CHAPTER III

DEVELOPMENT OF FINITE ELEMENT MODEL AND COMPARISON WITH TEST RESULTS

3.1 DEVELPOMENT OF FINITE ELEMENT MODEL

3.1.1 Description of Finite Element Analysis

Finite element (FE) models were used in this research to analytically study the behavior of the test specimens. A series of elements and nodes were used to represent the geometry of the column/stiffener connection. The material and cross-section definitions applicable to the steel sections were defined within the model. Constraints and boundary conditions were also applied to applicable nodes throughout the analysis. Since the section was loaded equally on both ends of the specimen during testing, the bottom flange of the column was restrained in the FE model at the equivalent line load location while the load is applied across the top flange. Constraints were therefore placed on the nodes representing the bottom flange of the column section. The behavior of the specimen is simulated through these boundary conditions which restricted linear and rotational movements of the applicable nodes in the model. The computer software ABAQUS (*ABAQUS/Standard* 1994) was used for this study to analyze the specimens in Test 1, Test 2 and additional column sections.

The tensile load was modeled as a distributed load acting across the flange width of the column at the stiffener location. This simulates the load acting on the column by the top beam flange in gravity type loading. The specimens in Test 1 and Test 2 were subjected to this type of loading in the experimental investigation. The FE models were considered elastic because only minor yielding occurred in the connections during the experimental investigation. A modulus of elasticity of 29,000 ksi and a Poisson's Ratio of 0.3 were used. The files containing the ABAQUS input data and the analysis results are contained in Appendices A and B for Test 1 and Test 2.

3.1.2 Shell Elements

Shell elements are provided in ABAQUS and allow for six degrees of freedom at all nodes. The cross sectional properties of the shell including the thickness of the material are required input to define the behavior (*ABAQUS/Standard Vol. II*, 1994). S8R type shell elements were used in the models. These elements were 8-node doubly curved thick shells and utilized reduced integration to minimize ABAQUS run time while providing accurate results. This element type contains 4-sides with nodes at the 4 corners and at the middle of each side. Triangular, or 3-sided, elements were not used because they have a tendency to introduce a false stiffness in the model. S8R's are thick elements (when the thickness is more than about 1/15 of the surface length of the shell) and also account for transverse shear flexibility.

The finite element model used in the Test 1 analysis is represented in Figure 3.1. When Test 2 geometry is applied, the FE model is the same. The width of each stiffener is represented by two elements (see Figure 3.1) and the stress values obtained at the nodes of these elements were used to compute the stiffener force.

3.2 FINITE ELEMENT RESULTS

3.2.1 Test 1

The finite element model was run in ABAQUS for a load case of 170 kips. The stresses in the stiffener and web elements were obtained for this load in order to calculate the load distributed between the web and stiffener. The variation of stress along the width of the stiffener is shown in Figure 3.2 for the stiffener elements closest to the column flange. Because the stress vs. distance relationship is linear, the load can be easily and accurately calculated using the area under the curve. The FE results used as a comparison with the experimental results are provided in Table 3.1 for a load of 170k and can be determined for any load variation because it is an elastic analysis.

3.2.2 Test 2

The finite element model for Test 2 is similar to that used in Test 1. The geometry of the model was modified to match the W section and stiffener dimensions used in the Test 2 experiment. The stresses in the stiffener and web were again obtained for a load of 170 kips. The variation of stress along the width of the stiffener is provided in Figure 3.2 for the stiffener elements closest to the column flange at a load of 170 k.

