load is some random load plugged into MATLAB, so that tension or compression analysis for every member can be obtained. The difference got from this equation is the uncertainty of the maximum load.

Note: Members with red circles in the diagrams or highlighted in the chart will buckle first.

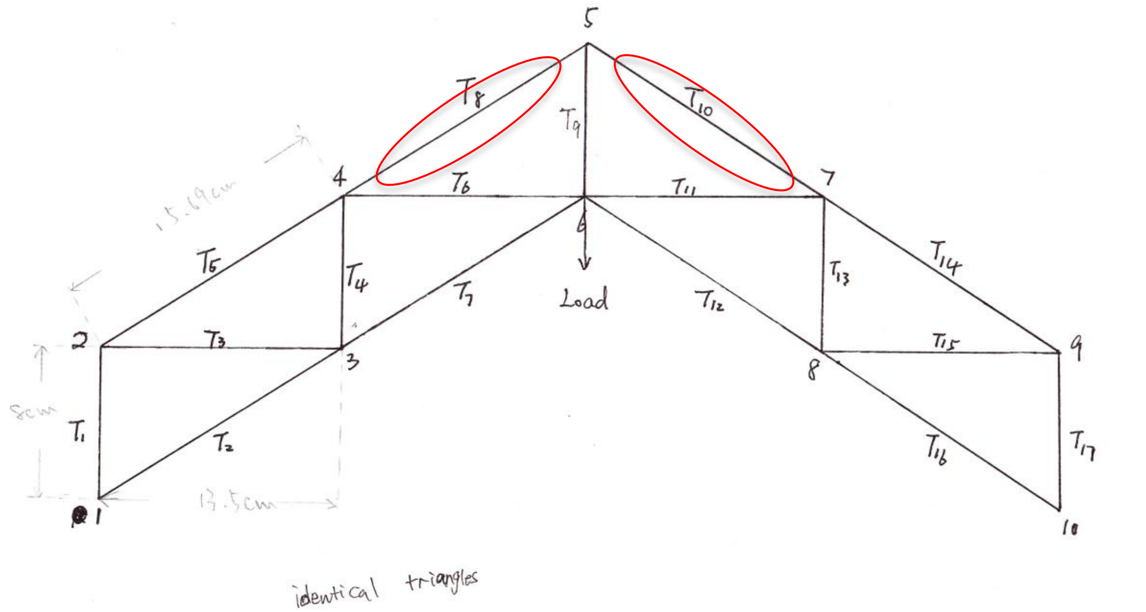
Design No.1s



(Original paper is on Appendix B)

member #	theoretical length (cm)	buckling strength	Uncertainty (N)	tension or compression @ 10.61N	theoretical maximum load and uncertainty (N)
T1	9	15.009		5.305 T	
T2	9	15.009		10.610 T	
T3	9	15.009		15.915 T	
T4	9	15.009		15.915 T	
T5	9	15.009		10.610 T	
T6	9	15.009		5.305 T	
T7	9	15.009		5.305 C	
T8	9	15.009	N/A	10.610 C	N/A
T9	9	15.009		10.610 C	
T10	9	15.009		5.305 C	
T11	9	15.009		5.305 T	
T12	9	15.009		5.305 T	
T13	9	15.009		10.610 T	
T14	9	15.009		5.305 T	
T15	9	15.009		5.305 T	
T16	12.73	7.502		7.502 C	
T17	12.73	7.502		7.502 C	
T18	12.73	7.502	0. 291	7.502 C	10. 61± 0. 438
T19	12.73	7.502		7.502 C	
T20	12.73	7.502		7.502 C	
T21	12.73	7.502		7.502 C	

Design No.2



(Original paper is on Appendix B)

member #	theoretical length (cm)	buckling strength (N)	uncertainty (N)	tension or compression @ 2.51N	theoretical maximum load and uncertainty(N)
T1	8	18.996		1.255 C	
T2	15.69	4.939		0	
T3	13.5	6.671		2.118 T	
T4	8	18.996	N/A	1.255 C	
T5	15.69	4.939		2.462 C	
T6	13.5	6.671		2.118 T	
T7	15.69	4.939		2.462 T	
T8	15.69	4.939	0.155	4.923 C	
T9	8	18.996	N/A	5.020 T	2.523± 0.079
T10	15.69	4.939	0.155	4.923 C	
T11	13.5	6.671		2.118 T	
T12	15.69	4.939		2.462 T	
T13	8	18.996		1.255 C	
T14	15.69	4.939	N/A	2.462 C	
T15	13.5	6.671		2.118 T	
T16	15.69	4.939		0	
T17	8	18.996		1.255 C	

Results:

For Design No.1, the critical members are m16, m17, m18, m19, m20 and m21, with a length of 12.73 cm, and the bucking strength is 7.502 N with an uncertainty of 0.291 N;
The maximum theoretical load is 7.502 N with an uncertainty of 0.438 N;
The cost is $331 and load-to-cost ratio is 0.0320 N/$.

For Design No.2, the critical members are m8 and m10, with a length of 15.69 cm, and the bucking strength is 4.939 N with an uncertain of 0.155 N,
The maximum theoretical load is 2.51 N with an uncertain of 0.079 N
The cost is $320 and load-to-cost ratio is 0.0079 N/$;

Discussion and Conclusion

Comparing the two designs, it is observed that the costs of two designs are not perfect since they don't very much meet the standard of efficient and economic.

Between these two designs, Design No.1 is better because it can hold the required minimum load 4.9 N while Design No.2 cannot. And the load-to-cost ratio of Design No.1 is more acceptable.

From the failure of Design No.2, it is learned that such structure is not suitable for trusses, which can be used as a bad example of trusses built of straws. In order to improve the design next time, the height of the truss can be smaller so that several members, including first-bucking members will be shorter and capable of greater loads.