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Structural Engineering and Materials

FLEXURAL CAPACITY PREDICTION METHOD FOR AN OPEN WEB JOIST LATERALLY SUPPORTED BY A STANDING SEAM ROOF SYSTEM

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Abstract

A new strength prediction approach is presented for open web joists partially braced by a standing seam roof. The approach employs the existing AISC column curve to calculate top chord flexural buckling capacity using the top chord critical elastic buckling load. Recently derived buckling load equations are presented that account for lateral stiffness provided by the roof and the parabolically varying axial load from a uniform vertical pressure along the span. A new hybrid experimental-computational protocol is introduced for approximating standing seam roof lateral stiffness for systems without and with intermediate bridging. The strength prediction approach is demonstrated to be accurate for a small set of experiments, however a larger scale validation effort is still needed.

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Chapter 1 Introduction

The goal of this project was to develop a prediction method to determine the capacity of an open web joist laterally supported by a standing seam roof system. Laboratory tests were performed at Virginia Tech that evaluated the roof system variables to determine the influence of each on the lateral restraint provided to the joists; the variables tested were clip height, insulation thickness, presence of a thermal block, number bridging rows, chord size, and loading condition (top or bottom chord) (Fehr 2012; Fehr et al. 2012). The goal of this research was to use the data collected in the laboratory experiments to create a prediction method that could be used to determine roof capacity.

Open-web steel joists are a staple of modern metal building construction. These joists typically span over 40 ft. between primary portal frames, supporting a roof skin that serves as the barrier to rain, snow, and wind. A common type of metal building roofing system supported by open-web joists is the standing seam roof (Figure 1.1). Flexible clips are through-fastened along the joist top chord and then the two edges of a metal roof panel are plastically folded with a special seaming machine around the flexible clips, forming a watertight seal.

The standing seam clips are designed to accommodate roof elongation and contraction from changes in temperature while still providing vertical support to the roof. Because the clips are through-fastened to the top chord, they can provide some lateral bracing if the roof panels are properly anchored to the eave and ridge. The roof panels can also envelop or “hug” the top chord under gravity loads, providing additional lateral restraint. A common question asked by joist manufacturers and metal building engineers is “How much top chord lateral support is provided by a standing seam roof and can this lateral bracing be counted on in the flexural design of a joist?"

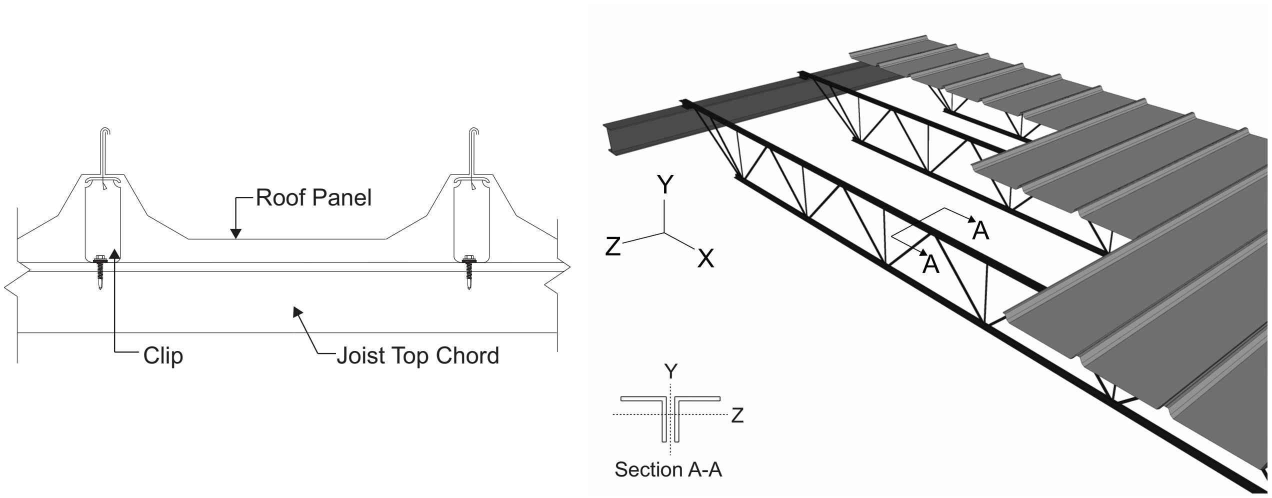


Figure 1.1 Standing seam roof supported by an open-web joist

There is clear experimental evidence that a standing seam roof can provide partial lateral restraint to a joist top chord. Holland and Murray (1983) evaluated the influence of standing seam clip type, top chord size, and bridging location on joist capacity using a vacuum chamber. Similar tests by Sherman and Fisher (1997) demonstrated that joist capacity decreased with increasing clip height because as clip height increases, the lateral stiffness of the clip decreased and the higher offset of the roof from the top chord reduced the "hugging" effect.

The laboratory tests performed at Virginia Tech (Fehr 2012; Fehr et al. 2012) showed that standing seam roof systems without bridging have capacities very similar to those that contain two and four rows of bridging. This shows that standing seam roofs without bridging are capable of providing adequate lateral restraint to develop flexural capacities equivalent to standing seam roof systems that use bridging. In addition, it was shown that both exclusion of thermal blocks, and an increase in clip height decrease the flexural capacity of the system. It was also shown that an increase in top chord size will increase the amount of top chord envelopment, increasing the roof stiffness and joist capacity.

Sherman and Fisher emphasize in their paper that the standing seam panel must be soundly connected to stiff eave and ridge members to ensure that the lateral bracing forces have a load path to the primary framing. They measured these bracing forces in their tests on a two-joist system and used the experimental results to validate engineering expressions motivated by Winter (1958) for predicting required roof panel capacity. Sherman and Fisher point out that for multiple joists the required bracing force provided by the roof is cumulative and that for sloped roofs the gravity load in the direction of the bracing forces should also be considered in the total demand.

One of the only existing analytical capacity prediction methods for joists braced by a standing seam roof was developed by Hodge (1986), a master's degree student advised by Professor Theodore Galambos. Hodge and Galambos treated the joist top chord as a column with an initial geometric imperfection, discrete springs at the clip locations (the hugging was not considered), discrete supports at the bridging lines, and a parabolically varying axial load. Second order elastic-plastic analysis of the column (joist top chord) was conducted by solving simultaneous slope deflection equations describing moment equilibrium at nodes along the column, where the node locations were at each clip (spring) location, bridging line, and end support. Hodge compared his capacity predictions to the Holland and Murray (1983) tests, however the validation was deemed unsatisfactory because of the lack of sweep imperfection measurements in the experiments. Also, Hodge mentions that the Fortran program used to solve the second-order analysis was quite slow.

This report builds on Hodge and Galambos's analytical model to provide a general strength prediction method for open-web steel joists braced by a standing seam roof. The prediction method utilized classical stability solutions, modern structural analysis tools, and existing code equations. Specifically, the existing AISC column curve is used to predict top chord capacity using closed formed equations for the critical elastic buckling load of the top chord including roof stiffness and bridging. A protocol for approximating the roof stiffness is outlined that uses vacuum chamber test data and second order elastic analysis in a structural analysis program (e.g., MASTAN2, SAP2000, RISA2D). The strength prediction method is verified with a small set of recent experiments. More validation is needed though and the author is hopeful that others will conduct similar tests to confirm the generality of the strength prediction approach described in the following sections.

Chapter 2 Strength Prediction Approach

2.1 Introduction

The pressure load applied to the roof system can be broken down into a force couple where the top chord of the joist is in compression while the bottom chord of the joist is in tension. The axial load increases parabolically from zero at the end of each joist to a maximum at midspan, and the standing seam roof provides adequate stiffness to allow each joist to be supported as a column on an elastic foundation. The controlling mode of failure is out of plane buckling of the top chord, this failure mode can be seen in Figure 2.1 and Figure 2.2.

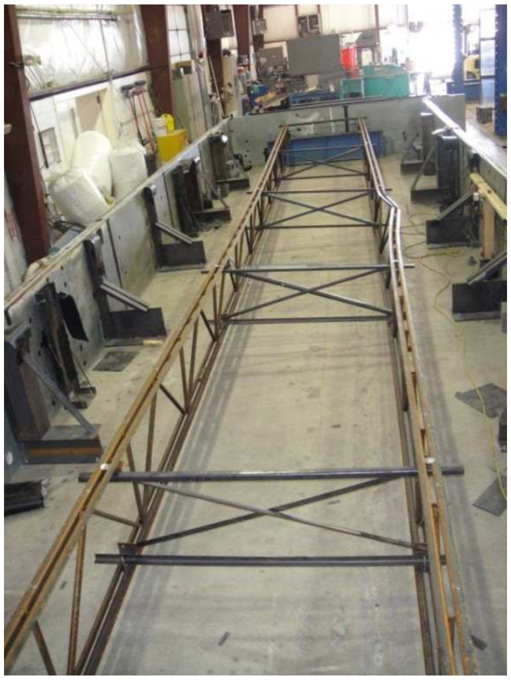


Figure 2.1 Test 1 buckled shape

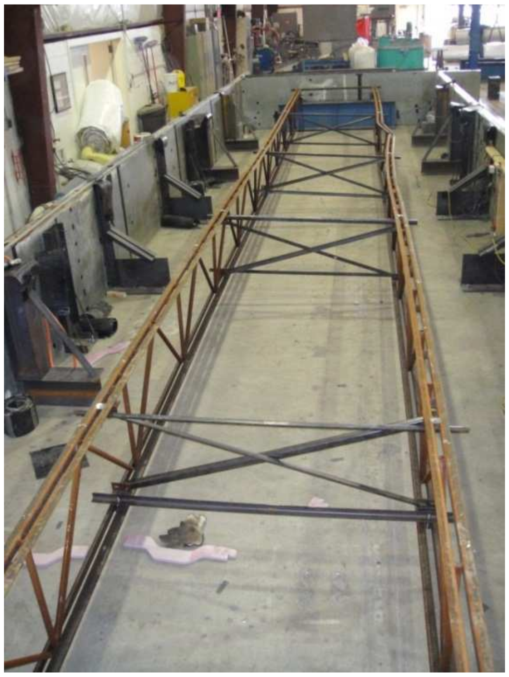
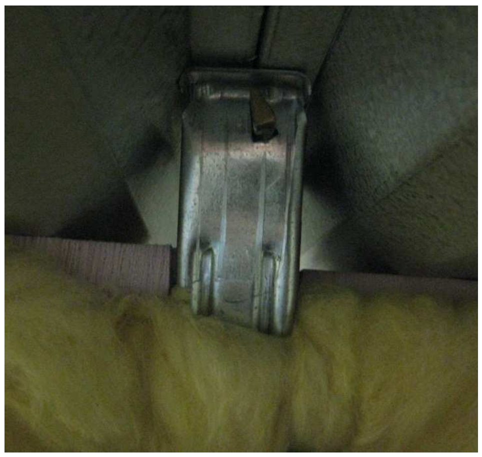
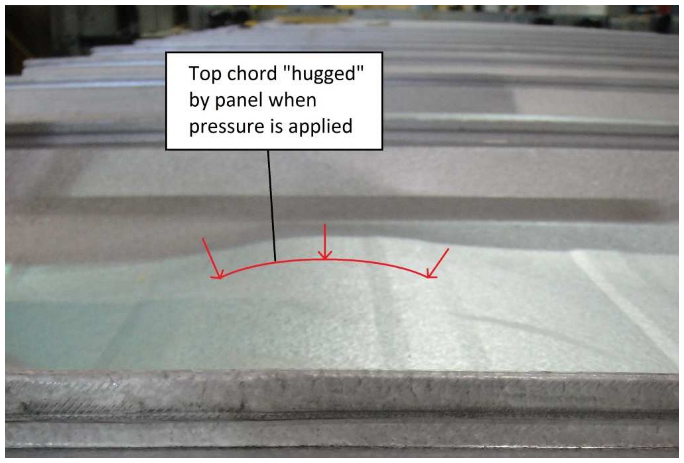


Figure 2.2 Test 2 buckled shape

As stated previously, the roof stiffness comes from two sources; the first is clip friction created when the roof is seamed; the second is from top chord envelopment or "hugging" under a uniform roof load; Figure 2.3 shows the two sources of roof stiffness.



(a)



(b)

Figure 2.3 roof stiffness sources (a) from clip friction and (b) from top chord envelopment or “hugging”

Because the top chord acts as a column (Figure 2.1) the existing column curve represented in Chapter E of the AISC Specification, “Design of Members for Compression”, can be used to predict joist capacity (AISC 2011). Figure 2.4 shows the column curve for a 24K4 joist top chord.

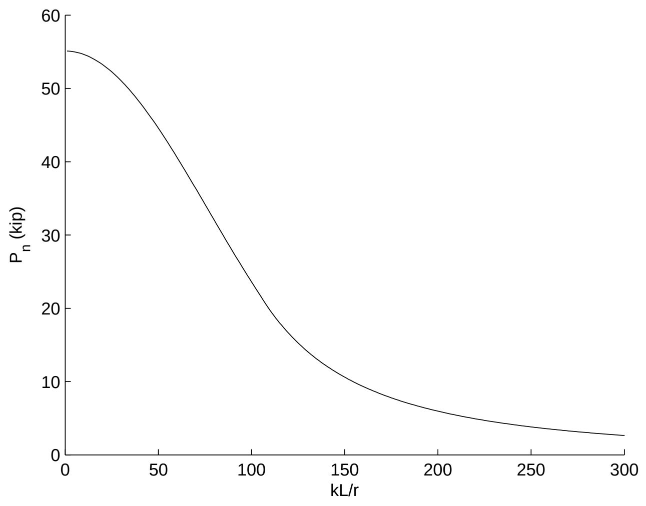


Figure 2.4 AISC column curve for 24K4 joists based on AISC Chapter E equations

The traditional AISC slenderness parameter *kL/r* was replaced with the equivalent slenderness parameter $(P_y/P_{cre})^{0.5}$ which is more frequently used to describe cold formed steel;

these two slenderness parameters are equivalent, as shown in Appendix A. By using this slenderness parameter the problem was simplified into determining the yield load and critical elastic buckling load to predict capacity.

Top chord capacity was determined for each test performed during the laboratory experiments using the models and measurements that were consistent with that test, a Microsoft Excel spreadsheet was used to perform the necessary calculations and determine the capacity of each top chord which could then be compared to the experimental capacity, equations used within the spreadsheet are described below.

The column slenderness parameter can be described with the equation:

$$\lambda_c = \sqrt{\frac{P_y}{P_{cre}}} \tag{2-1}$$

Where λ_c is the column slenderness parameter, P_{cre} is the critical elastic buckling load as determined from an eigenbuckling analysis, and P_y is the yield load of the top chord as determined from the tensile coupon tests.

For an open-web joist partially braced by a standing seam roof and failing by lateral buckling of the top chord (Figure 2.5), ultimate capacity, P_n, is approximated with the AISC column curve equations, reformatted such that the global buckling slenderness, *kL/r*, is represented instead as $\lambda_c=(P_y/P_{cre})^{0.5}$ (Eq. (2-1)), see Appendix A for a proof that these two slenderness values are equivalent

$$P_n = \left(0.658^{\lambda_c^2}\right) P_y \text{ for } \lambda_c \leq 1.5$$

$$P_n = \left(\frac{0.877}{\lambda_c^2}\right) P_y \text{ for } \lambda_c > 1.5 \tag{2-2}$$

where $P_y = AF_y$, A is the gross cross-sectional area of the top chord, F_y is the top chord steel yield stress, and P_{cre} is the critical elastic buckling load of the joist top chord. The column curve represented in Eq. (2-2) is used in both hot-rolled steel (AISC) and cold-formed steel (AISI) codes, and therefore this proposed strength prediction method is applicable to top chord angles made from either material. The calculation of P_{cre} can be performed with an elastic eigen-buckling analysis in a structural analysis program, for example, MASTAN2 (MASTAN2/version 3.3) or SAP2000 (SAP2000/Advanced version 14.0.0) with the same models shown in Figure 2.5 except without an initial imperfection and with or without intermediate bridging lines and including the parabolically varying axial load along the top chord.

Two methods are presented that allow for determining the capacity of the standing seam roof system. The first uses structural analysis software to run an eigenbuckling analysis of top chord models while the second method is an elastic buckling closed form solution that uses simplified equations to calculate top chord slenderness and predict capacity. The first method is to build a structural analysis model of the joist top chord, including discrete springs at bridging locations with a parabolically varying axial load, and perform an eigenbuckling analysis to determine the critical elastic buckling load; which is then used to determine top chord capacity. This method requires access to structural analysis software and some training in finite element modeling. The second method uses approximate hand solutions to predict the critical elastic buckling load of the top chord and column slenderness.

2.2 Strength prediction using a full top chord model to determine P_{cre}

2.2.1 Strength prediction using eigenbuckling analysis to determine P_{cre}

The first prediction method uses the full top chord length; this system is modeled as a column with a parabolically-varying axial load supported on an elastic foundation. The top chord is assumed to act as a singly-symmetric member with the two angles that comprise the top chord acting together (they are typically welded together every 24 in.) and therefore flexural-torsional buckling comprises two of the three buckling modes when solving the classic cubic buckling equation (Chajes 1974). However, in this prediction method only flexural buckling is considered because the diagonal and vertical web stems in combination with the roof are assumed to suppress torsional deformation.

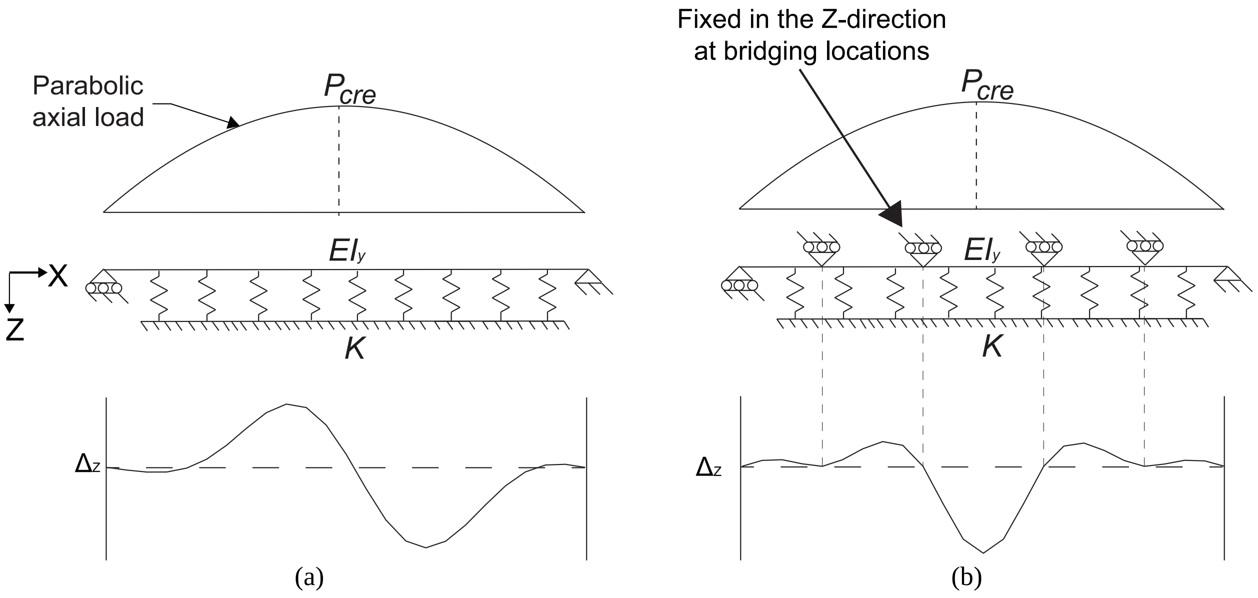


Figure 2.5 Top chord boundary conditions, loading, and lateral support (a) without and (b) with bridging lines

A uniformly distributed lateral spring with magnitude *K* (force/length/length) simulates a smeared effect of clip stiffness and hugging along the top chord. This is different from the

Hodge (1986) treatment where only the clip stiffness at discrete locations was considered in the prediction.

For the prediction method the stiffness of the clips was determined, see Chapter 4, and an equivalent elastic foundation stiffness (stiffness per unit length) was determined. The roof stiffness was then input into a similar model but without an imperfection, while the parabolic load remained. From this point an eigenbuckling buckling analysis was performed to determine the critical elastic buckling load, see Chapter 4 for full details of the top chord model. The yield load of the top chord was determined as discussed in Appendix B; this information was used within the column curve equations to determine top chord capacity.

2.2.2 Closed form solution to the full top chord model

Approximate hand methods are also available to calculate P_{cre}. A closed form solution of a joist without bridging is presented below; these solutions are derived in Chapter 3.

$$\frac{P_{cre}L^2}{EI_Y} = 0.1702\left(\frac{KL^4}{EI_Y}\right) + 20.00 \quad \text{for} \quad \frac{KL^4}{EI_Y} \le 311$$

$$\frac{P_{cre}L^2}{EI_Y} = 0.0302\left(\frac{KL^4}{EI_Y}\right) + 63.55 \quad \text{for} \quad 311 < \frac{KL^4}{EI_Y} \le 3874$$

$$\frac{P_{cre}L^2}{EI_Y} = 0.0119\left(\frac{KL^4}{EI_Y}\right) + 134.47 \quad \text{for} \quad 3874 < \frac{KL^4}{EI_Y} \le 16960$$

$$\frac{P_{cre}L^2}{EI_Y} = 0.00626\left(\frac{KL^4}{EI_Y}\right) + 230.03 \quad \text{for} \quad 16960 < \frac{KL^4}{EI_Y} \le 50000$$

$$\frac{P_{cre}L^2}{EI_Y} = 0.00427\left(\frac{KL^4}{EI_Y}\right) + 329.67 \quad \text{for} \quad 50000 < \frac{KL^4}{EI_Y} \le 80000$$

$$\frac{P_{cre}L^2}{EI_Y} = 0.00295\left(\frac{KL^4}{EI_Y}\right) + 435.00 \quad \text{for} \quad 80000 < \frac{KL^4}{EI_Y} \leq 200000$$

$$\frac{P_{cre}L^2}{EI_Y} = 0.00165\left(\frac{KL^4}{EI_Y}\right) + 685.80 \quad \text{for} \quad 200000 < \frac{KL^4}{EI_Y} \leq 700000 \qquad (2\text{-}3)$$

where L is the joist span. Eq. (2-3) is a linear curve fit to the slightly nonlinear exact solution shown in Figure 2.6. Eq. (2-3) can be used to determine P_{cre} before using Eq. (2-2) to determine top chord capacity.

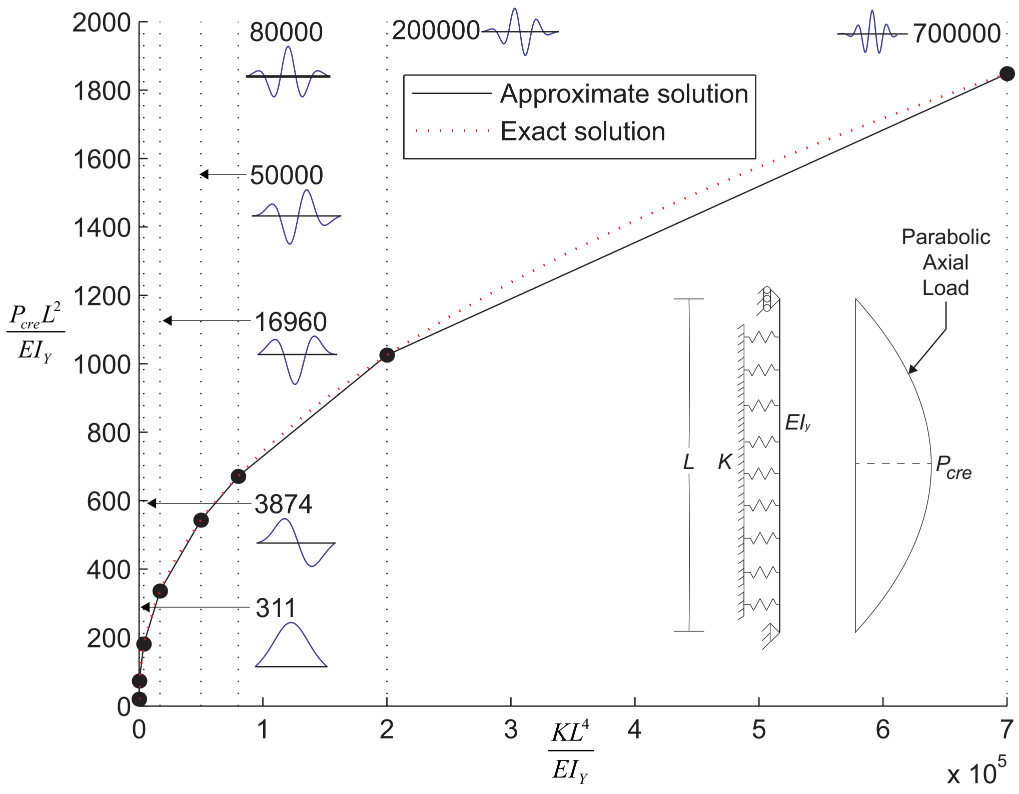


Figure 2.6 Flexural column buckling on an elastic foundation with a parabolically varying axial load

2.3 Simplified method for roof systems with bridging

Bridging is commonly used in standing seam roof systems for erection as well as stability purposes, an example of bridging can be found in Figure 2.7. It is necessary to include bridging for erection purposes even if the standing seam roof system provides full bracing along the length of the joist; a simplified method was created that took into account bridging within the standing seam roof system while making several conservative assumptions. The method uses the existing column curve much like that discussed previously; however there are several changes.

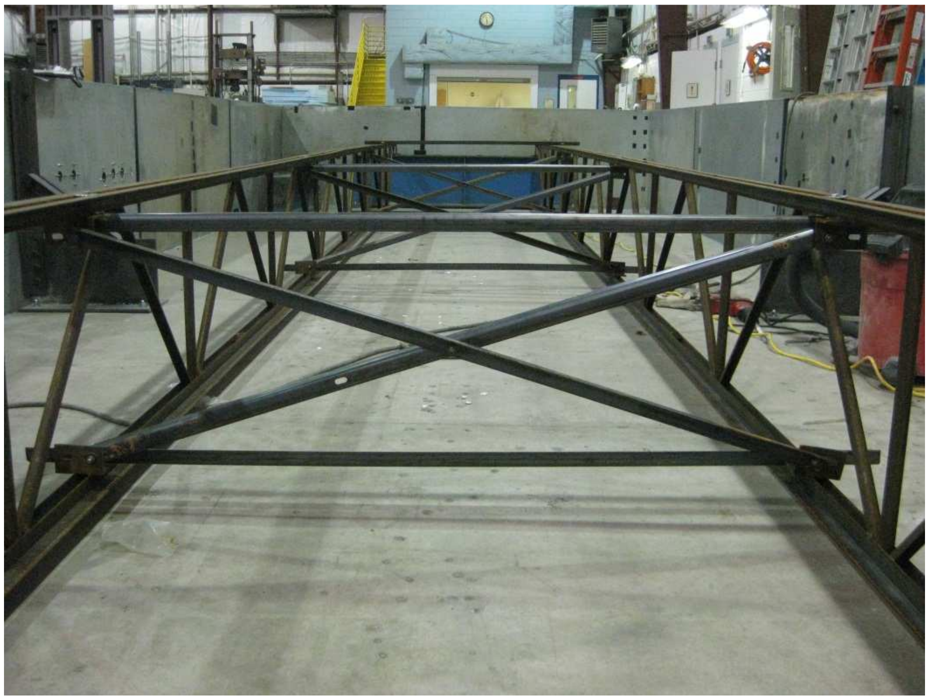


Figure 2.7 Bridging lines used during laboratory testing

2.3.1 Strength prediction using eigenbuckling analysis to determine P_{cre}

This method differs from the previous method in that the column length used in the simplified model is only the unbraced length about midspan of the joist (the distance between bridging lines); there will be an axial force gradient along the column; however, for typical bridging spacing it is reasonable and conservative to assume that the axial load is constant for this case. Some of the similarities with the previous model are that the boundary conditions are simply-supported, which is conservative because the bridging will provide some amount of rotational fixity, with the spring elements only providing lateral restraint (only affecting the lateral degree of freedom), Figure 2.8 shows how this condition was modeled.

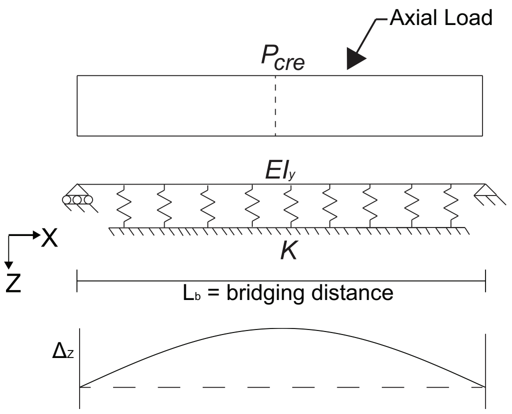


Figure 2.8 Top chord boundary conditions, loading, and lateral support for the simplified (bridging) model

The roof stiffness from the previous model was used and the same process was implemented to determine the top chord capacity for roof systems that use bridging. P_{cre} can be determined as described in the previous section, by using a structural analysis program to model the joist top chord as shown in Figure 2.8 and performing an eigenbuckling analysis.

2.3.2 Closed form solution to the simplified top chord model

Alternatively, a closed-form solution was derived to determine the top chord critical elastic buckling load:

$$\frac{P_{cre}L^2}{EI_Y} = 9.87 + \frac{KL^4}{9.87EI_Y} \quad \text{for} \quad \frac{KL^4}{EI_Y} \le 389$$

$$\frac{P_{cre}L^2}{EI_Y} = 39.48 + \frac{KL^4}{39.48EI_Y} \quad \text{for} \quad 389 < \frac{KL^4}{EI_Y} \le 3507$$

$$\frac{P_{cre}L^2}{EI_Y} = 88.83 + \frac{KL^4}{88.83EI_Y} \quad \text{for} \quad 3507 < \frac{KL^4}{EI_Y} \le 14030$$

$$\frac{P_{cre}L^2}{EI_Y} = 157.9 + \frac{KL^4}{157.9EI_Y} \quad \text{for} \quad 14030 < \frac{KL^4}{EI_Y} \le 38964$$

$$\frac{P_{cre}L^2}{EI_Y} = 246.7 + \frac{KL^4}{246.7EI_Y} \quad \text{for} \quad 39864 < \frac{KL^4}{EI_Y} \leq 87670 \tag{2-4}$$

Eq. (2-4) is an approximation of the classical solution for a column with a constant axial load on an elastic foundation (Chen and Lui 1987) shown in Figure 2.9.

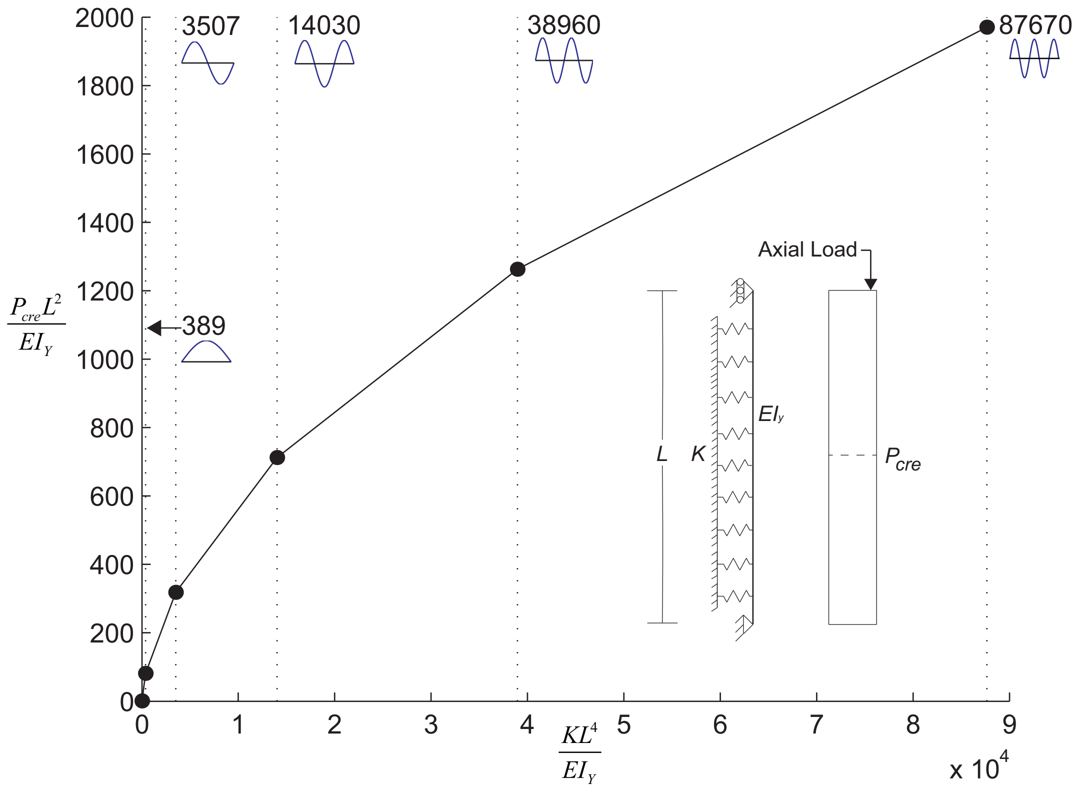


Figure 2.9 Flexural column buckling on an elastic foundation with a constant axial load

P_{cre} is used in Eq. (2-2) to calculate P_n for the top chord, joist capacity can be converted to a distributed load, w_n, with units of force per length

$$w_n = \frac{8P_n d}{L^2} \tag{2-5}$$

where d is the distance between centroids of the top and bottom joist chords.

There are several inherent assumptions in this strength prediction approach that may or may not be valid depending upon the joist type, standing seam roof details, and building boundary conditions. Catenary tension in the top chord is ignored which is most likely a conservative assumption. Downward local bending of the top chord caused by concentrated forces at the clip locations is ignored. A P-M interaction equation could be employed if there is concern that the web stem spacing is too large. The standing seam roof is assumed to be able to provide the distributed spring stiffness K and to have the capacity to carry the associated bracing forces. A procedure for approximating K and the bracing force demand with a standard vacuum chamber test and computer analysis is presented in Chapter 4.

Chapter 3 Fourth Order Linear Homogeneous Differential Equation Solution

3.1 Solution derivation – Parabolically varying load

To further check the prediction method outlined previously another method was created using structural stability concepts. Dr. Raymond H. Plaut of Virginia Tech created a solution using the computer program Mathematica that described the top chord as a simply-supported column on an elastic foundation loaded with a parabolically varying axial compressive load using a fourth-order linear homogeneous differential equation. The roof stiffness *K*, see Chapter 4, was input as the elastic foundation stiffness, and laboratory joist test properties, such as cross-sectional area and top chord moment of inertia, were used when determining the capacity of the top chord.

3.1.1 Differential equation derivation

Boundary conditions within the solution included zero deflection and zero moment at the ends of the column, corresponding to:

$$\begin{aligned} &Y(0) = 0 \\ &Y(L) = 0 \\ &Y''EI(0) = 0 \\ &Y''EI(L) = 0 \end{aligned} \tag{3-1}$$

Where *Y* represents the lateral deflection of the top chord, *Y’’EI* represents the moment in the top chord, and *L* represents the clear span distance of the joist.

Load was applied axially as a compressive load continuously along the length of the column varying parabolically; the load was expressed with Eq. (3-2).

$$P(X) = 4P_0\left(\frac{X}{L}\right)\left[1-\frac{X}{L}\right] \tag{3-2}$$

With the maximum axial load, P_0, occurring at midspan, and X representing the location along the top chord of the joist. Figure 3.1 shows how the top chord was modeled

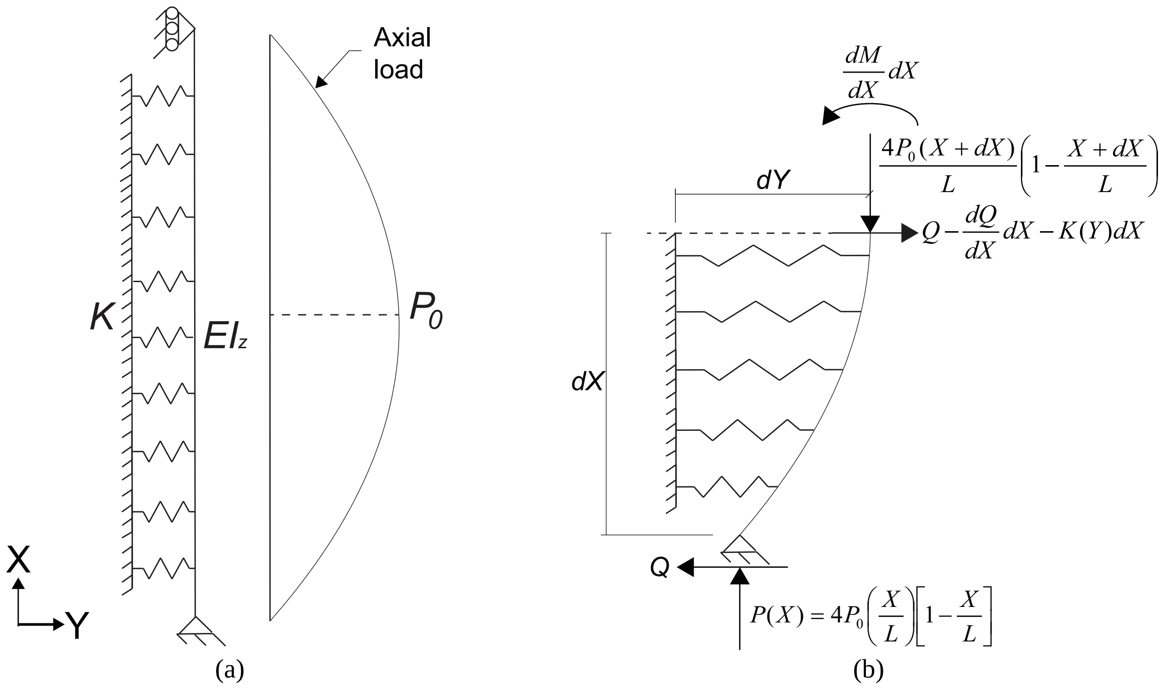

Axial load
K
EI_z
P_0
X
Y
(a)
$\frac{dM}{dX}dX$
$\frac{4P_0(X+dX)}{L}\left(1-\frac{X+dX}{L}\right)$
dY
$Q-\frac{dQ}{dX}dX-K(Y)dX$
dX
Q
$P(X)=4P_0\left(\frac{X}{L}\right)\left[1-\frac{X}{L}\right]$
(b)

Figure 3.1 (a) The full top chord model (b) a cut in the deflected shape showing the equations for axial load, shear, and moment

The fourth order linear homogeneous differential equation can be derived as follows:

By summing moments about the pinned end of the column:

$$\Sigma M = 0 = -QdX - P(-dY) + \frac{dM}{dX}dX$$

$$Q = \frac{dM}{dX} + P\frac{dY}{dX} = \frac{dM}{dX} + 4P_0\left(\frac{X}{L}\right)\left[1-\frac{X}{L}\right]\frac{dY}{dX}$$

Taking the derivative with respect to X:

$$\frac{dQ}{dX} = \frac{d^2M}{dX^2} + \left[\left[\frac{4P_0}{L}\left(1-\frac{X}{L}\right)\right]\frac{dY}{dX}\right]'$$

By summing forces in the Y-direction:

$$\Sigma F_Y = 0 = -Q + Q - \frac{dQ}{dX}dX - K(Y)dX$$

$$-\frac{dQ}{dX} = K(Y) \rightarrow \frac{dQ}{dX} = -K(Y)$$

$$-K(Y) = \frac{d^2M}{dX^2} + P\frac{d^2Y}{dX^2}$$

$$\frac{d^2M}{dX^2} + \left[\frac{4P_0X}{L}\left(1 - \frac{X}{L}\right)\frac{dY}{dX}\right]' + K(Y) = 0$$

Given that curvature can be described with the following relationship:

$$\frac{M}{EI} = \frac{d^2Y}{dX^2}$$

The substitution can then be made to arrive at the final equation:

$$EIY'''' + 4P_0\left[\left(\frac{X}{L}\right)\left(1 - \frac{X}{L}\right)Y'\right]' + KY = 0 \tag{3-3}$$

3.1.2 Solution using nondimensional quantities

The solution was simplified for use in Mathematica by using non-dimensional quantities for all variables as shown below:

$$x = \frac{X}{L}$$

$$y = \frac{Y}{L}$$

$$k = \frac{KL^4}{EI} \tag{3-4}$$

Where x and y are normalized by determining the percentage of the span can be represented by the location along the top chord and top chord displacement respectively.

Similarly *k* is a normalized version of the roof stiffness *K*, where *E* and *I* represent the modulus of elasticity and moment of inertia of the top chord respectively. The axial load, p_0, applied to the model can become unitless with the following conversion:

$$p_0 = \frac{P_0 L^2}{EI} \tag{3-5}$$

The solution used non-dimensional differential equation:

$$y'''' + 4p_0\left(xy' - x^2 y'\right)' + ky = 0 \tag{3-6}$$

The first solution to Eq. (3-6) is the trivial solution in which $y = 0$ everywhere; however, the buckling solution occurs when $y(x)$ does not equal zero. To solve this problem the shooting method was used in which an initial guess was made for either the first and third derivatives of $y(x)$ (since nothing is known about these values from the boundary conditions) which are then iterated until the solution converges and all of the boundary conditions are satisfied. For this solution $y'(0) = 0.1$ was used for the initial guess before the program performed the necessary iterations to determine the solution.

One problem with this solution was ensuring that the top chord was buckling in the correct mode. If the initial guess for the $y'(0)$ was too large the solution would converge on a capacity well above the capacity found in the laboratory tests; however, the load would be several times larger than the laboratory test capacity and was therefore easy to spot when this error would occur. It was easily corrected by lowering the initial guess to a lower value and running a new analysis.

The last step for this solution was to convert the maximum load back to a dimensional quantity, P_0, the critical elastic buckling load. This was done using the equation as follows:

$$P_0 = \frac{p_0 EI}{L^2} \tag{3-7}$$

3.2 Comparison with MASTAN2

An exact solution was found for each roof stiffness determined from the laboratory tests; this included entering the test information into Eq. (3-6) and solving for the critical elastic buckling load directly (solving for P_0). Once this step was completed it was possible to make comparisons with the critical elastic buckling load as determined using MASTAN2 models, the results of this comparison can be seen in Table 3.1.

Table 3.1 MASTAN2 to Exact Solution Comparison

Test	**P_{cre} (kips) MASTAN2**	**P_{cre} (kips) DE**	**P_{DE}/P_{M2}**
5	26.49	25.13	0.949
6	23.06	21.87	0.948
7	23.23	22.11	0.952
8	26.01	25.29	0.973
9	35.59	20.9	0.587
10	25.84	25.22	0.976
11	22.97	22.04	0.960
12	31.17	29.94	0.960
13	23.96	22.62	0.944
14	20.34	19.2	0.944
15	62.30	58.16	0.933
16	44.16	41.75	0.945
17	69.36	64.7	0.933
18	74.32	68.76	0.925

*Where P_{cre} *DE* represents the critical elastic buckling load for the exact solution to the fourth order differential equation

**P_{M2} represents the critical elastic buckling load from the column curve equations using MASTAN2

When comparing the exact solution to the fourth order differential equation for the critical elastic buckling load of the top chord to those determined using MASTAN2 Table 3.1

shows that the fourth order differential equation prediction tends to be relatively close to P_{cre} determined using MASTAN2, while also being slightly more conservative.

It should be noted that the values in Table 3.1 do not include tests 1-4. This is because the solution to this problem does not include discrete supports at bridging locations and thus the effect of bridging is not included in the model. It would not be appropriate to include the first four tests in this analysis because these tests would not be modeled correctly.

3.3 Comparison with the idealized linear solution

It can be seen in Figure 2.6 that there is a discrepancy between the exact solution (red dashed line) to the fourth order differential equation and those idealized with Eq. (2-3) (black solid line). It is therefore necessary to compare the closed form solution to the exact solution, Table 3.2 shows this comparison.

Table 3.2 Exact to Approximate Solution Comparison

Test	P_n (kips) DE	P_n (kips) Eq. (2-3)	P_{DE}/P_n
5	21.3	20.9	1.02
6	19.1	18.5	1.03
7	19.3	18.7	1.03
8	21.8	20.8	1.04
9	18.3	18.5	0.99
10	21.6	20.8	1.04
11	19.3	18.6	1.03
12	23.5	24.4	0.96
13	19.6	19.1	1.03
14	16.8	16.3	1.03
15	42.6	42.3	1.01
16	35.1	34.2	1.03
17	53.4	52.2	1.02
18	56.0	54.7	1.02

*Where P_n *DE* represents the top chord capacity as predicted by the exact solution to the fourth order differential equation

**P_n Eq. (2-3) represents the top chord capacity as predicted by Eq. (2-3)

It can be seen in Table 3.2 that the approximate solution determined using Eq. (2-3) is close to the exact solution adding a reasonable amount of conservatism (about three percent) to the prediction.

Chapter 4 Determination of Roof Stiffness

4.1 Procedure

The lateral stiffness provided by the standing seam roof to the top chord is influenced by many variables, including clip type, clip height, the presence of insulation between the panel and the joist, panel profile and gage, and the failure pressure which for a lower capacity joist will not cause hugging, or for a stronger joist, may result in significant hugging.

This new procedure for approximating *K* employs experimental data from a vacuum box test for systems without or with bridging in combination with a second order elastic analysis of the top chord performed in a structural analysis computer program (e.g., MASTAN2, SAP2000, RISA2D). The idea is to measure the lateral displacement of the joist top chord relative to the roof at multiple points along the span, and then to use a structural analysis program to solve for the *K* that results in the best match between the displaced shape in the structural analysis and the measured displaced shape of the joist.

The first step is to start with a vacuum box test and measure the displacement of the joists relative to the standing seam roof near failure as shown in Figure 4.1 (a). To be consistent with the assumptions in the prediction method that the roof eave and rafter boundary conditions are rigid, the roof edges should be reinforced with through-fastened angles and also braced at intermediate points along the span, for example, as shown in Figure 4.1 (b). The initial sweep imperfection shape and magnitudes along the span should be measured and recorded. It is recommended that three tests be performed to ensure that statistical variations can be averaged in the final determination of *K*.

Once the experiments are complete, a computer model is constructed where the top chord is simulated as a pinned-pinned column with distributed springs along its length (similar to Figure 2.5). The measured imperfection shape and magnitudes are imposed on the initial geometry of the model (so if three tests were performed then there would be three models), and a parabolically varying axial load is applied. A second order elastic analysis of the top chord including the imperfections and measured joist top chord section properties can then be run multiple times while varying the spring stiffness K. The roof stiffness K that minimizes the difference between the predicted and measured displacements from the experiment is averaged between the three tests and then used in Eq. (2-3), Eq. (2-4), or in an eigenbuckling analysis. The total bracing force demand can also be approximated by adding up all the spring forces in the model. <u>It is essential</u> when employing the joist strength prediction method described herein that K be experimentally determined for each combination of roof system variables (e.g., clip height, panel profile, insulation thickness).

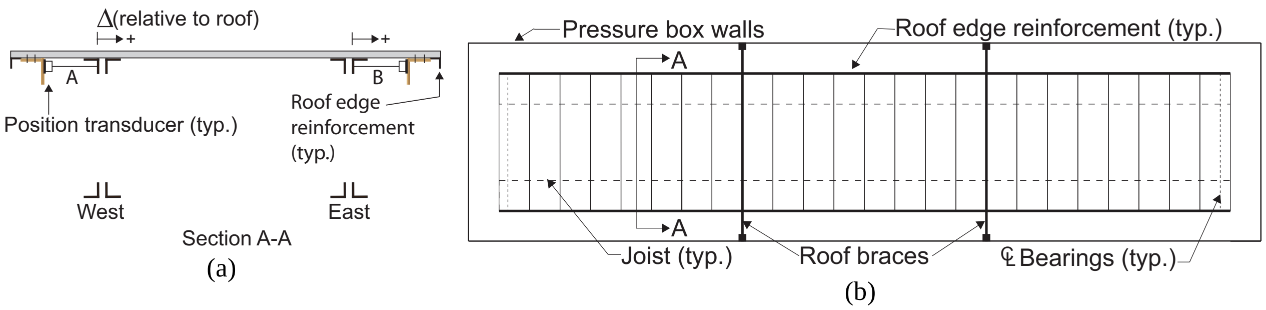


Figure 4.1 Vacuum box experiment details: (a) measurement of joist top chord relative to roof, and (b) proposed roof bracing details

The roof stiffness was determined for each laboratory experiment performed. The clips were modeled to allow for all of the stiffness provided from the standing seam roof system to be grouped together at the clip locations. This was; however, an approximation of the roof stiffness behavior because the lateral restraint provided from the roof system came from two sources, clamping force and envelopment of the top chord by the roofing panels under load. It was necessary to group the stiffness at the clip locations because there was no way to determine the amount of stiffness provided by the clips and hugging separately from the test information, not to mention modeling this condition was not possible in the programs used for analysis.

Once Matlab code was written to generate input files for MASTAN2 several models were created. From these models, and as was suspected from the experimental tests, it was discovered that the top chord behaved as a column loaded axially on an elastic foundation. This meant that the stiffness provided from the standing seam roof system could be thought of as a stiffness per length (force/length/length) measure rather than lumping the roof stiffness at the clip locations. To confirm the model results additional wirepots were added to the experimental test setup to measure lateral deflection along the length of the joist rather than just at midspan as was done previously. Figure 5.1 through Figure 5.12, show the deflected shape of the top chord from the experimental tests, as well as those predicted by the MASTAN2 models. These plots confirm the theory that the top chord behaves as if the standing seam roof supported the joists as an elastic foundation. Additionally, the figures in Appendix D show the deflected shapes from the MASTAN2 models of tests one through twelve, which were not able to be compared to the test deflected shapes because lateral displacements along the top chord were not recorded for these tests.

The only consistent lateral deflection measurement taken during the laboratory experiments were at the midspan of the joist. This value was measured for both the joist movement relative to the ground as well as the joist movement relative to the panel. Since the amount of restraint given to the joist by the standing seam roof system was desired the joist movement relative to the panel was used for each test at midspan.

To determine the roof stiffness an arbitrary value of one kip/in. was chosen for the spring stiffness and this value was iterated until the deflection of the center node in the top chord model matched up with the lateral deflection at midspan for each test. The deflection data from the MASTAN2 output was then collected and analyzed to determine the midspan deflection and the clip stiffness was modified as necessary until the deflection produced from the model matched that of the laboratory experiment.

The spring stiffness, K_{clip}, was determined from the MASTAN2 models and converted to an elastic foundation stiffness, K_{roof}, by dividing K_{clip} by the clip spacing, these values can be found in Table 4.1.

Table 4.1 Roof Stiffness Values

Test No.	K_{clip} (kips/in.)	K_{roof} (kips/in./in.)
1	0.16	0.0065
2	0.090	0.0038
3	0.077	0.0032
4	0.22	0.0092
5	0.082	0.0034
6	0.060	0.0025
7	0.062	0.0026
8	0.076	0.0032
9	0.052	0.0022
10	0.077	0.0032
11	0.060	0.0025
12	0.14	0.0058
13	0.065	0.0027
14	0.045	0.0019
15	0.20	0.0083
16	0.10	0.0040
17	0.15	0.0062
18	0.18	0.0073

4.2 Experimental roof stiffness observations

After the stiffness provided from the roof in each test was determined it was necessary to find a relationship between the test variables and the roof stiffness. This made it easy to determine the factors that had the largest influence on roof stiffness as well as those that did not contribute. The figures in this section are based on the total roof stiffness (lb./in./in.) because not all stiffness provided comes from the clips but there are other factors, such as hugging, that contribute to elastic foundation stiffness provided from the standing seam roof system.