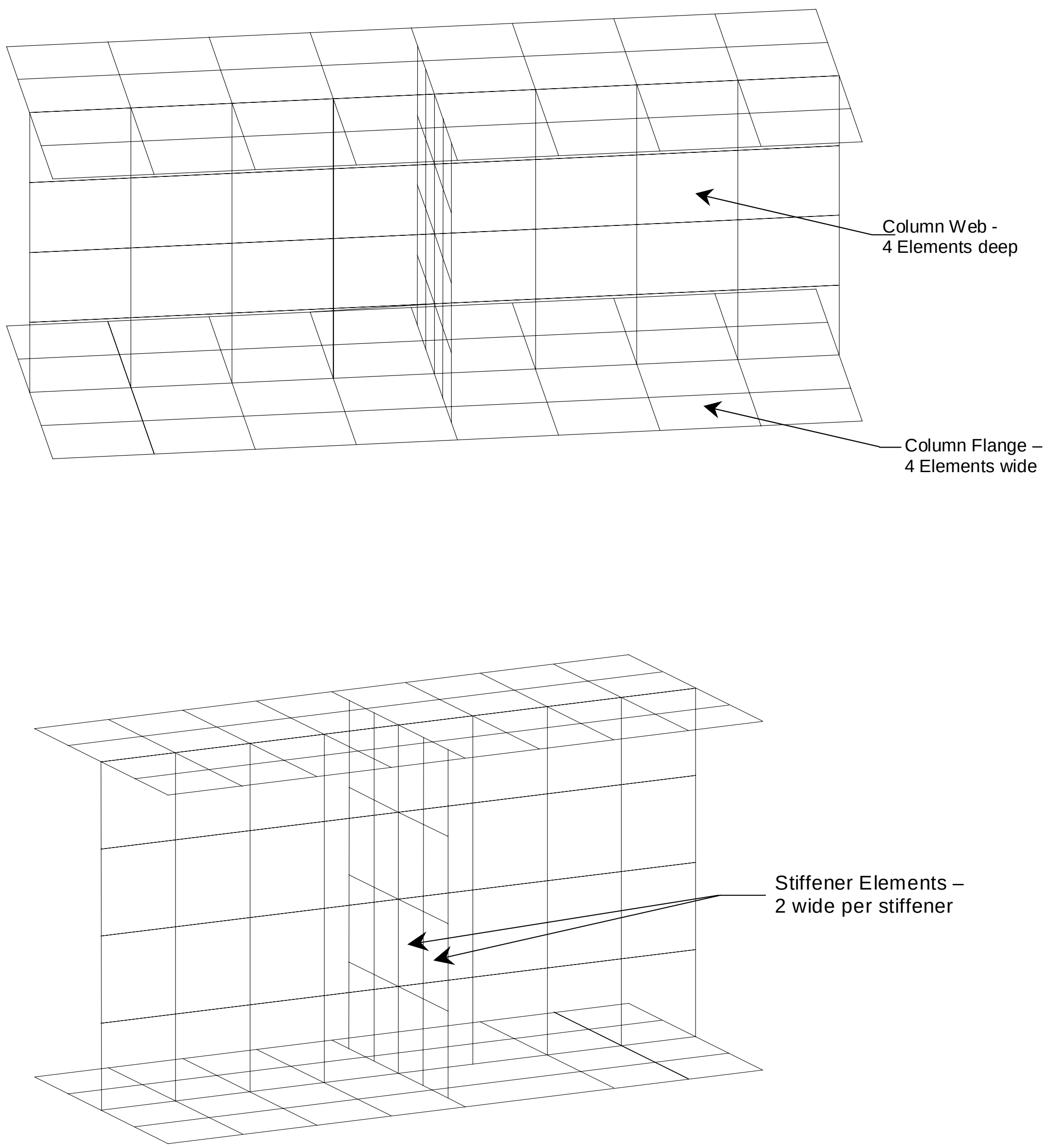
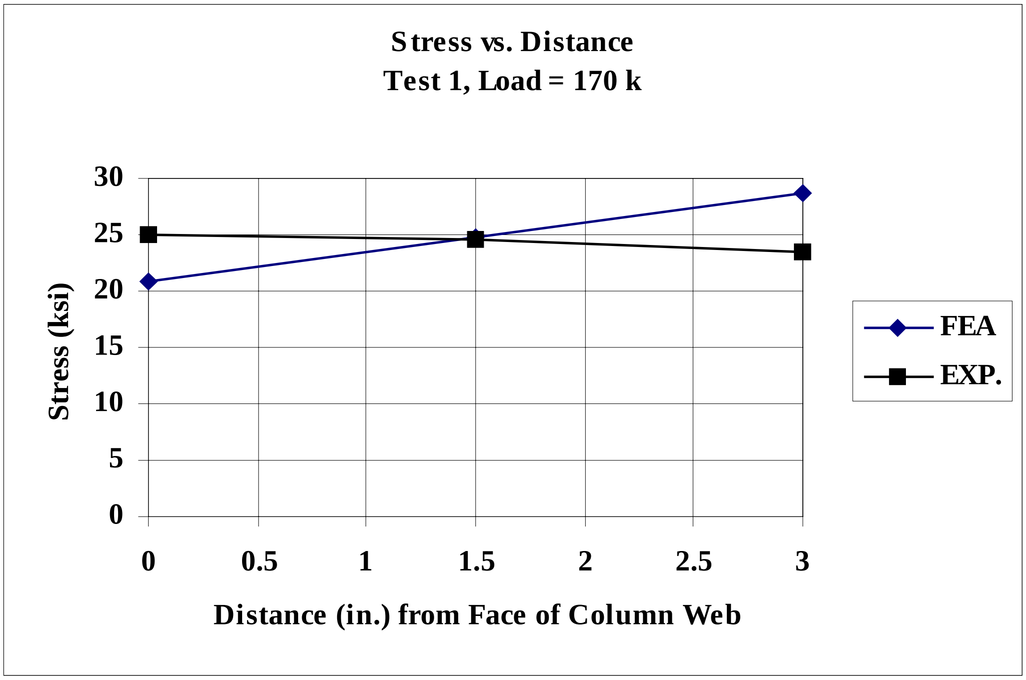