The first variable inspected when determining the influence of lateral restraint provided by the roofing system was geometric imperfections and the amount of lateral deflection that occurred during testing. The lateral imperfection, Δ_z, was measured prior to each laboratory test and was measured as the lateral distance between the edge at the end of the top chord and the top chord edge at quarter points along the joist, and example can be found in Figure 4.2.

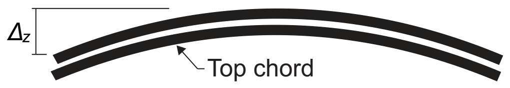


Figure 4.2 Example of how the top chord imperfection was measured

It was found that the lateral restraint of the roof was not influenced by the imperfection of the joist; this conclusion makes logical sense because these two factors are independent of one another and the elastic foundation stiffness caused by the influence of the clips should not vary regardless of the imperfection magnitude of the joist. Figure 4.3 shows the effect of the maximum imperfection on roof stiffness; this plot does not have any conclusive trends to it but is organized in a more random configuration. Some of the groups of data points appear to have trends in them; however, these are due to other common variables that are shared amongst them and are not due to the effect of the imperfection magnitude.

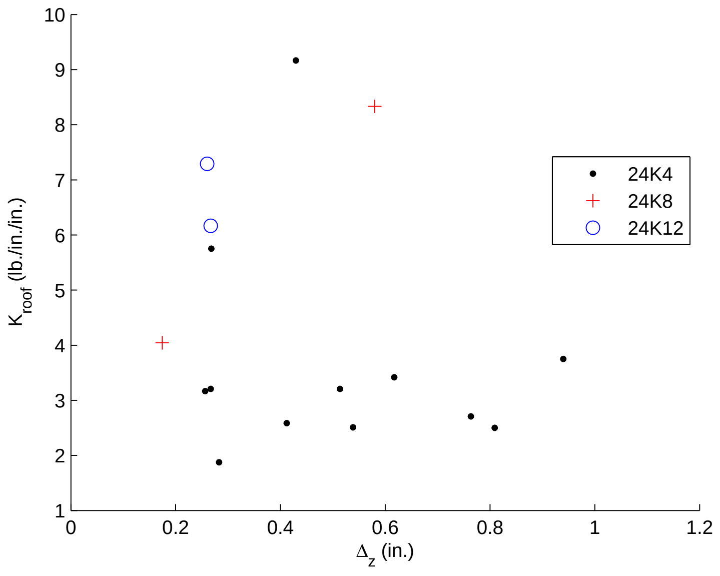


Figure 4.3 Effect of the maximum sweep imperfect on roof stiffness

The imperfection includes the imperfection magnitude as well as the location of the imperfection; as mentioned previously geometric imperfection (sweep) measurements were taken at quarter-points along the length (span) of the joist, it was found that the maximum imperfection did not always occur at midspan as would be expected for a perfect half-sine-wave imperfection. After observing that many of the maximum imperfection locations were at quarter or three-quarter points of the joist it was determined that imperfection location should be investigated to determine if it had any influence on K_{roof}.

Figure 4.4 shows the relationship between maximum imperfection location and roof stiffness; the correlation between imperfection location and roof stiffness is low and is shown to be an insignificant factor when determining roof stiffness.

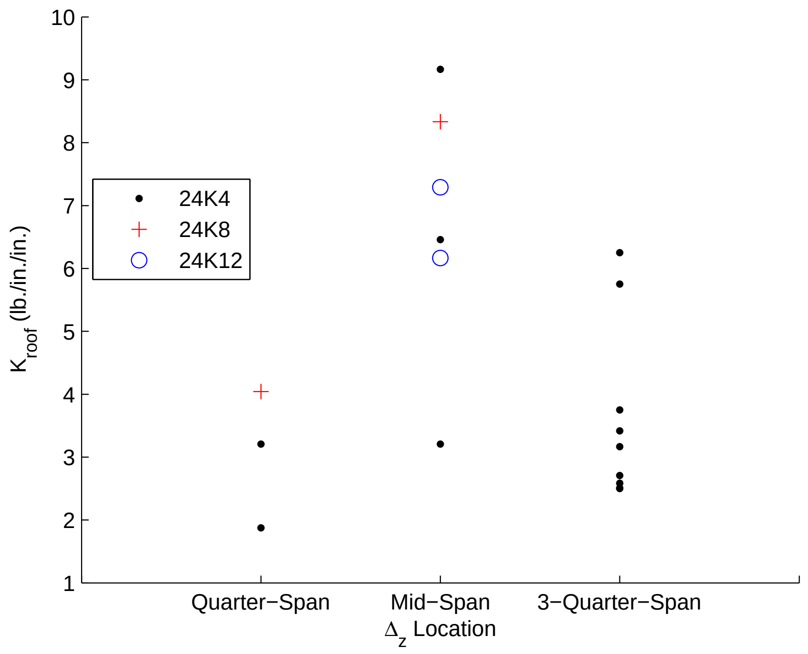


Figure 4.4 Effect of the location of the imperfection on roof stiffness

Each laboratory test had a different amount of lateral deflection of the top chord as loading progressed; because stiffness is directly related to displacement it was necessary to investigate the total lateral deflection to determine if the amount of deflection related to the stiffness provided from the standing seam roof. Figure 4.5 shows the relationship between the maximum lateral deflection in each test prior to failure and the stiffness provided from the roof; similar to the magnitude of the maximum imperfection the amount of lateral deflection during testing did not seem to influence the roof stiffness significantly.

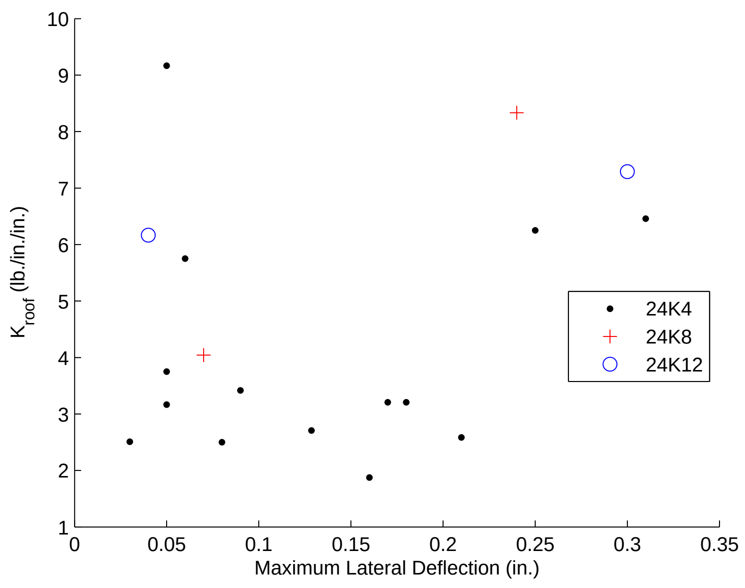


Figure 4.5 Effect of maximum lateral deflection on roof stiffness

As mentioned previously it was theorized that the more envelopment of the roof panel around the top chord of the joist (hugging) the more lateral support would be provided by the roofing system. It was possible to make this draw a conclusion about the influence of hugging by comparing the pressure at failure with the clip stiffness. Because the deck and clip spacing used for each test were the same it was possible to make this comparison by making the assumption that the deck would behave the same in each test with a higher deflection, and thus more envelopment of the top chord, resulting from a higher pressure. Figure 4.6 shows the relationship between roof stiffness and the maximum axial load P_{test} in the top chord, which is directly related to failure pressure; the best-fit line in the figure shows that hugging has a large influence on the amount of lateral restraint provided from the roof system. Only clip stiffness from 24K4 Joists are shown in the figure, when all joists are shown the relationship is still consistent; however, the roof stiffness values and P_{test} from the larger joists are much larger and make viewing the figure much more difficult.

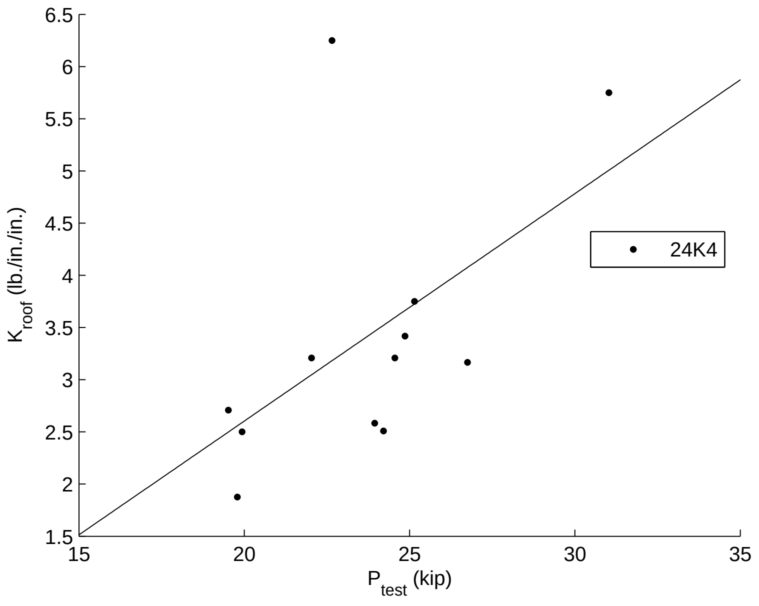


Figure 4.6 Effect of top chord envelopment by roof panel ("hugging") on roof stiffness

The next variables to be investigated were the insulation variables; these include inclusion or exclusion of the thermal block as well as the effect of insulation thickness. It was determined that neither of these variables have a significant effect on the stiffness provided from the roof system. Whether or not a thermal block is present the roof stiffness will be relatively similar; the average of K_{roof} = 4.62 lb./in./in. for tests using a thermal block and 4.43 lb./in./in. for tests excluding a thermal block, these values are very similar, with a COV of just 0.030 showing that the presence of a thermal block does not greatly affect the roof stiffness.

Figure 4.7 shows the influence of insulation thickness; the best-fit line in this plot shows that a thicker insulation will result in less stiffness from the roofing system. It is unclear if the insulation thickness has an effect on K_{roof} because the sample size is much smaller for the larger insulation thickness, further testing is required to draw a strong conclusion about the effects of insulation thickness on K_{roof}.

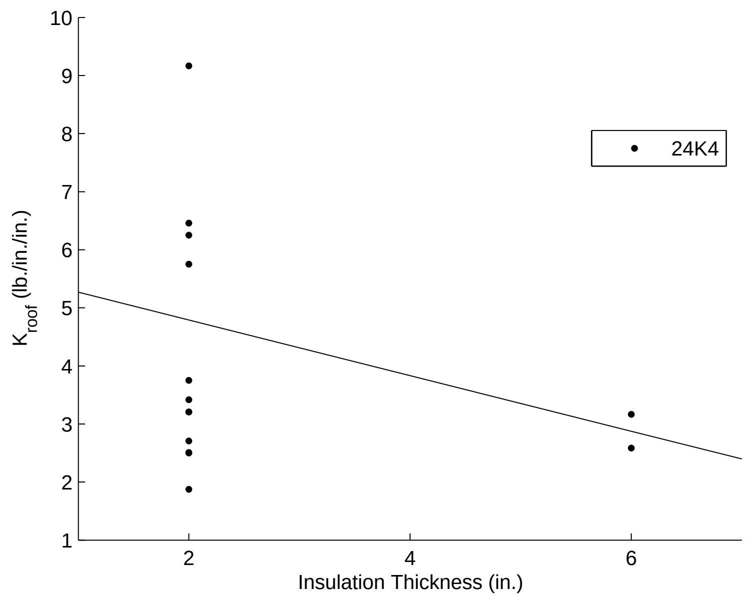


Figure 4.7 Effect of insulation thickness on roof stiffness

The last variable to investigate was the influence of clip height on the lateral stiffness provided from the standing seam roof. Figure 4.8 shows the relationship between clip height and K_{roof}; this plot shows that the smaller clip provides more lateral restraint from the roof system. The reason for this increase is because of hugging as well as an increase in clip stiffness; a smaller clip allows the roof panel to sit closer to the top chord of the joist, because the roof panel is closer to the top chord it takes less deflection to envelope the top chord. Because envelopment of the top chord comes at a lower load there is more hugging for a smaller clip than a larger clip for two roof systems under the same load. Furthermore, the smaller clip will sit closer to the roof panel while providing the same boundary condition for the connection to the joist (through-fastened), for the same lateral force there will be less deflection in the smaller clip than the larger clip and therefore an increased lateral stiffness.

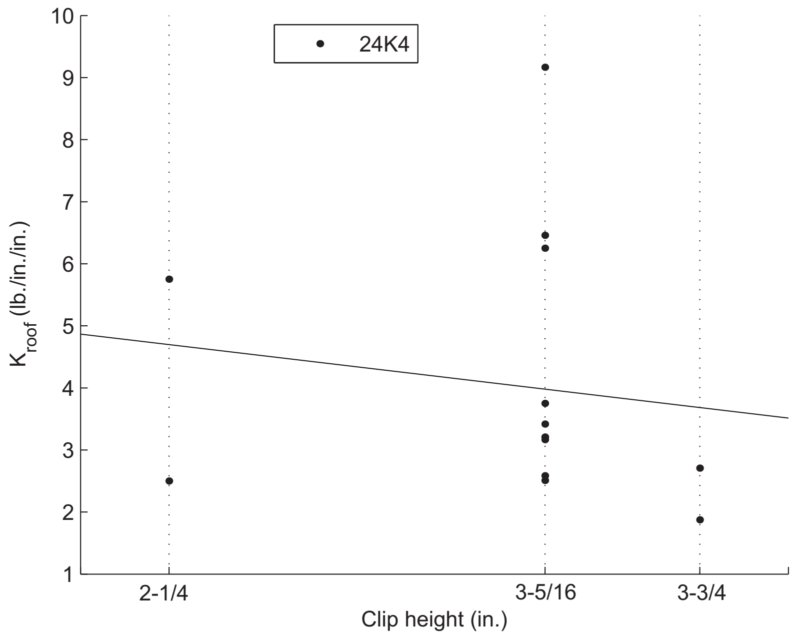


Figure 4.8 Effect of clip height on roof stiffness

It should be noted that only 24K4 joists were included in Figure 4.8, this is because the larger joists used 3-5/16 in. clips that had increased roof stiffness because of the larger top chord size. It can be seen from the figures in this section that the larger top chord size (corresponding to larger joist sizes (24K8's and 24K12's)) also have a larger roof stiffness; the 24K4 joists averaged K_{roof} = 4.04 lb./in./in., 24K8 joists averaged K_{roof} = 6.19 lb./in./in., and 24K12 joists averaged K_{roof} = 6.73 lb./in./in. This is because the larger top chord is able to take a larger load corresponding to more top chord envelopment and thus a larger K_{roof}.

Chapter 5 Test-to-Predicted Comparison

In order to validate the prediction method it was necessary to compare the test data with the capacity predicted by the methods outlined in Chapter 2. For this process the maximum axial load in each of the laboratory tests was calculated and this value was compared to the predicted maximum axial load.

Past literature was reviewed that included standing seam roof tests similar to those performed at Virginia Tech. It was desired to use the same prediction method outlined previously for validation with these tests; however, it was found that either the testing procedure differed too greatly or that measurements taken during testing did not provide enough information to accurately analyze the behavior of the roof system. Therefore only data was analyzed from information provided from the Virginia Tech tests.

5.1 Top chord test capacity vs. predicted capacity

A recent experimental program motivated the development of the prediction method described in Chapter 2. The procedure was implemented to find the roof stiffness K and to predict joist capacity for roof systems without and with bridging. The test results are compared to predictions in Table 5.1 where the top chord critical elastic buckling load, P_{cre}, was calculated with Eq. (2-4) for the tests without bridging and with eigenbuckling frame analysis in MASTAN2 for the cases with bridging.

The test-to-predicted mean and COV for the results in Table 5.1 are 1.08 and 0.12 respectively, demonstrating the prediction method is viable for the conditions considered. The roof stiffness K, derived with the iterative hybrid approach described in Chapter 4, increases with decreasing clip height and increasing failure pressure. These trends in roof stiffness are consistent with engineering intuition and with results from Sherman and Fisher (1996).

Joist capacity for the tests with bridging are also calculated using the simplified method for P_{cre} in Eq. (2-3). The capacity P_n in Table 5.2 is more conservative than using a frame eigen-buckling analysis (compare to Tests 1-4 in Table 5.1) however the strength prediction approach is still viable for the cases considered. The conservatism comes from the assumption that the top chord is a column with warping free boundary conditions at the bridging locations.

Table 5.1 As-tested and predicted roof stiffness and joist capacity

Test	Joist Type	Clip Height (in.)	Insulation Thickness (in.)	Thermal Block	Bridging Locations, x = (ft.)	Failure Pressure (psf)	P_{test} (kips)	F_y (ksi)	K (kips/in./in.)	P_y (kips)	P_{cre} (kips)	Number of half-waves	λ_c	P_n (kips)	P_{test}/P_n
1	24K4	3-5/16	2	Yes	9.6, 19.2, 28.8, 38.4	24.2	20.0	58.00	0.0065	47.6	35.8	5	1.15	27.3	0.73
2	24K4	3-5/16	2	Yes	9.6, 19.2, 28.8, 38.5	30.4	25.1	58.70	0.0038	48.5	28.6	5	1.30	23.8	1.05
3	24K4	3-5/16	2	Yes	19.2, 28.8	29.7	24.6	58.46	0.0032	47.1	25.7	4	1.35	21.9	1.12
4	24K4	3-5/16	2	Yes	19.2, 28.9	30.8	25.1	57.80	0.0092	45.7	40.6	3	1.06	28.5	0.88
5	24K4	3-5/16	2	Yes	N/A	30.0	24.9	57.50	0.0034	45.1	26.5	2	1.30	22.1	1.12
6	24K4	3-5/16	2	Yes	N/A	29.2	24.2	58.45	0.0025	46.6	23.1	3	1.42	20.0	1.21
7	24K4	3-5/16	6	Yes	N/A	29.0	23.9	58.49	0.0026	46.9	23.2	3	1.42	20.1	1.19
8	24K4	3-5/16	6	Yes	N/A	32.4	26.8	59.38	0.0032	48.9	26.0	4	1.37	22.3	1.20
9	24K4	3-5/16	2	No	N/A	27.3	22.7	59.34	0.0063	48.6	35.6	2	1.17	27.5	0.83
10	24K4	3-5/16	2	No	N/A	26.8	22.0	59.24	0.0032	48.0	25.8	3	1.36	22.1	1.00
11	24K4	2-1/4	2	No	N/A	24.4	19.9	58.73	0.0025	47.7	23.0	2	1.44	20.0	1.00
12	24K4	2-1/4	2	No	N/A	38.0	31.0	59.24	0.0058	42.8	31.2	5	1.17	24.1	1.29
13	24K4	3-3/4	2	Yes	N/A	23.5	19.5	57.60	0.0027	45.9	24.0	2	1.38	20.6	0.95
14	24K4	3-3/4	2	Yes	N/A	23.8	19.8	57.34	0.0019	45.5	20.3	3	1.50	17.8	1.11
15	24K8	3-5/16	2	Yes	N/A	58.2	49.0	56.92	0.0083	70.9	62.3	3	1.07	44.0	1.11
16	24K8	3-5/16	2	Yes	N/A	52.4	43.5	58.83	0.0040	72.8	44.2	3	1.28	36.5	1.19
17	24K12	3-5/16	2	Yes	N/A	76.1	64.1	56.23	0.0062	105.9	69.4	2	1.24	55.9	1.15
18	24K12	3-5/16	2	Yes	N/A	79.0	67.0	58.17	0.0073	108.5	74.3	3	1.21	58.9	1.14

Table 5.2 As-tested and predicted 24K4 joist capacity including bridging, P_{cre} calculated with Eq. (2-4)

Test	Joist Type	Clip Height (in.)	Insulation Thickness (in.)	Thermal Block	Bridging Locations, x = (ft.)	Failure Pressure (psf)	P_{test} (kips)	F_y (ksi)	K (kips/in./in.)	P_y (kips)	P_{cre} (kips)	Number of half-waves	λ_c	P_n (kips)	P_{test}/P_n
1	24K4	3-5/16	2	Yes	9.6, 19.2, 28.8, 38.4	24.2	20.0	58.0	0.0015	47.6	23.2	1	1.26	24.5	0.82
2	24K4	3-5/16	2	Yes	9.6, 19.2, 28.8, 38.5	30.4	25.1	58.7	0.0016	48.5	23.7	1	1.35	22.7	1.11
3	24K4	3-5/16	2	Yes	19.2, 28.8	29.7	24.6	58.5	0.0032	47.1	24.7	1	1.38	21.2	1.16
4	24K4	3-5/16	2	Yes	19.2, 28.9	30.8	25.1	57.8	0.0065	45.7	23.8	1	1.18	25.5	0.98

It was found that the prediction methods used for analysis matched up well with the results found in the experimental tests. The first method, which was used for all tests and was based on the column curve, predicted values that can be found in Table 5.1; this table shows test capacity, predicted capacity, the ratio of test capacity to predicted capacity.

Values in Table 5.2 show that the prediction from the column curve is generally conservative and reasonably accurate. Values for the test capacity ratio, P_{test}/P_n, greater than 1.0 show that the failure load is greater than the predicted capacity and is therefore conservative, this is true for majority of the test capacity ratios and those that are less than 1.0 generally do not deviate from 1.0 by a very large margin. It was expected that predictions would be on the conservative side considering that many of the assumptions made in the prediction method were conservative.

It can be seen from Table 5.1 that the only test with a capacity ratio well below 1.0 is from test 1. During laboratory testing there was a slip in the roof system prior to failure that is believed to have made the joist fail at a much lower load than expected, therefore P_{test} is low for this test making P_{test}/P_n lower than normal. The slip that occurred in Test 1 was not observed in any other tests and is thought to have occurred due to a mistake made while assembling the test and is not typical standing seam roof behavior.

The next prediction method to be analyzed was the simplified method that was used on roof systems that contained bridging. This system used the same prediction method using the column curve; however, the critical buckling load was determined with a MASTAN2 model with a constant axial load and length equivalent to the central bridging distance, see Chapter 2 for more details; the capacity prediction for this method can be seen in Table 5.2. The strength prediction for this method is once again conservative as well as accurate; the values are more conservative than those values found in Table 5.1 due to the additional conservative assumptions made. The values for the load capacity ratio are higher than those found previously; with the only non-conservative value occurring in Test 1 where there were problems during the laboratory test, as discussed previously.

5.2 Comparison of test vs. model displaced shape

This section shows both the displaced shapes for the test performed in the laboratory as well as the simulations run in the MASTAN2 models. It was necessary to make a comparison between the two to validate that the same failure modes were occurring in the models as were seen in the lab. The most important factor was to check that the model contained the same number of half-waves at the time of failure as measured within the test.

Several assumptions were made while modeling that made an exact match difficult, these included modeling the joist geometric imperfection as a half-sine wave with a maximum occurring at either quarter-span, midspan, or three-quarter-span, stiffness provided from the roofing system being lumped at clip locations, and bridging being modeled as a lateral fixity; however, results were found to be relatively similar in most cases.

The test displacements shown in this section are only applicable to tests 13-18. This is because these tests were performed prior to the model results that show that the top chord behaves as a column supported on an elastic foundation. In order to confirm that the top chord behaves in this manner additional wirepots were placed along the length of the top chord in order to measure lateral deflection (initially there was only one wirepot placed at midspan to measure lateral deflection).

The plots compare the test deflected shape (shown first) to the model deflected shape (shown second) for the applicable tests. The model deflected shape from the tests that did not include wirepots attached along the length of the top chord can be found in Appendix D.

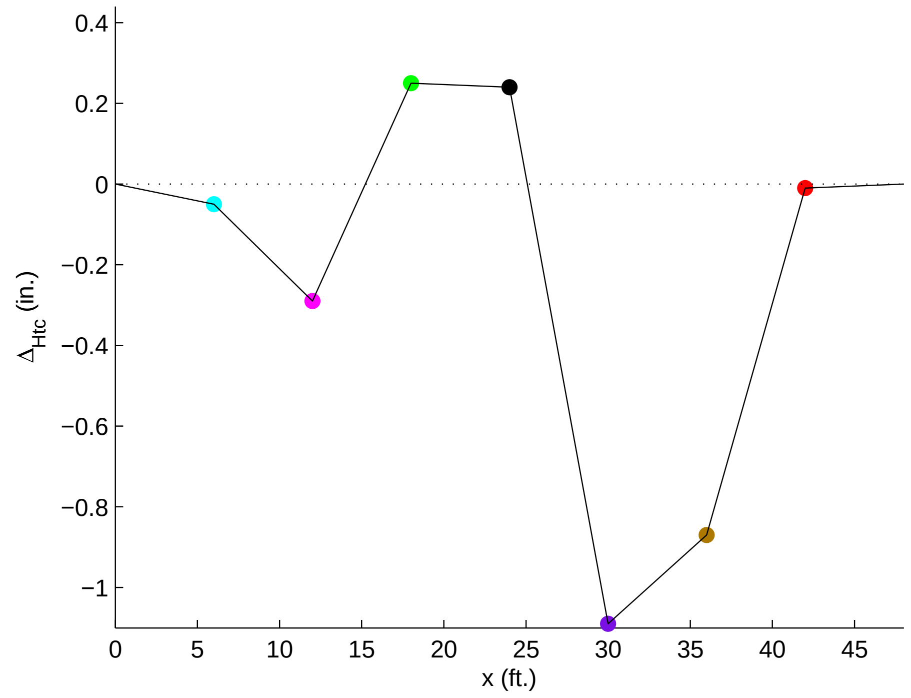


Figure 5.1 Test 13 top chord lateral displacement

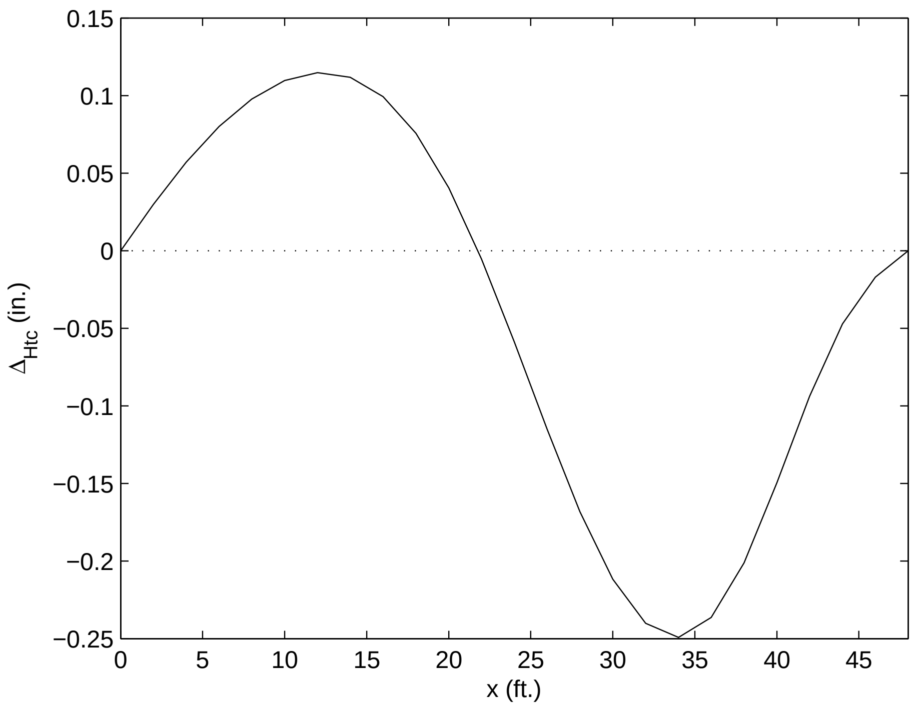


Figure 5.2 Test 13 top chord lateral displacement from MASTAN2 model

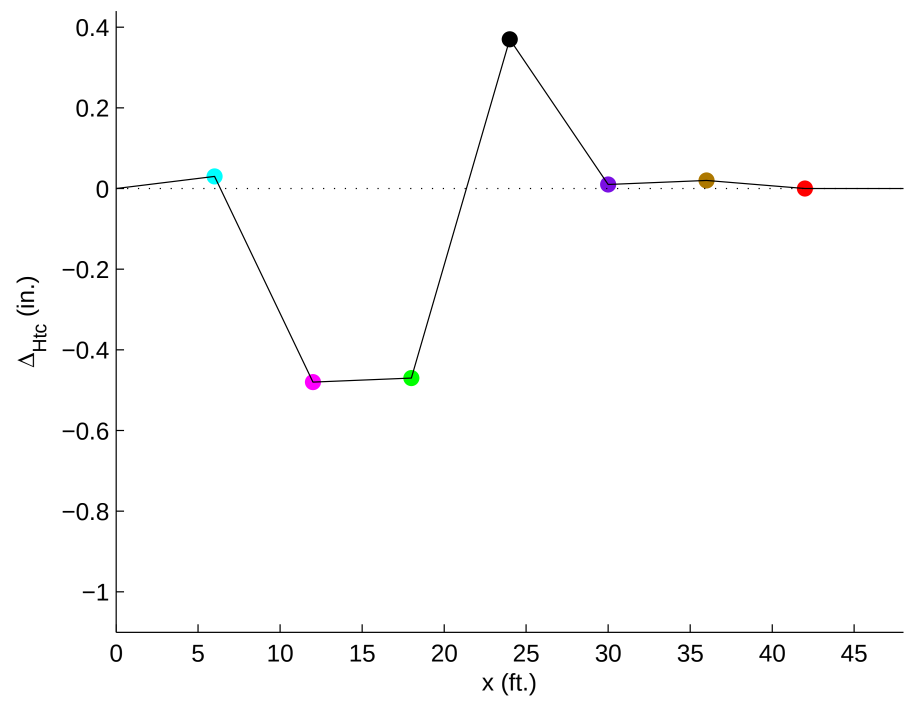


Figure 5.3 Test 14 top chord lateral displacement

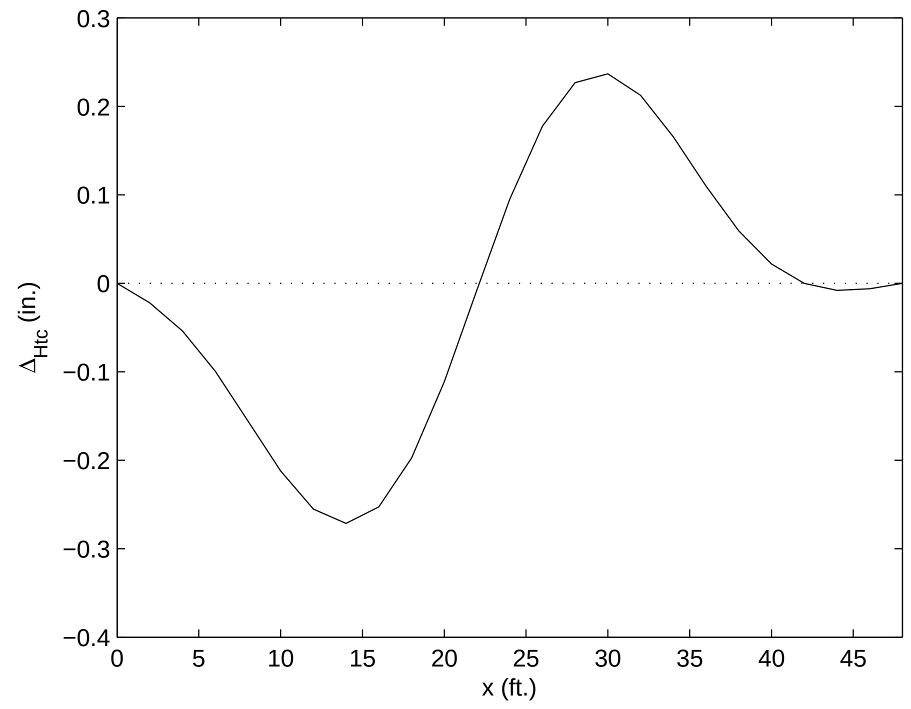


Figure 5.4 Test 14 top chord lateral displacement from MASTAN2 model

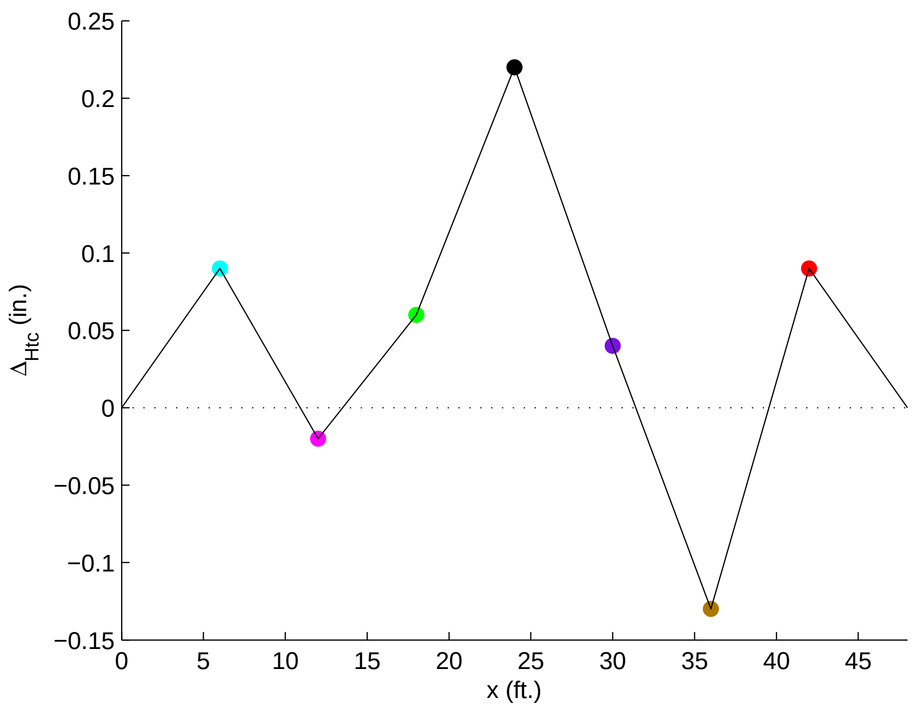


Figure 5.5 Test 15 top chord lateral displacement

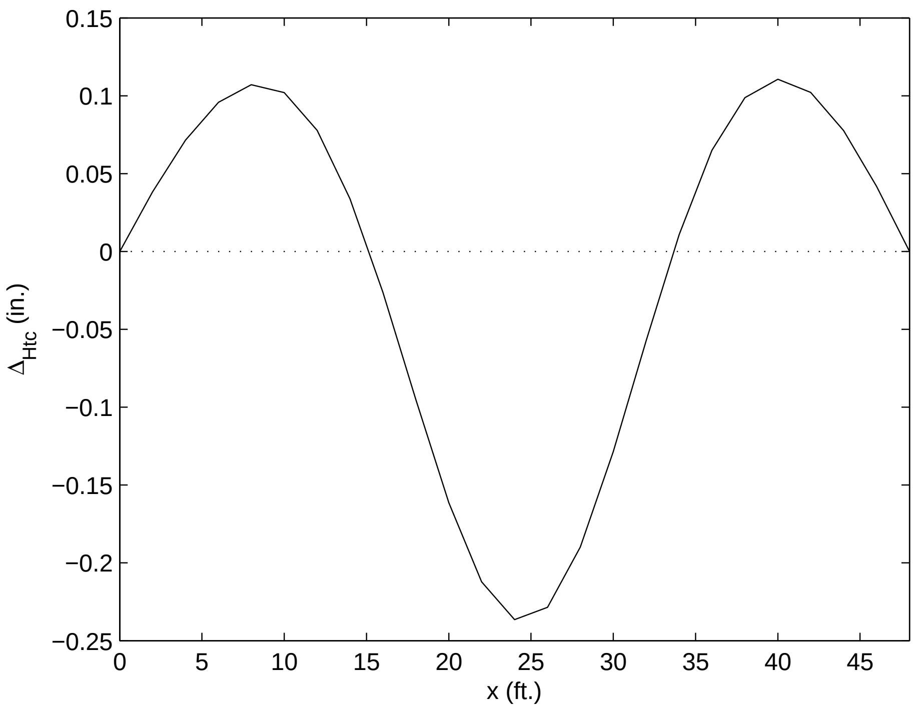


Figure 5.6 Test 15 top chord lateral displacement from MASTAN2 model

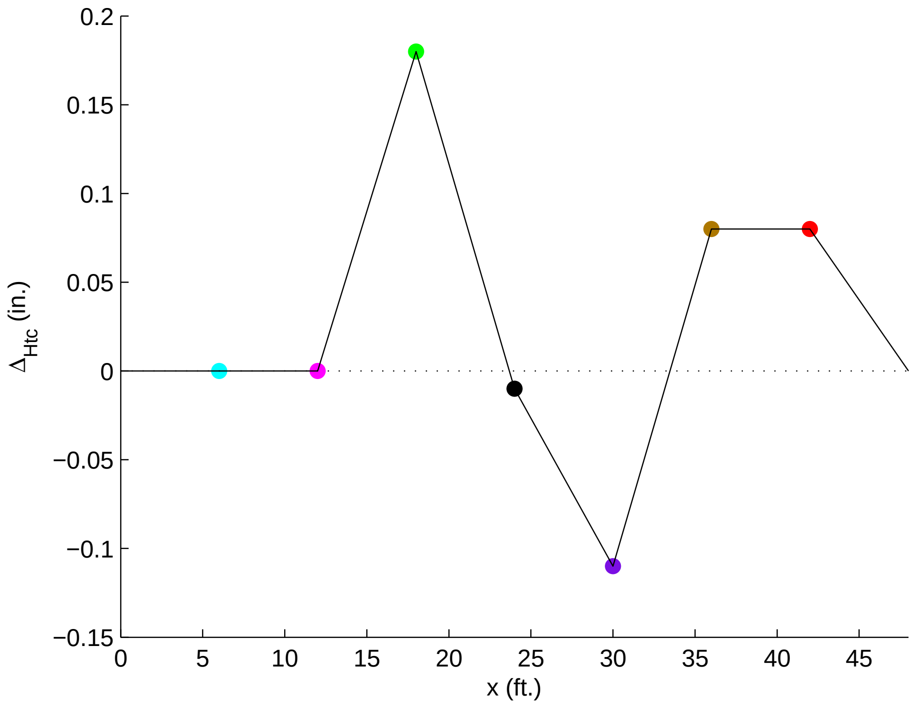


Figure 5.7 Test 16 top chord lateral displacement

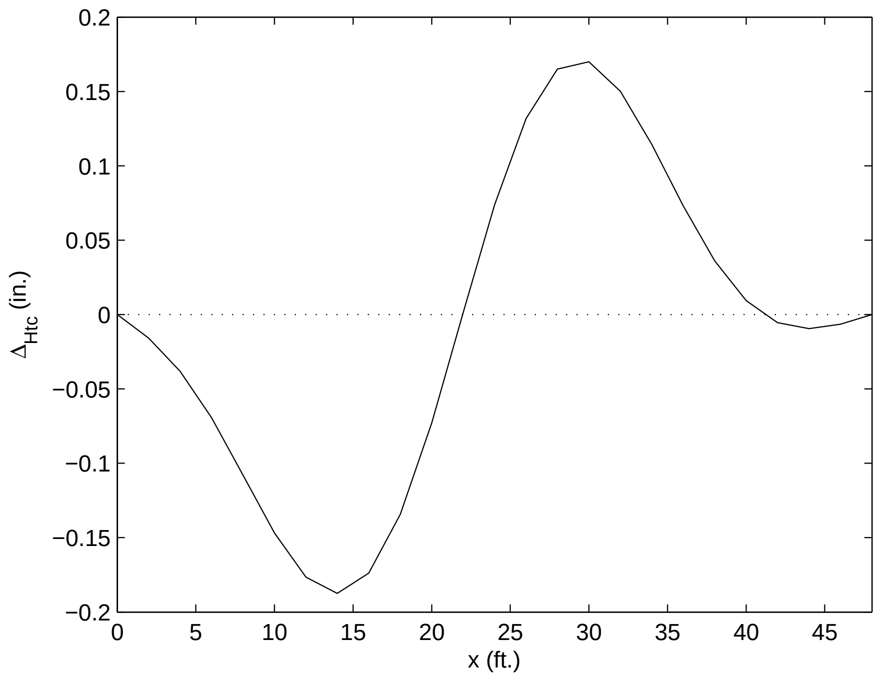


Figure 5.8 Test 16 top chord lateral displacement from MASTAN2 model

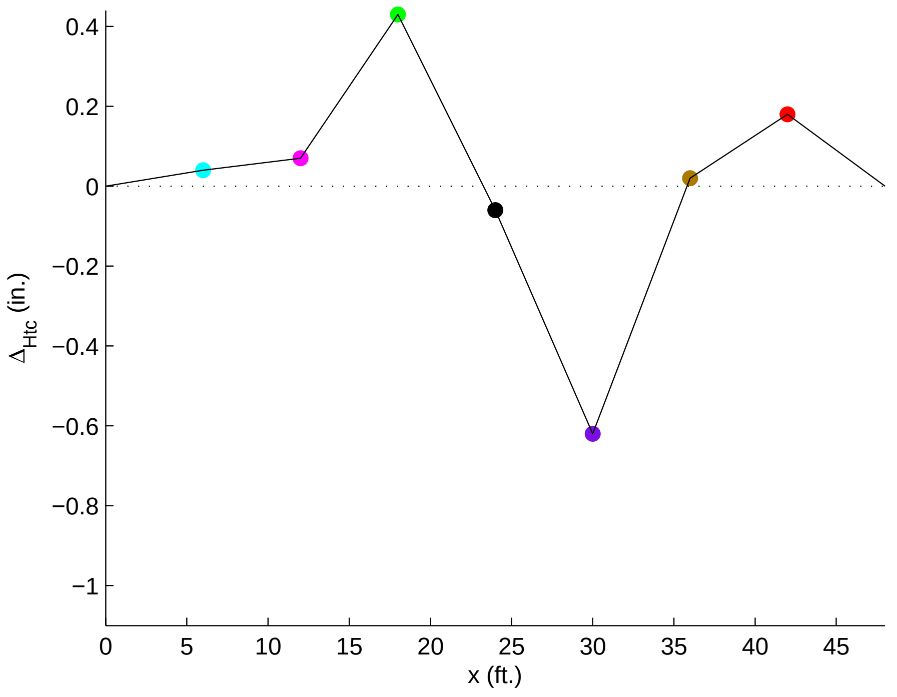


Figure 5.9 Test 17 top chord lateral displacement

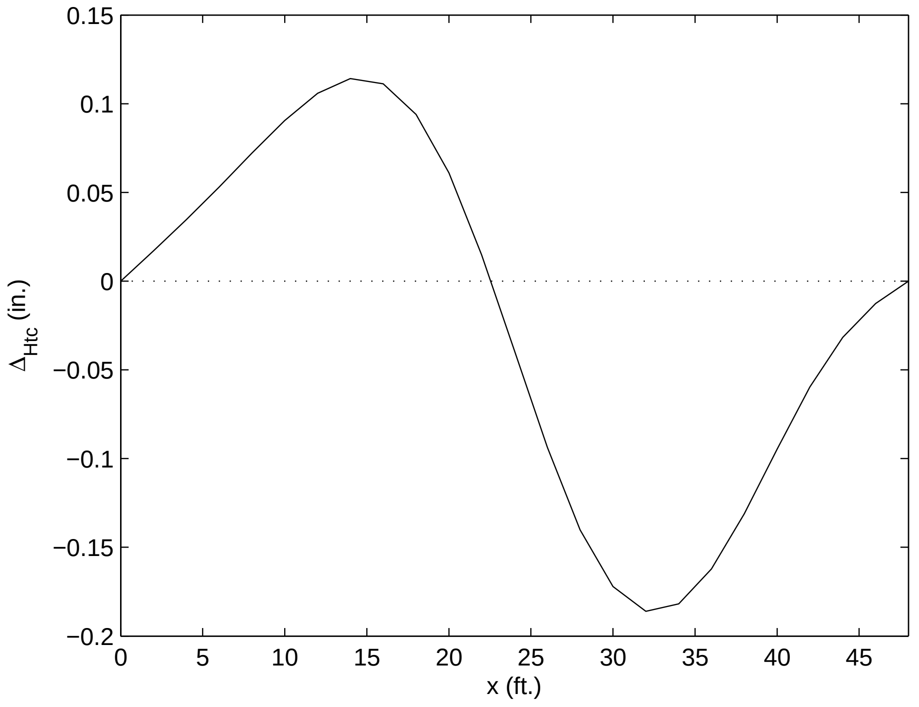


Figure 5.10 Test 17 top chord lateral displacement from MASTAN2 model

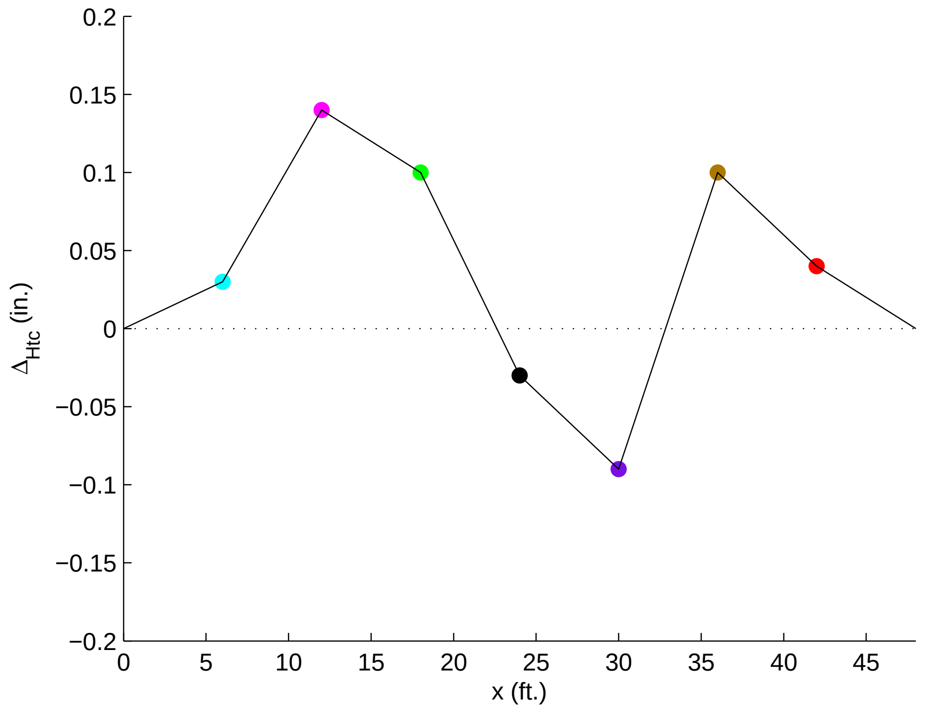


Figure 5.11 Test 18 top chord lateral displacement

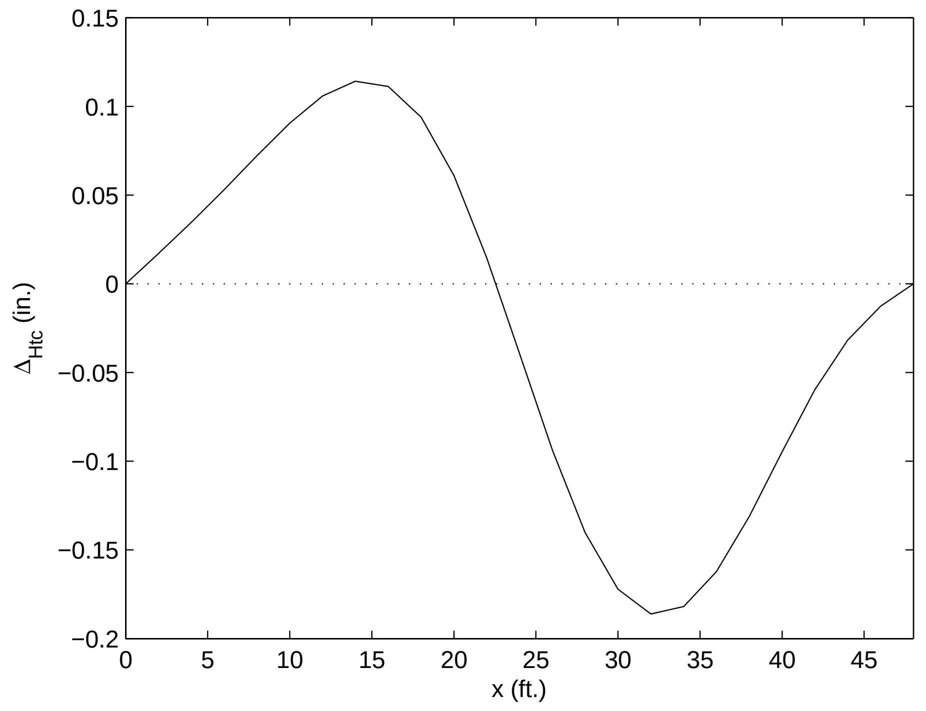


Figure 5.12 Test 18 top chord lateral displacement from MASTAN2 model

Chapter 6 Conclusions

A new strength prediction approach is presented for open web joists partially braced by a standing seam roof. The approach employs the AISC (AISI) column curve to calculate top chord flexural buckling capacity based on the top chord's critical elastic buckling load. Recently derived buckling load equations are summarized that account for lateral stiffness provided by the roof and the parabolically varying axial load from a uniform vertical pressure along the span. A new hybrid experimental-computational protocol is introduced for approximating standing seam roof lateral stiffness. The strength prediction approach was verified with a small set of experiments. Additional experimental verification is needed to fully validate the approach as a general prediction method for open web joists braced by a standing seam roof.

The strength prediction approach presented in Chapter 2 uses the existing AISC column curve equations to predict the strength of the top chord by assuming the top chord acts as a column supported on an elastic foundation. Column slenderness is calculated by using the equation $\lambda_c = (P_y/P_{cre})^{0.5}$ where P_y is the column yield load and P_{cre} is the critical elastic buckling load of the column. The slenderness parameter dictates which column curve equation will be used (elastic or inelastic buckling). In these equations the only variables needed are those used in the slenderness equation meaning that the only necessary values to be determined are the yield load, which is trivial, and the critical elastic buckling load, which is more complex.

To calculate the critical elastic buckling load two methods are given. The first is to model the top chord appropriately using a structural analysis software program and run an elastic eigenbuckling analysis; the second is to use the closed form equations given in Chapter 2. It is necessary to quantify the roof stiffness K (force/length/length) to perform this calculation in either of the two methods given to calculate the critical elastic buckling load.

To determine the stiffness contribution from the roof it is essential to employ a laboratory testing procedure because the roof stiffness is contingent on the unique properties of each roof such as clip type, clip height, insulation thickness, presence of a thermal block, joist imperfection, and the number and location of bridging. A structural analysis computer model of the joist top chord should then be constructed taking into account the appropriate standing seam roof properties as discussed in Chapter 3, with the roof stiffness being modeled as either discrete springs at clip locations or an elastic foundation. The roof stiffness should be iterated until the second order analysis deflection matches the deflection found in the laboratory experiments.

To validate the data, the results from the laboratory tests should be compared to those generated from the prediction method. Further validation can be obtained by successfully modeling the standing seam roof system in a finite element software; Matlab code is available for writing input files for ABAQUS and is discussed in Appendix F and it is provided in Appendix G.

Chapter 7 Future Work

The research performed at Virginia Tech made it possible to form a prediction method to determine the capacity of a standing seam roof system. It is necessary; however, for future studies to be performed on similar roof systems to determine their capacities based on the unique properties of each roof. This includes altering the joist depth, chord size, span length, clip type, clip size as well as the roof properties such as insulation thickness and presence of a thermal block.

There were few tests performed in the Virginia Tech laboratory that included bridging within the roof system; although the capacities for roof systems with and without bridging were similar, research that further investigates the behavior of standing seam roof systems including bridging is suggested.

To better understand the roof behavior a finite element model was created by writing Matlab code to generate ABAQUS input files. This code includes entering the properties of the joist, roof, and test to generate a finite element model, this is discussed thoroughly in Appendix F.

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Appendix A Slenderness proof

This appendix was created to show that the slenderness parameter commonly used in the AISC code, *kL/r*, is equivalent to that presented in this paper, $(P_y/P_{cre})^{0.5}$. This slenderness parameter is essential to the prediction method outlined in Chapter 2 because it was difficult to establish the exact value of *k* (the effective length factor) for the standing seam roof system. Rather, it was much simpler to determine the yield load, P_y, and the critical elastic buckling load, P_{cre}, and relate the top chord capacity to these values.

The proof begins with the AISC column slenderness parameter as defined in Chapter E of the AISC manual.

$$\frac{kL}{r} \leq 4.71\sqrt{\frac{E}{F_y}}$$

$$\frac{(kL)^2}{r^2} \leq 4.71^2 \frac{E}{F_y}$$

By substituting $r=(I/A)^{0.5}$

$$\frac{(kL)^2 A}{I} \leq 4.71^2 \frac{E}{F_y}$$

$$\frac{(kL)^2 A}{EI} \leq 4.71^2 \frac{1}{F_y}$$

$$\frac{(kL)^2 A}{\pi^2 EI} \leq \frac{4..71^2}{\pi^2} \frac{1}{F_y}$$

Because $P_{cre} = (\pi^2 EI)/(kL)^2$

$$\frac{A}{P_{cre}} \leq \frac{4.71^2}{\pi^2} \frac{1}{F_y}$$

Multiplying by the right side of the equation by *A*/*A* will produce the yield load in the denominator, and consequently cancel with the *A* on the left side of the equation.

$$\frac{A}{P_{cre}} \leq \frac{4.71}{\pi^2}\frac{A}{P_y}$$

$$\frac{P_y}{P_{cre}} \leq \frac{4.71^2}{\pi^2}$$

$$\sqrt{\frac{P_y}{P_{cre}}} \leq \frac{4.71}{\pi}$$

$$\sqrt{\frac{P_y}{P_{cre}}} \leq \frac{4.71}{\pi}$$

$$\sqrt{\frac{P_y}{P_{cre}}} \leq 1.5$$

Appendix B Determination of top chord yield strength

Testing procedure

The yield load of the top chord was found through determining the yield stress from tensile tests, in agreement with ASTM A370-05 “Standard Test Methods and Definitions for Mechanical Testing of Steel Products”, then multiplying the yield stress by the cross-sectional area of the top chord. Specimens were taken from each angle within the top chord and tested to find the yield strength which could then be used in the prediction method.

When joists were received from New Millennium Building Systems they contained extensions of both the top and bottom chord. Prior to testing the standing seam roof system in the laboratory the chord extensions were cut to allow for tensile specimens to be formed. Because the leg of each angle was flat, specimens were cut from the chord extensions in compliance with ASTM guidelines for the longitudinal flat tension test. The dimensions of the specimens were in accordance with ASTM 370-05 with a width of 0.5 in. $^{+}/_{-}$ 0.01 in. and were the full thickness of the section.

Extensions on the top and bottom chord were required while determining the research plan because the mode of failure was not known at this time. Because nearly all of the tests were controlled by out-of-plane buckling of the top chord, tension specimens were only taken from the top chord of each joist.

Prior to testing, the specimens were marked and measured to determine the full stress-strain relationship of the material as well as the percent elongation and reduction in cross-sectional area. Gage marks of approximately two inches spaced evenly between the center of the specimen were made prior to each test with a marker as to not risk cutting into the material thus creating a stress-concentration. Also measured were the width and thickness of the specimen;

calipers were used to measure both of these values and five measurements of each were taken along the length of the specimen, the average thickness was used while the minimum width was used, the minimum width was used because it was theorized that it was at the location of minimum width that the specimen would fracture.

To perform the test an MTS 30-kip capacity tensile machine was used. The data acquisition system consisted of an extensometer (part of the MTS setup) connected to a computer which used Testworks4 as the software. The load cell was set to zero before the specimen was placed in the grips of the tensile machine and was straightened to plumb with the use of a level before being tightened into place. Once the specimen was in place the extensometer was placed on the specimen at its approximate center and set to zero using the testing software, Figure B.1 shows the test setup for testing the tensile specimens. The test was then started; the initial rate of loading was 0.05 in./min. which increased to 0.5 in./min. after yielding occurred.

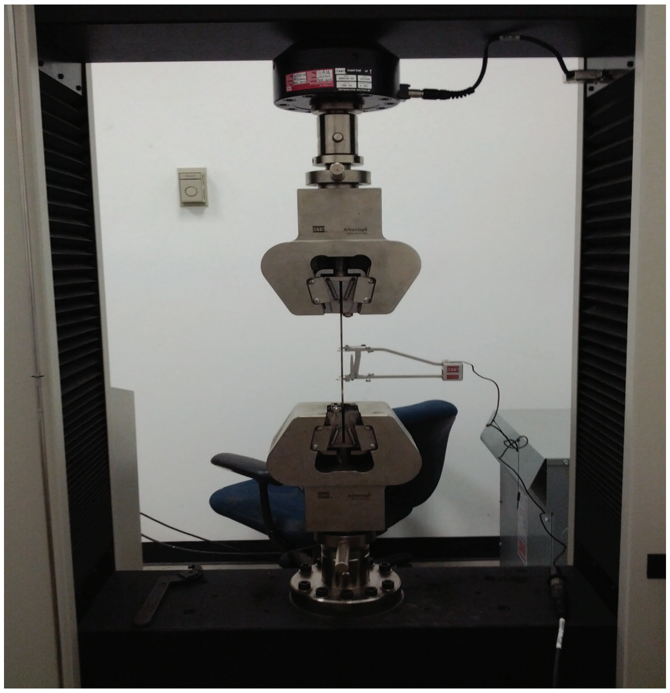


Figure B.1 Tensile test setup

True stress-strain relationship

Testworks4 was able to produce an engineering stress-strain curve as well as the data points necessary to create this curve; however, it did not produce true stress-strain values which were necessary to determine the yield strength of the material and for use in plastic analysis using the finite element model. To transform the engineering stress strain to true stress-strain the following equations were used:

$$\varepsilon_{true} = \ln(1 + \varepsilon_0)$$

$$\sigma_{true} = \sigma_0 (1 + \varepsilon_0)$$

ε_{true} and σ_{true} represent the true stress and strain while ε_0 and σ_0 represent engineering stress and strain respectively.

It was necessary for the finite element model to take into account plastic material stress-strain behavior because it was theorized that some of the chord steel was likely to yield prior to joist failure during the laboratory experiments. This is where the conversion from engineering stress-strain to true stress-strain was the most valuable; it can be seen in Figure B.2 that the linear-elastic region of the stress-strain diagram there is little deviation between the two curves while the deviation after yielding has occurred is much greater. To produce a model that accurately described the behavior of the joists as load was applied it was necessary to include this conversion. The stress-strain curves for the other tests are included at the end of this appendix.

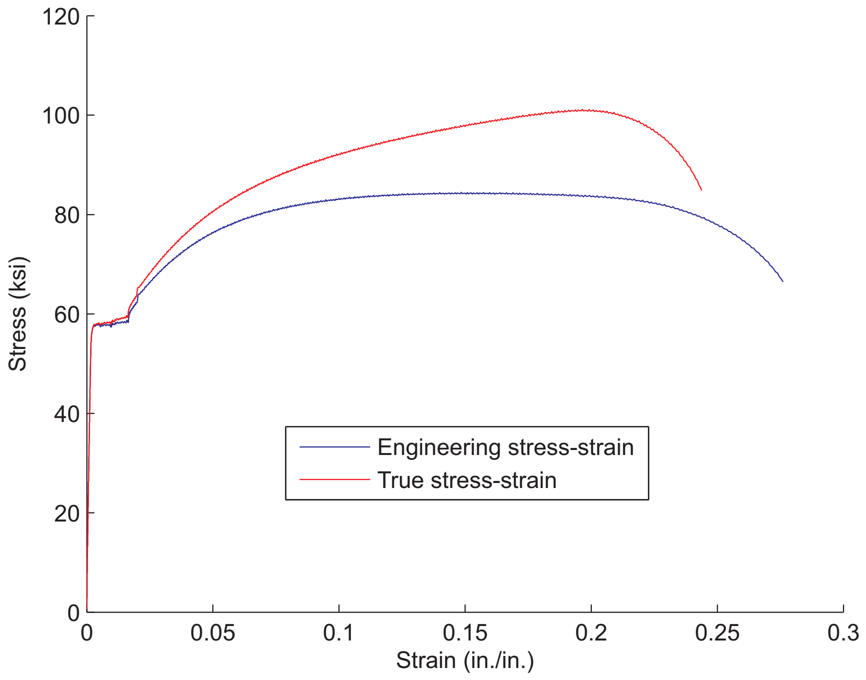


Figure B.2 Example engineering vs. true stress strain (for joist 1A)

Determination of yield strength

To determine the yield stress of each specimen the 0.2% offset method was used. The true stress-strain behavior was used and a line with an equivalent modulus of elasticity (29000ksi), but offset to an initial strain of 0.2% were plotted on the same graph, the intersection of the two lines was determined, and the stress at this intersection point was taken as the yield stress of the material, Figure B.3 shows an example of this process.

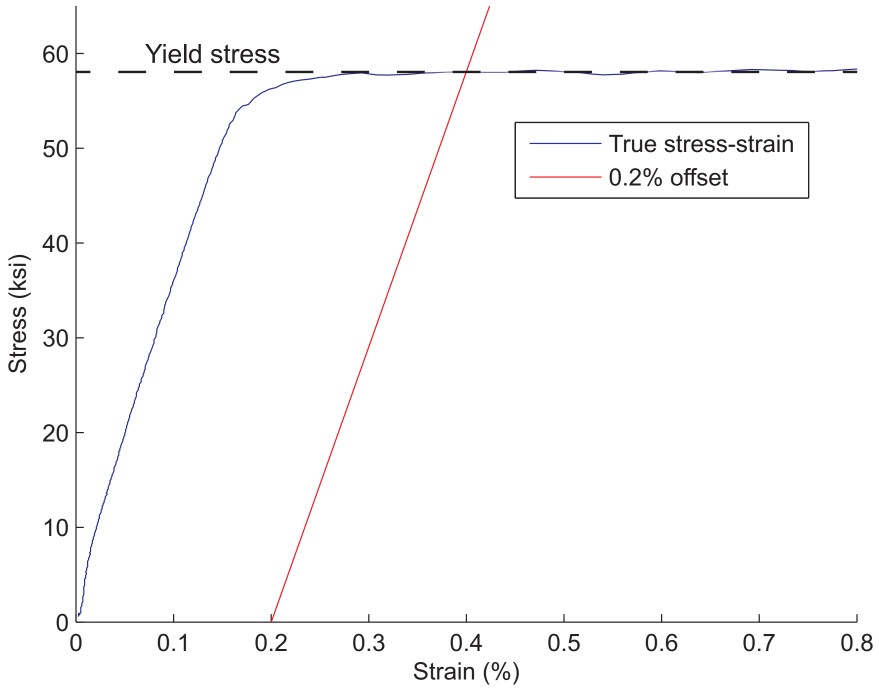


Figure B.3 0.2% offset example (for joist 1A)

Stress-strain plots

The following plots are the stress-strain diagrams for each top chord of each laboratory test performed.

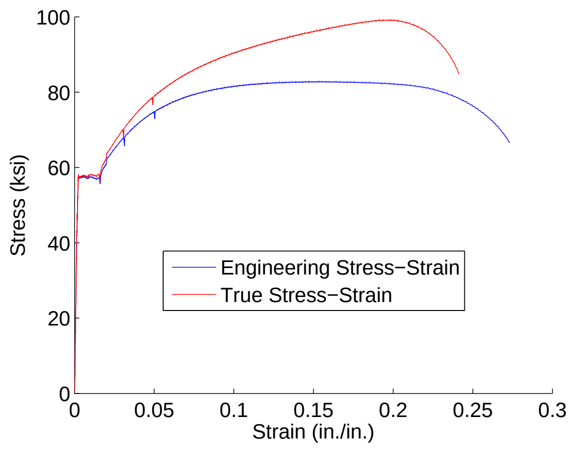


Figure B.4 Stress-strain relationship for Joist 2A

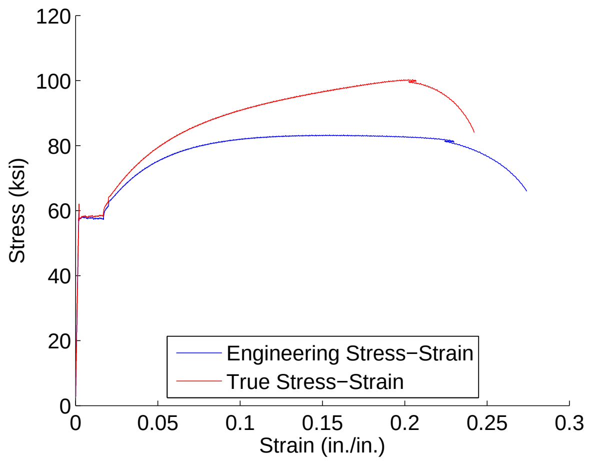


Figure B.5 Stress-strain relationship for Joist 3B

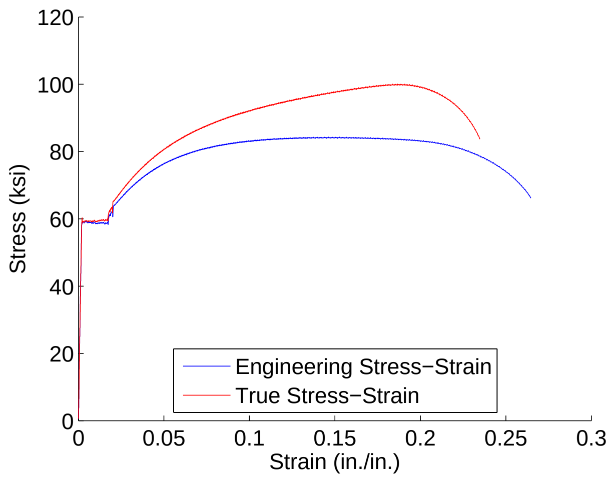


Figure B.6 Stress-strain relationship for Joist 4B

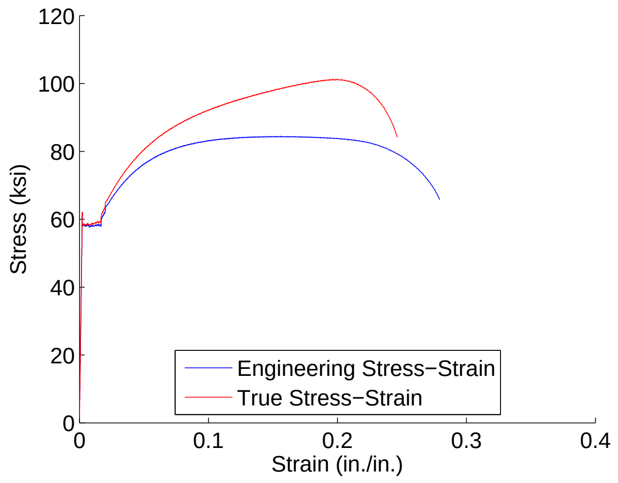


Figure B.7 Stress-strain relationship for Joist 6A

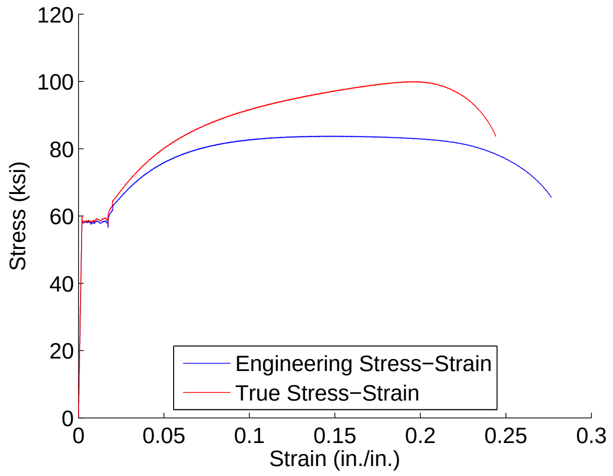


Figure B.8 Stress-strain relationship for Joist 7B

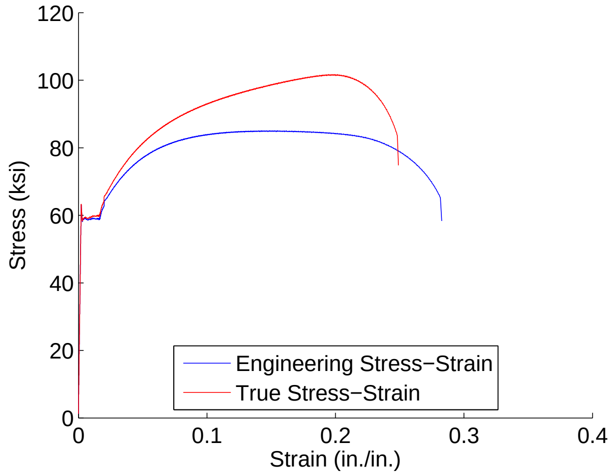


Figure B.9 Stress-strain relationship for Joist 8A

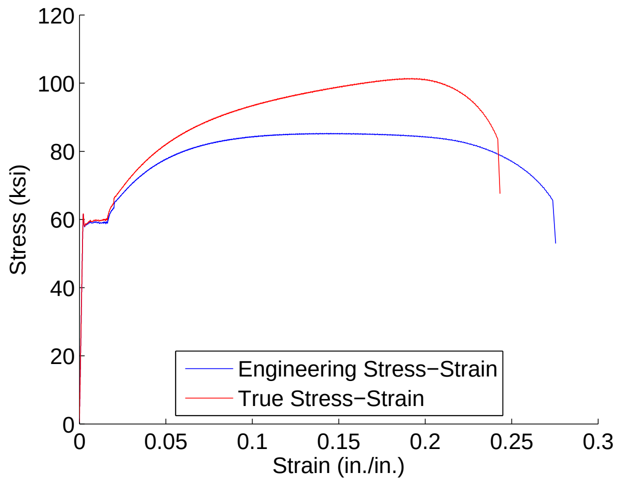


Figure B.10 Stress-strain relationship for Joist 9A

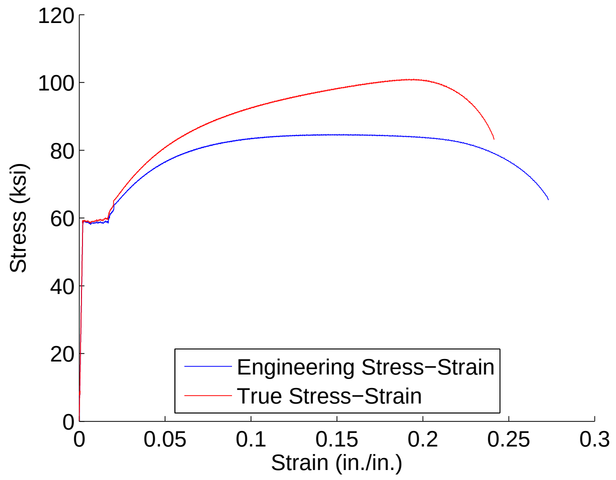


Figure B.11 Stress-strain relationship for Joist 10A

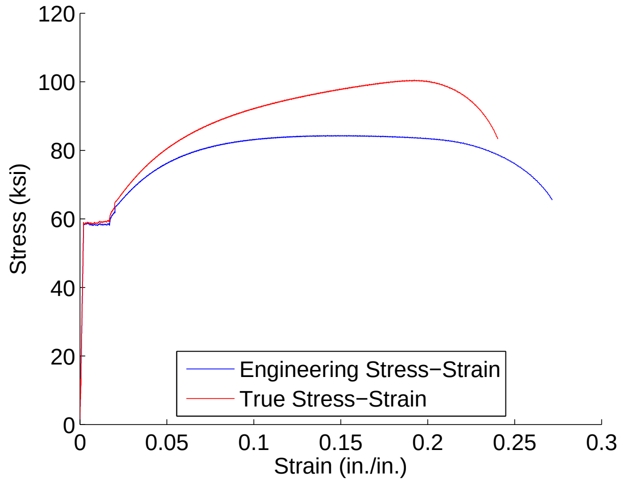


Figure B.12 Stress-strain relationship for Joist 11B

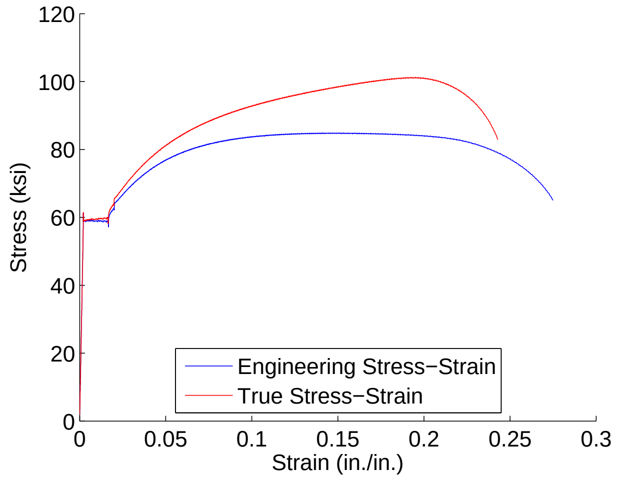


Figure B.13 Stress-strain relationship for Joist 12A

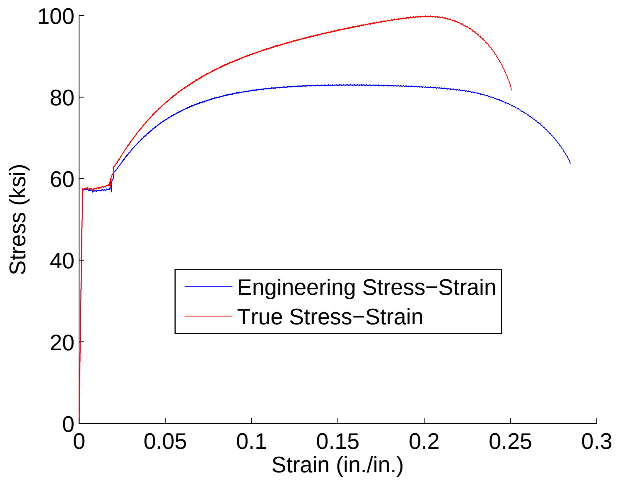


Figure B.14 Stress-strain relationship for Joist 13B

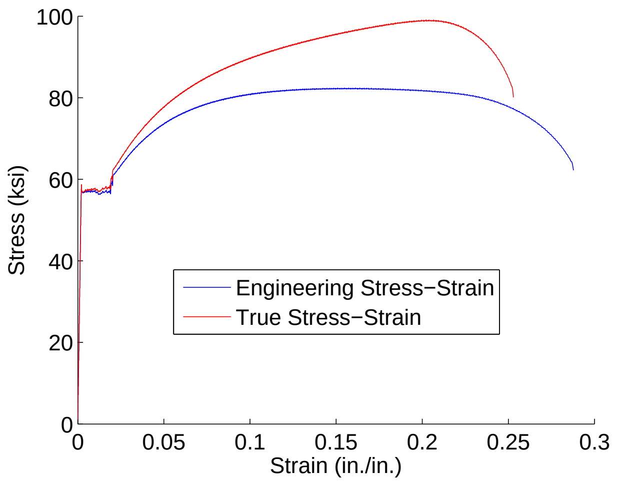


Figure B.15 Stress-strain relationship for Joist 14B

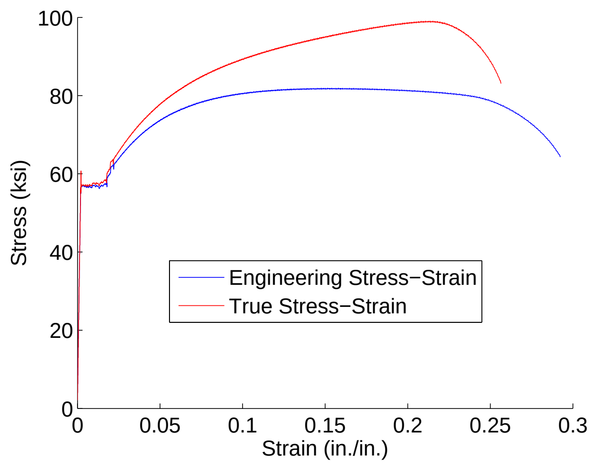


Figure B.16 Stress-strain relationship for Joist 15A

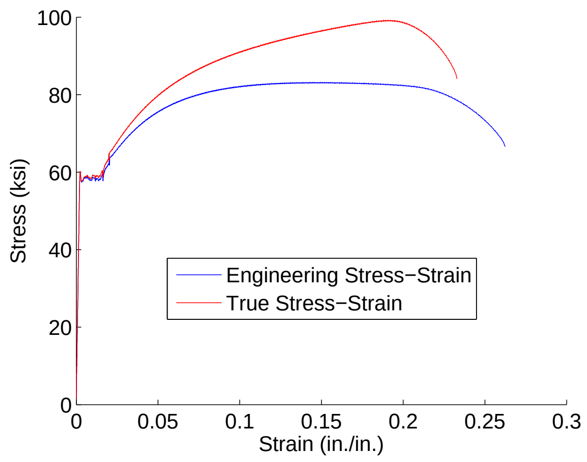


Figure B.17 Stress-strain relationship for Joist 16A

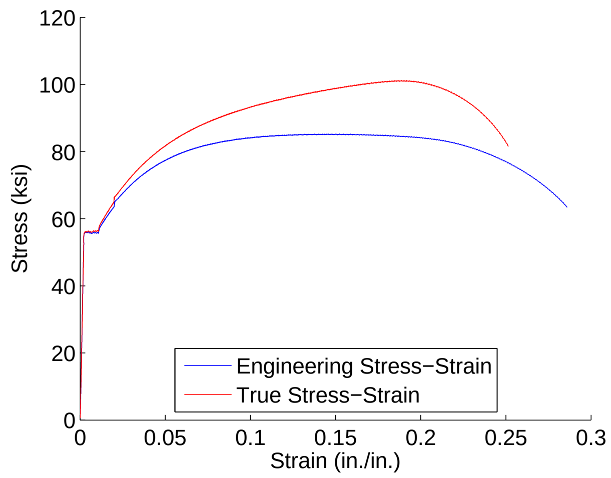


Figure B.18 Stress-strain relationship for Joist 18B

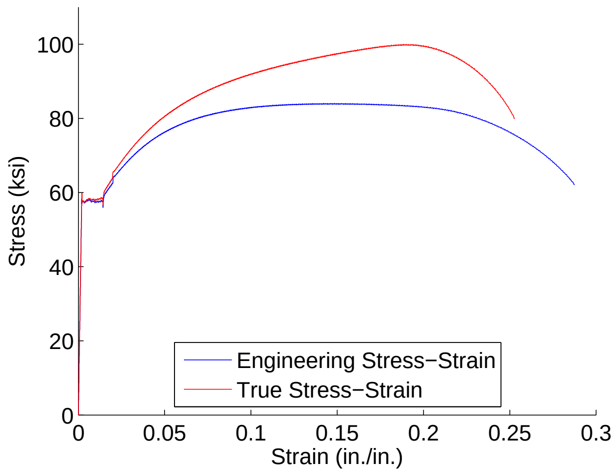


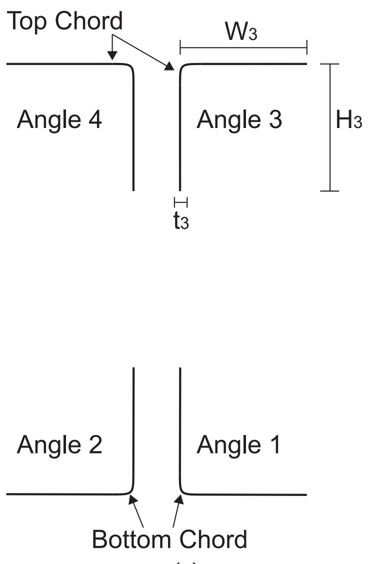
Figure B.19 Stress-strain relationship for Joist 25B

Appendix C Measurements

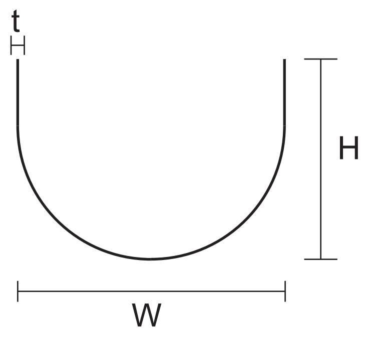
Measurements were taken prior to each laboratory test for analysis purposes as well as to enter the information into the computer models created. Measurements taken included cross-sectional measurements, width, height, and thickness of each joist member, web member location measurements, which included the location of each web member from the end of each joist, as well as imperfection and camber measurements, in which the initial out of straightness imperfection was measured; although the model used was simplified and two dimensional, it was thought that many measurements should be taken for future analysis, such as a finite element model.

The measurements were used to reach conclusions on effect of different variables, such as the correlation between imperfection and joist capacity (Fehr 2012; Fehr et al. 2012), as well as inputs to the structural analysis model, which used the measurements to calculate the moment of inertia in the lateral direction, cross-sectional area, and nodal coordinates. Furthermore, measurements taken during testing, such as deflection, and roof load, were used to calculate the roof stiffness (force/length/length) and loading for the model, see Chapter 4 for more information.

The cross-sectional measurements taken prior to testing can be seen in Figure C.1. It should be noted that there was no radius measurements taken for both chord and web members; however, the radius of the angles in the chord was negligible; while the radius of the web members was taken as one-half the width.



(a)



(b)

Figure C.1 Cross-sectional dimensions of joist members (a) chord dimensions (b) web member dimensions

Additionally initial out-of-straightness measurements were taken prior to each laboratory test, measurements were taken at quarter-points along each joist to determine the total imperfection. The imperfection was modeled as a half-sine wave with the model maximum imperfection location matching both the magnitude and location of that measured prior to testing.

The last measurements taken measured the location of each web member for placement in the joist; these measurements are valuable for future research if it is desired to model the full roof system, further discussion of web member placement can be found in Appendix F.

Appendix D Model displaced shape

The model displaced shapes in Chapter 5 showed that the difference between the actual behavior of the joists and the behavior as predicted from the MASTAN2 models. Many of the mode shapes are similar, with a similar number of half-waves in the displaced shape or share the location of largest displacement with one another.

The following plots show the additional deflected shape from the MASTAN2 second-order-elastic analysis; as mentioned previously lateral displacement was only measured at midspan for these tests, so plots that show the test deflected shape are not available.

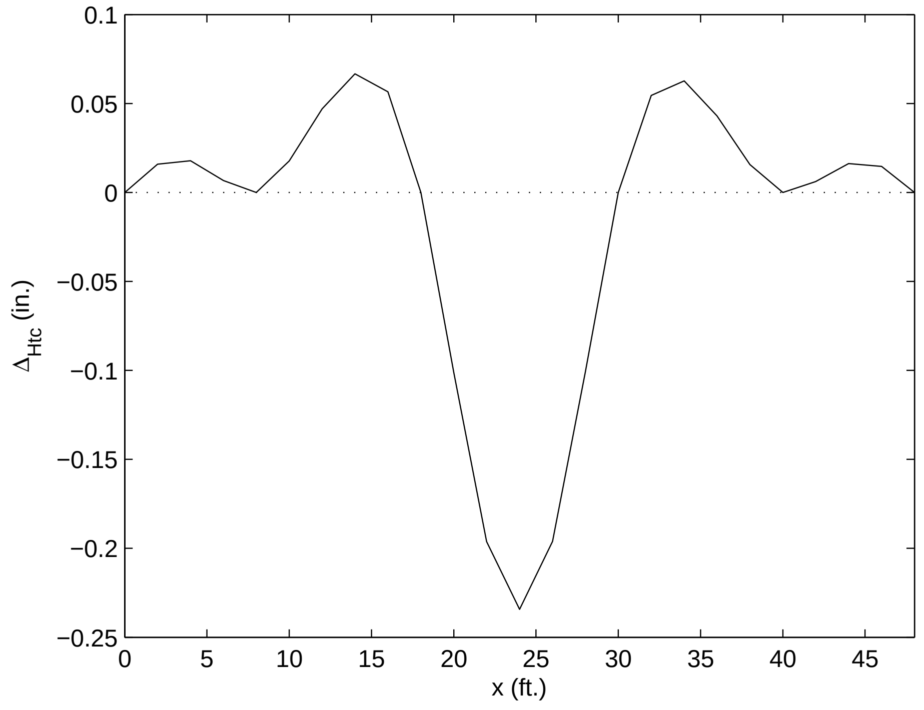


Figure D.1 Test 1 top chord lateral displacement from MASTAN2 model

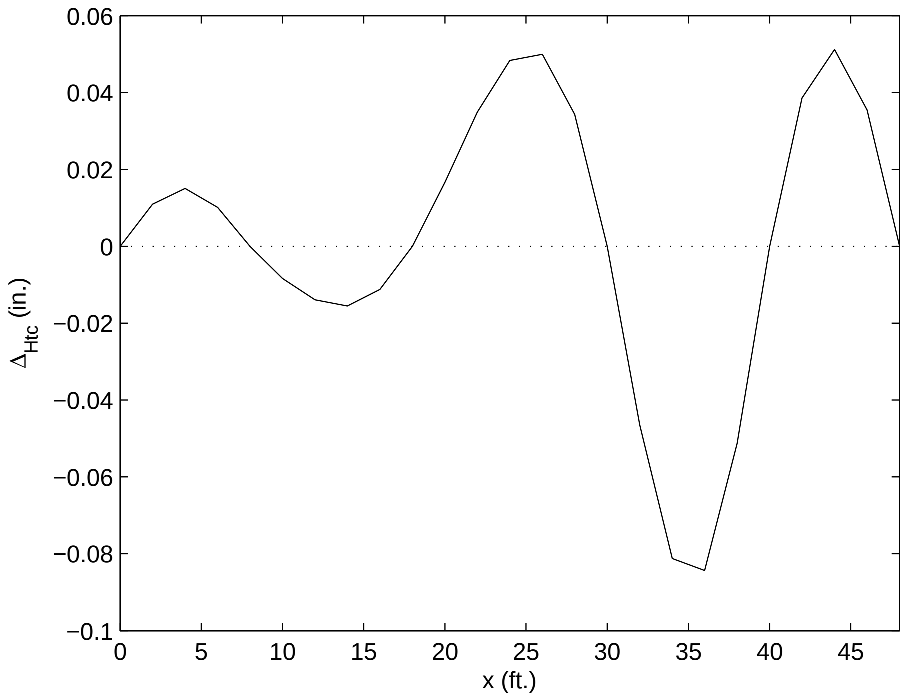


Figure D.2 Test 2 top chord lateral displacement from MASTAN2 model

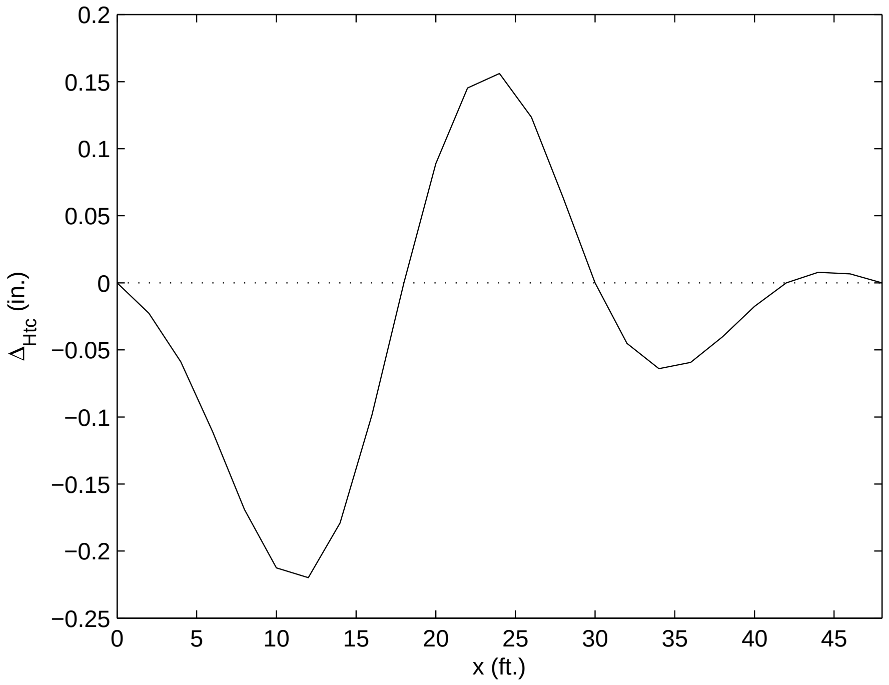


Figure D.3 Test 3 top chord lateral displacement from MASTAN2 model

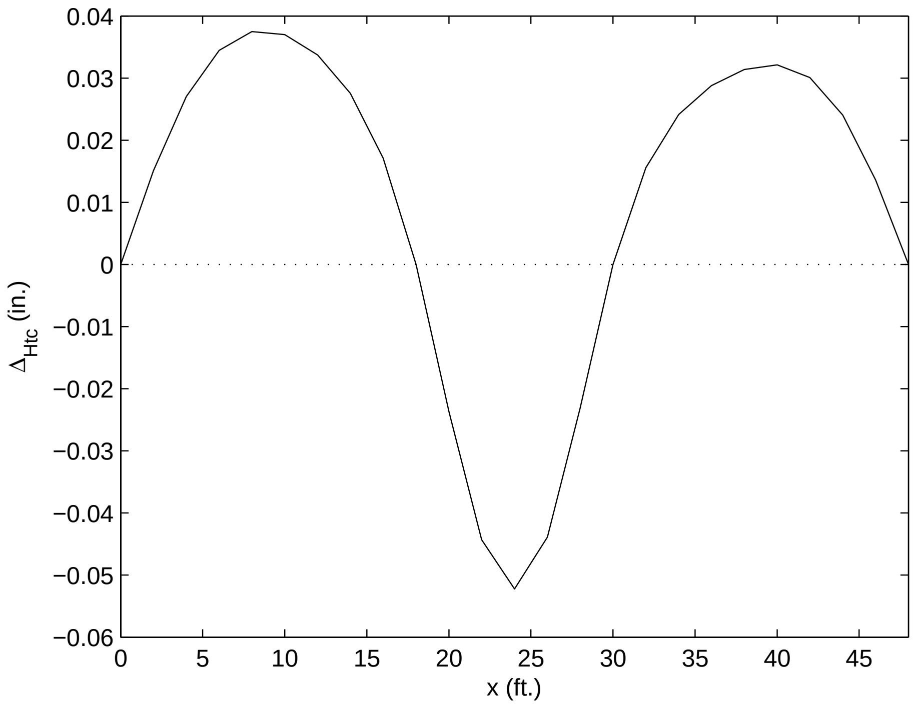


Figure D.4 Test 4 top chord lateral displacement from MASTAN2 model

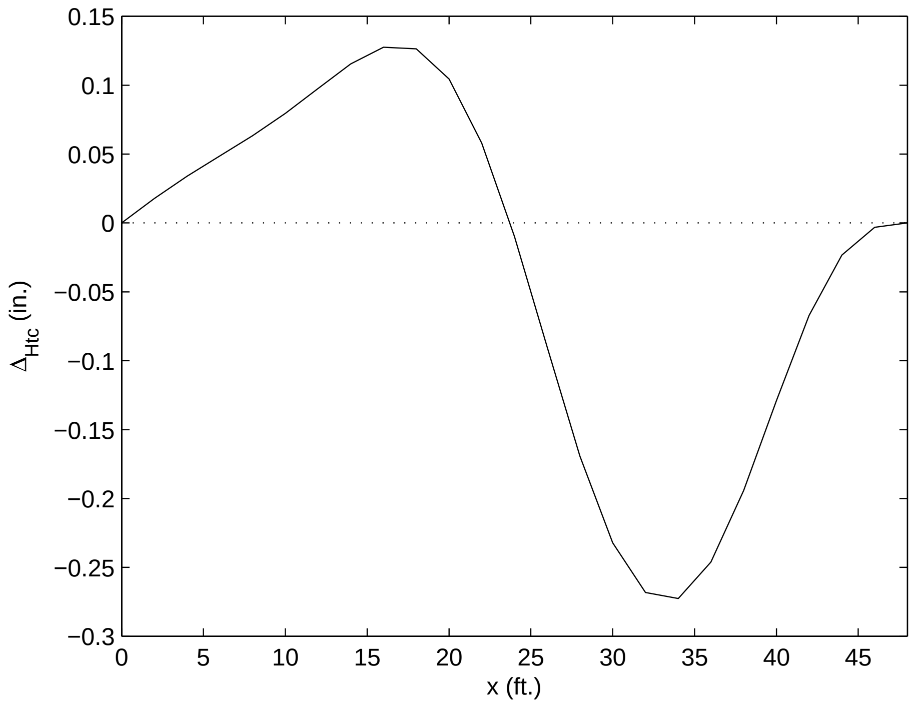


Figure D.5 Test 5 top chord lateral displacement from MASTAN2 model

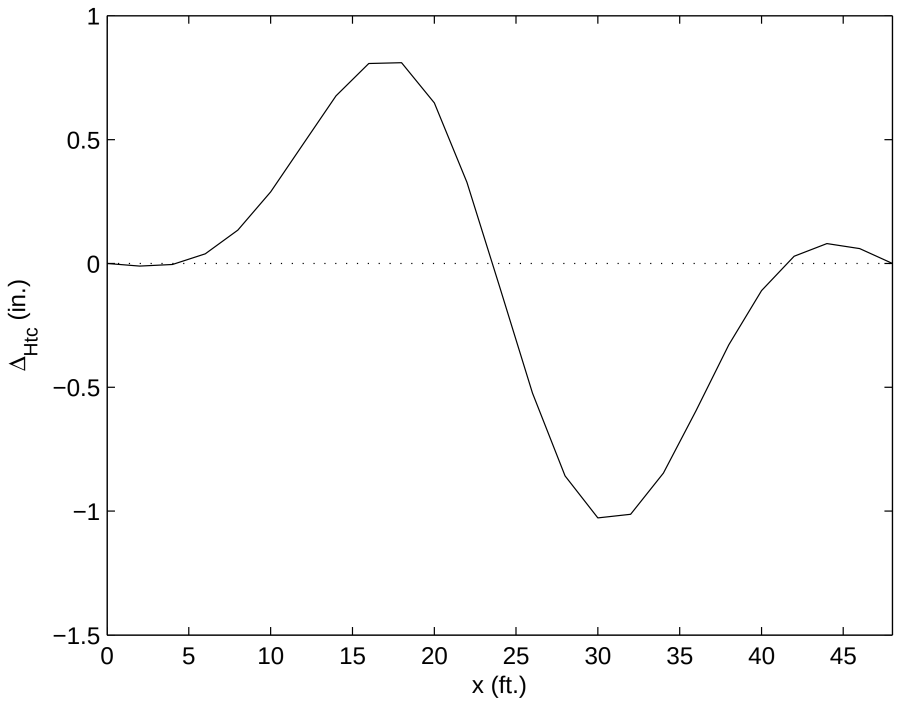


Figure D.6 Test 6 top chord lateral displacement from MASTAN2 model

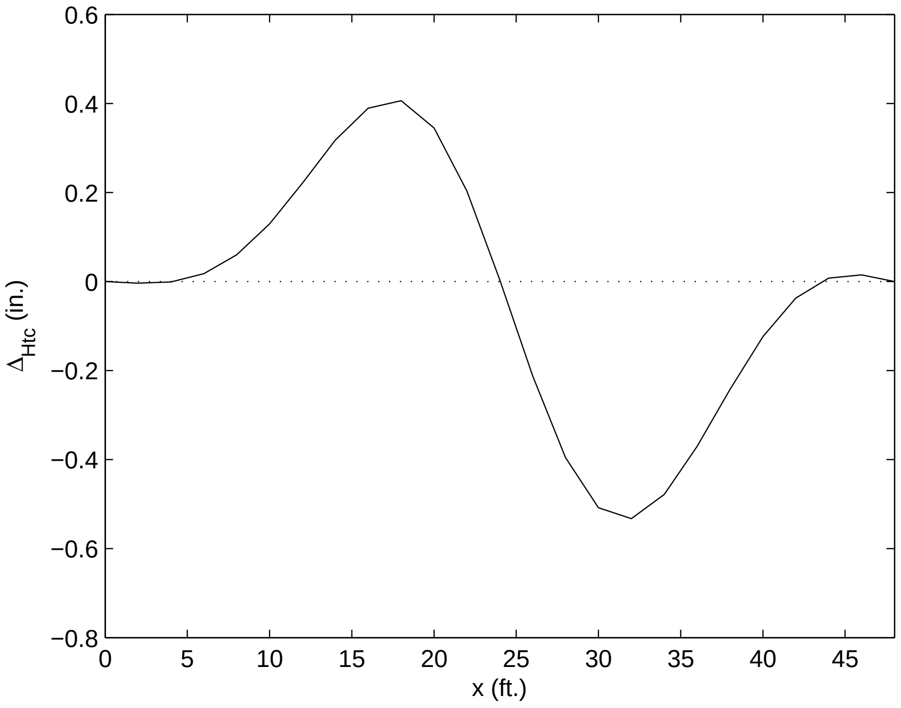


Figure D.7 Test 7 top chord lateral displacement from MASTAN2 model

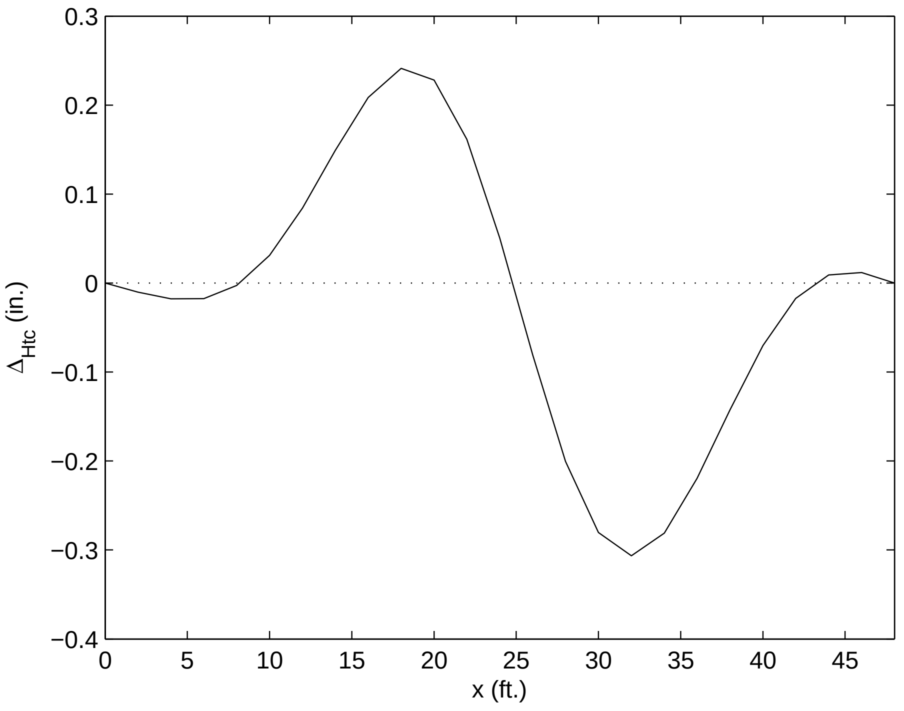


Figure D.8 Test 8 top chord lateral displacement from MASTAN2 model

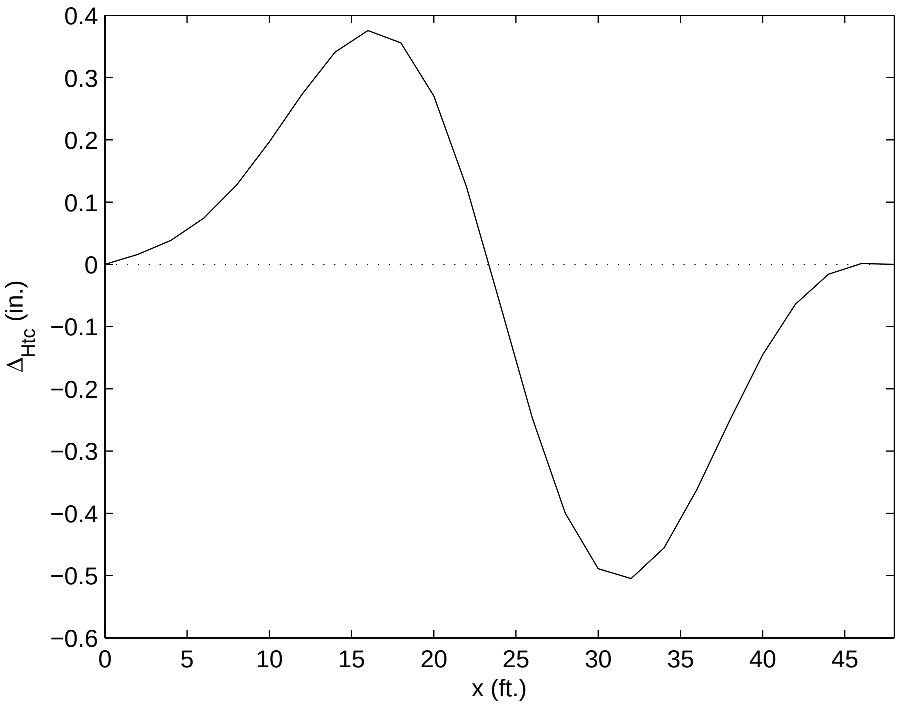


Figure D.9 Test 9 top chord lateral displacement from MASTAN2 model

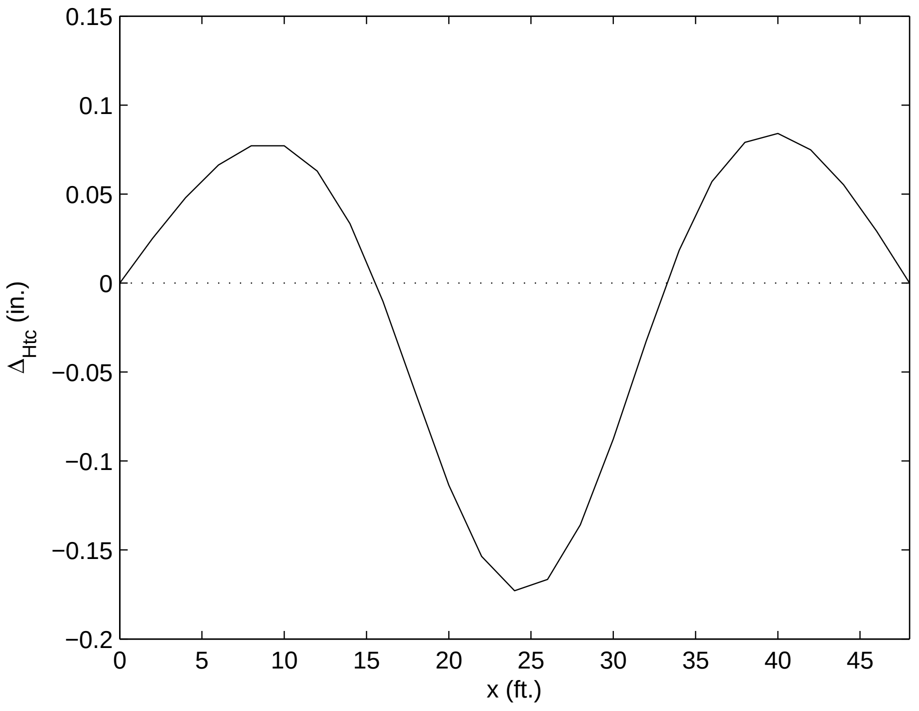


Figure D.10 Test 10 top chord lateral displacement from MASTAN2 model

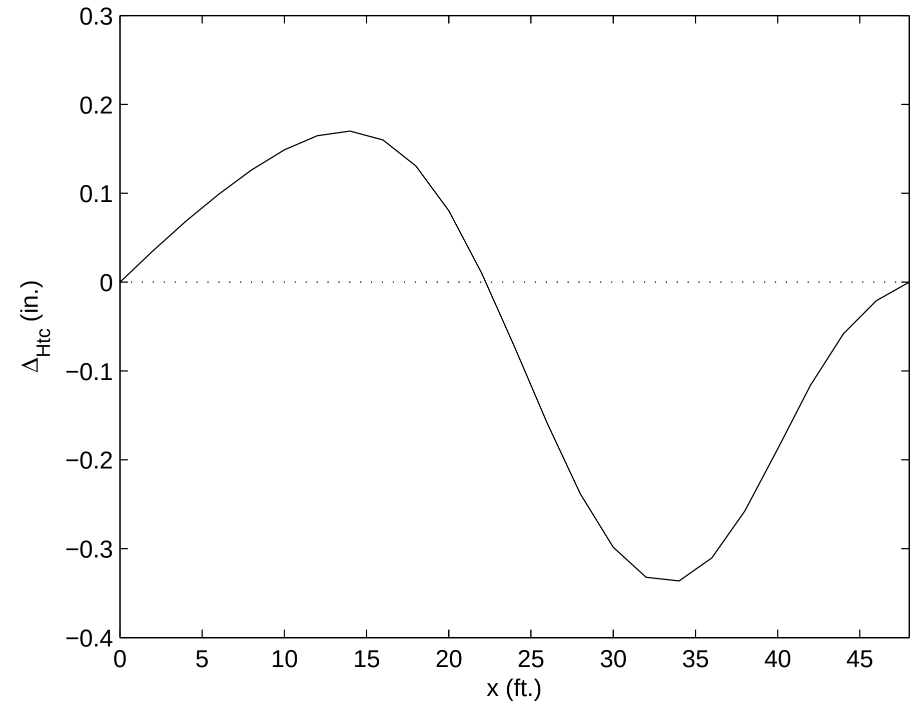


Figure D.11 Test 11 top chord lateral displacement from MASTAN2 model

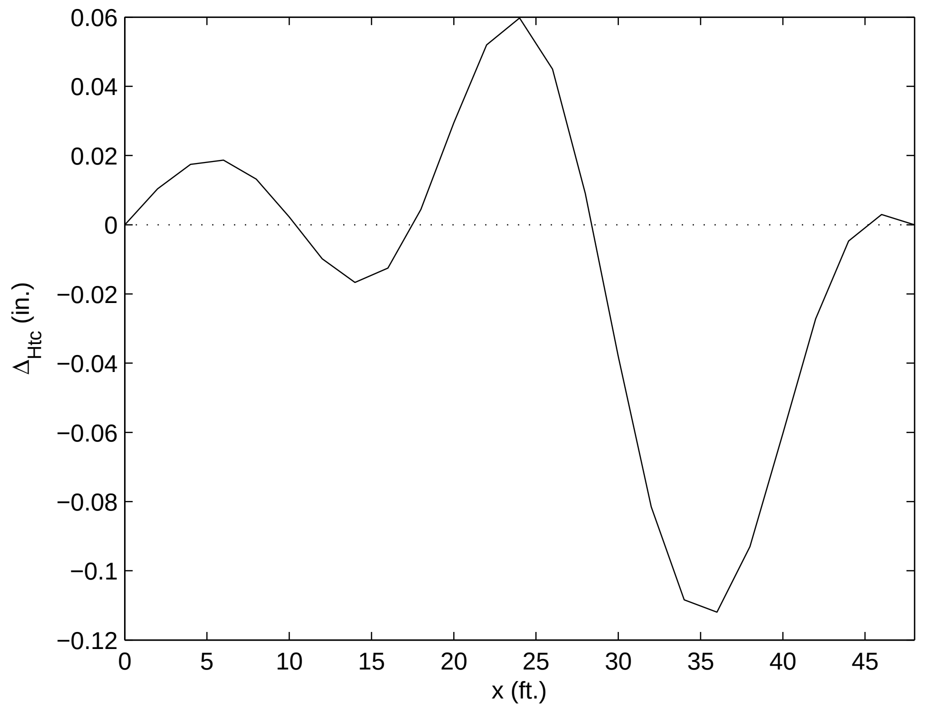


Figure D.12 Test 12 top chord lateral displacement from MASTAN2 model

Appendix E Input file code for the MASTAN2 models

This appendix references the Matlab code that was used to create input files for MASTAN2. This code was used for model generation of both the test models that were used to determine the roof stiffness as well as the models that were used to determine the critical elastic buckling load; both models used *ud_batch_model.m* and *clip_stiffness.m* with the only difference coming in that the test models included a value in the imperfection input while the models used to determine the critical elastic buckling load did not.