Figure 3.1 FE Model for Test Specimens



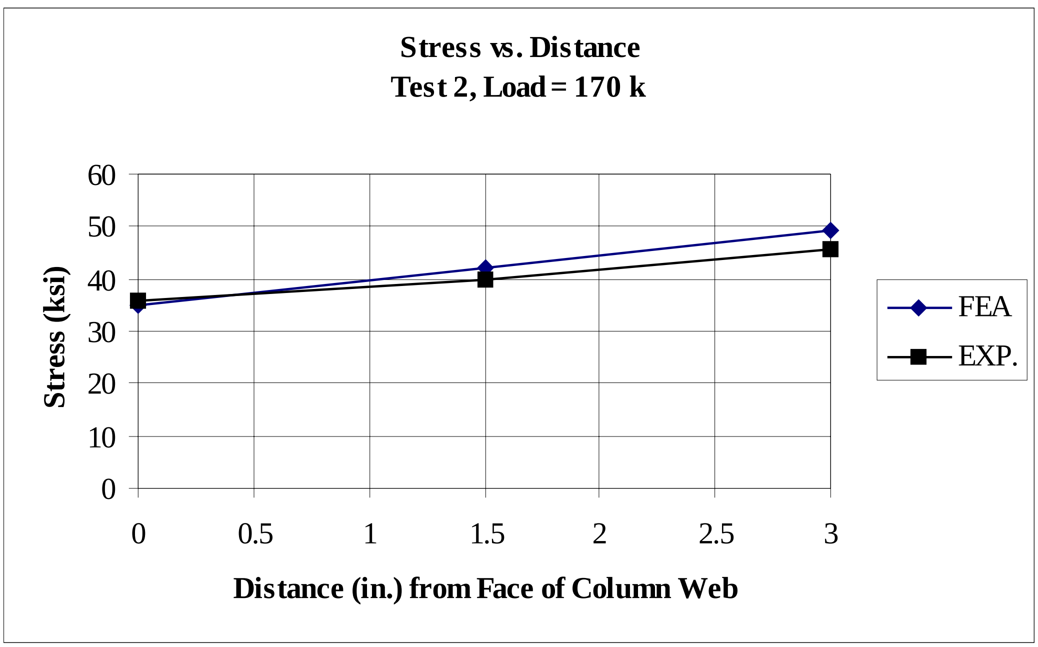


Figure 3.2 Finite Element Results for Stiffeners
Stress vs. Distance - Test 1 and 2

Figure 3.3 shows the variation of force along the length of the web at a load of 170 k. The ratio of stiffener force to the applied load is shown in Table 3.1 for Test 1 and Test 2.

Table 3.1 Stiffener Force from FE Models

Test	Applied Load (kips)	Stiffener Force (P_s)	% Stiffener Load
Test 1 – W16x45	170	111.4	65.5
Test 2 – W8x48	170	94.9	55.8

These values were obtained to confirm that the experimental data was consistent with the results obtained from analytical methods. Because the results are consistent, an accurate design procedure can be developed.

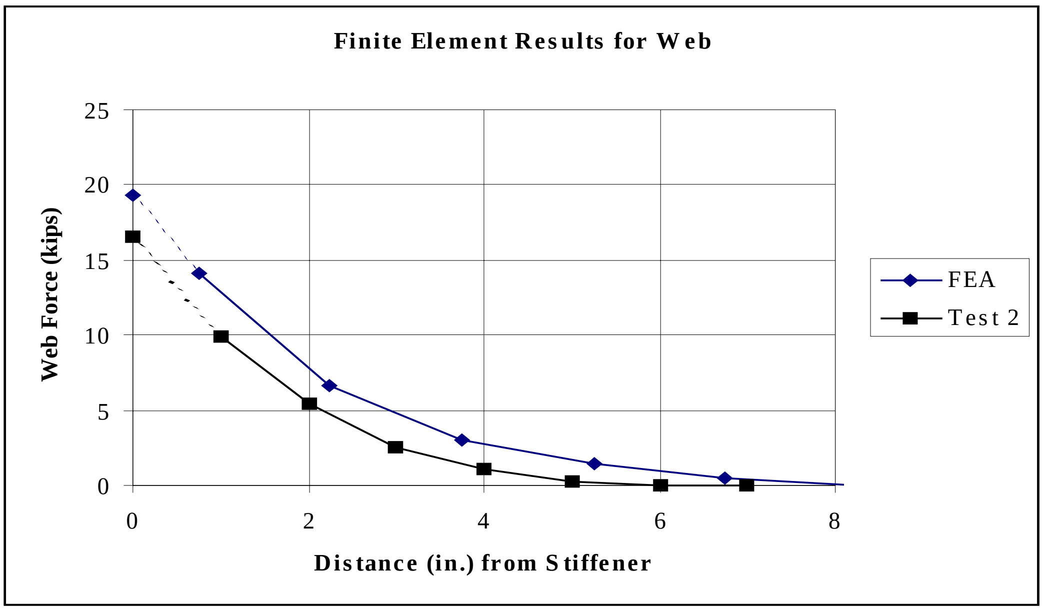


Figure 3.3 Finite Element Results for Web - Test 2

Additional FE models were performed on W-shaped column sections to show that the results also apply to larger column section.

3.2.3 Additional Finite Element Models

Additional finite element model analyses were performed to confirm that the results were consistent and could be applied to larger W-shaped sections. ABAQUS was used to analyze a W14x311 designed for a factored load of 1196 kips using 7/8 in. by 7 in. full depth stiffeners on each side of the column web. As with Test 1 and 2 column sections, the LRFD method was used for designing the W14x311 column stiffeners. The same element type, boundary conditions, and load distribution used for the previous analyses was applied to this section. A572, Grade 50 material properties (yield stress of 50 ksi) were used for the column and stiffeners. The stresses in the stiffeners were obtained for this load case. The variation of stress along the width of the stiffener is similar to that obtained from the ABAQUS output for Tests 1 and 2. The load can be easily calculated using the area under the stress/distance curve. The distribution of stiffener load along its length is shown in Figure 3.4 for an applied load of 1196 k.