All of the simplified models for tests that included bridging were created by hand in MASTAN2. This was because the clip stiffness had already been determined from the full-scale top chord models and therefore only the critical elastic buckling load needed to be calculated.

Function: *ud_batch_model.m*

This function is a function that comes with MASTAN2 for use to generate models from Matlab code. It has been altered to take the applicable values created in *clip_stiffness.m* and write an input file for MASTAN2.

```
function ud_batch_model
%
%  This MASTAN2 utility allows the user to create all
%  or a portion of a MASTAN2 model by numerical input
%  (instead of graphical input).  The user should start by
%  making a copy of the ud_batch.m file.  The copied file
%  can then be edited using Matlab's edit command and
%  eventually executed by typing the copied filename
%  at the Matlab command prompt.  For example,
%  >>!copy ud_batch.m tower.m
%  >>edit tower.m
%  >>tower.m

%
%  Create space for all arrays (Do not modify).
%
node_info = []; elem_info = [];
sect_info = []; sect_name = [];
mat_info = []; mat_name = [];
```

```
nload_info = []; uniload_info = [];
fixity_info = []; settle_info = [];
%
%^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
%  Start of user defined information (Should be modified).
%
% model_title = [text string describing section]
model_title = 'Practice 1';
%
% Node information
%  Requires three arrays to be constructed, including
%  node_info, support_info, nload_info
%

%--------------CALL CLIP INFORMATION FILE----------------
%
%use information from clip_stiffness file
%[nodes, elements, boundary conditions, nodal loads, cross-sectional areas,
%moment of inertia (array), modulus (array), poisson's ratio (array),
%Fy(array), w(nels,2) each row represents an elemental distributed load,
[coord,ends, fixity, concen, sect_prop, mat_prop, Ee, Fyy,
Es]=clip_stiffness();
%ORIGINAL: [coord,ends,fixity, concen, sect_prop, mat_prop]=clip_stiffness();


%-------------------NODES-------------------
%Pull node information from the clip_stiffness file
node_info=coord;

% node_info = [...
%           0   0   0;  ... %Node 1's XYZ Coordinates
%           0   120 0;  ... %Node 2's XYZ Coordinates
%           240 120 0;  ... %Node 3's XYZ Coordinates
%           240 0   0;  ... %Node 4's XYZ Coordinates
%           ];
%

%-------------------BOUNDARY CONDITIONS-------------------
%Pull boundary conditions from clip_stiffness file
support_info=fixity;

% support_info = [Support condition of nodes' six d.o.f. (free=NaN, fixed=0,
val for prescribed displacement)]
%
% support_info =    [...
%               0 0 0 NaN NaN NaN;...           Node 1's support condition
%               NaN NaN NaN NaN NaN NaN;...     Node 2's support condition
%               NaN NaN NaN NaN NaN NaN;...     Node 3's support condition
%               0 0 0 0 0 0;...         Node 4's support condition
%               ];
%

%--------------------NODAL LOADS----------------------
%Pull nodal loads from clip_stiffness file
nload_info=concen;
```

```
% nload_info = [concentrated force or moment on nodes' six d.o.f.]
%
% nload_info =  [...
%               0 0 0 0 0 0;...         Node 1's forces/moments
%               0 -100 0 0 0 0;...      Node 2's forces/moments
%               0 -100 0 0 0 0;...      Node 3's forces/moments
%               0 0 0 0 0 0;...         Node 4's forces/moments
%               ];
%

%--------------------ELEMENTS--------------------
%Pull element information from clip_stiffness file
elem_info=ends;
    %add in 'inf' into elem info to match up with man-made model

% Element information
%  Requires six arrays to be constructed, including
%  elem_info, uniload_info, thermal_info, sect_info, sect_name, mat_info,
mat_name
%
%
% elem_info = [Node i, Node j, Section #, Material #, Beta Angle (rads), ...
%               Flexure condition Node i (rigid=0,pin=1,spring=2), Flexure
condition Node j (rigid=0,pin=1,spring=2), ...
%               Warping condition Node i (fixed=0,free=1,cont=2), Warping
condition Node j (fixed=0,free=1,cont=2), ...
%               Major-axis spring stiffness node i (val = 0 (pin) to inf
(rigid)),...
%               Minor-axis spring stiffness node i (val = 0 (pin) to inf
(rigid)),...
%               Major-axis spring stiffness node j (val = 0 (pin) to inf
(rigid)),...
%               Minor-axis spring stiffness node j (val = 0 (pin) to inf
(rigid)),...
%               Major-axis spring moment capacity Mpz node i (val = value to
inf (unlimited)),...
%               Minor-axis spring moment capacity Mpz node i (val = value to
inf (unlimited)),...
%               Major-axis spring moment capacity Mpz node j (val = value to
inf (unlimited)),...
%               Minor-axis spring moment capacity Mpz node j (val = value to
inf (unlimited))]
% elem_info = [...
%           1 2 1 2 0 0 0 0 0 inf inf inf inf inf inf inf inf;...   %Element
1's information
%           2 3 2 1 0 0 0 0 0 inf inf inf inf inf inf inf inf;...   %Element
2's information
%           4 3 1 2 0 0 0 0 0 inf inf inf inf inf inf inf inf;...   %Element
3's information
%           ];



%-----------------------UNIFORM LOADS---------------------
%Pull distributed load information from clip_stiffness file
%This input can be the diaphragm force distributed over the length of the
```

```
%member if we need it, leave it out for now (just make it zeros)
% uniload_info=
uniload_info=zeros(size(elem_info,1),3);

% uniload_info = [uniformly distributed loads along elements' local axes
(x,y,z)]
%
% uniload_info =    [...
%                0 0 0 ;...          Element 1's distributed load
%                0 -.25 0 ;...       Element 2's distributed load
%                0 0 0;...           Element 3's distributed load
%                ];
% %


%Leave out thermal info, if MASTAN2 gets mad just enter zeros for
%everything
thermal_info=zeros(size(elem_info,1),4);
%
% thermal_info = [thermal effects along elements' local axes, including
%                    thermal coef, dT(centroid), Tgradient(y'), Tgradient(z')]
%

% thermal_info =    [...
%                0 0 0 0;...         Element 1's temp. effects
%                0 0 0 0;...         Element 2's temp. effects
%                0 0 0 0;...         Element 3's temp. effects
%                ];
%
% Section information
%  Requires two arrays to be constructed, including
%  sect_info and sect_name
%

%---------------------------SECTION INFORMATION----------------------------
%Pull in section information from clip_stiffness
sect_info=sect_prop;
%     sizei=size(sect_prop);
%     difference=12-sizei(1,2);
%
%     for i=difference:1:sizei(1,2)
%         for j=1:sizei(1,1)%Number of materials
%             sect_info(j,i)='inf';
%         end
%     end

% sect_info = [Area, Moment of inertia Izz, Moment of inertia Iyy, Torsion
constant J,
%                Warping coefficient Cw, Plastic section modulus Zzz, Plastic
section modulus Zyy, ...
%                Shear area Ayy, Shear area Azz YldSurf(1) YldSurf(2)
YldSurf(3)]
% sect_info = [...
%            4.44 48 3.41 0.137 51.8 13.6 2.67 Inf Inf 1 1 1; ...    %Section
1's properties
%           22.8 658 519 921 0 111 100 14 12 1 1 1;...              %Section
2's properties
%           ];
%
% sect_name = [brief text string describing section]
%
sect_name = {...
            'TOP CHORD';...             Section 1's name
            'SPRING';...        Section 2's name
            };
%

%----------------------MATERIAL INFORMATION-----------------------
%
%IMPORTANT--YOU MUST INPUT THE MATERIAL INFORMATION MANUALLY HERE, YOU
%CANNOT DEPEND ON clip_stiffness.m TO DO IT FOR YOU, THE PROGRAM WILL NOT
%WORK CORRECTLY IF YOU DO THIS
%
%Import the material information from clip_stiffness
% mat_info=mat_prop;
mat_info=[29500 0.3 50 0;
          10 0.3 50 0];
% mat_info=[Ee 0.3 Fyy 0;
%           Es 0.3 Fyy 0];

%  Requires two arrays to be constructed, including
%  mat_info and mat_name
%
% mat_info = [Modulus of elasticity E, Poisson Ratio v, Yield strength Fy,
Weight density Wt. Dens.]
%
% mat_info = [...
%           29000 0.3 50 0;...  %Material 1's properties
%           10500 0.28 35 0;...             %Material 2's properties
%           ];
%
% mat_name = [Brief text string describing material]
%
mat_name = {...
           'TOP CHORD';...              Material 1's name
           'SPRING';...                 Material 2's name
           };
%
% End of user defined information
%
%%
%vvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvv
%
%
%  Clean-up/pad arrays and save function (Do not modify).
%
webdir =
el_webdir(size(elem_info,1),elem_info(:,1:2),elem_info(:,5),node_info,node_in
fo,zeros(size(node_info,1),6));
%
```

```
elem_info = [   elem_info(:,1:5) ones(size(elem_info,1),2) webdir
ones(size(elem_info,1),1) ...
                elem_info(:,6:7) ones(size(elem_info,1),2) ...
                elem_info(:,8:9) ones(size(elem_info,1),2) ...
                elem_info(:,10:17)];
nload_info = [nload_info NaN(size(nload_info,1),6)];
fixity_info = support_info;
fixity_info(find(~isnan(support_info))) = 0;
fixity_info = [fixity_info NaN(size(fixity_info,1),6)];
settle_info = support_info;
settle_info(find(~isnan(settle_info)& settle_info==0)) = NaN;
settle_info = [settle_info NaN(size(settle_info,1),6)];
uniload_info = [uniload_info zeros(size(uniload_info,1),3)
NaN(size(uniload_info,1),6) thermal_info];

analysis_info=[]; periods_info=[]; first_el_settings=[]; sec_el_settings=[];
first_inel_settings=[]; sec_inel_settings=[]; ebuck_settings=[];
ibuck_settings=[];
period_settings=[]; deflect_settings=[]; axial_settings=[];
sheary_settings=[];
shearz_settings=[]; momx_settings=[]; momy_settings=[]; momz_settings=[];
bimom_settings = [];
%
filt = '*.mat';
[newmatfile, newpath, filterindex] = uiputfile(filt, 'Save Model As');
if filterindex
    file_str = [newpath newmatfile];
    save(file_str,'model_title','node_info','elem_info', 'sect_info',
'sect_name', ...

'mat_info','mat_name','fixity_info','nload_info','uniload_info','settle_info'
, ...

'analysis_info','periods_info','first_el_settings','sec_el_settings','first_i
nel_settings', ...

'sec_inel_settings','ebuck_settings','ibuck_settings','period_settings', ...
        'deflect_settings','axial_settings','sheary_settings', ...

'shearz_settings','momx_settings','momy_settings','momz_settings','bimom_sett
ings','-v6');
    disp('Batch model construction completed successfully');
else
    disp('Batch model construction cancelled');
end
```

Function: *clip_stiffness.m*

```
function [coord,ends, fixity, concen, sect_prop, mat_prop, Ee, Fyy, Es] =
clip_stiffness()
%ORIGINAL: function [coord,ends,fixity, concen, sect_prop, mat_prop] =
clip_stiffness()

%The following iterates clip stiffness until the deflection of the joist is
%matched
```

```
% close all
% clear all

%--------------------INPUTS------------ all units should be kips and inches
%Test properties
W3=1.504; %Height of the cross-section of the chord (in)
H3=1.505; %Width of the cross-section of the chord (in)
t3=0.149; %Thickness of the top chord (in)
W4=1.504; %Height of the cross-section of the chord (in)
H4=1.501; %Width of the cross-section of the chord (in)
t4=0.13785; %Thickness of the top chord (in)

pressure=24.15*1/1000*(1/12)^2; %Pressure on the joists (ksi)

delta_max_location=0.5;%Enter the location of the maximum measured
displacement in 1/4 points (0.25, 0.5, 0.75)
zo=0;%The initial imperfection (sweep) at the center of the joist
%default=2.4

s=1.125; %Spacing between the two angles in the top chord (in)
Ee=29500; %The modulus of the top chord (ksi) -- YOU MUST ENTER THIS UNDER
ud_batch_model.m NOT HERE!
% Aa=0.3922; %The area of the top chord (in^2)
Fyy=50; %The yield strength of the top chord (ksi)
% Ii=0.0843; %Moment of inertia of the TC (in^4)

yb=(((t3/2)*(W3*t3)+(t3+(H3-t3)/2)*(H3-t3)*t3)+((t4/2)*(W4*t4)+(t4+(H4-
t4)/2)*(H4-t4)*t4))/((W3*t3+(H3-t3)/2*t3)+(W4*t4+(H4-t4)/2*t4))

%----------OTHER STUFF THAT STAYS PRETTY CONSTANT---------
width=5.5*12; %Tributary width of each joist (in.)
wpanel=24; %The width of the panel (in.)
L=48*12; %Length of the joist (in.)
Lb=48*12; %Unbraced length of the joist (dist. between braces) (in.)
LP=2*12; %The spacing of the clips (length of the panel) (springs)
Lr=16*12; %The distance between the vertical reactions (inches)
d=24; %Depth of the joist (in.)
ybar=12; %neutral axis location (from the top of the joist)


zm=4;%The maximum deflection of the joist laterally (inches)
zmax=zm-zo; %The total deflection (movement) of the TC at failure

%Top chord properties


cw=0.23272;%Torsional warping constant (from CUFSM output)

F1=0.15;%Vertical roller force 1 (kips)
F2=0.15;%Vertical roller force 2 (kips)
    %Assume a linear relationship between the two horizontal reactions at
    %these locations
```

```
%--------------------SPRING STIFFNESS INFORMATION-------------------
%MASTAN does not directly use springs so we need to trick it by inputting
%an element and giving it the properties of the spring. Since the clips are
%acting as vertical springs (they only carry axial load) the MASTAN inputs
%that control this are area, modulus of elasiticity, and length. To keep
%things simple we will have a constant length (Ls=10, this is controlled by
%the nodal coordinates), and an equivalent modulus of elasicity (Es=10),
%since axial stiffness is AE/L, this should work out to have A=clip
%stiffness.

%New 10/4/2011 -- Change the clip stiffness since we are getting an
%instability in the analysis. Try to use a larger modulus, smaller area,
%and possibly change the length (we can use a length of 1 since all of our
%displacements are less than an inch)
As=1.0; %Clip stiffness is controlled by AE, make sure that the result of
AE/L is equal to the clip stiffness
Es=1;%THIS DOES NOT MATTER! YOU MUST ENTER MATERIAL INFORMATION UNDER
ud_batch_model.m
Lspring=10; %spring length, this should be the same as the spring modulus so
that stiffness is controlled by the "area" of the spring



%-----------------------ANALYSIS INFORMATION-------------------
%       anatype          ==  flag to indicate which type of analysis is
requested
%                              anatype = 1  First-Order Elastic
%                              anatype = 2  Second-Order Elastic
%                              anatype = 3  First-Order Inelastic
%                              anatype = 4  Second-Order Inelastic
%                              anatype = 5  Elastic Buckling (Eigenvalue)
%                              anatype = 6  Inelastic Buckling (Eigenvalue)
% anatype=1;


%**************************************************************************
%**************************************************************************
%Look at the top chord like a column with an imperfection. Using the spring
%stiffness guessed above iterate using the direct stiffness method until
%the deflection converges to the actual measured deflection.
%
%Assumpions:
%   * The imperfection and deflected shape occur in a half sine wave
%   * Model the deflected shape as moments at the location of the clips
%
% thresh=0.1;%The threshold of how close kclip must be before the loop is
terminated

%-----Initial basic calculations-----

    %Calculate the section properties
        %Moment of inertia
        %For this calculation the centroid is always in the center of the
        %two angles that make up the top chord
        Aa=t3*(W3+(H3-t3))+t4*(W4+(H4-t4)); %Total area (both angles) of the
top chord
```

```
        Ii=(1/12*t3*W3^3+(t3*W3)*(s/2+W3/2)^2+1/12*(H3-t3)*(t3^3)+t3*(H3-
t3)*(s/2+t3/2)^2)+(1/12*t4*W4^3+(t4*W4)*(s/2+W4/2)^2+1/12*(H4-
t4)*(t4^3)+t4*(H4-t4)*(s/2+t4/2)^2); %Moment of inertia of the top chord
(bending about the z-axis)
         %Ii=2*(1/12*t*b^3+(t*b)*(s/2+b/2)^2+1/12*(h-t)*(t^3)+t*(h-
t)*(s+t/2)^2); %Moment of inertia of the top chord (bending about the z-axis)
        r=sqrt(Ii/Aa);%Radius of gyration of the top chord
        J=1/3*W3*t3^3+1/3*(H3-t3)*t3^3+1/3*W4*t4^3+1/3*(H4-t4)*t4^3; %J for
the top chord

    %Unbraced lengths
        %For the full joist:
        k=1.0;  %Effective length factor (joist end conditions)
        L=L*k; %Joist effective length
        %For braced distances:
        if Lb<L
            kb=0.5;%Effective length factor of the unbraced length
        else
            kb=1;%Effective length factor of the unbraced length (1 if no
braces)
        end
            Lb=Lb*kb; %Effective unbraced length
    %Determine the number of clips on the top chord in the unbraced length
    %region
        numclips=Lb/LP-1; %The number of clips between braces
        numclips=round(numclips);



%---------------FORCES-----------------
%Determine the top chord compressive force P
wp=pressure*width;
M=wp*L^2/2;
P=M/d;
%Determine the equivalent distributed load on the panel (from the panel
%reactions (vertical rollers))
Pbrace=(F1+F2)/2;%The average of the brace forces
ww=2*Pbrace/L;



%Make an array of the displacements at the clip locations
for j=1:numclips
    x(j,1)=(j/(numclips+1))*Lb+(L/2-Lb/2);
    delta(j,1)=zmax*sin(pi*x(j,1)/L);
    sweep(j,1)=zo*sin(pi*x(j,1)/L);
end

ticker=2;
kclip=0.000001; %clip stiffness (k/in)


%*************************************************************************
%************************LOOP SHOULD START HERE***************************
%*************************************************************************
```

```
%---------------------------------NODES------------------------------


%Determine node locations in MASTAN
%For the beam-element (the TC itself)
nnodes=numclips+2;
for i=1:nnodes-1
% for i=1:2
    coord(i,1)=(i-1)*wpanel; %x-coordinate
    if delta_max_location==0.25
        %if the maximum imperfection is at the 1/4 point of the joist
        if coord(i,1)<0.25*Lb
            coord(i,2)=-zo*sin(pi/2*coord(i,1)/(1/4*Lb));
        else
            coord(i,2)=-zo*(sin(pi/2)*(Lb-coord(i,1))/(3/4*Lb));
        end
    elseif delta_max_location==0.75
        %if the maximum imperfection is at the 3/4 point of the joist
        if coord(i,1)<0.75*Lb
            coord(i,2)=-zo*sin(pi/2*coord(i,1)/(3/4*Lb));
        else
            coord(i,2)=-zo*sin(pi/2*(Lb-coord(i,1))/(1/4*Lb));
        end
    else
        %if the maximum imperfection is at the 1/2 point of the joist
        coord(i,2)=-zo*sin(pi*coord(i,1)/Lb); %y-coordinate (including
imperfection)
    end
end

%Put a single node at the center of the structure. This node will be used
%as a horizontal reaction (no lateral displacement will occur here) so that
%an axial load (P) may be applied (if we pin an end and try to apply an
%axial load to that side all of the horizontal load will flow into the pin)
new=find(coord(:,1)>=Lb/2);%Determine the nodes that are greater than 1/2 the
distance of the unbraced length (we need to add in a node at mid-span)
%*******UNCOMMENT IF WE NEED CENTRAL NODE******
% save=coord;
% for i=1:size(new,1)
%     coord(new(i,1)+1,:)=save(new(i,1),:); %Move all of the coordinates down
one spot to make room for the central node
% end

%Add one more node at the end for the roller
next=size(coord,1)+1;
coord(next,1)=Lb; %x-coordinate
coord(next,2)=0;%y-coordinate

%*********CHANGE 10/06 -- TO ACCOUNT FOR SYMMETRY OF NODES
% %Make a node at the center of the joist to monitor deflection
     minnew=min(new);%Determine the lowest value in new to know where the
central node is supposed to go
%                 %'new' is an array of nodes with an x-coordinate greater
%                 %than 1/2 span of the joist
%
%     nn=size(coord,1);
%     chord_length=coord(nn,1);
%
%     coord(minnew,1)=1/2*chord_length;
%     coord(minnew,2)=-zo;

%For the springs (clips)
%We need to include the springs as a constant length (all spring lengths
%equal) to do this move each one down the same distance it is from the node
%above it
%
nnodes=nnodes+numclips;
counter=1;
for i=size(coord,1)+1:1:nnodes
% for i=size(coord,1)+1
%     if 1+counter<=minnew;
        coord(i,1)=counter*wpanel;%x-coordinate
        coord(i,2)=coord(1+counter,2)-Lspring;%y-coordinate
%     elseif 1+counter>minnew;
%         coord(i-1,1)=(counter-1)*wpanel;%x-coordinate
%         coord(i-1,2)=coord(1+counter,2)-Lspring;%y-coordinate
%     end
    counter=counter+1;
end

%Check nodal coordinates
% figure(1)
% plot(coord(:,1),coord(:,2),'k.');

coord(:,3)=0;%2D analysis so the z-coordinate = 0




%-----------------------------ELEMENTS-----------------------------

% ends=zeros(47,17);
nele=numclips+1;%The number of elements that make up the joist
%Create the elements for the top chord of the joist
for i=1:nele
% for i=1
    ends(i,1)=i;%node at the i-end
    ends(i,2)=i+1; %node at the j-end
    ends(i,3:4)=1; %Section number (col 3) and material number (col 4)
    ends(i,5)=0; %member angle
    ends(i,6:7)=0; %0 for rigid connection, 1 for pinned connection, 3 for
partially restrained at the i-end of the element
                   %rigid connection at both the i (column 3) and the j
(column 4) end of the element
    ends(i,8:9)=0; %warping free
     ends(i,10:17)=inf; %use spring stiffness at the end of each element
(this is how a partial restraint is represented)
end
```

```
%Change the elements so that the node in the center of the top chord is
%included in the element list



%Create elements for the springs
    %change this to look like it does above (using the same columns)
nele=nele+numclips; %number of elements including the springs
nodemax=numclips+4;
counter=2;%Start with counter=2 b/c this is the first node that uses a spring
for i=size(ends,1)+1:1:nele
% for i=size(ends,1)+1
%     if counter<minnew
        ends(i,1)=nodemax+counter-3;
        ends(i,2)=counter;
        %We want to use a pin in each spring where it connects to the top
        %chord, this is to not allow the spring to hold moment (it is
        %strictly an axial member)
        ends(i,3:4)=2;%Section number (col 3) and material number (col 4)
        ends(i,5)=0; %member angle
        ends(i,6)=0;%0 for rigid connection, 1 for pinned connection, 3 for
partially restrained at the i-end of the element
                    %We want a rigid connection at the base (i end) of each
spring element
        ends(i,7)=0;%We want a rigid connection at the top (j end) of each
spring element
        ends(i,8:9)=0; %warping free
         ends(i,10:17)=inf; %use spring stiffness at the end of each element
(this is how a partial restraint is represented)
%     elseif counter>=minnew
%         next=size(ends,1);
%         ends(next+1,1)=nodemax+counter-2;%The spring node stays the same
%         ends(next+1,2)=counter;%We need to skip over the middle node since
it does not have a spring attached to it
%         ends(next+1,3:4)=2;%Section number (col 3) and material number (col
4)
%         ends(next+1,5)=0;%member angle
%         ends(next+1,6)=0;%0 for rigid connection, 1 for pinned connection,
3 for partially restrained at the i-end of the element
%                     %We want a rigid connection at the base (i end) of each
spring element
%         ends(next+1,7)=0;%We want a pinned connection at the top (j end) of
each spring element
%         ends(next+1,8:9)=0; %warping free
%          ends(next+1,10:17)=inf; %use spring stiffness at the end of each
element (this is how a partial restraint is represented)
%     end
    counter=counter+1;
end





%-------------------------BOUNDARY CONDITIONS-----------------------------
```

```
%Apply boundary conditions to the appropriate nodes
%CHANGE 10/7 -- ORIGINAL: fixity=NaN(size(coord,1),6)
fixity=NaN(size(coord,1),6);
for i=1:size(coord,1);
    if i==1
%         fixity(i,1)=0;%fixes the x-displacement of the first node (pin)
        fixity(i,2)=0;%fixes the y-displacement of the first node (pin)
%         fixity(i,3)=0;%fixes the z-displacement of the first node
%         (unnecessary)
    elseif i==numclips+2
%     elseif i==2
        fixity(i,2)=0;%fixes the y-displacement of the first node (pin)
    elseif i==minnew %Fix the x-dirctional displacement at the mid-span node
        fixity(i,1)=0;%Fixes the x-displacement at mid-span
    elseif i>numclips+2
        %Let's try to only have the springs be fixed in the y-direction
        %(rollers)
%         fixity(i,1)=0;%fixes the x-displacement of the spring nodes (pin)
        fixity(i,2)=0;%fixes the y-displacement of the spring nodes (pin)
    end
end





%---------------------CONCENTRATED LOADS-----------------------

%Apply concentrated moments at node locations
%These moments are due to second order effects--They ONLY take into account
%the moments before failure! (don't include the increase in deflection as
%the load is increased)

%CHANGE!!!! 9/16 -- We can just run a second order-analysis. We do NOT need
%to include these moments; however, the axial force increases as we move
%towards the center of the joist. Therefore we need to increase the load at
%each clip location

%Make an array of zeros and replace the zeros with the applied loads
concen=zeros(size(coord,1),6);

xloc(1)=(L/2-Lb/2); %Beginning of the brace location
xloc(2)=(L/2+Lb/2); %End of the brace location

pmax=wp*(L/2)^2/(2*d);

%Write code for an axial force that increases as we move towards the center
%of the top chord
% counter=1;
for i=1:numclips+2
% for i=1:2
    xcoord=coord(i,1);%The x-location of the node with the load being applied
to it
        concen(i,1)=(4*pmax*xcoord)/(L)*(1-xcoord/L);%axial load for those
nodes on the first 1/2 of the joist
    counter=counter+1;
```

```
end

% counter=1;
% for i=1:numclips+2
% % for i=1:2
%     xcoord=coord(i,1);%The x-location of the node with the load being
applied to it
%     if counter < numclips/2+2
%         concen(i,1)=(wp*xcoord^2)/(2*d);%axial load for those nodes on the
first 1/2 of the joist
%     elseif i>minnew
%         concen(i,1)=-(wp*(Lb-xcoord)^2)/(2*d);%axial load for those nodes
on the second 1/2 of the joist
%     end
%     counter=counter+1;
% end

% figure(1)
% plot(coord(:,1),concen(:,1))

%apply loads so that the TOTAL axial load increases parabolically towards
%the center
save=concen;%save the loads in concen before altering them to apply the
actual loads
new_concen=zeros(size(coord,1),6);
for i=1:numclips+2;
    if i==1
        new_concen(i,1)=concen(i,1);
    elseif i==size(concen,1)
        new_concen(i,1)=concen(i,1);
    else
        new_concen(i,1)=concen(i,1)-save(i-1,1);
    end
end

concen=new_concen;%change concen to the new loads
% figure(2)
% plot(coord(:,1),concen(:,1),'.k')

%Make a plot to show how the axial force is varying over the TC length
% Pmax=(wp*(Lb/2)^2)/(2*d);%The maximum axial force in the top chord
% xx=0:0.1:L; %The x-length runs from 0-48ft
% yy=Pmax*(sin(pi*xx/(L)));
% figure(1)
% plot(xx,yy)
% title('Top Chord Axial Load Variation')
% xlabel('Top Chord Length (ft.)')
% ylabel('Axial load (kips)')




% counter=1;
% for i=1:numclips+2
%     if i==1
%         concen(i,3)=-P*zo*sin(pi*xloc(1)/L);
%     elseif i==numclips+2
%         concen(i,3)=P*zo*sin(pi*xloc(2)/L);
%     else
%         if counter<numclips/2
%             concen(i,3)=-P*sweep(counter,1);%moments for the springs on the
first 1/2 of the joist
%             counter=counter+1;
%         else
%             concen(i,3)=P*sweep(counter,1);%moments for the springs on the
second 1/2 of the joist
%             counter=counter+1;
%         end
%     end
% end




%--------------------------SECTIONS AND MATERIALS-----------------------



%Define both sections as well as materials on an element-to-element basis
%the top chord members always are defined first and then the spring (clip)
%members are defined

%Make section properties an array of zeros and then fill it in with the
%appropriate values
% sect_prop=NaN(2,12);
% sect_prop=zeros(2,5);

%Define the section properties in terms of the number of sections (2) that
%we are using (we have two sections because we have two members (top chord
%and springs) that we are using)
    sect_prop(1,1)=Aa;%Area of the top chord as defined in the input
    sect_prop(1,2)=Ii;%The moment of inertia as defined in the input
    sect_prop(1,3)=Ii;%Iyy (doen't matter for 2D beam)
    sect_prop(1,4)=J;%Torsion constant J for the top chord
    sect_prop(1,5)=cw;%Torsional warping constant (from CUFSM output)
    sect_prop(1,6:7)=Inf;%Plastic section modulus (Zzz, and Zyy respectively)
    sect_prop(1,8:9)=Inf; %Shear area for the z and y axes respectively
    sect_prop(1,10:12)=1;%Shear area?
%     sect_prop(1,4:9)=5;%A bunch of things that don't apply to a 2D analysis
    %now the springs
    sect_prop(2,1)=As;%The clip stiffness is controlled by this parameter
IMPORTANT!!!
    sect_prop(2,2)=0.9999;%The moment of inertia does not matter for the
clips, stiffness is controlled by AE/L
    sect_prop(2,3)=1;%Iyy (doen't matter for 2D beam)
    sect_prop(2,4:5)=0;%Torsional coefficients J and Cw respectively
    sect_prop(2,6:9)=Inf;%A bunch of things that don't apply to a 2D analysis
    sect_prop(2,10:12)=1;%Shear area?

    mat_prop=[Ee 0.3 Fyy 1;
              Es 0.3 Fyy 1];
%     mat_prop(1,1)=Ee;%Top chord modulus of elasticity
%     mat_prop(1,2)=0.3;%Poisson's ratio of steel
%     mat_prop(1,3)=Fyy;%Yield strength
%     mat_prop(1,4)=1;%Weight density (it is not acting down so neglect this)
%     %now the springs
%     mat_prop(2,1)=Es;%Use the 'modulus' of the spring as defined in the
input, this should be the same as the length of each spring to allow for the
spring stiffness to be controlled by the area of the spring
%     mat_prop(2,2)=0.3;%Poisson's ratio
%     mat_prop(2,3)=Fyy;%Yield strength
%     mat_prop(2,4)=1;%Weight density (it is not acting down so neglect this)



% %Define the spring members
% for i=numclips+2:1:nele
%     A(i)=As;%The clip stiffness is controlled by this parameter
IMPORTANT!!!
%     Izz(i)=1; %The moment of inertia does not matter for the clips,
stiffness is controlled by AE/L
%     E(i)=Es; %Use the 'modulus' of the spring as defined in the input, this
should be the same as the length of each spring to allow for the spring
stiffness to be controlled by the area of the spring
%     v(i)=0.3;
%     Fy(i)=Fyy;
%     w(i,1:2)=0; %no distributed load on the springs
% end

%Define the top chord members
% for i=1:numclips+1
%     A(i)=Aa; %Area of the top chord as defined in the input
%     Izz(i)=Ii; %The moment of inertia as defined in the input
% %     Zzz(i)=1; %use 1 as default, enter if known
% %     Ayy(i)=1; %use 1 as default, enter if known
%     E(i)=Ee; %Young's modulus as defined in the input
%     v(i)=0.3; %Poisson's ratio of steel, change for other materials
%     Fy(i)=Fyy; %The yield strength as defined in the input
%
% %     YldSurf(i)=1;%element i's yield surface maximum values
% %                              YldSurf(i,1) = maximum P/Py value
% %                              YldSurf(i,2) = maximum Mz/Mpz value
% %                              YldSurf(i,3) = maximum My/Mpy value
% %     Wt(i)=1; %weight density
% %       webdir(i,1:3)  ==  element i's unit web vector.  This is a unit
vector
% %                          that defines the element's local y-y axis with
respect
% %                          to the global coordinate system.  It is based
only on the
% %                          structures undeformed geometry.
% %                            webdir(i,1) = x component of element's unit
web vector
% %                            webdir(i,2) = y component of element's unit
web vector
% %                            webdir(i,3) = z component of element's unit
web vector
% %                                          (which will always be zero for
2D analysis)
```

```
% %                           NOTE: An element's 3x3 rotation matrix, [g], is
constructed
% %                           as follows: First, calculate a unit vector,
x_vect, that
% %                           describes the element's local x-axis (be sure to
include
% %                           all three components with the z component always
being zero).
% %                           Second, take the cross product of x_vect and
webdir(i,:) to
% %                           obtain z_vect, i.e. z_vect =
cross(x_vect,webdir(i,:)). Third,
% %                           set z_vect to a unit vector, i.e. z_vect =
z_vect/norm(z_vect).
% %                           For 2D analysis, z_vect will be either [0 0 1]
or [0 0 -1].
% %                           Finally, the first row of [g] is x_vect, its
second row is
% %                           webdir(i,:), and its third row is z_vect.
%
%     w(i,2)=-ww; %Element i's uniform load in the y-direction, negative is
for a downward load
%     w(i,1)=0;%There is no load in the x=-direction
% end

% %Define the spring members
% for i=numclips+2:1:nele
%     A(i)=As;%The clip stiffness is controlled by this parameter
IMPORTANT!!!
%     Izz(i)=1; %The moment of inertia does not matter for the clips,
stiffness is controlled by AE/L
%     E(i)=Es; %Use the 'modulus' of the spring as defined in the input, this
should be the same as the length of each spring to allow for the spring
stiffness to be controlled by the area of the spring
%     v(i)=0.3;
%     Fy(i)=Fyy;
%     w(i,1:2)=0; %no distributed load on the springs
% end
    truss=0; %Flag to let MASTAN know that the system is NOT a truss


%**************************************************************************
%**************************************************************************
```

Appendix F Finite element model generation

It was desired to use a finite element model to analyze the standing seam roof systems to better understand their behavior as they were loaded. The finite element software used for this process was ABAQUS with input files being written from Matlab. Models were generated by supplying Matlab with measurements taken prior to testing, member cross-sectional properties, imperfection measurements, etc., as well as other applicable information, such as failure load, roof stiffness, etc. Analysis consisted of simulating the test using a collapse model which uses a load deflection analysis (reffered to as a Riks analysis). In this analysis both the load and the deflection are iterated in steps along the static equilibrium path until the solution is stable, then the next step is taken and the process continues until the model fails.

As research progressed it was determined that simplified models could be created and analyzed and that finite element models were not essential; although they would have been helpful. It was found that time spent on establishing and critiquing the prediction method was more beneficial than modifying the finite element models to share the same results as those found in the laboratory.

Because analysis finite element models were not used in establishing the prediction method, this section references the Matlab code and how the code is to be used to generate finite element models in ABAQUS. The goal of this section is to allow any future work performed on this subject to be able to utilize the Matlab input file code to easily create their own finite element models.

The Matlab code was created so that it could be used for different roofing systems by changing only a few inputs. Files are included for single joist models, multiple joist models, and top chord models, all models include default settings to include boundary conditions, constraints (for welds, spacers, and bridging), loads, and spring properties; all of which can be modified within the Matlab code if the defaults are not adequate.

There are few differences between the different code that produces each model, top chord only, single joist, and multiple joists. The following outlines the general procedure of operation for creating ABAQUS input files before showing the differences between each.

Joistmaker

The inputs gathered from the test information were entered into Matlab through a function called *joistmaker.m.* Inputs included both cross sectional dimensions of each component of the joist, and global joist dimensions (such as web member location). The first input into the program is the joist dimensions, these include common joist terminology such as "TC", "First", "depth", "BC", "FH", and "Seat" all which refer to placement of the different components of the joist; Figure F.1 shows the locations of the web members that apply to this terminology.

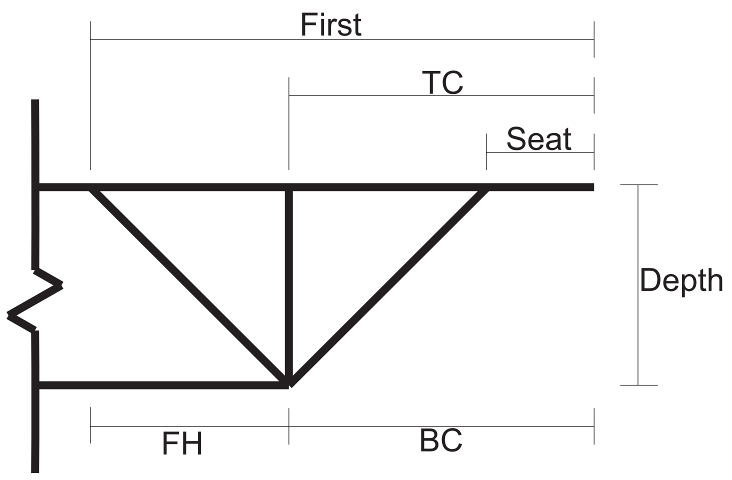


Figure F.1 Joist dimensional inputs for Matlab

Before discussing information about the function *joistmaker.m* it is important to know some general information about the joists themselves. Each joist consists of hot-rolled angles that make up each chord, and cold-formed steel web members. An easy way to think of the web members is in sets of three, as can be seen in Figure F.2.

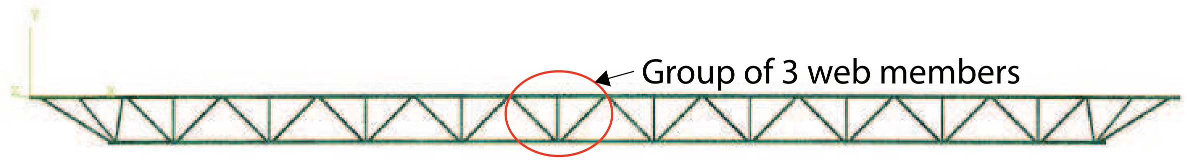


Figure F.2 Elevation of a typical joist showing web member “groups”

The orientation and placement of the first set of web members (on either side of the joist) depends on the initial inputs first, TC, seat, FH, and BC, while all other web members are placed based on the additional spacing between web members and overall joist length. All sets of web members other than the first set consist of two web members angled at 45 degrees above the horizontal in either direction, and one vertical member.

The inputs for the joist dimensions are input as vectors, this input was chosen to allow for multiple joist dimensions to be input into the same file so that if multiple joists are desired the program will be able to take the dimensions of each joist into account separately.

Other inputs into the program include the length of the top chord, the number of joists, the center-to-center spacing of the joists, the center-to-center spacing of the web members (the location where they come together in the top and bottom chords), the depth at which the web members sit below the extreme fiber of each chord, the number of brace points in each joist, the value of the maximum imperfection (assumed to be a half-sine wave), the loading condition (either point loads at the clip locations or a uniform pressure load across the top chord), and clip spacing. Many of the inputs are described in more detail later in this section.

The last input into the program is the cross-sectional information of each of the components of the joist. This includes the thickness, height, and width of each member; inputs are selected based on the values measured prior to each laboratory test, Figure F.3 shows these measurements. It should be noted that the web member length is never input into the program; rather *joistmaker.m* calculates the length of each web-member based on the web-member inputs (First, TC, etc.) as well as the length of the joist. It should be noted that the cross-sectional inputs are not in the very beginning of the *joistmaker.m* function but rather later in the function closer to where each component is generated.

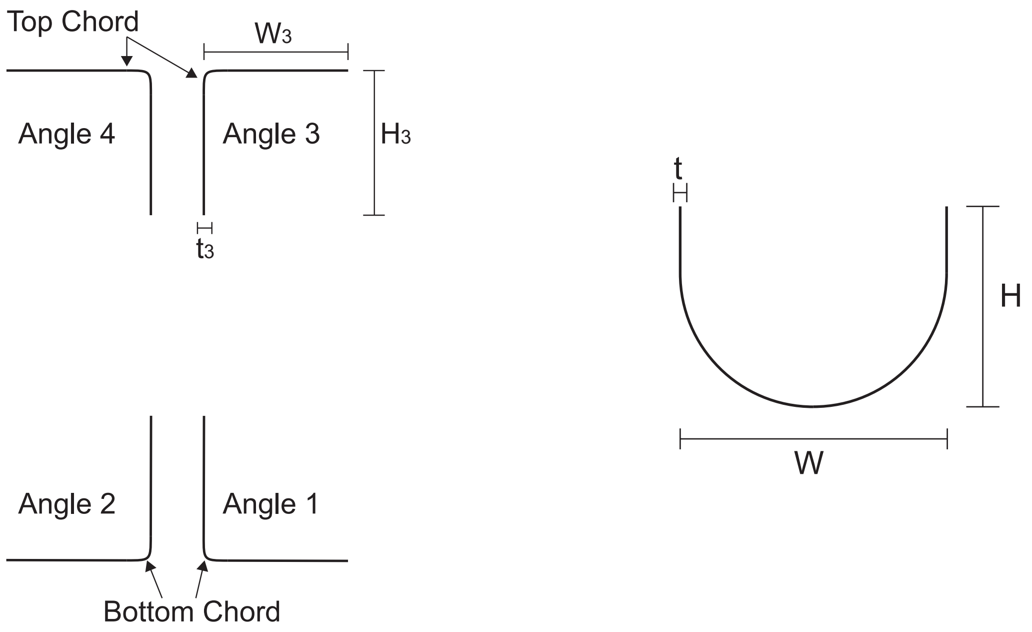


Figure F.3 Cross-sectional dimensions of joist members (a) chord dimensions (b) web member dimensions

The first step in creating the model is to place nodes around the cross-section. *joistmaker.m* uses S9R5 elements as a default and thus the number of elements within each cross-section must be an even number to allow a whole number of elements to be formed (corresponding to an odd number of nodes). This is because the S9R5 elements use 3 nodes per side of each element; when the program creates elements within the cross-section it links adjacent nodes together thinking that two nodes are an “element”; however, because it takes 3 nodes to form an S9R5 element this is the equivalent of two cross-sectional “elements”. The number of elements within each cross-section is controlled by the variable *n* which is a matrix that contains the number of elements that are present on each component of each member. For example, an angle in the top chord of a joist has three distinct parts, two legs and a fillet, the required inputs into *n* for this member are *n* = [4, 4, 4] for each of these sections (if four elements are required for each section), Figure F.4 shows an example of how *n* is translated into the cross-section.

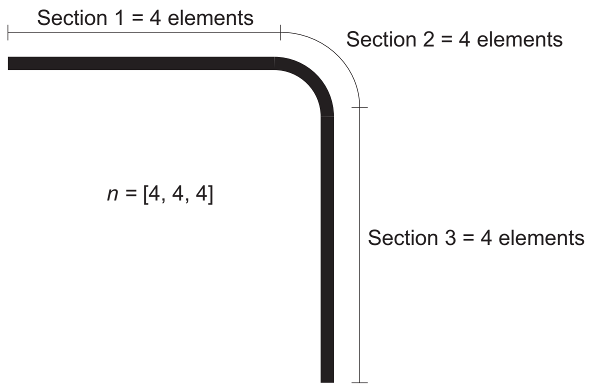


Figure F.4 Number of cross-sectional elements for a typical top chord angle

The previously mentioned inputs work with the cross-sectional information to form each cross-section. The cross-sections are formed by placing nodes evenly across each section of each member (for example Section 1, 2, or 3 of Figure F.4) and then placing elements between the appropriate nodes, this step is completed with a variety of functions (*webxy.m*, *TCxy3.m*, *BCxy1.m*, etc.) the exact function found for each component can be found in

Table F.1.

The next step is for the program to take the cross-sectional inputs and member lengths and extrude each joist component to its full length. It is extruded through a function called *x_sect_to_abaqus.m* which places nodes along the length of the member until the member length is met. Additionally it creates elements between the applicable nodes; this function is used multiple times, once for every time *joistmaker.m* creates a different member of the joist (and thus is found in multiple places in *joistmaker.m*).

After each member is created it is placed into the global coordinate system through an assembly function that is unique for each member type (there is a different assembly function for web members and chord members); Table F.1 shows the different assembly functions and their corresponding members. These functions take each member within its local coordinates and make the appropriate nodal transformations for each member to be placed in the global coordinate system.

The functions *TCassem3.m, TCassem4.m, BCassem1.m,* and *BCassem2.m* have another purpose, to create constraints, boundary conditions, loads, and springs (to model the clips) for the finite element model. Constraints are needed for welds, brace points, and spacers to simulate joist behavior during testing. Welds were modeled as multi-point-constraints (MPC) in which nodes are tied to one another sharing a certain number of degrees of freedom. To model the welds between the web members and the chord angles the assembly functions would search through the nodes of each angle of each chord and determine the node numbers within each chord angle that most-closely corresponded to those at the end of each web member and then tie them together with a MPC.

Similarly, for spacers (which are used as an intermediate connector for each chord between web members) are modeled as a MPC with each node within a leg of each chord being constrained with a MPC. It should be noted that there is a section within *joistmaker.m* that is used for the creation of spacers; this section is not used for creating physical spacers; however, it is used to determine the location of each spacer. It is also important to mention that spacer location is dependent on the joist design, which is dictated by the manufacturer, *joistmaker.m* is designed to place spacers in compliance with 48 ft. span 24K4 joists as designed by New Millennium Building Systems for the pressure box tests at Virginia Tech, which is unlikely to match up with other designs.

Bridging is handled in different ways depending on the model type; for a multiple-joist model each node on the vertical leg of each angle of each chord was constrained to each other by matching up the bridging location along the span (*X*-coordinate) with the nodes in each chord that most closely matched this location and constraining those nodes with a MPC. For the other models the nodes in the chords closest to the bridging locations were found in the same way as the multiple joist model; however, the bridging was modeled with a lateral (*Z*-coordinate) fixity rather than a MPC. This was found to be; however, inaccurate because the joists are allowed to displace laterally during testing; it is the recommendation of the author to use the multiple-joist model, or determine a way to use a lateral spring to represent bridging for the single joist and top chord models.