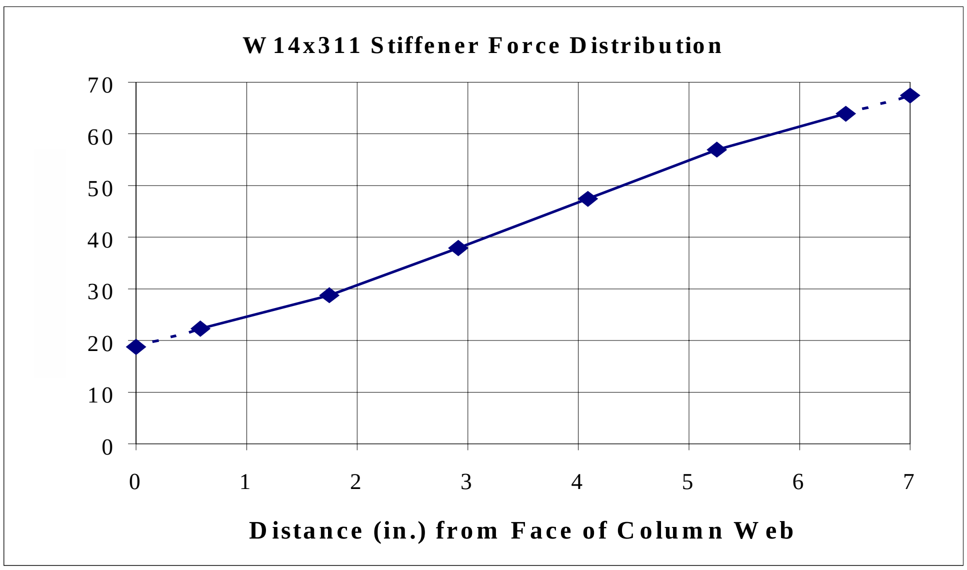


Figure 3.4 W14x311 Finite Element Results

The results are as follows:

Applied Load = 1196 kips
Stiffener Force = 2(266.30) = 532.60 kips
% Stiffener Load (Ps/P)(100) = 0.45(100) or 45%

Thus, the ABAQUS results for the W14x311 column section are consistent with that obtained from the smaller sections used in Tests 1 and 2.

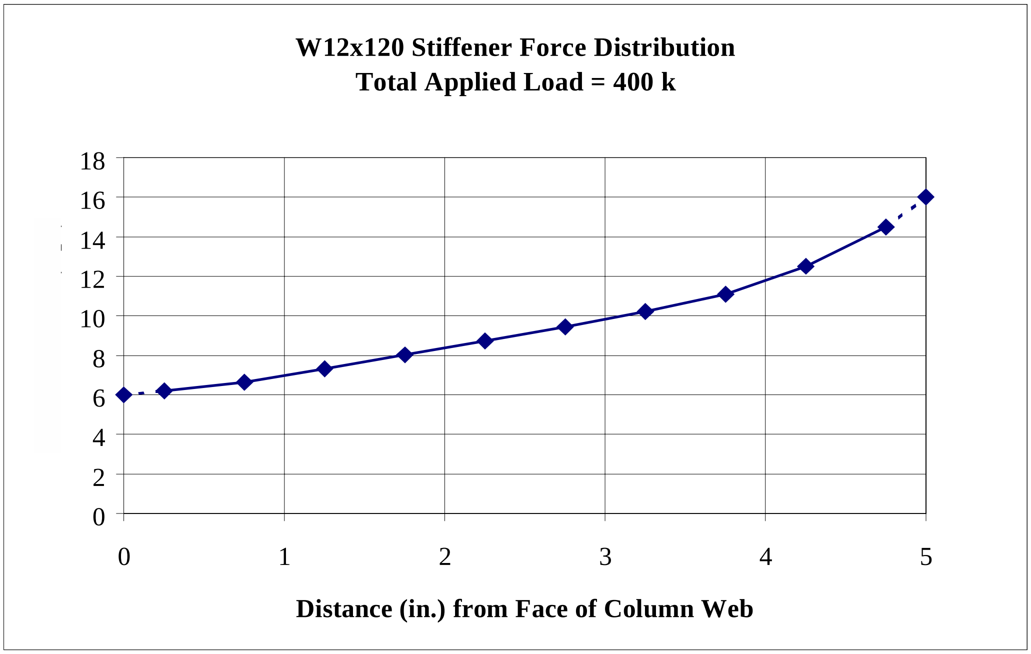
The finite element program provided by I-DEAS Master Series 6 was used to analyze a W12x120 and W14x500 column section. All finite element definitions, methodology, and procedure used for these models is the same as those used previously for the ABAQUS analyses. The W12x120 was designed for a factored load of 400 kips using 1/2 in. by 5 in. full depth stiffeners on each side of the column web (yield stress for all material was 50 ksi). A factored load of 2500 kips was applied to a W14x500 column section with 1-3/4 in. by 7 in. full depth stiffeners on each side of the column web. The LRFD method was used for designing these column stiffeners. The forces in the stiffener elements were recovered for the load cases in each column section. The element forces along the stiffener width were then added together to determine the total stiffener force. The variation of forces along the stiffener width is shown in Figure 3.5 and is similar to the results obtained from the ABAQUS output for the W14x311 column section. The results are summarized in Table 3.2.