The top and bottom chord assembly functions were also used to write the boundary conditions for the input file. In an effort to stay consistent with the laboratory tests the boundary conditions were made simple supports. The length of each seat was used for the boundary condition length, and the first three nodes along each vertical leg of the top chord that most closely corresponded to the seat locations had the boundary conditions applied to them.

Both the loads and springs were written to the input file using the chord assembly functions. The load is applied in two possible ways; the first is a uniform pressure over the horizontal leg of the top chord. To accomplish this each horizontal element within the top chord was determined, these element numbers were output to a function, discussed later, that creates a surface from these elements and then applies a load to that surface.

The alternative is to apply point loads at clip locations; this was convenient because lateral springs were placed at clip locations to model the lateral roof resistance of the standing seam, so there were already node sets within the input file that could be used to apply point loads at these locations. After watching laboratory tests it was also hypothesized that majority of the load was entering the joists through the clips. One of the initial inputs into *joistmaker.m* is the spacing of the clips; there is an input for the initial clip placement from the edge of the joist, with all subsequent clips being spaced an additional clip spacing from the previous clip through a second input that specifies clip spacing, and all clips being placed in the center of the horizontal leg of the top chord. It is important to note that all tests performed at the Virginia Tech Laboratory placed the clips on the outside angle of the top chord; this is reflective in the Matlab code; however, there is code available (but commented and thus inactive) that will place the clips on either angle in the top chord, in *TCassem3.m* and *TCassem4.m*. The goal of this function was to determine the clip locations by determining which node most closely matched the theoretical clip location; load magnitude and spring properties were later input when the input file was written.

The last step before sending the information generated in *joistmaker.m* to the input file generator was to alter the node locations to include the geometric imperfection and joist camber. This was done by modeling the joist imperfection and camber as a half-sine-wave with the maximum imperfection matching both the magnitude and the location as that measured prior to the laboratory tests. This was accomplished by first generating all of the node and element information (as outlined previously) without an imperfection and then altering each node location to match that observed in the laboratory.

The previous discussion on model generation can be overwhelming, to show the functions within *joistmaker.m* and their contribution to the finite element mode Table F.1 was created.

Table F.1 *joistmaker.m* Functions

Function	**Purpose**
joistmaker.m	References other functions to create the nodes, elements, boundary conditions, and constraints for the FE model
webxy.m	Converts the web-member dimensions to centerline for the cross-section
webcross.m	Defines cross sectional nodes and elements based on *n* (the number of elements around the cross-section) for each web member
xsect_to_abaqus.m	Extrude the element (both web and chord members)
webassem.m	Assembles the web members into the correct location into the joist (web member placement)
SPACERassem.m	Determines the location of each of the spacers within the joist
TCxy3.m	Converts the top chord angle (angle 3) dimensions to centerline for the cross-section
TCcross3.m	Defines cross sectional nodes and elements based on *n* (the number of elements around the cross-section) for top chord angle (angle 3)
TCassem3.m	Assembles top chord angle (angle 3) into the correct location into the joist (chord member placement)
TCxy4.m	Converts the top chord angle (angle 4) dimensions to centerline for the cross-section
TCcross4.m	Defines cross sectional nodes and elements based on *n* (the number of elements around the cross-section) for top chord angle (angle 4)
TCassem4.m	Assembles top chord angle (angle 4) into the correct location into the joist (chord member placement)
BCxy1.m	Converts the bottom chord angle (angle 1) dimensions to centerline for the cross-section
BCcross1.m	Defines cross sectional nodes and elements based on *n* (the number of elements around the cross-section) for bottom chord angle (angle 1)
BCassem1.m	Assembles bottom chord angle (angle 4) into the correct location into the joist (chord member placement)
BCxy2.m	Converts the bottom chord angle (angle 2) dimensions to centerline for the cross-section
BCcross2.m	Defines cross sectional nodes and elements based on *n* (the number of elements around the cross-section) for bottom chord angle (angle 2)
BCassem2.m	Assembles bottom chord angle (angle 2) into the correct location into the joist (chord member placement)

Input File Generator

joistmaker.m is used to determine the node and element location and numbers, constraints, boundary conditions, spring locations, and loading conditions; however, after this information has been found it still needs to be organized and written to an input file to allow the finite element software to generate a model. The first step to this process is the function *nlbatchr4.m* which references *joistmaker.m*, relays this information to other functions, which write different sections of the input file, before model generation can be completed.

The first step to this process is to determine the clip stiffness, see Chapter 4, and input that into *nlbatch4r.m*, along with the job name (which will be the name of the finite element model). The other initial input is the analysis type for which there are two choices, collapse analysis (denoted by inputting '*C*') or a buckling analysis (denoted by inputting '*B*'). *nlbatchr4.m* will then automatically pull in the necessary information from *joistmaker.m* to allow the input file to be written.

When performing a collapse analysis it is important to have plastic material behavior included in the model. This is possible to enter under the variable *matprops(1).plastic* in *nlbatch4r.m* where the first column represents stress and the second column represents strain past the yield point (the first point should be the yield stress and zero strain). This information should be gathered from a tensile test of the failing material, in the case of the Virginia Tech tests top chord material was used.

It is important to note that many of the inputs in this section are written within quotes. The purpose of this is to write the information to the input file, any text written inside of quotes will be written as text into the input file.

To control the analysis steps a matrix is provided that allows the user to input the steps required by the Riks analysis in ABAQUS. The Riks steps in ABAQUS are the initial increment arc length, the total arc length scale factor, the minimum arc length increment, the maximum arc length increment, and the maximum load proportionality factor, if this any of this information is neglected ABAQUS will use default information for analysis, see the ABAQUS documentation for more information. These values can be entered under the *step(1).solutionsteps* variable;

additionally, the total number of steps required of the analysis can be entered under *step(1).stepinfo* after "INC = ".

At this point the information generated previously (including that from *joistmaker.m*) is transferred to the function *jhabnl.m*, these functions are described briefly in Table F.2, and in further detail below.

Table F.2 Functions Within *jhabnl.m*

Function	**Purpose**
jhabnl.m	To write the information from *nlbatch.m* to an input file (transfer information to the following functions:)
writenodes_elements.m	Writes the node and element information to the input file from *joistmaker.m*
writesprings.m	Writes the spring information to the input file using stiffness given in *nlbatch4.m*
writematerials.m	Writes material information from elastic and plastic information in *nlbatch4.m*
write_load_surface.m	Creates a load surface (for a uniform pressure load only)
writeconstraint.m	Writes the constraints as determined in *joistmaker.m* to the input file
writeBC.m	Writes the boundary conditions to the input file as determined in *joistmaker.m*
writemonitor.m	Determines which nodes to monitor during analysis in ABAQUS (for both deflection and loading)
writestep.m	Writes loads (nodes/surfaces and magnitude), output for required nodes, writes Riks steps

The functions listed in Table F.2 are relatively self-explanatory; however, the following lists some clarification for details of several of the functions. First, for *writesprings.m*, this function writes the spring data to the input file; there are different types of springs in ABAQUS, those that attach to the ground, and those that attach to another node. For the models generated with the described Matlab code, the springs are attached to the ground; furthermore, the springs only provide stiffness in the lateral direction (*Z*-direction, or degree of freedom 3 in ABAQUS). This model was created with discrete springs at clip locations and did not include applying an elastic foundation stiffness as the roof stiffness. It is recommended by the author that if this finite element model is used in future research that the roof is modeled as an elastic foundation rather than with discrete springs; this can be accomplished using the **FOUNDATION* command in ABAQUS, for more information see the ABAQUS documentation.

For the file *writeBC.m*, it is important to include the correct degrees of freedom to be restrained. The translational degrees of freedom in ABAQUS are 1, 2, and 3, for the *X*, *Y*, and *Z* directions respectively; similarly, the rotational degrees of freedom are 4, 5, and 6, for the same directions. For the models created at Virginia Tech simple supports were used, these should be altered for other boundary conditions.

To analyze the results from the models it was necessary to track the displacement and the load on the joists. To track the load the node that was the closest to midspan in one of the angles of the bottom chord was found in the function *BCassem1.m* and transferred to *writemonitor.m* (which simply writes this node (or nodes for multiple joists) into the ABAQUS input file). Load was applied as even point loads at clip locations which made tracking the load easy; it was possible to monitor a single node where load was applied to determine the total load on the joist. The first node from the point load node set was taken to monitor the load, this can be found in the *writestep.m* function. From this point it was possible to compare load and displacement and determine when failure occurred for an easy comparison to the laboratory test data.

The function *writestep.m* controls writing all of the analysis steps to the input file. This includes writing the steps for the Riks analysis, setting the nodes (or elements) to which the load is applied, setting the maximum load magnitude and direction, and setting the nodes to monitor for load and displacement and write these values to the .dat file for post-processing.

Figure F.5 displays a flowchart that shows the process of model generation and the progression of functions created to establish a finite element model.

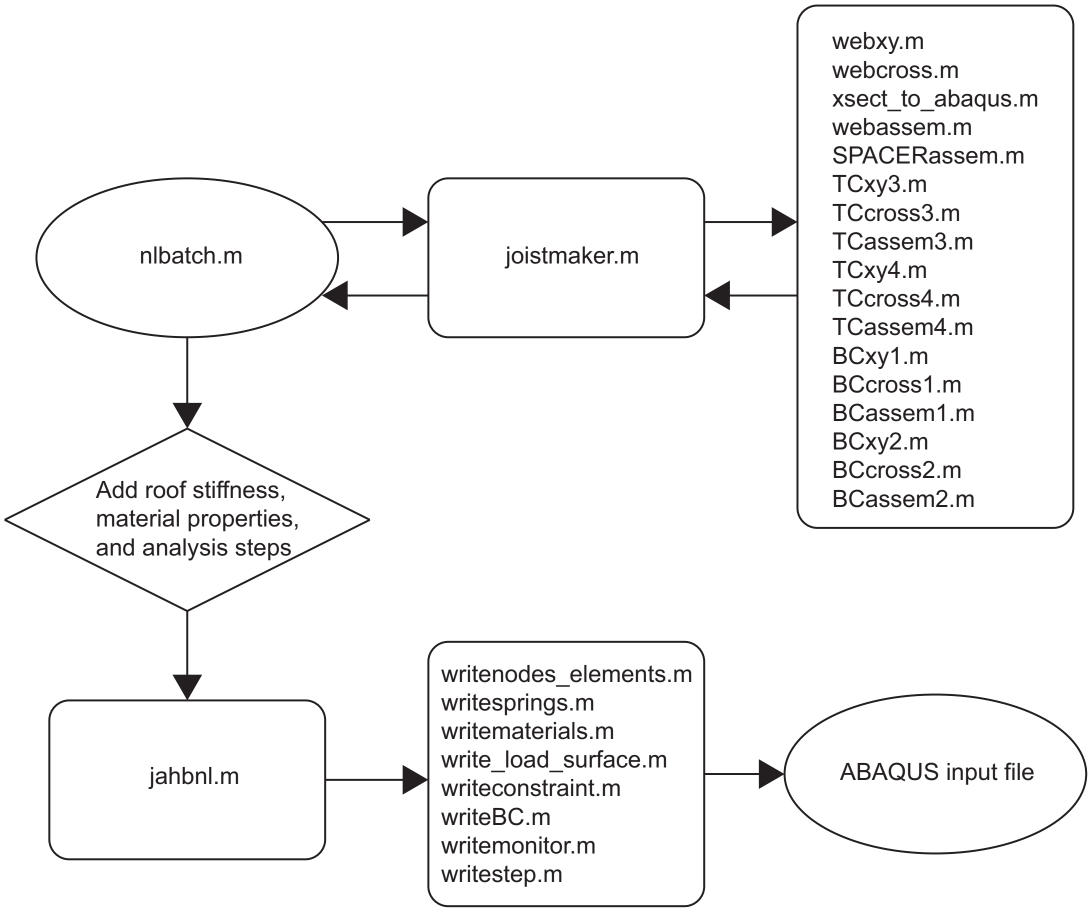


Figure F.5 Flowchart describing the process of finite element model generation

Appendix G Finite element input file code

The information provided in this section is the code for the finite element model generation. The code is set up to allow for multiple joists to be created under a single standing seam roof system for input files into ABAQUS. If single joist models or top chord models are required this code can be modified to create those models. An electronic version of this code is available by contacting the author at lcronin@vt.edu. The functions are listed in the order in which they are accessed within the code (following Figure F.5 Flowchart describing the process of finite element model generation).

Function: ***nlbatchr4.m***

```
clear all
close all

%set path to jhab folder where all functions live
sourceloc=what.path
addpath([sourceloc '\jhab\functions\filewriting\'])
addpath([sourceloc '\jhab\functions\holes\'])
addpath([sourceloc '\jhab\functions\'])
addpath([sourceloc '\jhab\templates\'])
addpath([sourceloc '\'])
addpath([sourceloc '\Joistmaker\'])

%define job name
%USE DATE-TIME-(collapse/buckle)(concentrated loads/pressure)
jobname={'T1-MAR01-1015-CC'}
analysis='C';
    %for analysis enter 'B' for buckling analysis and 'C' for collapse

kclip=0.025;%Enter the stiffness of the clip (k/in)

% FEnode=fscanf(fid,'%g, %g, %g, %g', [4 inf]);
% FEnode=FEnode';
% fclose(fid)
%
% %reads in meshed elements
% fid=fopen('6000x1625x0566x80elements.txt', 'r')
% FEelem=fscanf(fid,'%g, %g, %g, %g, %g, %g, %g, %g, %g', [9 inf]);
% FEelem=FEelem';
% fclose(fid)

% FEnode=load(joistmaker, FEn)wub
% FEelem=load(joistmaker, FEe)
```

```
%Use "joistmaker" to get out the nodes (FEn), elements (FEe), welds in both
%the web and the battens (webcon), nodes involved in the boundary
%conditions (nodeBC), elements for a distributed load (TCload), and nodes
%used to simulate brace points of the joist (BP)
[FEn,FEe,webcon,nodeBC,TCload,BP,TCbat,BCbat,cLoad,LOAD_TYPE,CHORDcon,CHORDc,
n_chord,numnodes,RR,midx,EF,clip_space]=joistmaker();
kroof=kclip/clip_space;%The elastic foundation stiffness (roof stiffness) is
equal to the clip stiffness divided by the spacing of the clips

FEnode=FEn;
FEelem=FEe;

%set element type
eltype='S9R5';

% %sheet thickness
% t=0.036;

%member length
L=max(FEnode(:,4));
%

%round node coordinates
FEnode(:,2:4)=round(FEnode(:,2:4)*1000)/1000;

%imperfection types, not used for elastic buckling analysis
imptypes=[25];

for i=1:1

    for j=1:length(imptypes)

        %NUMBER OF SECTION POINTS THROUGH THE THICKNESS
            sectionpoints=5;


        %ADD ADDITIONAL NODES
        nodeadd=[];

        %MATERIAL PROPERTIES
        %steel
        matprops(1).name='MAT100';
        matprops(1).elastic=[29500 0.3];




%-------------------PLASTIC MATERIAL BEHAVIOR------------------------
        %input some plastic material information from Dr. Moen's code
        %We can change this later to reflect our steel
    if analysis=='C'
        matprops(1).plastic=[57.94, 0.00000000
                            59.06, 0.000099756
                            59.56, 0.000199502
```

```
                                59.68, 0.003187254
                                60.06, 0.006066954
                                60.35, 0.009136112
                                60.36, 0.012688513
                                60.88, 0.013476225
                                61.68, 0.013673056
                                62.16, 0.014066602
                                62.62, 0.014558316
                                63.19, 0.015049789
                                63.7, 0.015737446
                                64.16, 0.01642463
                                64.75, 0.017013269
                                65.25, 0.017699577
                                65.7, 0.018287467
                                66.21, 0.018972901
                                66.67, 0.019657866
                                67.12, 0.020244606
                                67.6, 0.020831002
                                68.05, 0.021514696
                                68.54, 0.022197923
                                69.02, 0.022978182
                                69.49, 0.023757833
                                70.03, 0.024536877
                                70.53, 0.025315314
                                71.02, 0.02599595];
    else
        matprops(1).plastic=[];
    end

        %IMPERFECTIONS
        %*****IMPERFECTIONS*****
        %type=0   no imperfections
        %type=1   use mode shapes from ABAQUS results file
        %type=2   input from file
        %type 3   impose CUFSM shapes as imperfections

        %imperfections.member   =1 column
        %imperfections.member   =2 beam

        imperfections.type=0;
        imperfections.filename=[];
        imperfections.step=[];
        imperfections.mode=[]
        imperfections.member=[]
        imperfection.magnitude=[]
%         t=dims(15)
        %         if imptypes(j)==25
        %             imperfections.magnitude=[0.14*t 0.64*t]
        %         elseif imptypes(j)==75
        %             imperfections.magnitude=[0.66*t 1.55*t]
        %             %imperfections.magnitude=[0 1.55]
        %         end
        imperfections.plumb=[];
        imperfections.wavelength=[];
```

```
 nodesetinfo={ };


        %DEFINE SPRINGS
        springs=[]

        %DEFINE CONTACT SURFACES, NODE SURFACES, KINEMATIC CONSTRAINTS,....
        surface.type={}
        surface.type=[]
        surface.local=[]
        surface.coord=[]

        %set up warping fixed boundary conditions
        surface.coupling={};
        surface.interaction=[]
        surface.contact=[]
        surface.areadist=[]



        %DEFINE ANALYSIS STEP
       surface.type={'*Surface, Name=LEFTS, Type=Node' 'ENDXZERO' ' '}
    surface.local=[]
    surface.coord=[]
    surface.coupling=[{'*Coupling, Constraint Name=LEFTC, Ref
Node=SHEARCENTER,Surface=LEFTS', '*Kinematic', '1,2'}];
    surface.interaction=[]
    surface.contact=[]
    surface.areadist=[]

        %DEFINE ANALYSIS STEP
        %make this into two pieces, one for each type of analysis
if analysis=='B'
        step(1).stepinfo={'STEP 1,' 'perturbation' []};
        step(1).solutiontype='Buckle, eigensolver=lanczos';
        step(1).solutionsteps={'50, , ,'};
        step(1).solutioncontrols={ };
        step(1).coupling=[]

            step(1).loads={}

                    step(1).loads={}

    step(1).outrequest={'*Output, field, variable=PRESELECT';}
%         '*Node Print, NSET=ROT, SUMMARY=NO';
%         'U3';
%         '*Node Print, NSET=SHEARCENTER, SUMMARY=NO';
%         'UR1,RM1'}

        nele=length(FEelem(:,1))

        node=[]
        elem=[]
else
    %The following values are updated to always work with the last running
    %collapse model
            step(1).stepinfo={'STEP 1,' 'nlgeom, INC=75' []};
        step(1).solutiontype='Static, Riks';
        step(1).solutionsteps={'1.000000e-02,,1.000000e-12,, , , , ,'};
            %Here are the defaults for solutionsteps
            %1.000000e-002, ,1.000000e-010,1.000000e-002, , , , ,
            %The first line of *STATIC, RIKS are:
            %   initial increment arc length, total arc length scale factor,
minimum arc length increment, maximum arc length increment, maximum load
prop. factor
            %you need to figure something out for yourself
        step(1).solutioncontrols={ };
        step(1).coupling=[]

            step(1).loads={}

                    step(1).loads={}

    %Frequency=10 gives 10 points in the ODB file instead of the default of
    %20. This greatly reduces the file size, for this file it reduces it to
    %less than 1 GB compared a 8-12 GB file without it
    %This is controlled in the file: 'writestep.m'
%     step(1).outrequest={'*Output, field, variable=PRESELECT, frequency=10';
%         '*Node Print, NSET=ROT, SUMMARY=NO';
%         'U3';
%         '*Node Print, SUMMARY=NO'}

        nele=length(FEelem(:,1))

        node=[]
        elem=[]
end


        disp('Input Complete...starting model generation');
        %WRITE ABAQUS INP FILE
        %this is the important function, you can use this in for loops to
generate parameter studies

        jhabnl(step, jobname{i},matprops,imperfections,sectionpoints, FEnode,
FEelem, eltype, webcon,
nodeBC,TCload,BP,TCbat,BCbat,cLoad,LOAD_TYPE,CHORDcon,CHORDc,n_chord,numnodes
,analysis,kclip,RR,midx,EF,kroof)

    end

end
```

Function: ***joistmaker.m***

```
function[FEn,FEe,webcon,nodeBC,TCload,BP,TCbat,BCbat,cLoad,LOAD_TYPE,CHORDcon
,CHORDc,n_chord,numnodes,RR,midx,EF,clip_space]=joistmaker()
```

```
%%INPUTS
%
%           --------------FIRST----------
%                    ------TC-----------
%                             ---SEAT---
%_______________________________________
%            \       |       /              |
%             \      |      /               |
%              \     |     /                |
%               \    |    /                 |
%                \   |   /                depth        y
%                 \  |  /                   |          |
%                  \ | /                    |          | coords.
%___________________\|/___                 |          |______x
%
%                     ---------BC-------
%             --FH---
%

%  KEY:
%   *All distances (besides FH) are measured from the beginning of the TC
%   (including the seat) to the center of the web member and are measured
%   in inches.
%     1. SEAT = seat length
%     2. TC = distance from the beginning of the TC to the location of this
%     web member in the TC
%     3. FIRST = distance from the beginning of the TC to the location of
%     this web member in the TC
%     4. d = depth of the joist (out-to-out)
%     5. BC = distance from the beginning of the TC to the location of
%     this web member in the BC
%     6. FH = distance from the beginning of this web member in the BC to
%     the TC location
%
%The following measurements are in inches:
    %Default:
        % TC=22.688;
        % FIRST=47.768;
        % depth=24;
        % BC=41.741;
        % FH=3.833;
        % SEAT=4.25;

%Each row of the following represents a different joist (2 for VTJC 2011
%tests)
TC=[22.688;22.688];
FIRST=[47.768;47.768];
depth=[24;24];
BC=[41.741;41.741];
FH=[3.833;3.833];
SEAT=[4.25;4.25];

%Other joist properties:
%Chord Lengths
    %Default:
    % Ltc=48*12+8;
```

```
%
%Global test properties
Ltc=48*12+8; %Length of the top chord in inches including seat
Number_Joists=2; %The number of joists in model
Joist_Space=5*12; %The center-to-center spacing of the joists
%
%Local joist properties (within each joist)
SPACE=1; %the space between each of the web members in a group at the
beginning/end
GAP=0.25; %the space between each of the web members in majority of the joist
change=1; %the depth of the web member will always be less than the depth of
the joist, this value tells you by what amount
BracePts=0;%The number of brace points along the joist

%Imperfections & Camber
imp_amp=[2.411;1.5715];%The imperfection magnitude of each joist is
represented by its row location (1st row=1st joist, 2nd row=2nd joist, etc.)
            %if both imperfection amplitudes have the same sign they will
            %be in the same direction and vice versa
camber=[0.75;0.75];%The maximum amount of camber at mid-span

%LOAD TYPE - 'P' = pressure, 'C' = concentrated load (at clip locations)
LOAD_TYPE='C';
% Lbc=498; %Length of the bottom chord in inches

%Clip locations
FCL=24;%location of the first clip from the end of the joist (in)
clip_space=24;%Spacing of the clips (in)



%Make a global loop to allow for multiple joists to be produced
%Move the origin based on what joist you are on
for ii=1:Number_Joists
    origin=0+Joist_Space*(ii-1);

%%
%Change inputs so they are only the x-component of the web member and do
%not include the seat
BC(ii)=BC(ii,1)-SEAT(ii,1);
TC(ii)=TC(ii,1)-SEAT(ii,1);
FIRST(ii)=FIRST(ii,1)-SEAT(ii,1);



%make an array of lengths so the correct length can be extruded for each web
member
Length=[sqrt((2*((depth(ii,1)-SPACE)^2))) %45 degree members
        sqrt((BC(ii,1)-SPACE-GAP)^2+(depth(ii,1))^2) %outermost members
        sqrt((BC(ii,1)-SPACE-TC(ii,1))^2+depth(ii,1)^2) %2nd outermost
members
        sqrt((depth(ii,1)^2+(FH(ii,1))^2)) %3rd outermost members
        depth(ii,1)]; %vertical members

%%

%cross sectional dimensions
```

```
%these apply to all types of web-members; there are three types
%dimensions measured out-to-out
%(W, H, t, R1, F1, R2, F2, L)
%                                    FEnFEe
%              /           \         |
%             /             \        |
%            /F1_         _F2\       H      y-axis (global)
%            \               /       |      |
%             \             /        |      |
%            R1\___________/R2       |      |______z-axis (global)
%
%           ---------W--------
%
%section dimensions (total width (W), total height (H), thickness (t),
%radius 1 (R1), angle 1 (F1), radius 2 (R2), angle 2 (F2), member length)
%



%-----CROSS SECTIONAL INPUTS FOR THE WEB MEMBERS-----
%sectdims corresponds to the cross sectional dimensions of each of the web
members of the joist
%The first row of sectdims corresponds to the interior diagonal members,
%the second row corresponds to the outermost web members, the third row the
%second outermost web members, the fourth row the third outermost web
%members, and the fifth row the interior vertical members all rows after
%this correspond to additional joists
sectdims= [1.151 1.074 0.09500 1.5 90 1.5 90 Length(1)%joist 1
           1.152 1.078 0.10339 1.5 90 1.5 90 Length(2)%joist 1
           1.138 0.869 0.09150 1.5 90 1.5 90 Length(3)%joist 1
           1.140 0.862 0.09245 1.5 90 1.5 90 Length(4)%joist 1
           1.141 0.863 0.09210 1.5 90 1.5 90 Length(5)%joist 1
           1.150 1.080 0.10360 1.5 90 1.5 90 Length(1)%joist 2
           1.151 1.068 0.10655 1.5 90 1.5 90 Length(2)%joist 2
           1.147 0.866 0.09415 1.5 90 1.5 90 Length(3)%joist 2
           1.143 0.885 0.09345 1.5 90 1.5 90 Length(4)%joist 2
           1.132 0.868 0.09285 1.5 90 1.5 90 Length(5)];%joist 2
                %write a loop to make the radius of each web member 1/2 of
                %the height
                for i =1:size(sectdims)
                    sectdims(i,4)=sectdims(i,1)/2;
                    sectdims(i,6)=sectdims(i,1)/2;
                end

%            1.125 1.022 0.102 0.102 90 0.102 90];
%The last column of sectdims is the length of each member (which was
%calculated previously in the Length array (above)

sdmin=5*(ii-1)+1; %minimum row of sectdims that will be taken for each
iteration of ii
sdmax=5*(ii-1)+5; %maximum row of sectdims that will be taken for each
iteration of ii

nodestack=cell(size(5,1));
elemstack=cell(size(5,1));
```

```
depth=depth-change;%the depth of the web member will always be less than the
depth of the joist

tick=1;%Make a counter to use to count the web members made for each joist

%This is where the web members are made (in their own local coordinates)
for i=sdmin:1:sdmax

    L=sectdims(i,8);
    H=sectdims(sdmin:1:sdmax,2);
    W=sectdims(1,1); %The total width of the web members, this should be
consistent for all (it will need to change otherwise)

    %make each iteration have a separate nodestack (we are going to need
    %two loops)
    %
    %The second loop should include the assembly

    %Mesh along length
    nele=L;

    dims=sectdims(i,:);

    %Create the number of section points through the thickness
    sectionpoints=5;

    %Cross-section meshing
    %number of elements around the cross section
    n=[2 4 0 4 2];

    N=n(1,1)+n(1,2)+n(1,3)+n(1,4)+n(1,5)+1; %the total number of nodes in
each cross section

    %convert to centerline dimensions for the cross section
    [xy]=webxy(dims);

    %define nodes, elements and properties in CUFSM coords.
    kipin=1;
    [node, elem]=webcross(xy, dims, kipin, n);

    %plot node to check
%      figure(i)
%      plot(node(:,2), node(:,3),'k.')
%
    %extrude the element using xsect

[FEnode,FEelem,t,matnum,nnodes,nL,FEsection_increment,elemgroups,node]=xsect_
to_abaqus(L, nele, node, elem);

    %We can change the z-coordinate here to allow for multiple joists to be
    %produced (just add the spacing of the joist to FEnode and FEelem)
    FEnode(:,4)=FEnode(:,4)+origin;

    %plot 3D to see extrusion along the length of the member
```

```
%     figure(i+10)
%     plot3(FEnode(:,2),FEnode(:,4),FEnode(:,3),'k.')
%       FEnode
%       FEelem

%create an array of FEnode and FEelem so we can use them later in assembly
    nodestack{tick}=FEnode;
    elemstack{tick}=FEelem;
    tstack{tick}=sectdims(i,3);

    tick=tick+1;

end

%----------------ASSEMBLE WEB MEMBERS INTO THE JOIST----------------
%Create a value for the following so MATLAB does not freak out--for the
%first iteration (first joist) only
if ii==1
    FEn=0;
    FEe=0;
    cLoad=0;
    CHORDcount=0;
    pinend=0;
    %And now the cells:
    midx{1}=0;
    RR{1}=0;
    webcon{1}=0;
    TCload{1}=0;
    nodeBC{1}=0;
    BP{1}=0;
    TCbat{1}=0;
    BCbat{1}=0;
    EF{1}=0;
end
%This is where the web members are rotated and placed along the length of
%the joist
%Find FEnode (FEn) and FEelem (FEe) for the web members
[FEn,FEe,webcon,numdiag,numnodes,pinend]=webassem(nodestack, elemstack,
tstack, sectdims, TC, FIRST, depth, BC, FH, SEAT, Ltc,
change,SPACE,GAP,H,N,FEn,FEe,ii,webcon,pinend);

%%
% ---------------INPUTS FOR THE CHORD MEMBERS--------------------

depth=depth+change;

% Dimensions are measured from the intersection of the height and width to
% the ends of the angle
%
%section dimensions (per angle): angle width (W), angle height(H),
%thickness(t), outside radius(R), angle of W-H intersection (degrees)(F)
%
%S is the distance between the two angles, measured between the
%intersection of the H and W legs of each angle
%
```

```
%d is the depth of the section (measured out-to-out) - d should be measured
%from angle #1 to angle #3
%
% [W1, H1, t1, R1, F1, W2, H2, t2, R2, F2, S1, W3, H3, t3, R3, F3, W4, H4,
t4, R4, F4, S2, d]

%Cross-section dimensions
%
%               S2
%   ___W4____R4    R5____W3____
%         F4/        \F3                            |
%          /          \                             |
%         /H4        H3\                            |
%        /              \                           |
%       /                \                          |
%      t4                 t3                        |
%                                                   |
%                                                   d
%                                                   |
%                                                   |
%      t2                t1                         |
%       \                /                          |
%        \              /                           |
%         \H2       H1 /             ^              |
%          \          /              |              |
%           \        /            y-axis            |
%   _______F2\R2  R1/_F1_______      |__z-axis__>   |
%      W2       S1      W1

%TCdims
% [W1, H1, t1, R1, F1, W2, H2, t2, R2, F2, S1]

%BCdims
% [W3, H3, t3, R3, F3, W4, H4, t4, R4, F4, S2, d]

%top chord dimensions:
%Where
%TCdims are as follows:
%row 1 - Joist 1
%row 2 - Joist 2
TCdims=[1.504 1.508 .1490 0 90 1.504 1.501 0.13785 0 90 1.125 depth(ii)
        1.502 1.506 .1487 0 90 1.505 1.503 0.13990 0 90 1.125 depth(ii)];

    %rewrite the radius to be equal to the member thickness
    for i=1:size(TCdims)
        TCdims(i,4)=TCdims(i,3);
        TCdims(i,9)=TCdims(i,8);
    end

%TCdims are as follows:
%row 1 - Joist 1
%row 2 - Joist 2
%Bottom chord dimensions
BCdims=[1.519 1.480 0.14900 0 90 1.504 1.501 0.13785 0 90 1.125
        1.529 1.501 0.14195 0 90 1.498 1.508 0.14035 0 90 1.125];
        %rewrite the radius to be equal to the member thickness
        for i=1:size(TCdims)
            BCdims(i,4)=BCdims(i,3);
            BCdims(i,9)=BCdims(i,8);
        end

%         Lbc=498; %length for the bottom chord

% ---------------PLACE THE SPACERS MEMBERS--------------------

%Spacers are the small angles that are placed in between angles
%along the length of the chord, between web members

%            R
%    |       /\
%    |      /F \
%    H     /    \           y
%    |    /      \          | coords.
%    |   /        \         |____z
%                  t
%        ----W-----

%SPACERdims
% [W, H, t, R, F]

%Batten dimensions
SPACERdims=[1.75 1.75 0.1 0.1 90];

%%
%-------SPACER EXTRUSION-----
tick=1;

    for i=1:size(SPACERdims)

        %Member length
         H=SPACERdims(1,2);
         L=TCdims(1,11); %length of the batten is equal to the space in
between the chords
         %!!!!!!!!!!!!!!!!!!!!!THIS NEEDS TO CHANGE IF WE MAKE MULTIPLE
         %JOISTS!!!!!!!!!!

        %Mesh along length
        nele=L;

        %Create the number of section points through the thickness
        sectionpoints=5;

        %Cross-section meshing
        %number of elements around the cross section
        %[H, R, W]
        n=[4 4 4];
        N=n(1,1)+n(1,2)+n(1,3);
        dims=SPACERdims(i,:);

        %convert to centerline dimensions for the cross section
        [xy]=battenxy(dims);

        %Define nodes, elements and properties in CUFSM
        %kipin gives material properties, we need to input this whenever we
        %figure out what our material properties are
        kipin=1;

        [node, elem]=battencross1(xy, dims, kipin,n);

        %plot node to check
    %        figure(i)
    %        plot3(node(:,2),node(:,4),node(:,3),'k.')

        %extrude the element using xsect

[FEnode,FEelem,t,matnum,nnodes,nL,FEsection_increment,elemgroups,node]=xsect_
to_abaqus(L, nele, node, elem);

        %We can change the z-coordinate here to allow for multiple joists to
be
        %produced (just add the spacing of the joist to FEnode and FEelem)
        FEnode(:,4)=FEnode(:,4)+origin;

        %plot 3d to check
    %     figure(i+10)
    %     plot3(FEnode(:,2),FEnode(:,4),FEnode(:,3),'k.')

    %create an array of FEnode and FEelem so we can use them later in
assembly
    %However, for this initial program just use one joist
        nodestack{tick}=FEnode;
        elemstack{tick}=FEelem;
        tstack{tick}=[SPACERdims(i,3)];

        tick=tick+1;
    end

%-------------ASSEMBLE SPACERS INTO THE JOIST-------------
if ii==1 %only assemble the spacers based on the location of the first joist
because all other spacers will have the same x-location

[FEn,FEe,TCbatpos,BCbatpos,numbattens]=SPACERassem(nodestack,FEn,FIRST,SEAT,d
epth,GAP,FEe,elemstack,tstack,Ltc,webcon,N,H,numdiag,ii);
end

%%
%-------TOP CHORD EXTRUSION-----
sdmin=1*(ii-1)+1; %minimum row of sectdims that will be taken for each
iteration of ii

tick=1;
```

```
%For angle #3
    for i=sdmin:sdmin %one top chord per joist

        %Member length
         L=Ltc; %length of the top chord

        %Mesh along length
        nele=L;

        %Create the number of section points through the thickness
        sectionpoints=5;

        %Cross-section meshing
        %number of elements around the cross section
        %[W, R, H]
        n=[4 2 4];

        N=n(1,1)+n(1,2)+n(1,3); %The total number of elements per cross
section
        n_chord=n;

        dims=TCdims(i,:);
        s=TCdims(i,11);

        %convert to centerline dimensions for the cross section
        [xy]=TCxy3(dims);

        %Define nodes, elements and properties in CUFSM
        %kipin gives material properties, we need to input this whenever we
        %figure out what our material properties are
        kipin=1;

        [node, elem]=TCcross3(xy, dims, kipin,n);

        %plot node to check
    %        figure(i)
    %        plot3(node(:,2),node(:,4),node(:,3),'k.')

        %extrude the element using xsect

[FEnode,FEelem,t,matnum,nnodes,nL,FEsection_increment,elemgroups,node]=xsect_
to_abaqus(L, nele, node, elem);

        %We can change the z-coordinate here to allow for multiple joists to
be
        %produced (just add the spacing of the joist to FEnode and FEelem)
        FEnode(:,4)=FEnode(:,4)+origin;

        %plot 3d to check
    %     figure(i+10)
    %     plot3(FEnode(:,2),FEnode(:,4),FEnode(:,3),'k.')

    %create an array of FEnode and FEelem so we can use them later in
assembly
```

```
    %However, for this initial program just use one joist
        nodestack{tick}=FEnode;
        elemstack{tick}=FEelem;
        tstack{tick}=[TCdims(i,3)];

        tick=tick+1;
    end

%-------------ASSEMBLE angle #3 INTO THE JOIST-------------
[FEn,FEe,nodeBC,TCload,BP,TCbat,cLoad,CHORDcon,CHORDcount,RR,EF]=TCassem3(nod
estack,elemstack,tstack,FEn,FEe,s,depth,change,SEAT,Ltc,N,n,BracePts,TCbatpos
,numbattens,LOAD_TYPE,webcon,W,ii,cLoad,TCload,nodeBC,BP,TCbat,CHORDcount,pin
end,FCL,clip_space,RR,EF);

tick=1;
%For angle #4
    for i=sdmin:sdmin %2 angles per bottom chord
        %Member length
         L=Ltc; %length of the top chord

        %Mesh along length
        nele=L;

        %Create the number of section points through the thickness
        sectionpoints=5;

        %Cross-section meshing
        %number of elements around the cross section
        %[H, R, W]
        n=[4 2 4];
        N=n(1,1)+n(1,2)+n(1,3);

        dims=TCdims(i,:);
        s=TCdims(i,11);

        %convert to centerline dimensions for the cross section
        [xy]=TCxy4(dims);

        %Define nodes, elements and properties in CUFSM
        %kipin gives material properties, we need to input this whenever we
        %figure out what our material properties are
        kipin=1;

        [node, elem]=TCcross4(xy, dims, kipin,n);

        %plot node to check
    %        figure(i)
    %        plot3(node(:,2),node(:,4),node(:,3),'k.')

        %extrude the element using xsect

[FEnode,FEelem,t,matnum,nnodes,nL,FEsection_increment,elemgroups,node]=xsect_
to_abaqus(L, nele, node, elem);
```

```
        %We can change the z-coordinate here to allow for multiple joists to
be
        %produced (just add the spacing of the joist to FEnode and FEelem)
        FEnode(:,4)=FEnode(:,4)+origin;

        %plot 3d to check
    %     figure(i+10)
    %     plot3(FEnode(:,2),FEnode(:,4),FEnode(:,3),'k.')

    %create an array of FEnode and FEelem so we can use them later in
assembly
    %However, for this initial program just use one joist
        nodestack{tick}=FEnode;
        elemstack{tick}=FEelem;
        tstack{tick}=[TCdims(i,8)];

        tick=tick+1;
    end

    %-------------ASSEMBLE angle #4 INTO THE JOIST-------------

[FEn,FEe,nodeBC,TCload,BP,TCbat,CHORDcon,CHORDcount,cLoad,RR]=TCassem4(nodest
ack,elemstack,tstack,FEn,FEe,s,depth,change,SEAT,nodeBC,N,n,TCload,Ltc,BraceP
ts,TCbatpos,numbattens,BP,TCbat,webcon,W,CHORDcon,CHORDcount,ii,cLoad,pinend,
FCL,clip_space,RR);

%plot to check
%     figure(2)
%     plot(FEn(:,2),FEn(:,3),'k.')
%

%%
%-------BOTTOM CHORD EXTRUSION-----
tick=1;
    %For angle #1
        for i=sdmin:sdmin

            %Number of diagonals per 1/2 span
            numdiag=round(((Ltc-2*SEAT(ii,1)-
2*FIRST(ii,1))/(depth(ii,1)))*1/2); %the number of diagonals in the joist
(for each 45 degree orientation)

            %Member length
             L=Ltc-2*(SEAT(ii,1)+BC(ii,1))+numdiag*3*GAP-4*SPACE; %length of
the bottom chord

            %Mesh along length
            nele=L;

            %Create the number of section points through the thickness
            sectionpoints=5;

            %Cross-section meshing
            %number of elements around the cross section
            %[H, R, W]
            n=[4 2 4];

            dims=BCdims(i,:);
            s=BCdims(i,11);

            %convert to centerline dimensions for the cross section
            [xy]=BCxy1(dims);

            %Define nodes, elements and properties in CUFSM
            %kipin gives material properties, we need to input this whenever
we
            %figure out what our material properties are
            kipin=1;

            [node, elem]=BCcross1(xy, dims, kipin,n);

            %plot node to check
        %       figure(i)
        %       plot3(node(:,2),node(:,4),node(:,3),'k.')

            %extrude the element using xsect

[FEnode,FEelem,t,matnum,nnodes,nL,FEsection_increment,elemgroups,node]=xsect_
to_abaqus(L, nele, node, elem);

            %We can change the z-coordinate here to allow for multiple joists
to be
            %produced (just add the spacing of the joist to FEnode and
FEelem)
            FEnode(:,4)=FEnode(:,4)+origin;

            %plot 3d to check
        %     figure(i+10)
        %     plot3(FEnode(:,2),FEnode(:,4),FEnode(:,3),'k.')

        %create an array of FEnode and FEelem so we can use them later in
assembly
        %However, for this initial program just use one joist
            nodestack{tick}=FEnode;
            elemstack{tick}=FEelem;
            tstack{tick}=BCdims(i,3);

            tick=tick+1;
        end

        %-------------ASSEMBLE angle #1 INTO THE JOIST-------------

[FEn,FEe,BP,BCbat,CHORDcon,CHORDcount,nodeBC,midx]=BCassem1(nodestack,elemsta
ck,tstack,FEn,FEe,BC,s,depth,change,SEAT,SPACE,GAP,Ltc,BracePts,BCbatpos,numb
attens,BP,webcon,W,CHORDcon,CHORDcount,ii,BCbat,N,nodeBC,pinend,midx,n);
tick=1;
    %For angle #2
        for i=sdmin:sdmin
```

```
            %Member length
             L=Ltc-2*(SEAT(ii,1)+BC(ii,1))+numdiag*3*GAP-4*SPACE; %length of
the bottom chord

            %Mesh along length
            nele=L;

            %Create the number of section points through the thickness
            sectionpoints=5;

            %Cross-section meshing
            %number of elements around the cross section
            %[H, R, W]
            n=[4 2 4];

            dims=BCdims(i,:);

            %convert to centerline dimensions for the cross section
            [xy]=BCxy2(dims);

            %Define nodes, elements and properties in CUFSM
            %kipin gives material properties, we need to input this whenever
we
            %figure out what our material properties are
            kipin=1;

            [node, elem]=BCcross2(xy, dims, kipin,n);

            %plot node to check
        %        figure(i)
        %        plot3(node(:,2),node(:,4),node(:,3),'k.')

            %extrude the element using xsect

[FEnode,FEelem,t,matnum,nnodes,nL,FEsection_increment,elemgroups,node]=xsect_
to_abaqus(L, nele, node, elem);

            %We can change the z-coordinate here to allow for multiple joists
to be
            %produced (just add the spacing of the joist to FEnode and
FEelem)
            FEnode(:,4)=FEnode(:,4)+origin;

            %plot 3d to check
        %     figure(i+10)
        %     plot3(FEnode(:,2),FEnode(:,4),FEnode(:,3),'k.')

        %create an array of FEnode and FEelem so we can use them later in
assembly
        %However, for this initial program just use one joist
            nodestack{tick}=FEnode;
            elemstack{tick}=FEelem;
            tstack{tick}=BCdims(i,3);
            tick=tick+1;
        end

        %-------------ASSEMBLE angle #2 INTO THE JOIST-------------

[FEn,FEe,BP,BCbat,CHORDcon,CHORDcount,nodeBC]=BCassem2(nodestack,elemstack,ts
tack,FEn,FEe,BC,s,depth,change,SEAT,SPACE,GAP,Ltc,BracePts,BCbatpos,numbatten
s,BP,BCbat,webcon,W,CHORDcon,CHORDcount,ii,N,nodeBC,pinend,n);



        %------------WELD CONSTRAINTS--------------
        %Make a cell of nodesets (one per joist) for the chord members to tie
them
        %to their corresponding nodesets in the web members
        CHORDc{ii}=CHORDcount;




%%
        %---------------IMPERFECTIONS & CAMBER---------------
% %Imperfections
% imp_amp1=36;%The imperfection magnitude of the first joist (and all other
corresponding odd numbered joists (1,3,5,...))in inches
% imp_amp2=-36;%The imperfection magnitude of the second joist (and all other
corresponding even numbered joists (2,4,6,...)) in inches
%             %if both imperfection amplitudes have the same sign they will
%             %be in the same direction and vice versa

        Limp=Ltc; %The length of the imperfection



    %IMPERFECTIONS
        if ii==1 %We need to iterate for only the first joist
            for i=1:size(FEn,1)
                FEn(i,4)=FEn(i,4)+imp_amp(ii,1)*sin(pi*FEn(i,2)/Limp);%The
imperfection is in the z-direction but depends on the length of the joist in
the x-direction
            end
        else
            for i=impcount+1:1:size(FEn,1)
                FEn(i,4)=FEn(i,4)+imp_amp(ii,1)*sin(pi*FEn(i,2)/Limp);%The
imperfection is in the z-direction but depends on the length of the joist in
the x-direction
            end
        end
        impcount=size(FEn,1); %we need to know the size of FEn so we don't
recount nodes on the second iteration (for the second joist)



%OLD WAY, IF NEW WAY (ABOVE) WORKS WE CAN DELETE THE FOLLOWING
%         if mod(ii,2)==1%for the first joist, and other odd numbered joists
%             if ii==1 %We need to iterate for only the first joist
%                 for i=1:size(FEn,1)
```

```
%
FEn(i,4)=FEn(i,4)+imp_amp(ii,1)*sin(pi*FEn(i,2)/Limp);%The imperfection is in
the z-direction but depends on the length of the joist in the x-direction
%                 end
%             else%iteration for all other odd numbered joists
%                 for i=impcount+1:1:size(FEn,1)
%
FEn(i,4)=FEn(i,4)+imp_amp(ii,1)*sin(pi*FEn(i,2)/Limp);%The imperfection is in
the z-direction but depends on the length of the joist in the x-direction
%                 end
%             end
%             impcount=size(FEn,1); %we need to know the size of FEn so we
don't recount nodes on the second iteration (for the second joist)
%         elseif mod(ii,2)==0%this grabs the even numbered joists
%                 for i=impcount+1:1:size(FEn,1)
%
FEn(i,4)=FEn(i,4)+imp_amp(ii,1)*sin(pi*FEn(i,2)/Limp);%The imperfection is in
the z-direction but depends on the length of the joist in the x-direction
%                 end
%             imp_count=size(FEn,1);
%         end




    %CAMBER
            if ii==1 %We need to iterate for only the first joist
                for i=1:size(FEn,1)

FEn(i,3)=FEn(i,3)+camber(ii,1)*sin(pi*FEn(i,2)/Limp);%Camber is in the y-
direction but depends on the length of the joist in the x-direction
                end
            else %iteration for all other odd numbered joists
                for i=impcount+1:1:size(FEn,1)

FEn(i,3)=FEn(i,3)+camber(ii,1)*sin(pi*FEn(i,2)/Limp);%Camber is in the y-
direction but depends on the length of the joist in the x-direction
                end
            end
            impcount=size(FEn,1); %we need to know the size of FEn so we
don't recount nodes on the second iteration (for the second joist)



%OLD WAY!!!!!!!!!
%         if mod(ii,2)==1%for the first joist, and other odd numbered joists
%             if ii==1 %We need to iterate for only the first joist
%                 for i=1:size(FEn,1)
%                     FEn(i,3)=FEn(i,3)+camber1*sin(pi*FEn(i,2)/Limp);%Camber
is in the y-direction but depends on the length of the joist in the x-
direction
%                 end
%             else %iteration for all other odd numbered joists
%                 for i=impcount+1:1:size(FEn,1)
%                     FEn(i,3)=FEn(i,3)+camber1*sin(pi*FEn(i,2)/Limp);%Camber
is in the y-direction but depends on the length of the joist in the x-
direction
%                 end
%             end
%             impcount=size(FEn,1); %we need to know the size of FEn so we
don't recount nodes on the second iteration (for the second joist)
%         elseif mod(ii,2)==0%this grabs the even numbered joists
%                 for i=impcount+1:1:size(FEn,1)
%                     FEn(i,3)=FEn(i,3)+camber2*sin(pi*FEn(i,2)/Limp);%Camber
is in the y-direction but depends on the length of the joist in the x-
direction
%                 end
%             imp_count=size(FEn,1);
%         end

%%

%--------------------PLOT TO CHECK----------------------
    %plot profile
%     figure(2)
%     plot(FEn(:,2),FEn(:,3),'k.')

    %plot ZY plane
%     figure(3)
%     plot(FEn(:,3),FEn(:,4),'k.')

    %plot 3d
%     figure(4)
%     plot3(FEn(:,2),FEn(:,4),FEn(:,3),'k.')

end

end
```

Function: ***webxy.m***

```
function[geomfinal]=webxy(dims)

%creates centerline node points for web element cross section

%cross sectional dimensions
%these apply to all types of web-members; there are three types
%dimensions measured out-to-out
%(W, H, t, R1, F1, R2, F2)

%
%              /           \          |
%             /             \         |
%            /F1_         _F2\        H
%            \               /        |
%             \             /         |
%            R1\___________/R2        |
%
%           ---------W--------
%
```

```
%section dimensions (total width (W), total height (H), thickness (t),
%radius 1 (R1), radius 2 (R2)

%Enter dims for practice
% dims= [1 1 0.25 0.25 89 0.25 89];

W=dims(1);
H=dims(2);
t=dims(3);
R1=dims(4);
F1=dims(5)*pi/180;
R2=dims(6);
F2=dims(7)*pi/180;

%origin is the intersection of the left "leg" and the base

%r=centerline radius
r1=R1-t/2;
r2=R2-t/2;

%(x1,y1) represents the beginning of radius R1
x1=R1/tan(F1/2);
y1=t/2;
%(x2,y2) represents the beginning of radius R2
x2=W-R2/tan(F2/2);
y2=t/2;

%(x3,y3) represents the end of radius R1
%(xo3,yo3) represents the center of curvature of R1
xo3=x1;
yo3=R1;

 G1=pi-F1;

    if G1<=pi/2
        x3=xo3-r1*sin(G1);
        y3=yo3-r1*cos(G1);
    else
        x3=xo3-r1*cos(G1-pi/2);
        y3=yo3+r1*sin(G1-pi/2);
    end

%(x4,y4) represents the end of radius R2
%(xo4,yo4) represents the center of curvature of R2
xo4=x2;
yo4=R2;

 G2=pi-F2;

    if G2<=pi/2
        x4=xo4+r2*sin(G2);
        y4=yo4-r2*cos(G2);
    else
        x4=xo4+r2*cos(G2-pi/2);
        y4=yo4+r2*sin(G2-pi/2);
    end

%(x5,y5) represents the centerline point at the top of the R1 leg
x5=H*cos(F1)+t/2*sin(F1);
y5=H*sin(F1)-t/2*cos(F1);

%(x6,y6) represents the centerline point at the top of the R2 leg
x6=W-H*cos(F2)-t/2*sin(F2);
y6=H*sin(F2)-t/2*cos(F2);

%transform into CUFSM format
geom=[x1 y1
      x2 y2
      x3 y3
      x4 y4
      x5 y5
      x6 y6];

  %plot the points to check
%   figure(1)
%   plot(geom(:,1),geom(:,2),'k.')

geomfinal=geom;
```

Function: ***webcross.m***

```
function[node,elem]=webcross(geom,dims,kipin,n)

%webcross determines the cross-sectional nodes for joist web-members

%cross sectional dimensions
%these apply to all types of web-members; there are three types
%dimensions measured out-to-out
%(W, H, t, R1, F1, R2, F2)

%
%              /           \          |
%             /             \         |
%            /F1_         _F2\        H
%            \               /        |
%             \             /         |
%            R1\___________/R2        |
%
%           ---------W--------
%
%section dimensions (total width (W), total height (H), thickness (t),
%radius 1 (R1), radius 2 (R2)

%input for practice

%Enter inputs for practice
% dims= [1 1 0.25 0.25 89 0.25 89];
% n=[4 4 4 4 4];
% kipin=1;
%
% geom=  [0.2544    0.1250
%         0.7456    0.1250
%         0.1294    0.2522
%         0.8706    0.2522
%         0.1424    0.9977
%         0.8576    0.9977];


%inputs from webin
W=dims(1);
H=dims(2);
t=dims(3);
R1=dims(4);
F1=dims(5)*pi/180;
R2=dims(6);
F2=dims(7)*pi/180;

%r=centerline radius
r1=R1-t/2;
r2=R2-t/2;

%each n-value is the number of nodes in each component of the cross
%section, n1 is for the R1 leg, n2 is for R1, n3 is for the base length,
%n4 is for R2, and n5 is for the R2 leg
n1=n(1,1);
n2=n(1,2);
n3=n(1,3);
n4=n(1,4);
n5=n(1,5);

%determine the node numbers for the R1 leg
length1=((geom(5,1)-geom(3,1))^2+(geom(5,2)-geom(3,2))^2)^0.5;

for j=1:1:n1+1
    node(j,1)=j;
    node(j,2)=geom(5,1)-((j-1)*length1/(n1))*cos(F1);
    node(j,3)=geom(5,2)-((j-1)*length1/(n1))*sin(F1);
end

%determine the node numbers for R1
%Alter the radius based on "chord method"
%xo1, yo1 is the center of the R1
%The program uses the length from the center point (radius) and the angle
%from the center point to determine the coordinates of each node
xo1=geom(1,1);
yo1=geom(1,2)+r1;

for j=1:1:n2

    node(j+n1+1,1)=j+n1+1;
    G=(n2-j)*((pi-F1)/n2);
    if G<=pi/2
        node(j+n1+1,2)=xo1-r1*sin(G);
        node(j+n1+1,3)=yo1-r1*cos(G);
    else
        node(j+n1+1,2)=xo1-r1*cos(G-pi/2);
        node(j+n1+1,3)=yo1+r1*sin(G-pi/2);
    end

end

%Determine the node numbers for the base of the web-member
lengthb=geom(2,1)-geom(1,1);

for j=1:1:n3
    node(j+n1+n2+1,1)=j+n1+n2+1;
    node(j+n1+n2+1,2)=geom(1,1)+lengthb/(n3)*j;
    node(j+n1+n2+1,3)=geom(1,2);
end

%determine the node numbers for R2
%Alter the radius based on "chord method"
%xo2, yo2 is the center of the R2
%The program uses the length from the center point (radius) and the angle
%from the center point to determine the coordinates of each node
xo2=geom(2,1);
yo2=geom(2,2)+r2;

for j=1:1:n4

    node(j+n1+n2+n3+1,1)=j+n1+n2+n3+1;
    G=j*((pi-F2)/n4);

    if G<=pi/2
        node(j+n1+n2+n3+1,2)=xo2+r2*sin(G);
        node(j+n1+n2+n3+1,3)=yo2-r2*cos(G);
    else
        node(j+n1+n2+n3+1,2)=xo2+r2*cos(G-pi/2);
        node(j+n1+n2+n3+1,3)=yo2+r2*sin(G-pi/2);
    end

end


%Determine the node numbers for the R2 leg
length2=((geom(6,1)-geom(4,1))^2+(geom(6,2)-geom(4,2))^2)^0.5;

for j=1:1:n5
    node(j+n1+n2+n3+n4+1,1)=j+n1+n2+n3+n4+1;
    node(j+n1+n2+n3+n4+1,2)=geom(4,1)-(j*length2/(n5))*cos(F2);
    node(j+n1+n2+n3+n4+1,3)=geom(4,2)+(j*length2/(n5))*sin(F2);
end

%check node to see if it is in the correct format
%node
```

```
%plot node to check the full cross section
% figure(2)
% plot(node(:,2), node(:,3),'k.')

%set default for CUFSM format
node(:,4:7)=1;
node(:,8)=50;

%create elements for cross section
for i=1:1:(size(node,1)-1)
   elem(i,:)=[i i i+1 t 100];
end

%set some default properties
if kipin==1
prop=[100 29500 29500 0.3 0.3 29500/(2*(1+0.3))];
else
prop=[100 203000 203000 0.3 0.3 203000/(2*(1+0.3))];
end
```

Function: ***xsect_to_abaqus.m***

```
function
[FEnode,FEelem,t,matnum,nnodes,nL,FEsection_increment,elemgroups,node]=xsect_
to_abaqus(L,nele,node,elem)
%
%cufsm_to_abaqus.m
%Ben Schafer
%December 2005
%***********
%Modified by Cris Moen
%November 2006
%Notes:  modified cufsm_to_abaqus for use as bare bones S9R5 node and element
generator

%Round nodal coordinates to elimate accuracy noise
%node(:,2:3)=round(node(:,2:3)*1000)/1000;

%WARNINGS
%Has to be an even number of FSM elements for this to work
if rem(length(elem(:,1)),2)>0
    ['Warning! Your CUFSM model has an odd number of elements this will not
convert to ABAQUS S9R5 elements. Please modify your model so that the number
of elements is an even number']
end
%
%PRELIMINARIES
%Count FSM nodes and modes
nnodes=length(node(:,1));%Number of FSM cross-section nodes
%nmodes=length(curve(:,1)); %Number of FSM mode shapes for first mode, same
as number of lengths
%Determine FE number of nodes and increment
```

```
%Modify to a finer mesh:
    %original=nL=2*nele+1
nL=2*nele+1; %Number of FE nodes along the length
%Determine the node numbering increment along the length
if nnodes<100
    FEsection_increment=100; %so along the length the numbering goes up by
100's
else
    FEsection_increment=nnodes+1;
end

%NODAL COORDINATES IN FE FORM
%FEnode=[node# x y z] x is along the length
xincr=0;
for i=1:nL
    FEnode((i-1)*nnodes+1:(i-
1)*nnodes+nnodes,1)=node(:,1)+FEsection_increment*(i-1);
    %x in finite elements coordinate system
    FEnode((i-1)*nnodes+1:(i-1)*nnodes+nnodes,2)=xincr;
    %y in finite elements coordinate system
    FEnode((i-1)*nnodes+1:(i-1)*nnodes+nnodes,3)=node(:,3);
    %z in finite elements coordinate system
    FEnode((i-1)*nnodes+1:(i-1)*nnodes+nnodes,4)=node(:,2);
    xincr=xincr+L/(2*nele);
end
%
%ELEMENT DEFINITIONS
%Note, elements are done in strips, to reflect thickness or material
%changes which could exist in the FSM model. BUT! the S9R5 element used
%grabs the elements in pairs, so thickness or material should be the same
%for pairs of elements.
%Note
%Element Connectivity
%ABAQUS S9R5 for example
%       face3
%      4--7--3
%      |     |
%face4 8  9  6 face2
%      |     |
%      1--5--2
%       face1
%Go through the elements 2 at a time
closedcross=1;
if closedcross==1

    k=1; %counter for strip, i.e., strip along the length (group of 2 FSM
strips)
step=1;
for i=1:2:length(elem(:,1))-1
    for j=1:(nL-1)/2
        n1=elem(i,2);
        n2=elem(i+1,3);
        n3=elem(i+1,3) + 2*FEsection_increment;
        n4=elem(i,2)   + 2*FEsection_increment;
        n5=elem(i,3);
        n6=elem(i+1,3) + FEsection_increment;
        n7=elem(i,3)   + 2*FEsection_increment;
        n8=elem(i,2)   + FEsection_increment;
        n9=elem(i,3) + FEsection_increment;
        nnum=[n1 n2 n3 n4 n5 n6 n7 n8 n9]+(j-1)*2*FEsection_increment;
        enum=nnum(5);
        FEelem(step,:)=[enum nnum elem(i,5) k];
        step=step+1;
    end
    k=k+1;
end

% i=length(elem(:,1));
% %final closed segement
% for j=1:(nL-1)/2
%         n1=elem(i,2);
%         n2=elem(1,2);
%         n3=elem(1,2) + 2*FEsection_increment;
%         n4=elem(i,2)   + 2*FEsection_increment;
%         n5=elem(i,3);
%         n6=elem(1,2) + FEsection_increment;
%         n7=elem(i,3)   + 2*FEsection_increment;
%         n8=elem(i,2)   + FEsection_increment;
%         n9=elem(i,3) + FEsection_increment;
%         nnum=[n1 n2 n3 n4 n5 n6 n7 n8 n9]+(j-1)*2*FEsection_increment;
%         enum=nnum(5);
%         FEelem(step,:)=[enum nnum elem(i,5) k];
%         step=step+1;
% end


% FEelem
% stop

else

k=1; %counter for strip, i.e., strip along the length (group of 2 FSM strips)
step=1;
for i=1:2:length(elem(:,1))-1
    for j=1:(nL-1)/2
        n1=elem(i,2);
        n2=elem(i+1,3);
        n3=elem(i+1,3) + 2*FEsection_increment;
        n4=elem(i,2)   + 2*FEsection_increment;
        n5=elem(i,3);
        n6=elem(i+1,3) + FEsection_increment;
        n7=elem(i,3)   + 2*FEsection_increment;
        n8=elem(i,2)   + FEsection_increment;
        n9=elem(i,3) + FEsection_increment;
        nnum=[n1 n2 n3 n4 n5 n6 n7 n8 n9]+(j-1)*2*FEsection_increment;
        enum=nnum(5);
        FEelem(step,:)=[enum nnum elem(i,5) k];
        step=step+1;
    end
    k=k+1;
end
```

```
end

%ELEMENT THICKNESS AND MATERIAL NUMBER
k=1;
for i=1:2:length(elem(:,1))-1
    t(k)=elem(i,4);
    matnum(k)=elem(i,5);
    k=k+1;
end

%ELEMENT GROUPS
elemgroups=1:k-1;
```

Function: ***webassem.m***

```
function [FEn,FEe,webcon,numdiag,numnodes,pinend] = webassem(nodestack,
elemstack, tstack, sectdims, TC, FIRST, depth, BC, FH, SEAT, Ltc,
change,SPACE,GAP,H,N,FEn,FEe,ii,webcon,pinend)
%This function determines the node and element numbers for the web members
%in the joist

numnodes=3; %The number of nodes used for constraints of the web members (5
nodes corresponds to the first two elements)
%Change matrix values into their single values for easy use in this program
depth=depth(ii,1)+change;
TC=TC(ii,1);
FIRST=FIRST(ii,1);
BC=BC(ii,1);
FH=FH(ii,1);
SEAT=SEAT(ii,1);



%Member 1: the outermost member in the joist
%placement of each web member is based on the distance from the orgin of
%the TOP CHORD
%
%Make two scenarios, one if we are on the first joist, and another (when we
%will have a node list already) for the remaining joists
if ii==1
    %------Nodes for member 1-----
    nodes2=nodestack{2};
    for i=1:size(nodes2,1)
        theta=abs(atan(depth/BC))+pi;  %angle of web member
        length=(BC^2+depth^2)^.5; %length of the web member
        add=SEAT+SPACE; %additional x-value added to the web member
        FEn(i,1)=nodes2(i,1);   %node numbers
        FEn(i,2:3)=nodes2(i,2:3)*[cos(theta) -sin(theta); sin(theta)
cos(theta)];%Rotate x and y using matrix transformation
        FEn(i,2)=FEn(i,2)+add+abs(length*cos(theta)+2*abs(H(2)*sin(pi/2-
theta)));%Move the x-coordinate to the correct location
        FEn(i,3)=FEn(i,3)-abs(length*sin(theta))+change/2+abs(H(2)*cos(pi/2-
theta)); %y coordinate
        FEn(i,4)=nodes2(i,4); %z coordinate
    end

    %-----elements for member 1-----
    for i=1:size(elemstack{2},1)
       FEe(i,1)=i;
       FEe(i,2:10)=elemstack{2}(i,2:10); %Just add counter to FEe(i,2:10)
because it relates the elements to the relative node numbers
       FEe(i,11)=elemstack{2}(i,11);
       FEe(i,12)=elemstack{2}(i,12);
       FEe(i,13)=tstack{2}(1,1);
    end

    %-----Make node list to use for constraints-----
    for k=1:4 %for the four welds on each web member
        if k==1
            for j=1:numnodes
                constrain(j,:)=FEn(j,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn((N+j),:);
            end
        elseif k==2
            for j=1:numnodes
                constrain(j,:)=FEn((N-numnodes+j),:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn((N+N-numnodes+j),:);
            end
        elseif k==3
            rowcount=size(nodestack{2},1);
            for j=1:numnodes
                constrain(j,:)=FEn(rowcount-N+j,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn(rowcount-2*N+j,:);
            end
        else
            for j=1:numnodes
                constrain(j,:)=FEn(rowcount-numnodes+j,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn(rowcount-numnodes-N+j,:);
            end
        end
                webcon{k}=constrain;
    end
else
    %------Nodes for member 1-----
    nodes2=nodestack{2};
    counter=size(FEn,1);
    counter2=100000000*(ii-1);
    for i=1:size(nodes2,1)
        theta=abs(atan(depth/BC))+pi;  %angle of web member
        length=(BC^2+depth^2)^.5; %length of the web member
        add=SEAT+SPACE; %additional x-value added to the web member
        FEn(i+counter,1)=nodes2(i,1)+counter2;   %node numbers
        FEn(i+counter,2:3)=nodes2(i,2:3)*[cos(theta) -sin(theta); sin(theta)
cos(theta)];%Rotate x and y using matrix transformation

FEn(i+counter,2)=FEn(i+counter,2)+add+abs(length*cos(theta)+2*abs(H(2)*sin(pi
/2-theta)));%Move the x-coordinate to the correct location
        FEn(i+counter,3)=FEn(i+counter,3)-
abs(length*sin(theta))+change/2+abs(H(2)*cos(pi/2-theta)); %y coordinate
        FEn(i+counter,4)=nodes2(i,4); %z coordinate
    end

    %-----elements for member 1-----
    ecount=size(FEe,1);
    enum=FEe(ecount,1);
    for i=1:size(elemstack{2},1)
       FEe(i+ecount,1)=i+enum;
       FEe(i+ecount,2:10)=elemstack{2}(i,2:10)+counter2; %Just add counter to
FEe(i,2:10) because it relates the elements to the relative node numbers
       FEe(i+ecount,11)=elemstack{2}(i,11);
       FEe(i+ecount,12)=elemstack{2}(i,12);
       FEe(i+ecount,13)=tstack{2}(1,1);
    end

    %-----Make node list to use for constraints-----
    for k=1:4
        if k==1
            for j=1:numnodes
                constrain(j,:)=FEn(j+counter,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn((N+j+counter),:);
            end
        elseif k==2
            for j=1:numnodes
                constrain(j,:)=FEn((N-numnodes+j+counter),:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn((N+N-numnodes+j+counter),:);
            end
        elseif k==3
            rowcount=size(nodestack{2},1);
            for j=1:numnodes
                constrain(j,:)=FEn(rowcount-N+j+counter,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn(rowcount-2*N+j+counter,:);
            end
        else
            for j=1:numnodes
                constrain(j,:)=FEn(rowcount-numnodes+j+counter,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn(rowcount-numnodes-N+j+counter,:);
            end
        end
            cols=size(webcon);
            kk=cols(1,2);
            webcon{kk+1}=constrain;
    end

end

%plot profile to check
%     figure(2)
%     plot(FEn(:,2),FEn(:,3),'k.')

    %plot ZY plane
%     figure(3)
%     plot(FEn(:,3),FEn(:,4),'k.')

%CHECK 3D
%     figure(3)
%     plot3(FEn(:,2),FEn(:,4),FEn(:,3),'k.')

%Member 2: the 2nd outermost member in the joist

%-----nodes for member 2-----
nodes3=nodestack{3};
counter=size(FEn,1);
counter2=100000+100000000*(ii-1);
for i=1:size(nodes3,1)
    theta=pi+abs(atan(depth/(BC+SPACE-TC)));  %angle of web member
    length=((BC+SPACE-TC)^2+depth^2)^.5;
    add=SEAT+TC; %additional x-value added to the web member
    FEn(i+counter,1)=nodes3(i,1)+counter2;  %node numbers
    FEn(i+counter,2:3)=nodes3(i,2:3)*[cos(theta) -sin(theta); sin(theta)
cos(theta)];%Rotate x and y using matrix transformation

FEn(i+counter,2)=FEn(i+counter,2)+abs(length*cos(theta))+add+1/2*abs(H(3)*cos
(pi/2-theta)); %Move the x-coordinate to the correct location
    FEn(i+counter,3)=FEn(i+counter,3)-
abs(length*sin(theta))+change/2+1/2*abs(H(3)*sin(pi/2-theta));%y-coordinate
    FEn(i+counter,4)=nodes3(i,4); %z coordinate
end

%-----elements for member 2-----
ecount=size(FEe,1);
enum=FEe(ecount,1);
for i=1:size(elemstack{3},1)
   FEe(i+ecount,1)=(i+enum);
   FEe(i+ecount,2:10)=elemstack{3}(i,2:10)+counter2; %Just add counter to
FEe(i,2:10) because it relates the elements to the relative node numbers
   FEe(i+ecount,11)=elemstack{3}(i,11);
   FEe(i+ecount,12)=elemstack{3}(i,12);
   FEe(i+ecount,13)=tstack{3}(1,1);
end

    %-----Make node list to use for constraints-----
    for k=1:4
        if k==1
            for j=1:numnodes
                constrain(j,:)=FEn(j+counter,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn((N+j+counter),:);
            end
        elseif k==2
            for j=1:numnodes
                constrain(j,:)=FEn((N-numnodes+j+counter),:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn((N+N-numnodes+j+counter),:);
            end
        elseif k==3
            rowcount=size(nodestack{3},1);
            for j=1:numnodes
                constrain(j,:)=FEn(rowcount-N+j+counter,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn(rowcount-2*N+j+counter,:);
            end
        else
            for j=1:numnodes
                constrain(j,:)=FEn(rowcount-numnodes+j+counter,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn(rowcount-numnodes-N+j+counter,:);
            end
        end
            cols=size(webcon);
            kk=cols(1,2);
            webcon{kk+1}=constrain;
    end
%plot profile to check
%     figure(2)
%     plot(FEn(:,2),FEn(:,3),'k.')


%Member 3: the 3rd outermost member in the joist
%-----nodes for member 3-----
nodes4=nodestack{4};
counter=size(FEn,1);
counter2=counter2+100000;
for i=1:size(nodes4,1)
    theta=abs(atan(FH/depth))+pi/2;  %angle of web member
    length=(depth^2+FH^2)^.5;
    add=SEAT+FIRST-SPACE; %additional x-value added to the web member
    FEn(i+counter,1)=nodes4(i,1)+counter2;  %node numbers
    FEn(i+counter,2:3)=nodes4(i,2:3)*[cos(theta) -sin(theta); sin(theta)
cos(theta)];%Rotate x and y using matrix transformation
    FEn(i+counter,2)=FEn(i+counter,2)+add; %Move the x-coordinate to the
correct location
    FEn(i+counter,3)=FEn(i+counter,3)-change/2; %y coordinate
    FEn(i+counter,4)=nodes4(i,4); %z coordinate
end

%-----elements for member 3-----
ecount=size(FEe,1);
```

```
enum=FEe(ecount,1);
for i=1:size(elemstack{4},1)
   FEe(i+ecount,1)=(i+enum);
   FEe(i+ecount,2:10)=elemstack{4}(i,2:10)+counter2; %within element
   FEe(i+ecount,11)=elemstack{4}(i,11);
   FEe(i+ecount,12)=elemstack{4}(i,12);
   FEe(i+ecount,13)=tstack{4}(1,1);
end

%-----Make node list to use for constraints-----
    for k=1:4
        if k==1
            for j=1:numnodes
                constrain(j,:)=FEn(j+counter,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn((N+j+counter),:);
            end
        elseif k==2
            for j=1:numnodes
                constrain(j,:)=FEn((N-numnodes+j+counter),:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn((N+N-numnodes+j+counter),:);
            end
        elseif k==3
            rowcount=size(nodestack{4},1);
            for j=1:numnodes
                constrain(j,:)=FEn(rowcount-N+j+counter,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn(rowcount-2*N+j+counter,:);
            end
        else
            for j=1:numnodes
                constrain(j,:)=FEn(rowcount-numnodes+j+counter,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn(rowcount-numnodes-N+j+counter,:);
            end
        end
            cols=size(webcon);
            kk=cols(1,2);
            webcon{kk+1}=constrain;
    end

%plot profile to check
%     figure(2)
%     plot(FEn(:,2),FEn(:,3),'k.')


%Member 5: the 45 degree pieces of the joist -- and additional web members
%in this same orientation

numdiag=round(((Ltc-2*SEAT-2*FIRST)/(depth))*1/2); %the number of diagonals
in the joist (for each 45 degree orientation)
```

```
%this may need to change, this is not exact and my not be applicable to all
%joists

%-----nodes for these members-----
 nodes1=nodestack{1};
 counter=size(FEn,1);
 counter2=counter2+100000; %Before node
for j=1:numdiag
    for i=1:size(nodes1,1)
        theta=pi/2+atan(1);  %angle of web member
        length=sqrt(2*depth^2);
        add=SEAT+FIRST+(depth+GAP)*2+2*(depth+GAP)*(j-1); %additional x-value
added to the web member
        FEn(i+counter,1)=nodes1(i,1)+counter2;  %within node
        FEn(i+counter,2:3)=nodes1(i,2:3)*[cos(theta) -sin(theta); sin(theta)
cos(theta)];%Rotate x and y using matrix transformation
        FEn(i+counter,2)=FEn(i+counter,2)+add; %Move the x-coordinate to the
correct location
        FEn(i+counter,3)=FEn(i+counter,3)-change/2;%y coordinate
        FEn(i+counter,4)=nodes1(i,4); %z coordinate
    end

        %plot profile to check
%         figure(2)
%         plot(FEn(:,2),FEn(:,3),'k.')

%-----elements for these members-----
    ecount=size(FEe,1);
    enum=FEe(ecount,1);
        for i=1:size(elemstack{1},1)
           FEe(i+ecount,1)=(i+enum);
           FEe(i+ecount,2:10)=elemstack{1}(i,2:10)+counter2; %within element
           FEe(i+ecount,11)=elemstack{1}(i,11);
           FEe(i+ecount,12)=elemstack{1}(i,12);
           FEe(i+ecount,13)=tstack{1}(1,1);
        end
    counter2=counter2+100000; %Before node


    %-----Make node list to use for constraints-----
    for k=1:4
        if k==1
            for j=1:numnodes
                constrain(j,:)=FEn(j+counter,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn((N+j+counter),:);
            end
        elseif k==2
            for j=1:numnodes
                constrain(j,:)=FEn((N-numnodes+j+counter),:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn((N+N-numnodes+j+counter),:);
            end
        elseif k==3
```

```
            rowcount=size(nodestack{1},1);
            for j=1:numnodes
                constrain(j,:)=FEn(rowcount-2*N+j+counter,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn(rowcount-3*N+j+counter,:);
            end
        else
            for j=1:numnodes
                constrain(j,:)=FEn(rowcount-numnodes-N+j+counter,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn(rowcount-numnodes-
2*N+j+counter,:);
            end
        end
            cols=size(webcon);
            kk=cols(1,2);
            webcon{kk+1}=constrain;
    end

    counter=size(FEn,1); %Change counter for the next iteration

end

%plot profile to check
%     figure(2)
%     plot(FEn(:,2),FEn(:,3),'k.')



%Member 6: the 45 degree pieces of the joist (facing the opposite way)
nodes1=nodestack{1};
counter=size(FEn,1);
counter2=counter2+100000; %Before node
for j=1:numdiag
    for i=1:size(nodes1,1)
        theta=pi+atan(1);  %angle of web member
        length=sqrt(2*depth^2);
        add=SEAT+FIRST+2*(depth+GAP)*(j-1); %additional x-value added to the
web member
        FEn(i+counter,1)=nodes1(i,1)+counter2;  %within node
        FEn(i+counter,2:3)=nodes1(i,2:3)*[cos(theta) -sin(theta); sin(theta)
cos(theta)];%Rotate x and y using matrix transformation

FEn(i+counter,2)=FEn(i+counter,2)+abs(length*cos(theta))+add+H(1)*0.707;
%Move the x-coordinate to the correct location
        FEn(i+counter,3)=FEn(i+counter,3)-abs(length*sin(theta))+change;
        FEn(i+counter,4)=nodes1(i,4); %z coordinate
    end

%         %plot profile to check
%         figure(2)
%         plot(FEn(:,2),FEn(:,3),'k.')

    %-----elements for these members-----
    ecount=size(FEe,1);
    enum=FEe(ecount,1);
        for i=1:size(elemstack{1},1)
           FEe(i+ecount,1)=(i+enum);
           FEe(i+ecount,2:10)=elemstack{1}(i,2:10)+counter2; %within element
           FEe(i+ecount,11)=elemstack{1}(i,11);
           FEe(i+ecount,12)=elemstack{1}(i,12);
           FEe(i+ecount,13)=tstack{1}(1,1);
        end
        counter2=counter2+100000; %Before node

    %-----Make node list to use for constraints-----
    for k=1:4
        if k==1
            for j=1:numnodes
                constrain(j,:)=FEn(j+counter,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn((N+j+counter),:);
            end
        elseif k==2
            for j=1:numnodes
                constrain(j,:)=FEn((N-numnodes+j+counter),:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn((N+N-numnodes+j+counter),:);
            end
        elseif k==3
            rowcount=size(nodestack{1},1);
            for j=1:numnodes
                constrain(j,:)=FEn(rowcount-2*N+j+counter,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn(rowcount-3*N+j+counter,:);
            end
        else
            for j=1:numnodes
                constrain(j,:)=FEn(rowcount-numnodes-N+j+counter,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn(rowcount-numnodes-
2*N+j+counter,:);
            end
        end
            cols=size(webcon);
            kk=cols(1,2);
            webcon{kk+1}=constrain;
    end

    counter=size(FEn,1);

end

%plot profile to check
%     figure(2)
%     plot(FEn(:,2),FEn(:,3),'k.')
```

```
%additional amount to be taken out of joist
sub=numdiag*GAP;

%Member 8: the 3rd outermost member in the joist on the far side
nodes4=nodestack{4};
counter=size(FEn,1);
counter2=counter2+100000; %Before node
for i=1:size(nodes4,1)
    theta=pi+abs(atan(depth/FH));  %angle of web member
    length=sqrt(depth^2+FH^2);
    add=Ltc-SEAT-FIRST-sub+2*SPACE; %additional x-value added to the web
member
    FEn(i+counter,1)=nodes4(i,1)+counter2;  %within node
    FEn(i+counter,2:3)=nodes4(i,2:3)*[cos(theta) -sin(theta); sin(theta)
cos(theta)];%Rotate x and y using matrix transformation
    FEn(i+counter,2)=FEn(i+counter,2)+abs(length*cos(theta))+add; %Move the
x-coordinate to the correct location
    FEn(i+counter,3)=FEn(i+counter,3)-abs(length*sin(theta))+change/2;
    FEn(i+counter,4)=nodes4(i,4); %z coordinate
end

%-----elements for this member-----
ecount=size(FEe,1);
enum=FEe(ecount,1);
for i=1:size(elemstack{4},1)
   FEe(i+ecount,1)=(i+enum);
   FEe(i+ecount,2:10)=elemstack{4}(i,2:10)+counter2; %within element
   FEe(i+ecount,11)=elemstack{4}(i,11);
   FEe(i+ecount,12)=elemstack{4}(i,12);
   FEe(i+ecount,13)=tstack{4}(1,1);
end

    %-----Make node list to use for constraints-----
    for k=1:4
        if k==1
            for j=1:numnodes
                constrain(j,:)=FEn(j+counter,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn((N+j+counter),:);
            end
        elseif k==2
            for j=1:numnodes
                constrain(j,:)=FEn((N-numnodes+j+counter),:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn((N+N-numnodes+j+counter),:);
            end
        elseif k==3
            rowcount=size(nodestack{4},1);
            for j=1:numnodes
                constrain(j,:)=FEn(rowcount-N+j+counter,:);
            end
            for j=1:numnodes
```

```
                constrain(j+numnodes,:)=FEn(rowcount-2*N+j+counter,:);
            end
        else
            for j=1:numnodes
                constrain(j,:)=FEn(rowcount-numnodes+j+counter,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn(rowcount-numnodes-N+j+counter,:);
            end
        end
            cols=size(webcon);
            kk=cols(1,2);
            webcon{kk+1}=constrain;
    end

%plot profile to check
%     figure(2)
%     plot(FEn(:,2),FEn(:,3),'k.')

%Member 9: the 2nd outermost member in the joist on the far side

%-----nodes for this member-----
nodes3=nodestack{3};
counter=size(FEn,1);
counter2=counter2+100000; %Before node
for i=1:size(nodes3,1)
    theta=pi/2+abs(atan((BC+SPACE-TC)/depth));  %angle of web member
    length=sqrt((BC+SPACE-TC)^2+depth^2);
    add=Ltc-SEAT-TC-sub; %additional x-value added to the web member
    FEn(i+counter,1)=nodes3(i,1)+counter2;  %within node
    FEn(i+counter,2:3)=nodes3(i,2:3)*[cos(theta) -sin(theta); sin(theta)
cos(theta)];%Rotate x and y using matrix transformation
    FEn(i+counter,2)=FEn(i+counter,2)+add+1/2*abs(H(3)*cos(pi/2-theta));
%Move the x-coordinate to the correct location
    FEn(i+counter,3)=FEn(i+counter,3)-change/2+1/2*abs(H(3)*sin(pi/2-theta));
%y coordinate
    FEn(i+counter,4)=nodes3(i,4); %z coordinate
end

%-----elements for this member-----
ecount=size(FEe,1);
enum=FEe(ecount,1);
for i=1:size(elemstack{3},1)
   FEe(i+ecount,1)=(i+enum);
   FEe(i+ecount,2:10)=elemstack{3}(i,2:10)+counter2; %within element
   FEe(i+ecount,11)=elemstack{3}(i,11);
   FEe(i+ecount,12)=elemstack{3}(i,12);
   FEe(i+ecount,13)=tstack{3}(1,1);
end

    %-----Make node list to use for constraints-----
    for k=1:4
        if k==1
            for j=1:numnodes
                constrain(j,:)=FEn(j+counter,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn((N+j+counter),:);
            end
        elseif k==2
            for j=1:numnodes
                constrain(j,:)=FEn((N-numnodes+j+counter),:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn((N+N-numnodes+j+counter),:);
            end
        elseif k==3
            rowcount=size(nodestack{3},1);
            for j=1:numnodes
                constrain(j,:)=FEn(rowcount-N+j+counter,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn(rowcount-2*N+j+counter,:);
            end
        else
            for j=1:numnodes
                constrain(j,:)=FEn(rowcount-numnodes+j+counter,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn(rowcount-numnodes-N+j+counter,:);
            end
        end
            cols=size(webcon);
            kk=cols(1,2);
            webcon{kk+1}=constrain;
    end

%plot profile to check
%     figure(2)
%     plot(FEn(:,2),FEn(:,3),'k.')


%Member 10: the 1st outermost member in the joist on the far side

%-----nodes for this member-----
nodes2=nodestack{2};
counter=size(FEn,1);
counter2=counter2+100000; %Before node
for i=1:size(nodes2,1)
    theta=pi/2+abs(atan(BC/depth));  %angle of web member
    length=sqrt(depth^2+BC^2);
    add=Ltc-SEAT-sub; %additional x-value added to the web member
    FEn(i+counter,1)=nodes2(i,1)+counter2;  %within node
    FEn(i+counter,2:3)=nodes2(i,2:3)*[cos(theta) -sin(theta); sin(theta)
cos(theta)];%Rotate x and y using matrix transformation
    FEn(i+counter,2)=FEn(i+counter,2)+add+abs(H(2)*cos(pi/2-theta)); %Move
the x-coordinate to the correct location
    FEn(i+counter,3)=FEn(i+counter,3); %y coordinate
    FEn(i+counter,4)=nodes2(i,4); %z coordinate
end
%
```

```
%-----elements for this member-----
ecount=size(FEe,1);
enum=FEe(ecount,1);
for i=1:size(elemstack{2},1)
   FEe(i+ecount,1)=(i+enum);
   FEe(i+ecount,2:10)=elemstack{2}(i,2:10)+counter2; %within element
   FEe(i+ecount,11)=elemstack{2}(i,11);
   FEe(i+ecount,12)=elemstack{2}(i,12);
   FEe(i+ecount,13)=tstack{2}(1,1);
end

    %-----Make node list to use for constraints-----
    for k=1:4
        if k==1
            for j=1:numnodes
                constrain(j,:)=FEn(j+counter,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn((N+j+counter),:);
            end
        elseif k==2
            for j=1:numnodes
                constrain(j,:)=FEn((N-numnodes+j+counter),:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn((N+N-numnodes+j+counter),:);
            end
        elseif k==3
            rowcount=size(nodestack{2},1);
            for j=1:numnodes
                constrain(j,:)=FEn(rowcount-N+j+counter,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn(rowcount-2*N+j+counter,:);
            end
        else
            for j=1:numnodes
                constrain(j,:)=FEn(rowcount-numnodes+j+counter,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn(rowcount-numnodes-N+j+counter,:);
            end
        end
            cols=size(webcon);
            kk=cols(1,2);
            webcon{kk+1}=constrain;
    end

%plot profile to check
%     figure(2)
%     plot(FEn(:,2),FEn(:,3),'k.')


%Member 11: the VERTICAL pieces on the first 1/2 of the joist
%-----NODES for these members-----
```

```
numvert=round(numdiag*1/2); %number of vertical web members per 1/2 span (it
is equal to half of the number if diagonal members)
nodes5=nodestack{5};

for j=1:numvert
    counter=size(FEn,1);
    counter2=counter2+100000; %Before node
        for i=1:size(nodes5,1)
                theta=pi/2;  %angle of web member
                add=SEAT+FIRST+GAP+depth+2*(depth+GAP)*(j-1)+H(5)/2;
%additional x-value added to the web member
                FEn(i+counter,1)=nodes5(i,1)+counter2;  %within node
                FEn(i+counter,2:3)=nodes5(i,2:3)*[cos(theta) -sin(theta);
sin(theta) cos(theta)];%Rotate x and y using matrix transformation
                FEn(i+counter,2)=FEn(i+counter,2)+add; %Move the x-coordinate
to the correct location
                FEn(i+counter,3)=FEn(i+counter,3); %y coordinate
                FEn(i+counter,4)=nodes5(i,4); %z coordinate
        end

        %-----elements for this member-----
        ecount=size(FEe,1);
        enum=FEe(ecount,1);
        for i=1:size(elemstack{5},1)
           FEe(i+ecount,1)=(i+enum);
           FEe(i+ecount,2:10)=elemstack{5}(i,2:10)+counter2; %within element
           FEe(i+ecount,11)=elemstack{5}(i,11);
           FEe(i+ecount,12)=elemstack{5}(i,12);
           FEe(i+ecount,13)=tstack{5}(1,1);
        end

    %-----Make node list to use for constraints-----
    for k=1:4
        if k==1
            for j=1:numnodes
                constrain(j,:)=FEn(j+counter,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn((N+j+counter),:);
            end
        elseif k==2
            for j=1:numnodes
                constrain(j,:)=FEn((N-numnodes+j+counter),:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn((N+N-numnodes+j+counter),:);
            end
        elseif k==3
            rowcount=size(nodestack{5},1);
            for j=1:numnodes
                constrain(j,:)=FEn(rowcount-N+j+counter,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn(rowcount-2*N+j+counter,:);
            end
        else
```

```
            for j=1:numnodes
                constrain(j,:)=FEn(rowcount-numnodes+j+counter,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn(rowcount-numnodes-N+j+counter,:);
            end
        end
            cols=size(webcon);
            kk=cols(1,2);
            webcon{kk+1}=constrain;
    end

    %plot profile to check
%     figure(2)
%     plot(FEn(:,2),FEn(:,3),'k.')

end



%Member 12: the vertical pieces on the second 1/2 of the joist
%-----NODES for these members-----
nodes5=nodestack{5};

%Determine if there is an odd or even number of vertical pieces for placement
if mod(numdiag,2)==0
    numvert=numvert;
    addvert=numvert;
else
    addvert=numvert;
    numvert=numvert-1;
end

for j=1:numvert  %this may need to change if there is an uneven amount of
vertical pieces
    counter=size(FEn,1);
    counter2=counter2+100000; %Before node
        for i=1:size(nodes5,1)
                theta=3*pi/2;  %angle of web member

add=SEAT+FIRST+2*GAP+SPACE+depth+2*addvert*(GAP+depth)+2*(GAP+depth)*(j-1)-
H(5)/2; %additional x-value added to the web member
                FEn(i+counter,1)=nodes5(i,1)+counter2;  %within node
                FEn(i+counter,2:3)=nodes5(i,2:3)*[cos(theta) -sin(theta);
sin(theta) cos(theta)];%Rotate x and y using matrix transformation
                FEn(i+counter,2)=FEn(i+counter,2)+add+H(5)*3/4; %Move the x-
coordinate to the correct location
                FEn(i+counter,3)=FEn(i+counter,3)-depth;
                FEn(i+counter,4)=nodes5(i,4); %z coordinate
        end

        %-----elements for this member-----
        ecount=size(FEe,1);
        enum=FEe(ecount,1);
        for i=1:size(elemstack{5},1)
           FEe(i+ecount,1)=(i+enum);
           FEe(i+ecount,2:10)=elemstack{5}(i,2:10)+counter2; %within element
           FEe(i+ecount,11)=elemstack{5}(i,11);
           FEe(i+ecount,12)=elemstack{5}(i,12);
           FEe(i+ecount,13)=tstack{5}(1,1);
        end

    %-----Make node list to use for constraints-----
    for k=1:4
        if k==1
            for j=1:numnodes
                constrain(j,:)=FEn(j+counter,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn((N+j+counter),:);
            end
        elseif k==2
            for j=1:numnodes
                constrain(j,:)=FEn((N-numnodes+j+counter),:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn((N+N-numnodes+j+counter),:);
            end
        elseif k==3
            rowcount=size(nodestack{5},1);
            for j=1:numnodes
                constrain(j,:)=FEn(rowcount-N+j+counter,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn(rowcount-2*N+j+counter,:);
            end
        else
            for j=1:numnodes
                constrain(j,:)=FEn(rowcount-numnodes+j+counter,:);
            end
            for j=1:numnodes
                constrain(j+numnodes,:)=FEn(rowcount-numnodes-N+j+counter,:);
            end
        end
            cols=size(webcon);
            kk=cols(1,2);
            webcon{kk+1}=constrain;
    end

    %plot profile to check
%     figure(2)
%     plot(FEn(:,2),FEn(:,3),'k.')
end

%-----------------Plot to check----------------
    %plot profile
%     figure(2)
%     plot(FEn(:,2),FEn(:,3),'k.')

    %plot 3D to see extrusion along the length of the member
%     figure(1)
%     plot3(FEn(:,2),FEn(:,4),FEn(:,3),'k.')
```

```
%For the pinned boundary condition at the far end, determine where the seat
%should start
if ii==1 %Only for the first iteration, because if after that FEn contains
all the nodes from the first joist including the chord members which will
extend past this point
    pinend=max(FEn(:,2));%Maximum x-coordinate
end

end
```

Function: ***SPACERassem.m***

```
function
[FEn,FEe,TCbatpos,BCbatpos,numbattens]=SPACERassem(nodestack,FEn,FIRST,SEAT,d
epth,GAP,FEe,elemstack,tstack,Ltc,webcon,N,H,numdiag,ii)
%Add the nodes and elements for the bottom chord into the GLOBAL node and
%element matrices

numnodes=5; %The number of nodes used for the spacer constraints

%The number of spacers changes based on the design of each joist. The
%following is a general equation that inserts battens in the same manner as
%the 24K4 joists, it should be changed for designs that use a different
%algorithm for battens
numbattens=2*(numdiag-4); %the number of spacers for the TC ONLY!!!!!

%spacer members
%-----NODES FOR THE CHORD MEMBERS-----
batten1=nodestack{1};
%We need to swap the x and z coordinates of the spacer to account for its
%orientation
holder(:,1)=batten1(:,2);
batten1(:,2)=batten1(:,4);
batten1(:,4)=holder(:,1);

for j=1:numbattens
    for i=1:size(batten1,1)
        MPCbat(i,1)=batten1(i,1);

MPCbat(i,2)=batten1(i,2)+FIRST(ii)+SEAT(ii)+depth(ii)*4.5+6*GAP+(depth(ii)+GA
P)*(j-1)+1;  %x coordinate
        MPCbat(i,3)=batten1(i,3);  %y coordinate
        MPCbat(i,4)=batten1(i,4); %z coordinate plus the gap in between the
chord
    end
    TCbatpos{j}=MPCbat;
end



%-----SPACERS IN THE BC-----
for j=1:1  %For this design there is only one spacer in the BC
```

```
    for i=1:size(batten1,1)
        MPCbat(i,1)=batten1(i,1);  %within node
        MPCbat(i,2)=batten1(i,2)+Ltc/2+2*(depth(ii)+GAP)*(j-1);  %x
coordinate
        MPCbat(i,3)=batten1(i,3)-depth(ii)+H;  %y coordinate
        MPCbat(i,4)=batten1(i,4); %z coordinate plus the gap in between the
chord
    end
        BCbatpos{j}=MPCbat;
end



%OLD STUFF USING *FASTENER (DIDN'T WORK) THAT IS GOOD TO KEEP JUST IN CASE:

%-----SPACERS IN THE TC-----
%The following was from using fasteners
% for j=1:numbattens
%     counter=size(FEn,1);
%     counter2=100000000+1000000*j; %Before node
%     for i=1:size(batten1,1)
%         FEn(i+counter,1)=batten1(i,1)+counter2;  %within node
%
FEn(i+counter,2)=batten1(i,2)+FIRST+SEAT+depth*4.5+6*GAP+(depth+GAP)*(j-1);
%x coordinate
%         FEn(i+counter,3)=batten1(i,3);  %y coordinate
%         FEn(i+counter,4)=batten1(i,4); %z coordinate plus the gap in
between the chord
%     end



    %Plot battens to check
%     figure(7)
%     plot(FEn(:,2),FEn(:,3),'k.')

%CHECK 3D
%     figure(3)
%     plot3(FEn(:,2),FEn(:,4),FEn(:,3),'k.')


%NODE LIST USED FOR CONSTRAINTS FOR *FASTENER
    %-----Make node list to use for constraints-----
%     for k=1:4
%         if k==1
%             for l=1:numnodes
%                 constrain(l,:)=FEn(l+counter,:);
%             end
% %             for l=1:numnodes
% %                 constrain(l+numnodes,:)=FEn((N+l+counter),:);
% %             end
%         elseif k==2
%             for l=1:numnodes
%                 constrain(l,:)=FEn((N-numnodes+l+counter),:);
%             end
% %             for l=1:numnodes
% %                 constrain(l+numnodes,:)=FEn((N+N-
numnodes+l+counter+1),:);
% %             end
%         elseif k==3
%             rowcount=size(batten1,1); %CHANGE
%             for l=1:numnodes
%                 constrain(l,:)=FEn(rowcount-N+l+counter+1,:);
%             end
% %             for l=1:numnodes
% %                 constrain(l+numnodes,:)=FEn(rowcount-2*N+l+counter,:);
% %             end
%         else
%             for l=1:numnodes
%                 constrain(l,:)=FEn(rowcount-numnodes+l+counter,:);
%             end
% %             for l=1:numnodes
% %                 constrain(l+numnodes,:)=FEn(rowcount-numnodes-
N+l+counter-1,:);
% %             end
%         end
%             xbc=size(webcon);
%             next=xbc(1,2);
%             webcon{next+1}=constrain;
%     end

    %Elements used for this chord for *fastener
    %-----elements for this chord-----
%     ecount=size(FEe,1);
%     enum=FEe(ecount,1);
%     for i=1:size(elemstack{1},1)
%        FEe(i+ecount,1)=(i+enum);
%        FEe(i+ecount,2:10)=elemstack{1}(i,2:10)+counter2; %within element
%        FEe(i+ecount,11)=elemstack{1}(i,11);
%        FEe(i+ecount,12)=elemstack{1}(i,12);
%        FEe(i+ecount,13)=tstack{1}(1,1);
%     end
%
% end




% %-----SPACERS IN THE BC-----
% for j=1:1  %For this design there is only one spacer in the BC
%     counter=size(MPCbat,1);
%     counter2=2000000*j; %Before node
%     for i=1:size(batten1,1)
%         FEn(i+counter,1)=batten1(i,1)+counter2;  %within node
%         FEn(i+counter,2)=batten1(i,2)+Ltc/2+2*(depth+GAP)*(j-1);  %x
coordinate
%         FEn(i+counter,3)=batten1(i,3)-depth+H;  %y coordinate
%         FEn(i+counter,4)=batten1(i,4); %z coordinate plus the gap in
between the chord
%     end
%
%     %Plot spacers to check
% %     figure(7)
% %     plot(FEn(:,2),FEn(:,3),'k.')
%
% %CHECK 3D
% %     figure(3)
% %     plot3(FEn(:,2),FEn(:,4),FEn(:,3),'k.')
%
%     %-----Make node list to use for constraints-----
%     for k=1:4
%         if k==1
%             for l=1:numnodes
%                 constrain(l,:)=FEn(l+counter,:);
%             end
% %             for l=1:numnodes
% %                 constrain(l+numnodes,:)=FEn((N+l+counter-1),:);
% %             end
%         elseif k==2
%             for l=1:numnodes
%                 constrain(l,:)=FEn((N-numnodes+l+counter),:);
%             end
% %             for l=1:numnodes
% %                 constrain(l+numnodes,:)=FEn((N+N-numnodes+l+counter-
1),:);
% %             end
%         elseif k==3
%             rowcount=size(batten1,1); %CHANGE
%             for l=1:numnodes
%                 constrain(l,:)=FEn(rowcount-N+l+counter+1,:);
%             end
% %             for l=1:numnodes
% %                 constrain(l+numnodes,:)=FEn(rowcount-2*N+l+counter-1,:);
% %             end
%         else
%             for l=1:numnodes
%                 constrain(l,:)=FEn(rowcount-numnodes+l+counter,:);
%             end
% %             for l=1:numnodes
% %                 constrain(l+numnodes,:)=FEn(rowcount-numnodes-
N+l+counter-1,:);
% %             end
%         end
%             xbc=size(webcon);
%             next=xbc(1,2);
%             webcon{next+1}=constrain;
%     end
%
%
%     %-----elements for this chord-----
%     ecount=size(FEe,1);
%     enum=FEe(ecount,1);
%     for i=1:size(elemstack{1},1)
%        FEe(i+ecount,1)=(i+enum);
%        FEe(i+ecount,2:10)=elemstack{1}(i,2:10)+counter2; %within element
%        FEe(i+ecount,11)=elemstack{1}(i,11);
%        FEe(i+ecount,12)=elemstack{1}(i,12);
%        FEe(i+ecount,13)=tstack{1}(1,1);
%     end
%
```

```
% end

end
```

Function: *TCxy3.m*

```
function [geomfinal]=TCxy3(dims)

%LTC
%March 2011
%Takes out to out dimensions and corner angles of components of the cross
%section of a joist and converts them to xy coordinates for use in CUFSM

%To measure F you can find the angle of each segment from vertical (H & W)
%then determine the difference between the two.  The difference = F

% [W3, H3, t3, R3, F3, W4, H4, t4, R4, F4, S2, d]
%input dims for practice
% dims=[4 4 0.25 0.25 80 4 4 0.25 0.25 80 1 24];

%Cross-section dimension
%
%               S2
%   ___W4____R4    R5____W3____
%         F4/        \F3                                    |
%          /          \                                     |
%         /H4        H3\                                    |
%        /              \                                   |
%       /                \                                  |
%      t4                 t3                                |
%                                                           |
%                                                           d
%                                                           |
%                                                           |
%      t2                t1                                 |
%       \               /                                   |
%        \             /                                    |
%         \H2       H1 /             ^                      |
%          \         /               |                      |
%           \       /            y-axis                     |
%   _______F2\R2  R1/_F1_______      |__z-axis__>           |
%      W2       S1      W1

% [W3, H3, t3, R3, F3, W4, H4,
% t4, R4, F4, S2, d]
W3=dims(1);
H3=dims(2);
t3=dims(3);
R3=dims(4);
F3=dims(5)*pi/180;
W4=dims(6);
H4=dims(7);
t4=dims(8);
```

```
R4=dims(9);
F4=dims(10)*pi/180;
S2=dims(11);
d=dims(12);

%orgin is intersection of H1-line and W1-line

%r=the centerline radius of the angle
r3=R3-t3/2;

%(x9,y9) represents the beginning of the radius of the W-3 leg
xx3=0;
yy3=d;

x9=R3/tan(F3/2);
y9=yy3-t3/2;

%(xc3, yc3) represents the center of the arc 3
xc3=x9;
yc3=y9-r3;

%(x10,y10) represents the beginning of the radius on the H3-leg
 G3=pi-F3;

    if G3<=pi/2
        x10=xc3-r3*sin(G3);
        y10=yc3+r3*cos(G3);
    else
        x10=xc3-r3*cos(G3-pi/2);
        y10=yc3-r3*sin(G3-pi/2);
    end

%(x11,y11) represents the centerline point at the end of length W3
x11=xx3+W3;
y11=yy3-t3/2;

%(x12,y12) represents the centerline point at the end of length H3
x12=xx3+H3*cos(F3)+t3/2*sin(F3);
y12=yy3-H3*sin(F3)+t3/2*cos(F3);


%transform into CUFSM format
geom=[ x9 y9
       x10 y10
       x11 y11
       x12 y12];

 %plot the points to check
%  figure(1)
%  plot(geom(:,1),geom(:,2),'k.');

geomfinal=geom;
```