Table 3.2 FEA Results for Additional Column Sections

Column Section	**Stiffeners – 2 Plates**	**P_{tot} (kips)**	**P_{stiff} (kips)**	**P_{stiff}/P_{tot}**
W14x311	7/8x7	1196	532.6	0.45
W12x120	1/2x5	400	196.4	0.49
W14x500	1-3/4x7	2500	1086.8	0.43

3.2.4 Parametric Study of Stiffener Sizes

Finite Element Analysis was used to examine the effects of stiffener size on load distribution between the column web and stiffener. I-DEAS Master Series 6 was again used to analyze the column section and stiffener as described in the previous section. A factored load of 200 kips was applied to a W14x90 column section and analyzed three times using a different stiffener size for each run. The forces in the stiffener elements were recovered from each analysis for the load case. The element forces along the stiffener width were then added together to determine the total stiffener force. The variation of force along the width of the stiffener for these FEA runs was consistent with the analysis results provided in the previous subsections. The results are provided in Table 3.3.



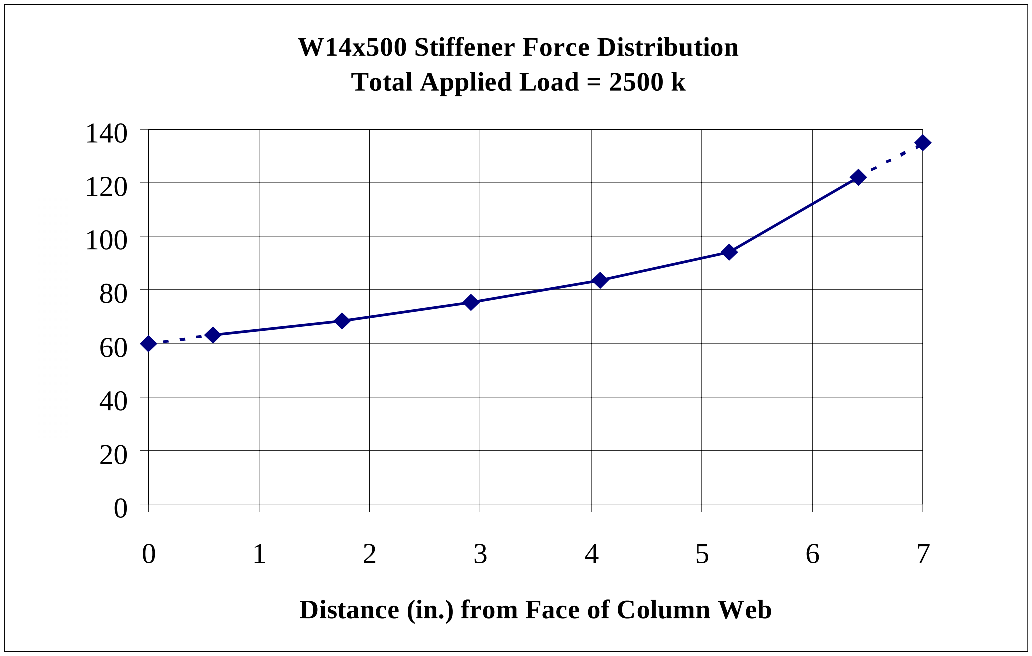


Figure 3.5 W12x120 and W14x500 Finite Element Results

Table 3.3 FEA Results for W14x90 Stiffeners

Column Section	**Stiffeners**		**P_{tot} (kips)**	**P_{stiff} (kips)**	**P_{stiff}/P_{tot}**
	2 Plates	**Area (in.^{2})**			
W14x90 (a)	3/8x5	3.75	200	106.52	0.53
W14x90 (b)	1/4x6	3.00	200	105.54	0.53
W14x90 (c)	3/8x4-1/4	3.38	200	100.88	0.50

3.3 COMPARISON OF EXPERIMENTAL AND ANALYTICAL DATA

The results obtained from the finite element analysis and experimental tests provided consistent data. The distribution of load between the stiffeners and column web was similar in both types of investigations. The main difference between the results obtained from the two methods of investigation was in the determination of load. Stiffener load was calculated from strain values in the experimental method while the finite element method used stress values.