Function: *TCcross3.m*

```
function [node,elem]=TCcross(geom,dims,kipin, n)

%geom gives the xy-coordinates of each of the four nodes previously defined

%DETERMINES THE NODE NUMBERS FOR THE TOP CHORD (angles "3" and "4")

% [W3, H3, t3, R3, F3, W4, H4, t4, R4, F4, S2, d]

%Cross-section dimensions
%
%               S2
%   ___W4____R4    R5____W3____
%         F4/        \F3                                    |
%          /          \                                     |
%         /H4        H3\                                    |
%        /              \                                   |
%       /                \                                  |
%      t4                 t3                                |
%                                                           |
%                                                           d
%                                                           |
%                                                           |
%      t2                t1                                 |
%       \                /                                  |
%        \              /                                   |
%         \H2       H1 /             ^                      |
%          \          /              |                      |
%           \        /            y-axis                    |
%   _______F2\R2  R1/_F1_______      |__x-axis__>           |
%      W2        S1      W1


%input dims for practice
% dims=[4 4 0.25 0.25 80 4 4 0.25 0.25 80 1 24];
% n=[4 4 4];
%  geom =[0.2979   23.8750
%         0.1748   23.7283
%         4.0000   23.8750
%         0.8177   20.0825
%        -1.2979   23.8750
%        -1.1748   23.7283
%        -5.0000   23.8750
%        -1.8177   20.0825];
%  kipin=1;
%
%input section dimensions from chordin
W3=dims(1);
H3=dims(2);
t3=dims(3);
R3=dims(4);
F3=dims(5)*pi/180;
W4=dims(6);
H4=dims(7);
```

```
t4=dims(8);
R4=dims(9);
F4=dims(10)*pi/180;
S2=dims(11);
d=dims(12);

r3=R3-t3/2;
r4=R4-t4/2;

%use 'chordin' to input the number of nodes wanted along each part of the
%section from matrix n
%
%anglemesh for H
MESH1=n(1,1);
%anglemesh for radius
MESH2=n(1,2);
%anglemesh for W
MESH3=n(1,3);

%        ----------NOW CREATE NODE NUMBERS FOR ANGLE3----------

%Determine the node numbers for the W3 leg
lengthW3=(geom(3,1)-geom(1,1));
for j=1:1:MESH3+1
    node(j,1)=j;
    node(j,2)=geom(3,1)-lengthW3/n(1,3)*(j-1);
    node(j,3)= geom(3,2);
end

%Determine the node numbers for the radius
%Alter the radius based on "chord method"
%xo3, yo3 is the center of the radius for angle 3
%The program uses the length from the center point (radius) and the angle
%from the center point to determine the coordinates of each node
xo3=geom(1,1);
yo3=geom(1,2)-r3;

for j=1:1:MESH2

    node(j+MESH3+1,1)=j+MESH3+1;

    G3=j*((pi-F3)/MESH2);

    if G3<=pi/2
        node(j+MESH3+1,2)=xo3-r3*sin(G3);
        node(j+MESH3+1,3)=yo3+r3*cos(G3);
    else
        node(j+MESH3+1,2)=xo3-r3*cos(G3-pi/2);
        node(j+MESH3+1,3)=yo3-r3*sin(G3-pi/2);
    end

end

%Determine the node numbers for the top leg of the section
%based on the distance from the top of the radius to the top of the section
```

```
lengthH3=((geom(4,1)-geom(2,1))^2+(geom(4,2)-geom(2,2))^2)^0.5;

for j=1:1:MESH1;
        node(j+MESH3+MESH2+1,1)=j+MESH3+MESH2+1;
        node(j+MESH3+MESH2+1,2)=geom(2,1)+(j*lengthH3/(MESH1))*cos(F3);
        node(j+MESH3+MESH2+1,3)=geom(2,2)-(j*lengthH3/(MESH1))*sin(F3);
end

%Check node to see if it is the correct format
%node

%plot node to check the full cross section (angles 1, 2, and 3)
% figure(2)
% plot(node(:,2), node(:,3),'k.')


%                ----------CREATE ELEMENTS FOR ANGLE 3----------
%(element number, node i, node j, thickness, 100)

for i=1:(size(node,1)-1)
   elem(i,:)=[i i i+1 t3 100];
end

%set some default properties
if kipin==1
prop=[100 29500 29500 0.3 0.3 29500/(2*(1+0.3))];
else
prop=[100 203000 203000 0.3 0.3 203000/(2*(1+0.3))];
end

% check node
% node
% check elem
%  elem
```

Function: ***TCassem3.m***

```
function
[FEn,FEe,nodeBC,TCload,BP,TCbat,cLoad,CHORDcon,CHORDcount,RR,EF]=TCassem3(nod
estack,elemstack,tstack,FEn,FEe,s,depth,change,SEAT,Ltc,N,n,BracePts,TCbatpos
,numbattens,LOAD_TYPE,webcon,W,ii,cLoad,TCload,nodeBC,BP,TCbat,CHORDcount,pin
end,FCL,clip_space,RR,EF)
%Assemble the TC nodes and elements into the GLOBAL FEnode and FEelement

%Change matrix values into their single values for easy use in this program
depth=depth(ii,1);
SEAT=SEAT(ii,1);

%Chord members
%---------------------NODES FOR THE CHORD MEMBERS---------------------
chord1=nodestack{1};
counter=size(FEn,1);
```

```
begloop=size(FEn,1)+1;%Determine where the first node in the TC is
counter2=10000000+100000000*(ii-1); %Before node

%Determine the number of nodes to be looped within the SEAT to
%establish a boundary condition
%default:less=1
less=1.0;%the distance subtracted from SEAT to terminate the loop that
determines the amount of nodes at the boundary condition
support=SEAT+less;%The length of chord involved at the support

for i=1:size(chord1,1)
    FEn(i+counter,1)=chord1(i,1)+counter2;  %within node
    FEn(i+counter,2)=chord1(i,2);  %x coordinate
    FEn(i+counter,3)=chord1(i,3)-depth;  %y coordinate
    FEn(i+counter,4)=chord1(i,4)+s; %z coordinate plus the gap in between the
chord

    %Write a loop to determine at which node the seat ends in the TC (at
    %the beginning of the TC)
    x=FEn(i+counter,2);
    begseat=FEn(1+counter,1);
    if x<support
        endseat=FEn(i+counter,1);
        endloop=size(FEn,1);
    end

end

%-------------------------------ELEMENTS------------------------------
ecount=size(FEe,1);
enum=FEe(ecount,1);



                %****ELASTIC FOUNDATION CREATION*****
%Determine elements in TC for elastic foundation (one element in the
%cross-section)
nS9R5=N/2;%The number of S9R5 elements in each cross-section
one_strip=size(elemstack{1},1)/nS9R5;%One "strip" of elements along the
entire top chord

for i=1:size(elemstack{1},1)
   FEe(i+ecount,1)=(i+enum);%element number
   FEe(i+ecount,2:10)=elemstack{1}(i,2:10)+counter2; %within element
   FEe(i+ecount,11)=elemstack{1}(i,11);
   FEe(i+ecount,12)=elemstack{1}(i,12);
   FEe(i+ecount,13)=tstack{1}(1,1);

   if i<=one_strip
       EF{ii}(i,1)=FEe(i+ecount,1);%collect the element number for the first
"strip"
   end

end

%-----BOUDARY CONDITIONS-----
```

```
    %Nodes in boundary condition at the beginning of the TC
    %Create a nodeset for those nodes that will be at the ends of the joist
    %The nodes along the bottom of the chord within the "SEAT" region are
    %assumed to be pinned
    %Determine the nodes that are at the boundary conditions

    anode=3;%The number of nodes in each "pinned" element
    nodes=N+1;%The number of nodes in each cross-section

   %The following loop loops around the number of nodes in each cross
   %section and pulls out the nodes that correspond to the last element in
   %each cross section (for the length of the seat)

    for i=begloop:1:endloop
        nodeset(i-(begloop-1),1)=FEn(i,1);
        rowcount=size(nodeset,1);
        num=nodeset(i-counter,1)-counter2;
        n1=nodes;
        r1=rem(rowcount,n1); %Remainder function to determine what node we
are at in the cross-section
        if r1==0 %If the remainder is zero we are at the last node in this
set
            newset(i-(begloop-1)-4:i-(begloop-1),1)=FEn(i-4:i,1); %The amount
of nodes within the cross section that will be pinned
        end
    end

[~,~,newset]=find(newset);%Eliminates the zeros from this array

if ii==1
    nodeBC{1}=newset(:,1);%puts the array in a cell to be referenced later
when creating the input file
else
    xbc=size(nodeBC);
    next=xbc(1,2);
    nodeBC{next+1}=newset(:,1);
end

    %****NODES IN THE TC AT THE END OF THE JOIST
    pinend=pinend-less; %Move the same distance away from the web member as
on the opposing side
    endjoist=size(FEn,1);
    ENDBC=find(FEn(begloop:1:endjoist,2)>=pinend); %Determines the number of
nodes that are greater than the largest x-value of of the web-members
    %Determine the amount of nodes that need to be looped around for the
    %end-boundary-condition
    subtract=size(ENDBC,1);
    floop=endjoist-subtract;
    %Loop around those last nodes to apply the boundary condition
        for i=floop:1:endjoist
            nodeset(i-(begloop-1),1)=FEn(i,1);
            rowcount=size(nodeset,1);
            num=nodeset(i-counter,1)-counter2;
            n1=nodes;
            r1=rem(rowcount,n1);
            if r1==0
```

```
                newset2(i-(begloop-1)-2:i-(begloop-1),1)=FEn(i-2:i,1);
            end
        end

    [~,~,newset2]=find(newset2);%Eliminates the zeros from this array
    xbc=size(nodeBC);
    next=xbc(1,2);
    nodeBC{next+1}=newset2(:,1);




%------ROTATIONAL RESTRAINT-------
%This section applies a rotational restraint at the beginning/end of the
%joist

    %***BEGINNING OF THE JOIST***
    rx=4;%the distance in the x-diretion that the rotational restraint
applies to
    ENDr=find(FEn(begloop:1:endjoist,2)<=rx)-nodes+1+counter;%find the first
node in each cross-section that has a coordinate closest to the rotational
restraint length
    last=max(ENDr);
    ext=n(1,1);

    %Loop around the node values less than the rotational restraint
    %distance to collect all of these values
    for i=begloop:nodes:last
        if i==begloop
            if ii==1
                RR{1}=FEn(i:i+ext,1);
            else
                ali=size(RR);
                next=ali(1,2);
                RR{next+1}=FEn(i:i+ext,1);
            end
        else
            ali=size(RR);
            next=ali(1,2);
            RR{next+1}=FEn(i:i+ext,1);
        end
    end

    %***END OF THE JOIST***
    maxx=max(FEn(begloop:1:endjoist,2));%The maximum x-coordinate in the TC
    BEGr=find(FEn(begloop:1:endjoist,2)>=maxx-rx)+counter;%find the first
node in each cross-section that has a coordinate closest to the rotational
restraint length

    for i=BEGr:nodes:endjoist
            ali=size(RR);
            next=ali(1,2);
            RR{next+1}=FEn(i:i+ext,1);
    end
```

```
            %-----TOP CHORD LOADING **UNIFORM PRESSURE**-----
    %Determine the appropriate elements to load the top chord of the joist

    csize=size(FEe,1)-ecount;
    endloop=csize*n(1,1)/N;

    for i=1:endloop
        chordload(i,1)=FEe(i+ecount,1);
    end

    if ii==1
        TCload{1}=chordload;
    else
        xbc=size(TCload);
        next=xbc(1,2);
        TCload{next+1}=chordload;
    end


                %-----TOP CHORD LOADING **POINT LOADS**-----

%This is also used to collect the nodes that are at the clip locations to
%allow us to place springs here

%Apply point loads along the length of the TC. ONLY ONE ANGLE within the TC
%should be receiving load since clips are only inserted on one side

%FOR SYMMETRIC LOADING---you can change this iteration along with TCassem4
%to have one of them pick up a load for EVEN numbers and one of them pick
%up load for ODD numbers

numclip=round((Ltc)/clip_space); %The number of clips per chord (one every
24"(roughly))
initial=FCL; %use the measured value from test results

loadnode=n(1,1)/2; %the node in the cross section that the load is to be
applied to
sub=N-loadnode;

%Determine the x-location of the clips along the length of the chord
for i=1:numclip
        xclip(i,1)=initial+clip_space*(i-1); %The clip placement occurs about
every 2'
end


            %***PT LOADS APPLIED TO THE SAME SIDE OF ALL JOISTS***

% %Create a node set of where the loads are applied on the TC
% if ii==1 %ii==1 represents the first joist the load is applied to
%     for k=1:numclip
%         for j=counter:1:size(FEn,1)
%             xx=xclip(k,1);
%             %The following iterates until it finds the last node number in
the
%             %cross section with this x-coord. and then subtracts out the
%             %appropriate amount of nodes from the cross section to grab the
%             %node where we want the load applied
%             if FEn(j,2)<xx
%                 TCcload=size(FEn(1:j,1),1);
%                 xnode=TCcload-sub;
%                 cLoad(k,1)=FEn(xnode,1); %We only have one chord loaded so
we do not have to make a cell out of it
%             end
%         end
%     end
% %Below should be uncommented if the clips are on the same side of the joist
% else %This represents the next joists the load is applied to
%     loadcount=size(cLoad,1);
%     for k=1:numclip
%         for j=counter:1:size(FEn,1)
%             xx=xclip(k,1);
%             if FEn(j,2)<xx
%                 %Determine the size of cLoad that has already been created
%                 TCcload=size(FEn(1:j,1),1);
%                 xnode=TCcload-sub;
%                 cLoad(loadcount+k,1)=FEn(xnode,1); %We only have one chord
loaded so we do not have to make a cell out of it
%             end
%         end
%     end
% end



            %***PT LOADS APPLIED TO THE INSIDE CHORD OF THE JOIST***

% %Create a node set of where the loads are applied on the TC
% if ii==1 %ii==1 represents the first joist the load is applied to
%     for k=1:numclip
%         for j=counter:1:size(FEn,1)
%             xx=xclip(k,1);
%             %The following iterates until it finds the last node number in
the
%             %cross section with this x-coord. and then subtracts out the
%             %appropriate amount of nodes from the cross section to grab the
%             %node where we want the load applied
%             if FEn(j,2)<xx
%                 TCcload=size(FEn(1:j,1),1);
%                 xnode=TCcload-sub;
%                 cLoad(k,1)=FEn(xnode,1); %We only have one chord loaded so
we do not have to make a cell out of it
%             end
%         end
%     end
% %Below should be uncommented if the clips are on the same side of the joist
% % else %This represents the next joists the load is applied to
% %     loadcount=size(cLoad,1);
% %     for k=1:numclip
% %         for j=counter:1:size(FEn,1)
% %               xx=xclip(k,1);
% %               if FEn(j,2)<xx
% %                   %Determine the size of cLoad that has already been
created
% %                   TCcload=size(FEn(1:j,1),1);
% %                   xnode=TCcload-sub;
% %                   cLoad(loadcount+k,1)=FEn(xnode,1); %We only have one
chord loaded so we do not have to make a cell out of it
% %               end
% %           end
% %       end
% end



            %***PT LOADS APPLIED TO THE OUTSIDE CHORD OF THE JOIST***
if ii==2 %This is specific to VTJC summer 2011 tests, it should not be used
to simulate other situations
    loadcount=size(cLoad,1);
    for k=1:numclip
            xx=xclip(k,1);
            loadloc=find(FEn(counter:1:size(FEn,1),2)<=xx)+counter-1;
            xnode=max(loadloc)-sub;
            cLoad(loadcount+k,1)=FEn(xnode,1); %We only have one chord loaded
so we do not have to make a cell out of it
    end
end

%-----BRACE POINTS-----
%Determine the nodes that will be constrained to each other to simulate
%braces on the joist
if BracePts>0
    div=BracePts+1;
    blength=Ltc/div;%The unbraced length of the joist
        for j=1:BracePts
            bx=j*blength;%Make an array of the unbraced length distances in
the x-direction
            findx=find(FEn(counter:1:size(FEn,1),2)<=bx)+counter-1;
            maxx=max(findx);
            brace(j,1)=FEn(maxx,1);
        end

        if ii==1
            BP{1}=brace;
        else
            xbc=size(BP);
            next=xbc(1,2);
            BP{next+1}=brace;
        end
end

%-----DETERMINE THE SPACER LOCATIONS ALONG THE TC-----
%USE MPC'S TO SIMULATE SPACERS
xbc=size(TCbatpos);
loop=xbc(1,2);

for j=1:loop
```

```
    xar(j,1)=TCbatpos{j}(1,2);%find the x position of each spacer (just use
minimum)
end

%Determine the number of nodes to use for each spacer (just use the entire
%vertical face of each angle in the chord)
splen=n(1,3);%The number of nodes along the vertical face of the angle in the
TC in addition to the one that is already selected
                %number of elements+1=number of nodes (but we already have
                %one of the nodes so we just need to add the additional
                %amount to the set)

%We need to grab the nodes for each spacer. To do this let's find the node
%in the chord that is closest to the x-coordinate of the spacer and grab
%every node on that vertical face of the angle
tick=1;
for j=1:splen+1:numbattens*(splen+1)
        findx=find(FEn(counter:1:size(FEn,1),2)<=xar(tick,1))+counter-1;%find
the nodes in FEn that are closest to each spacer (x-coordinate)
        maxx=max(findx);%Find the closest node
        batcon(j:j+splen,1)=FEn(maxx-splen:maxx,1);%Get all of the nodes for
each spacer (maxx-splen:maxx  is to grab every node along a single face of
each angle)
        tick=tick+1;
end

if ii==1 %for the first joist created
    TCbat{1}=batcon;
else %for all other additional joists
    xbc=size(TCbat);
    next=xbc(1,2);
    TCbat{next+1}=batcon;
end



%------------CONSTRAIN THE CHORDS TO THE WEB MEMBERS------------
%Determine where to constrain the web members with these node sets!
kqn=size(webcon);
loo=kqn(1,2)/ii;%the loop size for determining the node sets
skip=1;

% for i=1:loo
%     for j=1:size(webcon{i},1)
%         if webcon{i}(j,3)>-depth/2;
%             xweb=webcon{i}(j,2);%The x value that the chord must be less
than to be constrained to
%             %Search the nodes for an x coordinate <= the location of the
web member (weld placement)
%             findx=find(FEn(counter:1:size(FEn,1),2)<=xweb)+counter-1; %All
the x's in FEn less than xweb
%             for k=1:size(findx,1)
%                 z_coord=FEn(findx(k,1),4);
%                 if z_coord>W/2
%                     findz(skip,1)=findx(k,1);
%                     skip=skip+1;
%                 end
%             end
%             maxx=max(findz);
%             CHORDcount(i,:)=maxx;
%             CHORDcon(i,:)=FEn(maxx,:);
%         end
%     end
% end

for i=1:loo
    for j=1:size(webcon{i},1)
        if webcon{i}(j,3)>-depth/2;
            xweb=webcon{i}(j,2);%The x value that the chord must be less than
to be constrained to
            %Now loop around the nodes in TC3 until you find a winner!
            for k=counter:1:size(FEn,1);
                if FEn(k,2)<xweb
                if webcon{i}(j,4)>W/2
                    CHORDcon(i,:)=FEn(k,:);
                    CHORDcount(i,1)=k;
                end
                end
            end
        end
    end
end

% for i=1:loo
%     for j=1:size(webcon{i},1)
%         if webcon{i}(j,3)>-depth/2;
%             xweb=webcon{i}(j,2);%The x value that the chord must be less
than to be constrained to
%             %Now loop around the nodes in TC3 until you find a winner!
%             for k=counter:1:size(FEn,1);
%                 if FEn(k,2)<xweb
%                 if webcon{i}(j,4)>W/2
%                     CHORDcon(i,:)=FEn(k,:);
%                     CHORD(i,1)=k;
%                 end
%                 end
%             end
%         end
%     end
% end
%
%     [~,~,CHORD]=find(CHORD);%Eliminates all of the zeros from this array
%
%     if ii==1
%         CHORDcount{1}=CHORD;
%     else
%         xbc=size(CHORDcount);
%         next=xbc(1,2);
%         CHORDcount{next+1}=CHORD;
%     end
```

```
end
```

Function: *TCxy4.m*

```
function [geomfinal]=TCxy(dims)

%LTC
%March 2011
%Takes out to out dimensions and corner angles of components of the cross
%section of a joist and converts them to xy coordinates for use in CUFSM

%To measure F you can find the angle of each segment from vertical (H & W)
%then determine the difference between the two.  The difference = F

% [W3, H3, t3, R3, F3, W4, H4, t4, R4, F4, S2, d]
%input dims for practice
% dims=[4 4 0.25 0.25 80 4 4 0.25 0.25 80 1 24];

%Cross-section dimension
%
%               S2
%   ___W4____R4    R5____W3____
%         F4/        \F3                                    |
%          /          \                                     |
%         /H4        H3\                                    |
%        /              \                                   |
%       /                \                                  |
%      t4                 t3                                |
%                                                           |
%                                                           d
%                                                           |
%                                                           |
%      t2                t1                                 |
%       \                /                                  |
%        \              /                                   |
%         \H2       H1 /             ^                      |
%          \          /              |                      |
%           \        /           y-axis                     |
%   _______F2\R2  R1/_F1_______      |__z-axis__>           |
%      W2       S1      W1

% [W3, H3, t3, R3, F3, W4, H4,
% t4, R4, F4, S2, d]
W3=dims(1);
H3=dims(2);
t3=dims(3);
R3=dims(4);
F3=dims(5)*pi/180;
W4=dims(6);
H4=dims(7);
t4=dims(8);
R4=dims(9);
F4=dims(10)*pi/180;
S2=dims(11);
```

```
d=dims(12);

%orgin is intersection of H1-line and W1-line

%r=the centerline radius of the angle
r3=R3-t3/2;
r4=R4-t4/2;



%(x9,y9) represents the beginning of the radius of the W-3 leg
xx3=0;
yy3=d;

x9=R3/tan(F3/2);
y9=yy3-t3/2;

%(x13,y13) represents the beginning of the radius of the W-4 leg
x13=-S2-R4/tan(F4/2);
y13=yy3-t4/2;

%(xc3, yc3) represents the center of the arc 3
xc3=x9;
yc3=y9-r3;
%(xc4, yc4) represents the center of the arc 4
xc4=x13;
yc4=y13-r4;

%(x10,y10) represents the beginning of the radius on the H3-leg
 G3=pi-F3;

    if G3<=pi/2
        x10=xc3-r3*sin(G3);
        y10=yc3+r3*cos(G3);
    else
        x10=xc3-r3*cos(G3-pi/2);
        y10=yc3-r3*sin(G3-pi/2);
    end

%(x14,y14) represents the beginning of the radius on the H4-leg
 G4=pi-F4;

    if G4<=pi/2
        x14=xc4+r4*sin(G4);
        y14=yc4+r4*cos(G4);
    else
        x14=xc4+r4*cos(G4-pi/2);
        y14=yc4-r4*sin(G4-pi/2);
    end

%(x11,y11) represents the centerline point at the end of length W3
x11=xx3+W3;
y11=yy3-t3/2;
%(x15,y15) represents the centerline point at the end of length W4
x15=xx3-S2-W4;
```

```
y15=yy3-t4/2;

%(x12,y12) represents the centerline point at the end of length H3
x12=xx3+H3*cos(F3)+t3/2*sin(F3);
y12=yy3-H3*sin(F3)+t3/2*cos(F3);
%(x16,y16) represents the centerline point at the end of length H4
x16=xx3-S2-H4*cos(F4)-t4/2*sin(F4);
y16=yy3-H4*sin(F4)+t4/2*cos(F4);

%transform into CUFSM format
geom=[ x13 y13
       x14 y14
       x15 y15
       x16 y16];

 %plot the points to check
%  figure(1)
%  plot(geom(:,1),geom(:,2),'k.');

geomfinal=geom;
```

Function: ***TCcross4.m***

```
function [node,elem]=TCcross4(geom,dims,kipin, n)

%geom gives the xy-coordinates of each of the four nodes previously defined

%DETERMINES THE NODE NUMBERS FOR THE TOP CHORD (angles "3" and "4")

% [W3, H3, t3, R3, F3, W4, H4, t4, R4, F4, S2, d]

%Cross-section dimensions
%
%               S2
%   ___W4____R4    R5____W3____
%         F4/        \F3                                    |
%           /          \                                    |
%         /H4        H3\                                    |
%        /              \                                   |
%       /                \                                  |
%      t4                 t3                                |
%                                                           |
%                                                           d
%                                                           |
%                                                           |
%      t2                t1                                 |
%       \                /                                  |
%        \              /                                   |
%         \H2       H1 /             ^                      |
%          \          /              |                      |
%           \        /            y-axis                    |
%   _______F2\R2  R1/_F1_______      |__x-axis__>           |
%      W2       S1      W1


%input dims for practice
% dims=[4 4 0.25 0.25 80 4 4 0.25 0.25 80 1 24];
% n=[4 4 4];
%  geom =[0.2979   23.8750
%         0.1748   23.7283
%         4.0000   23.8750
%         0.8177   20.0825
%        -1.2979   23.8750
%        -1.1748   23.7283
%        -5.0000   23.8750
%        -1.8177   20.0825];
%  kipin=1;
%
%input section dimensions from chordin
W3=dims(1);
H3=dims(2);
t3=dims(3);
R3=dims(4);
F3=dims(5)*pi/180;
W4=dims(6);
H4=dims(7);
t4=dims(8);
R4=dims(9);
F4=dims(10)*pi/180;
S2=dims(11);
d=dims(12);

r3=R3-t3/2;
r4=R4-t4/2;

%use 'chordin' to input the number of nodes wanted along each part of the
%section from matrix n
%
%anglemesh for H
MESH1=n(1,1);
%anglemesh for radius
MESH2=n(1,2);
%anglemesh for W
MESH3=n(1,3);



%        ----------NOW CREATE NODE NUMBERS FOR ANGLE4----------

%Determine the node numbers for the W4 leg
lengthW4=(geom(3,1)-geom(1,1));
for j=1:1:MESH3+1
    node(j,1)=j;
    node(j,2)=geom(3,1)-lengthW4/n(1,3)*(j-1);
    node(j,3)= geom(3,2);
end

%Determine the node numbers for the radius
```

```
%Alter the radius based on "chord method"
%xo4, yo4 is the center of the radius for angle 4
%The program uses the length from the center point (radius) and the angle
%from the center point to determine the coordinates of each node
xo4=geom(1,1);
yo4=geom(1,2)-r4;

for j=1:1:MESH2

    node(j+MESH3+1,1)=j+MESH3+1;

    G4=j*((pi-F4)/MESH2);

    if G4<=pi/2
        node(j+MESH3+1,2)=xo4+r4*sin(G4);
        node(j+MESH3+1,3)=yo4+r4*cos(G4);
    else
        node(j+MESH3+1,2)=xo4+r4*cos(G4-pi/2);
        node(j+MESH3+1,3)=yo4-r4*sin(G4-pi/2);
    end

end

%Determine the node numbers for the top leg of the section
%based on the distance from the top of the radius to the top of the section
lengthH4=((geom(4,1)-geom(2,1))^2+(geom(4,2)-geom(2,2))^2)^0.5;

for j=1:1:MESH1;
        node(j+MESH3+MESH2+1,1)=j+MESH3+MESH2+1;
        node(j+MESH3+MESH2+1,2)=geom(2,1)-(j*lengthH4/(MESH1))*cos(F4);
        node(j+MESH3+MESH2+1,3)=geom(2,2)-(j*lengthH4/(MESH1))*sin(F4);
end

node(:,4:7)=1;
node(:,8)=50;

%Check node to see if it is the correct format
%node

%plot node to check the full cross section
% figure(2)
% plot(node(:,2), node(:,3),'k.')

%                ----------CREATE ELEMENTS FOR ANGLE 4----------
%(element number, node i, node j, thickness, 100)

for i=1:(size(node,1)-1)
   elem(i,:)=[i i i+1 t4 100];
end

%set some default properties
if kipin==1
prop=[100 29500 29500 0.3 0.3 29500/(2*(1+0.3))];
else
```

```
prop=[100 203000 203000 0.3 0.3 203000/(2*(1+0.3))];
end

% check node
% node
% check elem
%  elem
```

Function: TCassem4.m

```
function
[FEn,FEe,nodeBC,TCload,BP,TCbat,CHORDcon,CHORDcount,cLoad,RR]=TCassem4(nodest
ack,elemstack,tstack,FEn,FEe,s,depth,change,SEAT,nodeBC,N,n,TCload,Ltc,BraceP
ts,TCbatpos,numbattens,BP,TCbat,webcon,W,CHORDcon,CHORDcount,ii,cLoad,pinend,
FCL,clip_space,RR)
%Assemble the TC nodes and elements into the GLOBAL FEnode and FEelement

%Change matrix values into their single values for easy use in this program
depth=depth(ii,1);
SEAT=SEAT(ii,1);

%Chord members
%-----NODES FOR THE CHORD MEMBERS-----
chord1=nodestack{1};
counter=size(FEn,1);
begloop=size(FEn,1)+1;%Determine where the first node in the TC is
counter2=20000000+100000000*(ii-1); %Before node

%Determine the number of nodes to be looped within the SEAT to
%establish a boundary condition
less=1.0;%the distance subtracted from SEAT to terminate the loop that
determines the amount of nodes at the boundary condition
support=SEAT+less;%The length of chord involved at the support

for i=1:size(chord1,1)
    FEn(i+counter,1)=chord1(i,1)+counter2;  %within node
    FEn(i+counter,2)=chord1(i,2);  %x coordinate
    FEn(i+counter,3)=chord1(i,3)-depth;  %y coordinate
    FEn(i+counter,4)=chord1(i,4)+s; %z coordinate plus the gap in between the
chord

    %Write a loop to determine at which node the seat ends in the TC (at
    %the beginning of the TC)
    x=FEn(i+counter,2);
    begseat=FEn(1+counter,1);
    if x<support
        endseat=FEn(i+counter,1);
        endloop=size(FEn,1);
    end

end
```

```
%-----elements for this chord-----
ecount=size(FEe,1);
enum=FEe(ecount,1);
for i=1:size(elemstack{1},1)
   FEe(i+ecount,1)=(i+enum);
   FEe(i+ecount,2:10)=elemstack{1}(i,2:10)+counter2; %within element
   FEe(i+ecount,11)=elemstack{1}(i,11);
   FEe(i+ecount,12)=elemstack{1}(i,12);
   FEe(i+ecount,13)=tstack{1}(1,1);
end

%-----BOUDARY CONDITIONS-----
    %Nodes in boundary condition at the beginning of the TC
    %Create a nodeset for those nodes that will be at the ends of the joist
    %The nodes along the bottom of the chord within the "SEAT" region are
    %assumed to be pinned
    %Determine the nodes that are at the boundary conditions

    anode=3;%The number of nodes in each "pinned" element
    nodes=N+1;

   %The following loop loops around the number of nodes in each cross
   %section and pulls out the nodes that correspond to the last element in
   %each cross section (for the length of the seat)
    for i=begloop:1:endloop
        nodeset(i-(begloop-1),1)=FEn(i,1);
        rowcount=size(nodeset,1);
        num=nodeset(i-counter,1)-counter2;
        n1=nodes;
        r1=rem(rowcount,n1); %Remainder function to determine what node we
are at in the cross-section
        if r1==0 %If the remainder is zero we are at the last node in this
set
            newset(i-(begloop-1)-4:i-(begloop-1),1)=FEn(i-4:i,1); %The amount
of nodes within the cross section that will be pinned
        end
    end

    [~,~,newset]=find(newset);%Eliminates the zeros from this array

    xbc=size(nodeBC);
    next=xbc(1,2);
    nodeBC{next+1}=newset(:,1);



    %****NODES IN THE TC AT THE END OF THE JOIST
    pinend=pinend-less; %Move the same distance away from the web member as
on the opposing side
    endjoist=size(FEn,1);
    ENDBC=find(FEn(begloop:1:endjoist,2)>=pinend); %Determines the number of
nodes that are greater than the largest x-value of of the web-members
    %Determine the amount of nodes that need to be looped around for the
    %end-boundary-condition
    subtract=size(ENDBC,1);
    floop=endjoist-subtract;
    %Loop around those last nodes to apply the boundary condition
        for i=floop:1:endjoist
            nodeset(i-(begloop-1),1)=FEn(i,1);
            rowcount=size(nodeset,1);
            num=nodeset(i-counter,1)-counter2;
            n1=nodes;
            r1=rem(rowcount,n1);
            if r1==0
                newset2(i-(begloop-1)-2:i-(begloop-1),1)=FEn(i-2:i,1);
            end
        end

    [~,~,newset2]=find(newset2);%Eliminates the zeros from this array
    xbc=size(nodeBC);
    next=xbc(1,2);
    nodeBC{next+1}=newset2(:,1);



%------ROTATIONAL RESTRAINT-------
%This section applies a rotational restraint at the beginning/end of the
%joist

    %***BEGINNING OF THE JOIST***
    rx=4;%the distance in the x-diretion that the rotational restraint
applies to
    ENDr=find(FEn(begloop:1:endjoist,2)<=rx)-nodes+1+counter;%find the first
node in each cross-section that has a coordinate closest to the rotational
restraint length
    last=max(ENDr);
    ext=n(1,1);

    %Loop around the node values less than the rotational restraint
    %distance to collect all of these values
    for i=begloop:nodes:last
        ali=size(RR);
        next=ali(1,2);
        RR{next+1}=FEn(i:i+ext,1);
    end

    %***END OF THE JOIST***
    maxx=max(FEn(begloop:1:endjoist,2));%The maximum x-coordinate in the TC
    BEGr=find(FEn(begloop:1:endjoist,2)>=maxx-rx)+counter;%find the first
node in each cross-section that has a coordinate closest to the rotational
restraint length

    for i=BEGr:nodes:endjoist
            ali=size(RR);
            next=ali(1,2);
            RR{next+1}=FEn(i:i+ext,1);
    end




%---------TC LOADING--------
```

```
                            %*****UNIFORM PRESSURE LOAD*****
%For a pressure load -- get this working and get it working with the same
%chord being loaded on each joist before changing it to a symmetric loading
    %-----TOP CHORD LOADING-----
    %Determine the appropriate elements to load the top chord of the joist
    csize=size(FEe,1)-ecount;
    endloop=csize*n(1,1)/N;

    for i=1:endloop
        chordload(i,1)=FEe(i+ecount);
    end
        xbc=size(TCload);
        next=xbc(1,2);
        TCload{next+1}=chordload;

                            %*****CONCENTRATED LOADS AT CLIPS*****
%Use this load for a symmetric loading (both clips on the outside) which
%simulates the VTJC tests from summer 2011
%
%For other loading cases (such as if simulating field conditions) where
%clips are on the same side of the chord for each joist, this part should
%be neglected and TCassem3 should be used to apply all loads
%
%This also is useful for finding the nodes used at clip locations so that
%springs can be inserted here

%If you want the clips on the outside then use this code

        numclip=round((Ltc)/clip_space); %The number of clips per chord (one
every 24"(roughly))
        initial=FCL; %use the measured value from test results

        loadnode=n(1,1)/2; %the node in the cross section that the load is to
be applied to
        sub=N-loadnode;
        %Determine the x-location of the clips along the length of the chord
        for i=1:numclip
                xclip(i,1)=initial+clip_space*(i-1); %The clip placement
occurs about every 2'
        end


            %***PT LOADS APPLIED TO THE INSIDE CHORD OF THE JOIST***

% if ii==2 %This is specific to VTJC summer 2011 tests, it should not be used
to simulate other situations
%     loadcount=size(cLoad,1);
%     for k=1:numclip
%         for j=counter:1:size(FEn,1)
%             xx=xclip(k,1);
%             if FEn(j,2)<xx
%                 %Determine the size of cLoad that has already been created
%                 TCcload=size(FEn(1:j,1),1);
%                 xnode=TCcload-sub;
%                  cLoad(loadcount+k,1)=FEn(xnode,1); %We only have one chord
loaded so we do not have to make a cell out of it
%              end
%          end
%      end
% end



           %***PT LOADS APPLIED TO THE OUTSIDE CHORD OF THE JOIST***
if ii==1 %ii==1 represents the first joist the load is applied to
    for k=1:numclip
            xx=xclip(k,1);
            loadloc=find(FEn(counter:1:size(FEn,1),2)<=xx)+counter-1;
            xnode=max(loadloc)-sub;
            cLoad(k,1)=FEn(xnode,1); %We only have one chord loaded so we do
not have to make a cell out of it
    end
end



                        %-----BRACE POINTS-----
%Determine the nodes that will be constrained to each other to simulate
%braces on the joist
if BracePts>0
    div=BracePts+1;
    blength=Ltc/div;%The unbraced length of the joist
        for j=1:BracePts
            bx=j*blength;%Make an array of the unbraced length distances in
the x-direction
            findx=find(FEn(counter:1:size(FEn,1),2)<=bx)+counter-1;
            maxx=max(findx);
            brace(j,1)=FEn(maxx,1);
        end
            xbc=size(BP);
            next=xbc(1,2);
            BP{next+1}=brace;
end

%-----DETERMINE THE SPACER LOCATIONS ALONG THE TC-----
%USE MPC'S TO SIMULATE SPACERS
% xbc=size(TCbatpos);
% loop=xbc(1,2);
%
% for j=1:loop
%     xar(j,1)=TCbatpos{j}(1,2);%find the x position of each batten (just use
minimum)
% end
%
% for j=1:numbattens
%         findx=find(FEn(counter:1:size(FEn,1),2)<=xar(j,1))+counter-1;
%         maxx=max(findx);
%         batcon(j,1)=FEn(maxx,1);
% end
%     xbc=size(TCbat);
%     next=xbc(1,2);
%     TCbat{next+1}=batcon;
```

```
xbc=size(TCbatpos);
loop=xbc(1,2);

for j=1:loop
    xar(j,1)=TCbatpos{j}(1,2);%find the x position of each spacer (just use
minimum)
end

%Determine the number of nodes to use for each spacer (just use the entire
%vertical face of each angle in the chord)
splen=n(1,3);%The number of nodes along the vertical face of the angle in the
TC in addition to the one that is already selected
                %number of elements+1=number of nodes (but we already have
                %one of the nodes so we just need to add the additional
                %amount to the set)

%We need to grab the nodes for each spacer. To do this let's find the node
%in the chord that is closest to the x-coordinate of the spacer and grab
%every node on that vertical face of the angle
tick=1;
for j=1:splen+1:numbattens*(splen+1)
        findx=find(FEn(counter:1:size(FEn,1),2)<=xar(tick,1))+counter-1;%find
the nodes in FEn that are closest to each spacer (x-coordinate)
        maxx=max(findx);%Find the closest node
        batcon(j:j+splen,1)=FEn(maxx-splen:maxx,1);%Get all of the nodes for
each spacer (maxx-splen:maxx  is to grab every node along a single face of
each angle)
        tick=tick+1;
end
    xbc=size(TCbat);
    next=xbc(1,2);
    TCbat{next+1}=batcon;




%-----CONSTRAIN THE CHORDS TO THE WEB MEMBERS-----
%Determine where to constrain the web members with these node sets!
kqn=size(webcon);
loo=kqn(1,2)/ii;%the loop size for determining the node sets

for i=1:loo
    for j=1:size(webcon{i},1)
        if webcon{i}(j,3)>-depth/2;
            xweb=webcon{i}(j,2);%The x value that the chord must be less than
to be constrained to
            %Now loop around the nodes in TC3 until you find a winner!
            for k=counter:1:size(FEn,1);
                if FEn(k,2)<xweb
                if webcon{i}(j,4)<W/2
                    CHORDcon(i,:)=FEn(k,:);
                    CHORDcount(i,1)=k;
                end
                end
            end
        end
    end
end

end
```

Function: *BCxy1.m*

```
function [geomfinal]=BCxy1(dims)

%LTC
%March 2011
%Takes out to out dimensions and corner angles of components of the cross
%section of a joist and converts them to xy coordinates for use in CUFSM

%To measure F you can find the angle of each segment from vertical (H & W)
%then determine the difference between the two.  The difference = F

% [W1, H1, t1, R1, F1, W2, H2, t2, R2, F2, S1, W3, H3, t3, R3, F3, W4, H4,
t4, R4, F4, S2, d]
%input dims for practice
% dims=[4 4 .25 .25 80 4 4 0.25 0.25 80 1];


%Cross-section dimensions

%
%      t2                t1
%       \                /
%        \              /
%         \H2       H1 /              ^
%          \          /               |
%           \        /            y-axis
%   _______F2\R2  R1/_F1_______       |__Z-axis__>
%      W2       S1      W1

% [W1, H1, t1, R1, F1, W2, H2, t2, R2, F2, S1, W3, H3, t3, R3, F3, W4, H4,
% t4, R4, F4, S2, d]
W1=dims(1);
H1=dims(2);
t1=dims(3);
R1=dims(4);
F1=dims(5)*pi/180;
W2=dims(6);
H2=dims(7);
t2=dims(8);
R2=dims(9);
F2=dims(10)*pi/180;
S1=dims(11);

%orgin is intersection of H1-line and W1-line

%r=the centerline radius of the angle
r1=R1-t1/2;
```

```
r2=R2-t2/2;

%(x1,y1) represents the beginning of the radius on the W1-leg
x1=R1/tan(F1/2);
y1=t1/2;
%(x5,y5) represent the beginning of the radius of the W2-leg
x5=-S1-R2/tan(F2/2);
y5=t2/2;

%(xc, yc) represents the center of the arc 1
xc=x1;
yc=y1+r1;
%(xc2, yc2) represents the center of the arc 2
xc2=x5;
yc2=y5+r2;

%(x2,y2) represents the beginning of the radius on the H1-leg
 G=pi-F1;

    if G<=pi/2
        x2=xc-r1*sin(G);
        y2=yc-r1*cos(G);
    else
        x2=xc-r1*cos(G-pi/2);
        y2=yc+r1*sin(G-pi/2);
    end

%(x6,y6) represents the beginning of the radius on the H2-leg
 G2=pi-F2;

    if G2<=pi/2
        x6=xc2+r2*sin(G2);
        y6=yc2-r2*cos(G2);
    else
        x6=xc2+r2*cos(G2-pi/2);
        y6=yc2+r2*sin(G2-pi/2);
    end

%(x3,y3) represents the centerline point at the end of length W1
x3=W1;
y3=t1/2;
%(x7,y7) represents the centerline point at the end of length W2
x7=-W2-S1;
y7=t2/2;

%(x4,y4) represents the centerline point at the end of length H1
x4=H1*cos(F1)+t1/2*sin(F1);
y4=H1*sin(F1)-t1/2*cos(F1);
%(x8,y8) represents the centerline point at the end of length H2
x8=-S1-H2*cos(F2)-t2/2*sin(F2);
y8=H2*sin(F2)-t2/2*cos(F2);

%transform into CUFSM format
geom=[ x1 y1
       x2 y2
       x3 y3
       x4 y4];

 %plot the points to check
%  figure(1)
%  plot(geom(:,1),geom(:,2),'k.');

geomfinal=geom;
```

Function: *BCcross1.m*

```
function [node,elem]=BCcross1(geom,dims,kipin, n)

%geom gives the xy-coordinates of each of the four nodes previously defined

%This program determines nodes for "angle 1" first, then determines the
%node numbers for "angle 2"

% [W1, H1, t1, R1, F1, W2, H2, t2, R2, F2, S1]

%Cross-section dimensions
%
%      t2               t1
%       \               /
%        \             /
%         \H2       H1 /             ^
%          \         /               |
%           \       /             y-axis
%   _______F2\R2  R1/_F1_______      |__z-axis__>
%      W2       S1      W1


%input dims for practice
%  dims=[4 4 .25 .25 80 4 4 0.25 0.25 80 1 4 4 0.25 0.25 80 4 4 0.25 0.25 80
1 24];
%  n=[4 4 4];
%  geom =[0.2979    0.1250
%         0.1748    0.2717
%         4.0000    0.1250
%         0.8177    3.9175
%        -1.2979    0.1250
%        -1.1748    0.2717
%        -5.0000    0.1250
%        -1.8177    3.9175];
%  kipin=1;

%input section dimensions from chordin
W1=dims(1);
H1=dims(2);
t1=dims(3);
R1=dims(4);
F1=dims(5)*pi/180;
```

```
W2=dims(6);
H2=dims(7);
t2=dims(8);
R2=dims(9);
F2=dims(10)*pi/180;
S1=dims(11);

r1=R1-t1/2;
r2=R2-t2/2;

%use 'chordin' to input the number of nodes wanted along each part of the
%section from matrix n
%
%anglemesh for H
MESH1=n(1,1);
%anglemesh for radius
MESH2=n(1,2);
%anglemesh for W
MESH3=n(1,3);



% ------------CREATE NODE NUMBERS FOR ANGLE 1----------------

%Determine the node numbers for the W leg
lengthW=(geom(3,1)-geom(1,1));
for j=1:1:MESH3+1
    node(j,1)=j;
    node(j,2)=geom(3,1)-lengthW/n(1,3)*(j-1);
    node(j,3)= geom(3,2);
end

%Determine the node numbers for the radius
%Alter the radius based on "chord method"
%xo, yo is the center of the radius
%The program uses the length from the center point (radius) and the angle
%from the center point to determine the coordinates of each node
xo=geom(1,1);
yo=geom(1,2)+r1;

for j=1:1:MESH2

    node(j+MESH3+1,1)=j+MESH3+1;

    G=j*((pi-F1)/MESH2);

    if G<=pi/2
        node(j+MESH3+1,2)=xo-r1*sin(G);
        node(j+MESH3+1,3)=yo-r1*cos(G);
    else
        node(j+MESH3+1,2)=xo-r1*cos(G-pi/2);
        node(j+MESH3+1,3)=yo+r1*sin(G-pi/2);
    end

end
```

```
%Determine the node numbers for the top leg of the section
%based on the distance from the top of the radius to the top of the section
lengthH=((geom(4,1)-geom(2,1))^2+(geom(4,2)-geom(2,2))^2)^0.5;

for j=1:1:MESH1;
        node(j+MESH3+MESH2+1,1)=j+MESH3+MESH2+1;
        node(j+MESH3+MESH2+1,2)=geom(2,1)+(j*lengthH/(MESH1))*cos(F1);
        node(j+MESH3+MESH2+1,3)=geom(2,2)+(j*lengthH/(MESH1))*sin(F1);
end

node(:,4:7)=1;
node(:,8)=50;

%Check node to see if it is the correct format
%node

%plot node to check frist angle
% figure(2)
% plot(node(:,2), node(:,3),'k.')


%                ----------CREATE ELEMENTS FOR ANGLE 1----------
%(element number, node i, node j, thickness, 100)

for i=1:(size(node,1)-1)
   elem(i,:)=[i i i+1 t1 100];
end

% elem


% check node
% node
% check elem
%  elem
```

Function: ***BCassem1.m***

```
function
[FEn,FEe,BP,BCbat,CHORDcon,CHORDcount,nodeBC,midx]=BCassem1(nodestack,elemsta
ck,tstack,FEn,FEe,BC,s,depth,change,SEAT,SPACE,GAP,Ltc,BracePts,BCbatpos,numb
attens,BP,webcon,W,CHORDcon,CHORDcount,ii,BCbat,N,nodeBC,pinend,midx,n)
%Add the nodes and elements for the bottom chord into the GLOBAL node and
%element matrices

%Change matrix values into their single values for easy use in this program
depth=depth(ii);
SEAT=SEAT(ii);
BC=BC(ii);
```

```
%Chord members
%-----NODES FOR THE CHORD MEMBERS-----
chord1=nodestack{1};
counter=size(FEn,1);
counter2=30000000+100000000*(ii-1); %Before node

% %TEMPORARY STUFF FOR BC PINS
%     less=0.5;%the distance subtracted from SEAT to terminate the loop that
determines the amount of nodes at the boundary condition
%     support=BC-less+SEAT;%The length of chord involved at the support
%     begloop=size(FEn,1)+1;
%     BCpinend=pinend-(SEAT+BC);

for i=1:size(chord1,1)
    FEn(i+counter,1)=chord1(i,1)+counter2;  %within node
    FEn(i+counter,2)=chord1(i,2)+BC+SEAT-2*SPACE-3*GAP;  %x coordinate
    FEn(i+counter,3)=chord1(i,3)-depth;  %y coordinate
    FEn(i+counter,4)=chord1(i,4)+s; %z coordinate plus the gap in between the
chord

%     %TEMPORARY STUFF FOR BC PINS
%     x=FEn(i+counter,2);
%     begseat=FEn(1+counter,1);
%     if x<support
%         endseat=FEn(i+counter,1);
%         endloop=size(FEn,1);
%     end

end

%-----------ELEMENTS FOR THIS CHORD------------
ecount=size(FEe,1);
enum=FEe(ecount,1);
for i=1:size(elemstack{1},1)
   FEe(i+ecount,1)=(i+enum);
   FEe(i+ecount,2:10)=elemstack{1}(i,2:10)+counter2; %within element
   FEe(i+ecount,11)=elemstack{1}(i,11);
   FEe(i+ecount,12)=elemstack{1}(i,12);
   FEe(i+ecount,13)=tstack{1}(1,1);
end

%-----BRACE POINTS-----
%Determine the nodes that will be constrained to each other to simulate
%braces on the joist
if BracePts>0
    div=BracePts+1;
    blength=Ltc/div;%The unbraced length of the joist
        for j=1:BracePts
            bx=j*blength;%Make an array of the unbraced length distances in
the x-direction
            findx=find(FEn(counter:1:size(FEn,1),2)<=bx)+counter-1;
            maxx=max(findx);
            brace(j,1)=FEn(maxx,1);
        end
            xbc=size(BP);
            next=xbc(1,2);
            BP{next+1}=brace;
end

%-----DETERMINE THE SPACER LOCATIONS ALONG THE BC-----
%USE MPC'S TO SIMULATE SPACERS
xbc=size(BCbatpos);
loop=xbc(1,2);
j=loop;

xar(j,1)=BCbatpos{j}(1,2);%find the x position of each spacer (just use
minimum)

splen=n(1,3);%The number of nodes along the vertical face of the angle in the
TC in addition to the one that is already selected
                %number of elements+1=number of nodes (but we already have
                %one of the nodes so we just need to add the additional
                %amount to the set)

findx=find(FEn(counter:1:size(FEn,1),2)<=xar(j,1))+counter-1;
maxx=max(findx);
batcon(j:j+splen,1)=FEn(maxx-splen:maxx,1);



if ii==1
    BCbat{1}=batcon;
else
    xbc=size(BCbat);
    next=xbc(1,2);
    BCbat{next+1}=batcon;
end



%-------------DEFLECTION MONITOR-------------
%Find the node that is closest to midspan to monitor its deflection
%By monitoring this node we will be able to determine when the joist
%buckles
%
%We already found the node at mid-span (because of the spacer) so let's
%just use this to monitor the displacement
%Find the node that is closest to midspan to monitor its deflection
%
%We only need to monitor the deflection on one chord only (this is the only
%monitor in the bottom chord for THIS JOIST) (one is made for each joist)
midnode=FEn(maxx,1);%The node with the x-coordinate that is closest to mid-
span
if ii==1
    midx{1}=midnode;
else
    xbc=size(midx);
    next=xbc(1,2);
    midx{next+1}=midnode;
end



%-----CONSTRAIN THE CHORDS TO THE WEB MEMBERS-----
```

```
%Determine where to constrain the web members with these node sets!
kqn=size(webcon);
loo=kqn(1,2)/ii;%the loop size for determining the node sets

for i=1:loo
    for j=1:size(webcon{i},1)
        if webcon{i}(j,3)<-depth/2;
            xweb=webcon{i}(j,2);%The x value that the chord must be less than
to be constrained to
            %Now loop around the nodes in TC3 until you find a winner!
            for k=counter:1:size(FEn,1);
                if FEn(k,2)<xweb
                if webcon{i}(j,4)>W/2
                    CHORDcon(i,:)=FEn(k,:);
                    CHORDcount(i,1)=k;
                end
                end
            end
        end
    end
end

end
```

Function: *BCxy2.m*

```
function
[FEn,FEe,BP,BCbat,CHORDcon,CHORDcount,nodeBC,midx]=BCassem1(nodestack,elemsta
ck,tstack,FEn,FEe,BC,s,depth,change,SEAT,SPACE,GAP,Ltc,BracePts,BCbatpos,numb
attens,BP,webcon,W,CHORDcon,CHORDcount,ii,BCbat,N,nodeBC,pinend,midx,n)
%Add the nodes and elements for the bottom chord into the GLOBAL node and
%element matrices

%Change matrix values into their single values for easy use in this program
depth=depth(ii);
SEAT=SEAT(ii);
BC=BC(ii);

%Chord members
%-----NODES FOR THE CHORD MEMBERS-----
chord1=nodestack{1};
counter=size(FEn,1);
counter2=30000000+100000000*(ii-1); %Before node

% %TEMPORARY STUFF FOR BC PINS
%     less=0.5;%the distance subtracted from SEAT to terminate the loop that
determines the amount of nodes at the boundary condition
%     support=BC-less+SEAT;%The length of chord involved at the support
%     begloop=size(FEn,1)+1;
%     BCpinend=pinend-(SEAT+BC);

for i=1:size(chord1,1)
    FEn(i+counter,1)=chord1(i,1)+counter2;  %within node
    FEn(i+counter,2)=chord1(i,2)+BC+SEAT-2*SPACE-3*GAP;  %x coordinate
    FEn(i+counter,3)=chord1(i,3)-depth;  %y coordinate
    FEn(i+counter,4)=chord1(i,4)+s; %z coordinate plus the gap in between the
chord

%     %TEMPORARY STUFF FOR BC PINS
%     x=FEn(i+counter,2);
%     begseat=FEn(1+counter,1);
%     if x<support
%         endseat=FEn(i+counter,1);
%         endloop=size(FEn,1);
%     end

end

%-----------ELEMENTS FOR THIS CHORD------------
ecount=size(FEe,1);
enum=FEe(ecount,1);
for i=1:size(elemstack{1},1)
   FEe(i+ecount,1)=(i+enum);
   FEe(i+ecount,2:10)=elemstack{1}(i,2:10)+counter2; %within element
   FEe(i+ecount,11)=elemstack{1}(i,11);
   FEe(i+ecount,12)=elemstack{1}(i,12);
   FEe(i+ecount,13)=tstack{1}(1,1);
end

%-----BRACE POINTS-----
%Determine the nodes that will be constrained to each other to simulate
%braces on the joist
if BracePts>0
    div=BracePts+1;
    blength=Ltc/div;%The unbraced length of the joist
        for j=1:BracePts
            bx=j*blength;%Make an array of the unbraced length distances in
the x-direction
            findx=find(FEn(counter:1:size(FEn,1),2)<=bx)+counter-1;
            maxx=max(findx);
            brace(j,1)=FEn(maxx,1);
        end
            xbc=size(BP);
            next=xbc(1,2);
            BP{next+1}=brace;
end

%-----DETERMINE THE SPACER LOCATIONS ALONG THE BC-----
%USE MPC'S TO SIMULATE SPACERS
xbc=size(BCbatpos);
loop=xbc(1,2);
j=loop;

xar(j,1)=BCbatpos{j}(1,2);%find the x position of each spacer (just use
minimum)

splen=n(1,3);%The number of nodes along the vertical face of the angle in the
TC in addition to the one that is already selected
```

```
                %number of elements+1=number of nodes (but we already have
                %one of the nodes so we just need to add the additional
                %amount to the set)

findx=find(FEn(counter:1:size(FEn,1),2)<=xar(j,1))+counter-1;
maxx=max(findx);
batcon(j:j+splen,1)=FEn(maxx-splen:maxx,1);



if ii==1
    BCbat{1}=batcon;
else
    xbc=size(BCbat);
    next=xbc(1,2);
    BCbat{next+1}=batcon;
end



%-------------DEFLECTION MONITOR-------------
%Find the node that is closest to midspan to monitor its deflection
%By monitoring this node we will be able to determine when the joist
%buckles
%
%We already found the node at mid-span (because of the spacer) so let's
%just use this to monitor the displacement
%Find the node that is closest to midspan to monitor its deflection
%
%We only need to monitor the deflection on one chord only (this is the only
%monitor in the bottom chord for THIS JOIST) (one is made for each joist)
midnode=FEn(maxx,1);%The node with the x-coordinate that is closest to mid-
span
if ii==1
    midx{1}=midnode;
else
    xbc=size(midx);
    next=xbc(1,2);
    midx{next+1}=midnode;
end



%-----CONSTRAIN THE CHORDS TO THE WEB MEMBERS-----
%Determine where to constrain the web members with these node sets!
kqn=size(webcon);
loo=kqn(1,2)/ii;%the loop size for determining the node sets

for i=1:loo
    for j=1:size(webcon{i},1)
        if webcon{i}(j,3)<-depth/2;
            xweb=webcon{i}(j,2);%The x value that the chord must be less than
to be constrained to
            %Now loop around the nodes in TC3 until you find a winner!
            for k=counter:1:size(FEn,1);
                if FEn(k,2)<xweb
                if webcon{i}(j,4)>W/2
                    CHORDcon(i,:)=FEn(k,:);
                    CHORDcount(i,1)=k;
                end
                end
            end
        end
    end
end

end
```

Function: *BCcross2.m*

```
function
[FEn,FEe,BP,BCbat,CHORDcon,CHORDcount,nodeBC,midx]=BCassem1(nodestack,elemsta
ck,tstack,FEn,FEe,BC,s,depth,change,SEAT,SPACE,GAP,Ltc,BracePts,BCbatpos,numb
attens,BP,webcon,W,CHORDcon,CHORDcount,ii,BCbat,N,nodeBC,pinend,midx,n)
%Add the nodes and elements for the bottom chord into the GLOBAL node and
%element matrices

%Change matrix values into their single values for easy use in this program
depth=depth(ii);
SEAT=SEAT(ii);
BC=BC(ii);

%Chord members
%-----NODES FOR THE CHORD MEMBERS-----
chord1=nodestack{1};
counter=size(FEn,1);
counter2=30000000+100000000*(ii-1); %Before node

% %TEMPORARY STUFF FOR BC PINS
%     less=0.5;%the distance subtracted from SEAT to terminate the loop that
determines the amount of nodes at the boundary condition
%     support=BC-less+SEAT;%The length of chord involved at the support
%     begloop=size(FEn,1)+1;
%     BCpinend=pinend-(SEAT+BC);

for i=1:size(chord1,1)
    FEn(i+counter,1)=chord1(i,1)+counter2;  %within node
    FEn(i+counter,2)=chord1(i,2)+BC+SEAT-2*SPACE-3*GAP;  %x coordinate
    FEn(i+counter,3)=chord1(i,3)-depth;  %y coordinate
    FEn(i+counter,4)=chord1(i,4)+s; %z coordinate plus the gap in between the
chord

%     %TEMPORARY STUFF FOR BC PINS
%     x=FEn(i+counter,2);
%     begseat=FEn(1+counter,1);
%     if x<support
%         endseat=FEn(i+counter,1);
%         endloop=size(FEn,1);
%     end

end
```

```
%-----------ELEMENTS FOR THIS CHORD------------
ecount=size(FEe,1);
enum=FEe(ecount,1);
for i=1:size(elemstack{1},1)
   FEe(i+ecount,1)=(i+enum);
   FEe(i+ecount,2:10)=elemstack{1}(i,2:10)+counter2; %within element
   FEe(i+ecount,11)=elemstack{1}(i,11);
   FEe(i+ecount,12)=elemstack{1}(i,12);
   FEe(i+ecount,13)=tstack{1}(1,1);
end

%-----BRACE POINTS-----
%Determine the nodes that will be constrained to each other to simulate
%braces on the joist
if BracePts>0
    div=BracePts+1;
    blength=Ltc/div;%The unbraced length of the joist
        for j=1:BracePts
            bx=j*blength;%Make an array of the unbraced length distances in
the x-direction
            findx=find(FEn(counter:1:size(FEn,1),2)<=bx)+counter-1;
            maxx=max(findx);
            brace(j,1)=FEn(maxx,1);
        end
            xbc=size(BP);
            next=xbc(1,2);
            BP{next+1}=brace;
end

%-----DETERMINE THE SPACER LOCATIONS ALONG THE BC-----
%USE MPC'S TO SIMULATE SPACERS
xbc=size(BCbatpos);
loop=xbc(1,2);
j=loop;

xar(j,1)=BCbatpos{j}(1,2);%find the x position of each spacer (just use
minimum)

splen=n(1,3);%The number of nodes along the vertical face of the angle in the
TC in addition to the one that is already selected
                %number of elements+1=number of nodes (but we already have
                %one of the nodes so we just need to add the additional
                %amount to the set)

findx=find(FEn(counter:1:size(FEn,1),2)<=xar(j,1))+counter-1;
maxx=max(findx);
batcon(j:j+splen,1)=FEn(maxx-splen:maxx,1);


if ii==1
    BCbat{1}=batcon;
else
    xbc=size(BCbat);
    next=xbc(1,2);
    BCbat{next+1}=batcon;
end



%-------------DEFLECTION MONITOR-------------
%Find the node that is closest to midspan to monitor its deflection
%By monitoring this node we will be able to determine when the joist
%buckles
%
%We already found the node at mid-span (because of the spacer) so let's
%just use this to monitor the displacement
%Find the node that is closest to midspan to monitor its deflection
%
%We only need to monitor the deflection on one chord only (this is the only
%monitor in the bottom chord for THIS JOIST) (one is made for each joist)
midnode=FEn(maxx,1);%The node with the x-coordinate that is closest to mid-
span
if ii==1
    midx{1}=midnode;
else
    xbc=size(midx);
    next=xbc(1,2);
    midx{next+1}=midnode;
end



%-----CONSTRAIN THE CHORDS TO THE WEB MEMBERS-----
%Determine where to constrain the web members with these node sets!
kqn=size(webcon);
loo=kqn(1,2)/ii;%the loop size for determining the node sets

for i=1:loo
    for j=1:size(webcon{i},1)
        if webcon{i}(j,3)<-depth/2;
            xweb=webcon{i}(j,2);%The x value that the chord must be less than
to be constrained to
            %Now loop around the nodes in TC3 until you find a winner!
            for k=counter:1:size(FEn,1);
                if FEn(k,2)<xweb
                if webcon{i}(j,4)>W/2
                    CHORDcon(i,:)=FEn(k,:);
                    CHORDcount(i,1)=k;
                end
                end
            end
        end
    end
end

end
```

Function: ***BCassem2.m***

```
function
[FEn,FEe,BP,BCbat,CHORDcon,CHORDcount,nodeBC]=BCassem2(nodestack,elemstack,ts
tack,FEn,FEe,BC,s,depth,change,SEAT,SPACE,GAP,Ltc,BracePts,BCbatpos,numbatten
s,BP,BCbat,webcon,W,CHORDcon,CHORDcount,ii,N,nodeBC,pinend,n)
%Add the nodes and elements for the bottom chord into the GLOBAL node and
%element matrices

%Change matrix values into their single values for easy use in this program
depth=depth(ii,1);
SEAT=SEAT(ii,1);
BC=BC(ii);

%Chord members
%-----NODES FOR THE CHORD MEMBERS-----
chord1=nodestack{1};
counter=size(FEn,1);
counter2=40000000+100000000*(ii-1); %Before node
%
% %TEMPORARY STUFF FOR BC PINS
%     less=0.5;%the distance subtracted from SEAT to terminate the loop that
determines the amount of nodes at the boundary condition
%     support=BC-less+SEAT;%The length of chord involved at the support
%     begloop=size(FEn,1)+1;
%     BCpinend=pinend-(SEAT+BC);

for i=1:size(chord1,1)
    FEn(i+counter,1)=chord1(i,1)+counter2;  %within node
    FEn(i+counter,2)=chord1(i,2)+BC+SEAT-2*SPACE-3*GAP;  %x coordinate
    FEn(i+counter,3)=chord1(i,3)-depth;  %y coordinate
    FEn(i+counter,4)=chord1(i,4)+s; %z coordinate plus the gap in between the
chord

%     %TEMPORARY STUFF FOR BC PINS
%     x=FEn(i+counter,2);
%     begseat=FEn(1+counter,1);
%     if x<support
%         endseat=FEn(i+counter,1);
%         endloop=size(FEn,1);
%     end

end

%-----elements for this chord-----
ecount=size(FEe,1);
enum=FEe(ecount,1);
for i=1:size(elemstack{1},1)
   FEe(i+ecount,1)=(i+enum);
   FEe(i+ecount,2:10)=elemstack{1}(i,2:10)+counter2; %within element
   FEe(i+ecount,11)=elemstack{1}(i,11);
   FEe(i+ecount,12)=elemstack{1}(i,12);
   FEe(i+ecount,13)=tstack{1}(1,1);
end
```

```
%-----BRACE POINTS-----
%Determine the nodes that will be constrained to each other to simulate
%braces on the joist
if BracePts>0
    div=BracePts+1;
    blength=Ltc/div;%The unbraced length of the joist
        for j=1:BracePts
            bx=j*blength;%Make an array of the unbraced length distances in
the x-direction
            findx=find(FEn(counter:1:size(FEn,1),2)<=bx)+counter-1;
            maxx=max(findx);
            brace(j,1)=FEn(maxx,1);
        end
            xbc=size(BP);
            next=xbc(1,2);
            BP{next+1}=brace;
end

%-----DETERMINE THE SPACER LOCATIONS ALONG THE BC-----
%USE MPC'S TO SIMULATE SPACERS
xbc=size(BCbatpos);
loop=xbc(1,2);
j=loop;

xar(j,1)=BCbatpos{j}(1,2);%find the x position of each batten (just use
minimum)

splen=n(1,3);%The number of nodes along the vertical face of the angle in the
TC in addition to the one that is already selected
                %number of elements+1=number of nodes (but we already have
                %one of the nodes so we just need to add the additional
                %amount to the set)

findx=find(FEn(counter:1:size(FEn,1),2)<=xar(j,1))+counter-1;
maxx=max(findx);
batcon(j:j+splen,1)=FEn(maxx-splen:maxx,1);

    xbc=size(BCbat);
    next=xbc(1,2);
    BCbat{next+1}=batcon;

%-----CONSTRAIN THE CHORDS TO THE WEB MEMBERS-----
%Determine where to constrain the web members with these node sets!
kqn=size(webcon);
loo=kqn(1,2)/ii;%the loop size for determining the node sets

for i=1:loo
    for j=1:size(webcon{i},1)
        if webcon{i}(j,3)<-depth/2;
            xweb=webcon{i}(j,2);%The x value that the chord must be less than
to be constrained to
            %Now loop around the nodes in TC3 until you find a winner!
            for k=counter:1:size(FEn,1);
                if FEn(k,2)<xweb
                if webcon{i}(j,4)<W/2
                    CHORDcon(i,:)=FEn(k,:);
                    CHORDcount(i,1)=k;
                end
                end
            end
        end
    end
end

end
```

Function: *jhabnl.m*

```
function [FEnode, FEelem]= jhabnl(step, jobname,matprops, imperfections,
sectionpoints, FEnode, FEelem, eltype,
webcon,nodeBC,TCload,BP,TCbat,BCbat,cLoad,LOAD_TYPE,CHORDcon,CHORDc,n_chord,n
umnodes,analysis,kclip,RR,midx,EF,kroof)

%This function generates eigenbuckling .inp files using ABAQUS S9R5 elements
and the Lanczos eigensolver.
%Used by VTJC for joist input into ABAQUS

%CDM (with lots of help from BWS)
%December 2007
%Modified by LTC for VTJC use
%July 2011

%HEADING PARAMETERS
title='Joist:24K4';
modelname='*Test designation';
preprint.echo='NO';
preprint.model='NO';
preprint.history='NO';
preprint.contact='NO';

%CREATE INP FILE

%open file
fid=fopen([jobname '.inp'],'w');

%write heading info
heading(fid,title,jobname,modelname,preprint);
disp('Header Input Complete...input file');
matnum=100
t=0.01
elemgroups=1
%write nodes and element info to file
writenodes_elements(fid,
FEnode,FEelem,elemgroups,eltype,matnum,t,sectionpoints);
disp('Nodes Complete....input file');
```

```
maxel=max(FEelem(:,1));
%write spring element information to file
writesprings(fid,cLoad,maxel,kclip,EF,kroof);

%write nodeset info to file
%writenodeset(fid,nodesetinfo,nodeset);

%write material info to file
writematerials(fid,matprops);
disp('Write Materials Complete...input file');

%write imperfections to file
if imperfections.type~=3
writeimper(fid,imperfections);
end

%write surface definitions
%writesurface(fid,surface,surface.areadist,nodeset);
if LOAD_TYPE=='P'
    write_load_surface(fid,TCload);
end

%write constraints info to file
writeconstraint(fid,webcon,BP,TCbat,BCbat,CHORDcon,CHORDc,FEnode,n_chord,numn
odes,RR);

%write boundary conditions into file
writeBC(fid,nodeBC,BP);
disp('Boundary Conditions Complete...input file')

%write ABAQUS monitoring information to a file (things to monitor while
%ABAQUS performs the analysis)
writemonitor(fid,midx);

%write analysis step info to file
writestep(fid,step,nodeBC,LOAD_TYPE,cLoad,TCload,analysis,midx);
disp('Step Complete...input file')

%close file
fclose(fid);
```

Function: ***writenodes_elements.m***

```
function writenodes_elements(fid,
FEnode,FEelem,elemgroups,eltype,matnum,t,sectionpoints,ftcn,ltcn,ftce,ltce)

%This needs to only apply to the nodes corresponding to the tdiff values in
%FEelem

%save FEelem FEelem
%stop

%Resize elements to only include those in the TC
```

```
% FEelem=FEelem(ftce:ltce,:);

%write nodes to file
fprintf(fid,'*Node\n');
for i=1:size(FEnode,1)
    fprintf(fid,'%6.0f, %6.4f, %6.4f, %6.4f\n',FEnode(i,1:4));
end

%FEelem
%stop

%Make an array of the individual stiffnesses of different components within
%the joist
tdiff=unique(FEelem(:,13)); %check

%Find the elements that correspond to these different thicknesses
for i=1:size(tdiff,1)
    copy=find(FEelem(:,13)==tdiff(i,1));
    stack{i}=FEelem(copy(:,1),:);

%Old, slow way that loops around all of the elements
%     next=0;%zeros this counter for the next i
%     %Use FIND to organize the materials of different thicknesses into
%     %seperate matrices
%     for j=1:size(FEelem,1)%begin a loop around FEelem to find all of the
elements with different thicknesses and keep them in the array "hold"
%         if FEelem(j,13)==tdiff(i,1)
%             next=next+1;
%             stack{i}(next,:)=FEelem(j,:);%put the array containing the
elements of like thickness into the cell stack, this sorts the different
thickness elements which are accessed later and written to the inp file
%         end
%     end

end

%The old way that doesn't work
% for i=1:length(tdiff)
%     a=find(FEelem(:,13)==tdiff(i));
%     begFE=a(1,1);
%     finFE=max(a);
%     stack{i}=FEelem(begFE:finFE,:);
% end

if eltype=='S9R5'

%write elements to file
for i=1:length(tdiff)
%     stripel=find(FEelem(:,13)==tdiff(i));
    fprintf(fid,'*Element, type=%s, ELSET=GROUP%d\n',char(eltype),i);
    fprintf(fid,'%6.0f, %6.0f, %6.0f, %6.0f, %6.0f, %6.0f, %6.0f, %6.0f,
%6.0f, %6.0f\n',stack{i}(:,1:10)');
    fprintf(fid,'*SHELL SECTION, ELSET=GROUP%d, MATERIAL=MAT%d\n',[i
matnum]);
    fprintf(fid,'%g,%g \n',tdiff(i),sectionpoints);
```

```
end

elseif eltype=='S8R5'
    for i=1:length(elemgroups)
    stripel=find(FEelem(:,11)==elemgroups(i));
    fprintf(fid,'*Element, type=%s,
ELSET=GROUP%d\n',char(eltype),elemgroups(i));
    fprintf(fid,'%6.0f, %6.0f, %6.0f, %6.0f, %6.0f, %6.0f, %6.0f, %6.0f,
%6.0f\n',FEelem(stripel,1:9)');
    fprintf(fid,'*SHELL SECTION, ELSET=GROUP%d,
MATERIAL=MAT%d\n',[elemgroups(i) matnum(i)]);
    fprintf(fid,'%g,%g \n',t(i),sectionpoints);
    end
end
```

Function: ***writesprings.m***

```
%PROGRAM writesprings
%This program writes spring elements to the ABAQUS input file.

function writesprings(fid,cLoad,maxel,kclip,EF,kroof)

% %----------------CREATE SPRINGS---TYPE I----------------
% loop=size(cLoad,1);
%     for i=1:loop
%         fprintf(fid,'*ELEMENT, TYPE=SPRING1, ELSET=SPRING%d\n',i);
%         fprintf(fid,'%6.0f,%6.0f\n',maxel+i,cLoad(i,1));
%     end
%
% %Give spring properties
%     for i=1:loop
%         fprintf(fid,'*SPRING, ELSET=SPRING%d\n',i);
%         fprintf(fid,'3\n');%we want the spring to influence DOF 3
(displacement in the z-direction)
%         fprintf(fid,'%6.16f\n',kclip);
%     end




%For SPRING1 and SPRING2 elements:
%first line: DOF that the spring is resisting (3 is z-direction)
%second line: spring stiffness



%----------------CREATE SPRINGS---TYPE II----------------
%We need to connect the first joist to the second joist
numclips=size(cLoad,1)/2;%number of clips on each joist
fprintf(fid,'*ELEMENT, TYPE=SPRING2, ELSET=SPRING%d\n',1);
for i=1:numclips
    check=[cLoad(i,1),cLoad(i+numclips,1)];

fprintf(fid,'%6.0f,%6.0f,%6.0f\n',maxel+i,cLoad(i,1),cLoad(i+numclips,1));%
```

```
end

%Give spring properties
%     for i=1:numclips
        fprintf(fid,'*SPRING, ELSET=SPRING%d\n',1);
        fprintf(fid,'3,3\n');%we want the spring to influence DOF 3
(displacement in the z-direction)
        fprintf(fid,'%6.16f\n',kclip);
%     end

% %-----------------ELASTIC FOUNDATION STIFFNESS-------------
% %for these apply the elastic foundation stiffness to the elements
%     %create different surfaces using different element sets for each joist
%     cols=size(EF);
%     loop=cols(1,2);%Number of cells in EF
%
%     for i=1:loop
%         fprintf(fid,'*ELSET, ELSET=Elastic_foundation_ele%d\n',i)%create
the element set for the elastic foundation (for a single joist
%
%         for j=1:size(EF{i},1)
%             fprintf(fid,'%d\n',EF{i}(j,1))
%         end
%     end
%
%     %Create a surface for the elastic foundation
%     fprintf(fid,'******CREATE A SURFACE FOR THE ELASTIC
FOUNDATION*******\n');
%     for i=1:loop
%         fprintf(fid,'*SURFACE, NAME=EF%d, TYPE=ELEMENT\n',i);
%         fprintf(fid,'Elastic_foundation_ele%d, SPOS\n',i);
%
%         fprintf(fid,'*FOUNDATION\n');
%         fprintf(fid,'EF%d, F3, %6.16f\n',i,kroof);
%     end

end
```

Function: *writematerials.m*

```
%PROGRAM materials
%This program writes the MATERIALS portion of the ABAQUS input file.
%Fall 2005
%Plate Buckling Study
%CDM

function materials(fid,matprops)


fprintf(fid,'** MATERIALS\n');
fprintf(fid,'**\n');

for i=1:length(matprops(:));
```

```
fprintf(fid,'*Material, name=%s\n',matprops(i).name);
fprintf(fid,'*Elastic\n');
fprintf(fid,'%10.2f, %6.2f\n',matprops(i).elastic);

if isempty(matprops(i).plastic)==0;
fprintf(fid,'*Plastic\n');
for j=1:length(matprops(i).plastic);
fprintf(fid,'%g, %g\n',matprops(i).plastic(j,:));
end
end
fprintf(fid,'**\n');
end
```

Function: ***write_load_surface.m***

```
function [] = write_load_surface(fid,TCload)
%create a element sets and surfaces to apply the load
fprintf(fid,'******LOAD ELEMENT SETS*****\n');

xbc=size(TCload);
loop=xbc(1,2);

for i=1:loop
    fprintf(fid,'*ELSET, ELSET=TCload%d \n', i);
        for j=1:length(TCload{i})
            fprintf(fid,'%6.0f\n',TCload{i}(j,1));
        end
end

%Create a surface to apply the load
fprintf(fid,'******CREATE A SURFACE FOR THE PRESSURE LOAD*******\n');
for i=1:loop
    fprintf(fid,'*SURFACE, NAME=CTOP%d, TYPE=ELEMENT\n',i);
    fprintf(fid,'TCload%d, SPOS\n',i);
end

end
```

Function: ***writeconstraint.m***

```
function [] =
writeconstraint(fid,webcon,BP,TCbat,BCbat,CHORDcon,CHORDc,FEnode,n_chord,numn
odes,RR)
%This function produces the constraints (welds) within the joist

%New July 10, 2011
%Change from *FASTENER to MPC's - use *RIGID or *MPC
%CHORDcon contains a node from each of the chord members that matches up
%exactly (1-144 for the 24K4 joist) with the node sets created at each end
%of the web members
```

```
%-----------------INFORMATION FOR THE WELD CONSTRAINTS---------------

%All we need to do now is to connect the node sets of the welds to those of
%the chord members

    %Determine the nodes involved in the chord for the weld constraints
    %use the same number of nodes per nodeset as are in the weld groups in
    %the web members
    N=n_chord(1,1)+n_chord(1,2)+n_chord(1,3)+1;%The total number of nodes per
cross section of each angle in the chord

    %We now have an array of constraint values that need to match up with
    %the array values of webcon

    %Take the array of values from CHORD and make nodesets that can be used
    %for the multi-point-constraints (to model the welds)
    cols=size(CHORDc);
    loop=cols(1,2);

    for m=1:loop
        for i=1:size(CHORDc{m},1)
            nodenum=CHORDc{m}(i,1);
                for j=1:numnodes%find nodes corresponding to the second
element in the chord closest to the weld
                    weld(j,1)=FEnode((j-1)+nodenum-N-numnodes,1);
                end
                for j=1:numnodes%find nodes corresponding to the first
element in the chord closest to web weld
                    weld(j+numnodes,1)=FEnode((j-1)+nodenum-numnodes,1);
                end
                if m==1
                        c_weld{i}=weld;
                else
                    c_weld{i+size(CHORDc{m-1},1)*(m-1)}=weld;
                end
        end
    end

    %look through c_weld to make sure there are no repeats, if there are
    %the model will be overconstrained and it will not run
    cols=size(c_weld);
    loop=cols(1,2);
    counter=0;

    for i=1:loop
        for j=1:size(c_weld{i})
            %Make an array of values from c_weld so we can look through
            %them to try to find repeats
            finder(j+counter,1)=c_weld{i}(j,1);
                if size(finder,1)>1 %let the first one get a free ride
                    for l=1:10 %iterate 10 times to insure that you don't
cover up a repeat with another repeat
```

```
                        for k=1:size(finder,1)-1
                            if c_weld{i}(j,1)==finder(k,1);
                                c_weld{i}(j,1)=c_weld{i}(j,1)+100;
                                finder(j+counter,1)=c_weld{i}(j,1);
                            end
                        end
                    end
                end
        end
        counter=size(finder,1);
    end




%----------------WELD CONNECTION (3 POSSIBLE TYPES)-------------------






% **********************RIGID BODY************************

%     fprintf(fid,'******WEB WELDS USING *RIGID BODY******\n');
%     %write a loop to relate the rigid body reference node (in CHORDcon) to
%     %the nodeset that is tied to it (in webcon)
%
%
%     %Build a nodeset of values that include ALL of the webcon values and
%     %all of the CHORDcon values except for the first one in each matrix
%     %
%     %You need a nodeset of ALL of the nodes involved because *RIGID BODY
%     %references all of the nodes in this node set and constrains them to a
%     %single node (the first node in each node set)
%     ltc=size(c_weld);
%     loop=ltc(1,2);
%     for i=1:loop
%         for j=1:(size(c_weld{i},1)-1)
%             arc(j,1)=c_weld{i}(j+1,1);
%         end
%         row=size(c_weld{i},1)-1;
%         for j=1:size(webcon{i},1)
%             arc(j+row,1)=webcon{i}(j,1);
%         end
%         j_weld{i}=arc;
%     end
%
%     %Make a nodeset to reference in *RIGID call
%     col=size(j_weld);
%     loop=col(1,2);
%     fprintf(fid,'******WELD CONSTRAINT NODE SETS--BOTH WEB AND
CHORDS******\n');
%     for i=1:loop
%         fprintf(fid,'*NSET, NSET=J_WELD%d\n',i);
%             for j=1:size(j_weld{i},1)
%                 fprintf(fid,'%6.0f\n',j_weld{i}(j,1));
%              end
%     end
%
%
%     %Use *RIGID to model the welds
%     fprintf(fid,'******MODEL WELDS USING *RIGID BODY*******\n')
%     for i=1:loop
%         fprintf(fid,'*RIGID BODY, REF NODE=%d, TIE NSET=J_WELD%d\n',
c_weld{i}(1,1),i);
%     end





%**********************MULTI-POINT CONSTRAINTS**********************
%You no longer need the reference node (like you do in *RIGID) because this
%is only used to tie the rest of the nodes to this reference node. Rather
%you just need to tie the two node sets together (web and chord)



%*********  WEB MEMBER NODE SETS  ***************
    xbc=size(webcon);
    loop=xbc(1,2);

    %You can just put the different node sets here and reference them later
    fprintf(fid,'*******WEB MEMBER WELD CONSTRAINT NODE SETS******\n');
    for i=1:loop
        %write constraint node info
        fprintf(fid,'*NSET, NSET=WEBCON%d \n', i);
            for j=1:size(webcon{i},1)
            fprintf(fid,'%6.0f\n',webcon{i}(j,1));
            end
    end



%********** CHORD MEMBER NODE SETS *********
    %make chord member node sets that match up with the web member chord
    %sets
    ltc=size(c_weld);
    loop=ltc(1,2);
    fprintf(fid,'******CHORD MEMBER WELD CONSTRAINT NODE SETS******\n');
    for i=1:loop
        fprintf(fid,'*NSET, NSET=C_WELD%d\n',i);
            for j=1:size(c_weld{i},1)
                fprintf(fid,'%6.0f\n',c_weld{i}(j,1));
            end
    end



    %-Using MPC's
    fprintf(fid,'*****WEB WELD USING MPCS*****\n');
    %write a loop to relate the webcon node sets to the chordcon node sets
    fprintf(fid,'*MPC\n');
    for i=1:loop
%         for j=1:size(webcon{i},1) %A loop for tying together individual
%         nodes
%             fprintf(fid,'TIE,  %6.0f,
%6.0f\n',webcon{i}(j,1),c_weld{i}(j,1));
%         end
        fprintf(fid,'BEAM,  WEBCON%d, C_WELD%d\n',i,i); %tying together node
sets
    end







%****************************FASTENER***********************************
%This didn't work initially, but leave it just in case we can figure it out
%later
% radius=.125; %The radius of the fastener
% SEARCH_RADIUS=0.5;
% RADIUS_OF_INFLUENCE=0.5;
%
% %Web member weld information
% xbc=size(webcon);
% loop=xbc(1,2);
% name='BasicWeld'; %The name given to the fastner, if we use multiple types
we will need to make another one
%
% %Battenweld information
% % sizebatten=size(battenweld);
% % loop2=sizebatten(1,2);
% % battename='BattenWeld';%The name for these fasteners
% % battenrad=0.25; %The radius for the batten fasteners
%
% %-----NODE SETS-----
%
% %Web member node sets
% %You can just put the different node sets here and reference them later
% fprintf(fid,'*******WEB MEMBER WELD CONSTRAINT NODE SETS******\n');
% for i=1:loop
%     %write constraint node info
%     fprintf(fid,'*NSET, NSET=WEBCON%d \n', i);
%         for j=1:size(webcon{i},1)
%         fprintf(fid,'%6.0f\n',webcon{i}(j,1));
%         end
% end
%
% %Batten node sets
% % fprintf(fid,'*****BATTEN WELD NODE SETS*****\n');
% % for i=1:loop2
% %     fprintf(fid,'*NSET, NSET=BATTENWELD%d\n',i);
% %     for j=1:length(battenweld{i})
% %         fprintf(fid,'%6.0f\n',battenweld{i}(j,1));
% %     end
% % end
%
%
```

```
% %-----FASTENER PROPERTIES-----
% %separate fastener properties can be defined here (such as different weld
% %size) that can be referenced later (for now we are only using one weld
% %size)
%
% %Fastener properties for the web member welds
% fprintf(fid,'******FASTENER PROPERTIES******\n');
% fprintf(fid,'*FASTENER PROPERTY, NAME=%s\n',name);
% fprintf(fid,'%g\n\n',radius);
%
% %-----CONSTRAINING NODES (*FASTENER)-----
% fprintf(fid,'******FASTENERS******\n');
%     for i=1:loop
%         %There are additional parameters that can be specified in the input
%         %file that are not explicitly stated below (they defer to the
%         %default for each of these) these include things such as the search
%         %radius, attachment method, etc. See ABAQUS user manual under the
%         %*FASTENER section for more information
%         fprintf(fid,'*FASTENER, INTERACTION NAME=WELD%d, PROPERTY=%s,
REFERENCE NODE SET=WEBCON%d, RADIUS OF INFLUENCE= %6.16f, SEARCH RADIUS=
%6.16f\n',i,name,i, RADIUS_OF_INFLUENCE, SEARCH_RADIUS);
%     end

% Fastener properties for the batten welds
% fprintf(fid,'*FASTENER PROPERTY, NAME=%s\n',battename);
% fprintf(fid,'%g\n\n',battenrad);

%-----CONSTRAINING NODES (*FASTENER)-----
% fprintf(fid,'******FASTENERS******\n');
%     for i=1:loop2
%         %There are additional parameters that can be specified in the input
%         %file that are not explicitly stated below (they defer to the
%         %default for each of these) these include things such as the search
%         %radius, attachment method, etc. See ABAQUS user manual under the
%         %*FASTENER section for more information
%         fprintf(fid,'*FASTENER, INTERACTION NAME=Bweld%d, PROPERTY=%s,
REFERENCE NODE SET=BATTENWELD%d, RADIUS OF INFLUENCE= %6.16f, SEARCH RADIUS=
%6.16f\n',i,battename,i, RADIUS_OF_INFLUENCE, SEARCH_RADIUS);
%     end





%--------------------------BRACES-------------------------

%Use multi-point constraints to simulate the braces in place along the
%length of the joist

%Determine the number of matrices to loop around
usa=size(BP);
loop2=usa(1,2);
loop=loop2/4;%use four because there are always four angles per joist (two
chords with two angles apiece per joist)
```

```
bpts=size(BP{1},1);%The number of brace points in the joist (four for one
joist, one in each angle of both the TC and BC)

%Create matrices that link together each node
%Grab each node and link them together for each brace location
%
%The way this works is it goes through each cell of BP and gets the node in
%each row to match up with one another
for i=1:bpts
    for j=1:loop2
        brace(j,i)=BP{j}(i,1);
    end
end

usa=size(brace);
loop=usa(1,2);

%separate brace into cells (each cell is a node set)
for i=1:loop
    brace_pts(:,1)=brace(:,i);
    B{i}=brace_pts;
end

% for j=1:loop
%     for i=1:bpts
%         brace(i,1)=BP{i+(j-1)*bpts}(i,1);
%     end
%     B{j+(j-1)*bpts}=brace;
% end

% for j=1:loop
%     for i=1:bpts
%         brace(1,1)=BP{1*j}(i,1);
%         brace(2,1)=BP{2*j}(i,1);
%         brace(3,1)=BP{3*j}(i,1);
%         brace(4,1)=BP{4*j}(i,1);
%         B{i*j}=brace;
%     end
% end

tick=size(B);
tock=tick(1,2);

fprintf(fid,'******BRACE CONSTRAINT NODE SETS***** \n');
for i=1:tock
    %write constraint node info
    fprintf(fid,'*NSET, NSET=BRACE%d \n', i);
        for j=1:length(B{i})
            fprintf(fid,'%6.0f\n',B{i}(j,1));
        end
end


fprintf(fid,'******BRACE CONSTRAINTS*****\n');
fprintf(fid,'*MPC\n');
```

```
for i=1:tock
    for j=1:size(B{i})-1
        for k=1:N
            fprintf(fid,'BEAM, %d, %d\n',B{i}(j,1)-N+k,B{i}(j+1,1)-N+k);
        end
    end
end




%--------------------------ROTATIONAL-RESTRAINT-------------------------

%Use multi-point constraints to simulate the braces in place along the
%length of the joist

%Determine the number of matrices to loop around
usa=size(RR);
loop2=usa(1,2);
numcols=loop2/2;%use two because there are always two angles per joist for
the rotational restraints

rpts=size(RR{1},1);%The number of rotational restraint points in the joist
(four for one joist, one in each angle of both the TC and BC)

for i=1:numcols
    for j=1:rpts
        if i==1
            if j==1
                rbrace(1,i)=RR{i}(j,1);
                rbrace(2,i)=RR{i+numcols}(j,1);
            else
                rbnext=size(rbrace);
                rbn=rbnext(1,2);
                rbrace(1,rbn+1)=RR{i}(j,1);
                rbrace(2,rbn+1)=RR{i+numcols}(j,1);
            end
        else
                rbnext=size(rbrace);
                rbn=rbnext(1,2);
                rbrace(1,rbn+1)=RR{i}(j,1);
                rbrace(2,rbn+1)=RR{i+numcols}(j,1);
        end
    end
end

%Create matrices that link together each node
%Grab each node and link them together for each brace location
%
%The way this works is it goes through each cell of BP and gets the node in
%each row to match up with one another

usa=size(rbrace);
loop=usa(1,2);

% %separate brace into cells (each cell is a node set)
% for i=1:loop
%     rbrace_pts(:,1)=rbrace(:,i);
%     V{i}=rbrace_pts;
% end

% fprintf(fid,'******ROTATIONAL CONSTRAINT NODE SETS***** \n');
% for i=1:tock
%     %write constraint node info
%     fprintf(fid,'*NSET, NSET=RBRACE%d \n', i);
%         for j=1:length(V{i})
%             fprintf(fid,'%6.0f\n',V{i}(j,1));
%         end
% end

% tick=size(V);
% tock=tick(1,2);

fprintf(fid,'******ROTATIONAL CONSTRAINTS*****\n');
fprintf(fid,'*MPC\n');

for i=1:loop
        fprintf(fid,'BEAM, %d, %d\n',rbrace(1,i),rbrace(2,i));
end

% fprintf(fid,'******BRACE CONSTRAINTS*****\n');
% fprintf(fid,'*MPC\n');
% for i=1:tock
%     for j=1:size(B{i})-1
%             fprintf(fid,'BEAM, %d, %d\n',B{i}(j,1),B{i}(j+1,1));
%     end
% end



%-------------SPACERS-SIMULATE WITH MPC'S---------------

%**SPACERS IN THE TC
%Determine the number of matrices to loop around

%We need to make this global so it can apply to multiple joists not just
%one

count=size(TCbat);
loop=count(1,2);
numbat=size(TCbat{1},1);
for j=1:2:loop
    for i=1:numbat
        spacer(1,1)=TCbat{j}(i,1);
        spacer(2,1)=TCbat{j+1}(i,1);
        if j==1
            if i==1
                TCspace{1}=spacer;
            else
                space_count=size(TCspace);
                next=space_count(1,2);
                TCspace{next+1}=spacer;
            end
        else
            space_count=size(TCspace);
            next=space_count(1,2);
            TCspace{next+1}=spacer;
        end
    end
end

%Original, used for only one joist
% loop3=length(TCbat{1});
% for i=1:loop3
%     batten(1,1)=TCbat{1}(i,1);
%     batten(2,1)=TCbat{2}(i,1);
%     TCBATTER{i}=batten;
% end

tick=size(TCspace);
tock=tick(1,2);

fprintf(fid,'******TOP CHORD SPACER CONSTRAINT NODE SETS***** \n');
for i=1:tock
    %write constraint node info
    fprintf(fid,'*NSET, NSET=TC_SPACER%d \n', i);
        for j=1:length(TCspace{i})
        fprintf(fid,'%6.0f\n',TCspace{i}(j,1));
        end
end

fprintf(fid,'******TOP CHORD SPACER CONSTRAINTS*****\n');
fprintf(fid,'*MPC\n');
for i=1:tock
    for j=1:size(TCspace{i})-1
        fprintf(fid,'BEAM, %d, %d\n',TCspace{i}(j,1),TCspace{i}(j+1,1));
    end
end

%**SPACERS IN THE BC

count=size(BCbat);
loop=count(1,2);
numbat=size(BCbat{1},1);
for j=1:2:loop
    for i=1:numbat
        spacer(1,1)=BCbat{j}(i,1);
        spacer(2,1)=BCbat{j+1}(i,1);
        if j==1
            if i==1
                BCspace{1}=spacer;
            else
                space_count=size(BCspace);
                next=space_count(1,2);
                BCspace{next+1}=spacer;
            end
        else
```

```
            space_count=size(BCspace);
            next=space_count(1,2);
            BCspace{next+1}=spacer;
        end
    end
end

%The old way--Only good for one joist
% %Determine the number of matrices to loop around
% loop4=length(BCbat{1});
%
% %Create matrices that link together each node
% %BP should always run from 1-4 because we will always have four angles that
make up our two chords
% for i=1:loop4
%     batten(1,1)=BCbat{1}(i,1);
%     batten(2,1)=BCbat{2}(i,1);
%     BCBATTER{i}=batten;
% end

tick=size(BCspace);
tock=tick(1,2);

fprintf(fid,'******BOTTOM CHORD SPACER CONSTRAINT NODE SETS***** \n');
for i=1:tock
    %write constraint node info
    fprintf(fid,'*NSET, NSET=BC_SPACER%d \n', i);
        for j=1:length(BCspace{i})
            fprintf(fid,'%6.0f\n',BCspace{i}(j,1));
        end
end

fprintf(fid,'******BOTTOM CHORD SPACER CONSTRAINTS*****\n');
fprintf(fid,'*MPC\n');
for i=1:tock
    for j=1:size(BCspace{i})-1
        fprintf(fid,'BEAM, %d, %d\n',BCspace{i}(j,1),BCspace{i}(j+1,1));
    end
end
```

Function: ***writeBC.m***

```
function [] = writeBC(fid,nodeBC,BP)
%This function produces the boundary conditions at the ends of the joists

xbc=size(nodeBC);
loop=xbc(1,2);%The number of matrices inside the cell nodeBC

fprintf(fid,'******BOUNDARY CONDITIONS******\n');

%-----NODE SETS-----
%You can just put the different node sets here and reference them later
fprintf(fid,'**BOUNDARY CONDITION NODE SETS**\n');
for i=1:loop
```

```
    %write constraint node info
    fprintf(fid,'*NSET, NSET=nodeBC%d \n', i);
        for j=1:length(nodeBC{i})
            fprintf(fid,'%6.0f\n',nodeBC{i}(j,1));
        end
end

%Create Boundary conditions
fprintf(fid,'*Boundary\n');
%Loop around the number of joists to supply boundary conditions to all of
%the joist ends
%ORIGINAL: CHANGE BACK TO THIS LATER:
%numjoist=loop/4;%the number of joists will always be the number of matrices
in nodeBC divided by 4 (the number of angles (within the chords) in each
joist)
% for i=1:numjoist
%     fprintf(fid,'nodeBC%d,%g,%g\n',1+(i-1)*4,1,3); %pinned end
%     fprintf(fid,'nodeBC%d,%g,%g\n',2+(i-1)*4,2,3); %roller end
%     fprintf(fid,'nodeBC%d,%g,%g\n',3+(i-1)*4,1,3); %pinned end
%     fprintf(fid,'nodeBC%d,%g,%g\n',4+(i-1)*4,2,3); %roller end
% end

%TEMPORARY: CONTAINS PINS IN THE BC
numjoist=loop/8;
for i=1:numjoist
    fprintf(fid,'nodeBC%d,%g,%g\n',1+(i-1)*8,1,3); %pinned end
    fprintf(fid,'nodeBC%d,%g,%g\n',2+(i-1)*8,2,3); %roller end
    fprintf(fid,'nodeBC%d,%g,%g\n',3+(i-1)*8,1,3); %pinned end
    fprintf(fid,'nodeBC%d,%g,%g\n',4+(i-1)*8,2,3); %roller end
    %-----------------bottom chord pins----------------------
    fprintf(fid,'nodeBC%d,%g,%g\n',5+(i-1)*8,1,3); %pinned end
    fprintf(fid,'nodeBC%d,%g,%g\n',6+(i-1)*8,2,3); %roller end
    fprintf(fid,'nodeBC%d,%g,%g\n',7+(i-1)*8,1,3); %pinned end
    fprintf(fid,'nodeBC%d,%g,%g\n',8+(i-1)*8,2,3); %roller end
end

%
% %----PUT PINS AT THE BRACE POINTS---- (TEMPORARILY! until we have 2 joists
% %in)
% %place)
% %Determine the number of matrices to loop around
% usa=size(BP);
% loop2=usa(1,2);
%
% bpts=size(BP{1},1);%The number of brace points in the joist (four for one
joist, one in each angle of both the TC and BC)
%
% %Create matrices that link together each node
% %BP should always run from 1-4 because we will always have four angles that
make up our two chords
% for i=1:loop2
%     brace(1,1)=BP{1}(i,1);
%     brace(2,1)=BP{2}(i,1);
%     brace(3,1)=BP{3}(i,1);
%     brace(4,1)=BP{4}(i,1);
%     B{i}=brace;
% end
%
% tick=size(B);
% tock=tick(1,2); %This goes through all of the matrices inside of cell "B"
%
% fprintf(fid,'******PIN-BRACE CONSTRAINT NODE SETS (TEMPORARY!!!!!)*****
\n');
% for i=1:tock
%     %write constraint node info
%     fprintf(fid,'*NSET, NSET=BRACEpin%d \n', i);
%         for j=1:size(B{i},1);
%             fprintf(fid,'%6.0f\n',B{i}(j,1));
%         end
% end
%
% %**CREATE BC'S AT BRACE POINTS
% fprintf(fid,'*Boundary\n');
% for i=1:tock
%         fprintf(fid,'BRACEpin%d,%g,%g\n',i,1,3); %pinned end
% end

end
```

Function: ***writemonitor.m***

```
function [] = writemonitor(fid, midx)
%This function finds nodes that need to be monitored during analysis

%----------DEFLECTION MONITOR NODE SETS--------
fprintf(fid,'**BOTTOM CHORD DEFLECTION MONITOR NODE SETS**\n');
idk=size(midx);%The size (it comes out as a matrix) of midx
loop=idk(1,2);%The number of matrices inside the cell midx

for i=1:loop
    fprintf(fid,'*NSET, NSET=BC_MONITOR%d\n',i);
    fprintf(fid,'%6.0f\n',midx{i}(1,1));%each matrix in midx consists on ONLY
ONE NODE!
end

end
```

Function: ***writestep.m***

```
function []=writestep(fid,step,nodeBC,LOAD_TYPE,cLoad,TCload,analysis,midx)
    i = 1; %we only have one step
    fprintf(fid,'******START STEP%g******\n',i);
    %write stepinfo
    fprintf(fid,'*Step, name=%s %s %g\n',step(i).stepinfo{1:3});
    %write solutiontype
    fprintf(fid,'*%s\n',step(i).solutiontype);
    %write solutionsteps
    if isempty(step(i).solutionsteps)==0
    for j=1:length(step(i).solutionsteps);
```

```
        if step(i).solutionsteps{j}==0
            fprintf(fid,' ,');
        else
            fprintf(fid,'%s',step(i).solutionsteps{j});
        end
        if j==length(step(i).solutionsteps);
            fprintf(fid,'\n');
        end
    end
    end
    %write solution controls
    if isempty(step(i).solutioncontrols)==0;
        fprintf(fid,'******SOLUTION CONTROLS******\n');
        for j=1:length(step(i).solutioncontrols)
            if step(i).solutioncontrols{j}==' '
                fprintf(fid,' ,');
            else
                if ischar(step(i).solutioncontrols{j});
                    fprintf(fid,'%s',step(i).solutioncontrols{j});
                else
                    fprintf(fid,'%g,',step(i).solutioncontrols{j});
                end
            end
            if j==length(step(i).solutioncontrols)
                fprintf(fid,'\n');
            end
        end
    end




%------APPLY LOADS------


%***PRESSURE LOAD
%use TCload to iterate and apply loads to the correct surfaces of the
%joists
if LOAD_TYPE=='P'
    AMPLITUDE=5;

    %Create the distributed loads on the joist
    fprintf(fid,'********LOADS*******\n');

    xbc=size(TCload);
    loop=xbc(1,2);

    %loop through the odd numbered matrices in cell TCload, these matrices
    %have a positive load up (because of the right hand rule)
    for i=1:2:loop
            fprintf(fid,'*Dsload\n');
            fprintf(fid,'CTOP%d, P, %6.16f \n',i,-AMPLITUDE);
    end

    %loop through the even numbered matrices in cell TCload, these matrices
    %have a positive load down (because of the right hand rule)
    for i=2:2:loop
        fprintf(fid,'*Dsload\n');
        fprintf(fid,'CTOP%d, P, %6.16f \n',i,AMPLITUDE);
    end

%Below is the original and is only used for a single joist
%     fprintf(fid,'*Dsload\n');
%     fprintf(fid,'CTOP, P, %6.16f \n',-AMPLITUDE);
%     fprintf(fid,'*Dsload\n');
%     fprintf(fid,'CCTOP, P, %6.16f \n',AMPLITUDE);

end



%------------CONCENTRATED LOADS------------
if LOAD_TYPE=='C'
    %Define the node set
    fprintf(fid,'*****CONCENTRATED LOAD NODE SETS*****\n')
    fprintf(fid,'*NSET, NSET=cLoad%d\n',1); %only 1 right now because we are
only loading one angle of the chord
    for i=1:size(cLoad,1)
        fprintf(fid,'%6.0f\n',cLoad(i,1));
    end

    AMPLITUDE=-3.0;
    fprintf(fid,'*******LOADS*******\n');
    fprintf(fid,'*CLOAD\n');
    fprintf(fid,'cLoad1,2,%6.16f\n',AMPLITUDE);



%------------POSTPROCESSING-LOADS------------
%Use any node that the load is being applied to to track the load on the
%joist, this can be used for a load-displacement plot
%
%Since the load is the same at every node that loads are being applied to
%just grab one of them-get the first just to make it easy
fprintf(fid,'******TRACK LOADS FOR POST-PROCESSING******\n');
fprintf(fid,'*NSET, NSET=LOADTRACKER\n');
fprintf(fid,'%6.0f\n',cLoad(1,1));%Just use the first node that the load is
applied to


end




%put in output request for collapse analysis
if analysis=='C'
    fprintf(fid,'******OUTPUT******\n');
    fprintf(fid,'*Output, field, variable=PRESELECT, frequency=10\n');
%     fprintf(fid,'*Contact Output, variable=PRESELECT\n');
    fprintf(fid,'*Element Output, variable=PRESELECT\n');
    fprintf(fid,'1,3,5\n');
    %fprintf(fid,'*Node Print, SUMMARY=NO\n');

    %Write output to .dat file for the node information
    xbc=size(midx);
    loop=xbc(1,2);

    %Write a loop to output the displacements at a node in the bottom chord
    %of each joist
    for i=1:loop
        fprintf(fid,'*Node Print, NSET=BC_MONITOR%d, SUMMARY=NO\n',i);%List
the node sets (each node set only has one node) to monitor
        fprintf(fid,'U2\n');%List the DOF to monitor (U2 represents
deflection in the y-direction)
    end

    %Output the loads to the .dat file
    fprintf(fid,'*NODE PRINT, NSET= LOADTRACKER, SUMMARY=NO\n');
    fprintf(fid,'CF2\n');%Track the vertical load (y-direction)

end

    %End Step
    fprintf(fid,'*End Step\n');
    fprintf(fid,'******END STEP%g******\n',i);

end
```