The method for predicting the column and stiffener design load based on Load and Resistance Factor Design (LRFD) requirements was discussed in Chapter I. LRFD requirements assign stiffener load based on limit state strengths of the column section. The results of the predicted, experimental and analytical investigation are compared in Table 3.4. These results are calculated in the same manner as discussed in Chapter II (using the area under either the strain vs. distance curve for experimental data or stress vs. distance curve for analytical data). The ratio of the stiffener load to the total load (P_s/P) is given for the LRFD method, as determined experimentally, and from the finite element results where P is the total load applied to the test specimen and P_s is the load carried by both stiffeners. It can be seen from Table 3.4 that the differences between the experimental and finite element results are small (less than 5%).

The P_s/P ratios are consistent between the experimental and finite element tests and exhibit the same linear behavior. In all cases, the ratio of stiffener load to the applied load remains constant for all load cases. The LRFD method for determining stiffener

Table 3.4 Predicted versus Test Results

Test	Load (kips)	P_s/P: LRFD	P_s/P: Experiment	P_s/P: Finite Element
Test 1-W16x45	170	0.44	0.64	0.65
Test 2-W8x48	170	0.43	0.53	0.56
W14x311	1196	0.16	N/A	0.45
W12x120	400	0.38	N/A	0.49
W14x500	2500	0.31	N/A	0.43
W14x90	200	0.47	N/A	0.53

load, however, does not demonstrate a linear relationship and therefore does not correspond to the behavior of the connection. Figure 3.6 shows the difference between the experimental results and the LRFD method for assigning the distribution of load to the column stiffener. The results of the analyses provide a basis for accurately predicting the load distribution between the stiffener and column that will follow the behavior of the connection. The distribution of load between the stiffener and column web will be dependent upon an effective column area and the area of its associated stiffener.

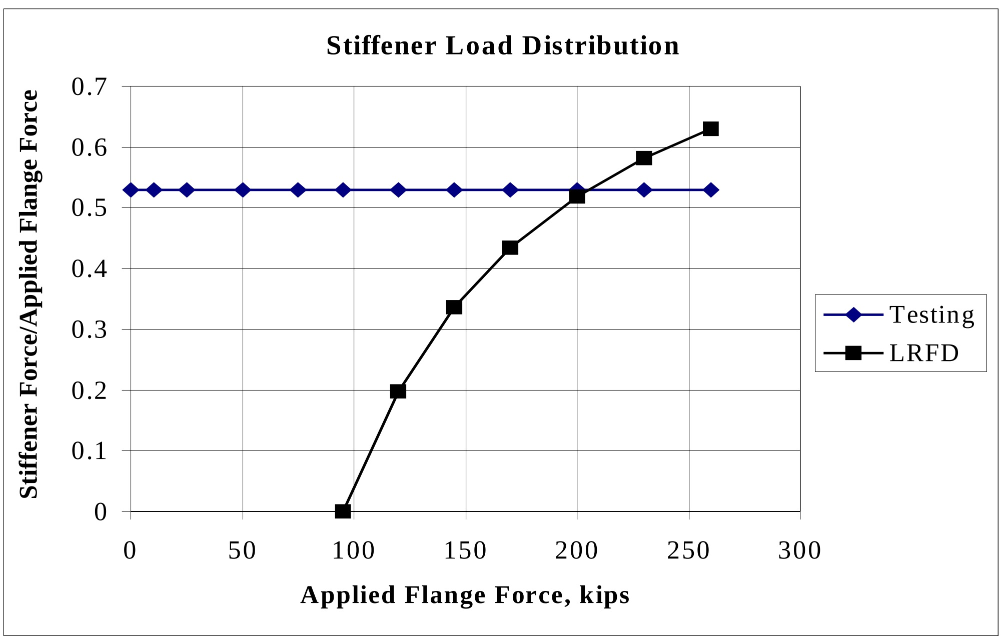


Figure 3.6 Comparison of Stiffener Force