CHAPTER 2

EVALUATION OF FINITE ELEMENT MODELS FOR STEEL JOIST - CONCRETE SLAB SYSTEMS

2.1 Overview

Developing a computer model first requires the evaluation of existing modeling techniques. This evaluation will use the results of previous experimental setups composed of one or two steel joists supporting a concrete slab. The stiffness and first fundamental frequency of each were obtained from the test data reported.

This information was then used to test the accuracy of several different types of computer models for steel joist-concrete slab systems. Each setup was modeled four different ways, and once all of the test specimens were modeled, the computer results for each type of model were compared with their experimentally determined values. The model with the best characteristics and accuracy was then chosen for the other investigations in this research.

2.2 Description of Previous Joist Tests Used for Computer Model Evaluations

For this study, six experimental setups were used. Setups 1 and 2 have two joists supporting a concrete deck, while Setups 3 through 6 have only one joist supporting a concrete deck. Following is a description of the joist characteristics of each setup, slab configuration, and the experimentally determined values of interest for this study. To describe the geometry of the joists, four measurements are used, as defined in Figure 2.1. The total number of interior panels, P, is also given, each panel having the dimension given by L4. A member list specifies the top chord, bottom chord, verticals (if any), and the web members.

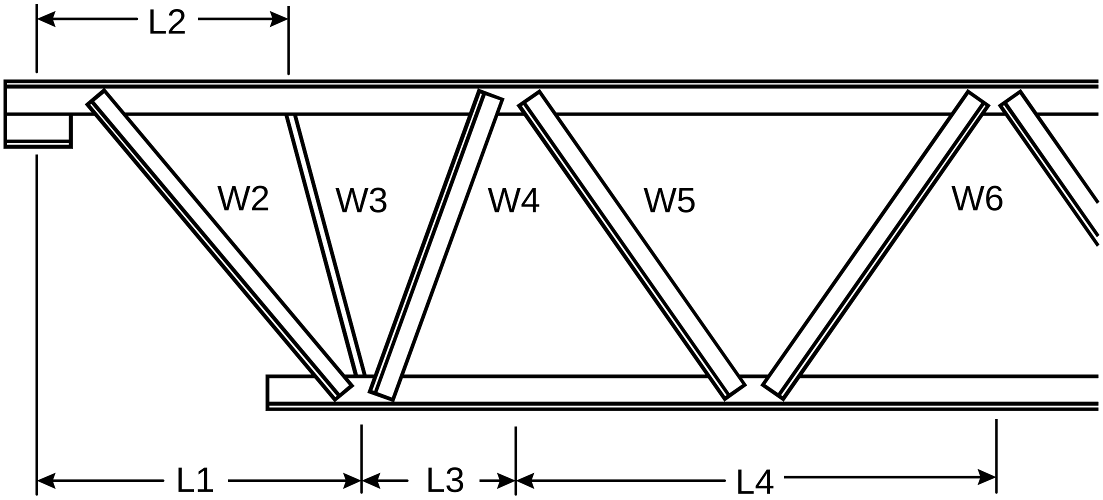

Figure 2.1 Key for Joist Geometry

2.2.1 Setup 1

This setup used two joists which were 304 in. long, 26 in. deep, and spaced 30 in. on center. For both of these joists, L1 was 38 in., L2 was 26 in., L3 was 18 in., L4 was 48 in., and P was 4. Table 2.1 lists the member sizes of these joists.

Table 2.1 Member Sizes for Setup 1 Joists

Member	Size (in.)
Top Chord	2L-1.75x1.75x0.155
Bottom Chord	2L-1.50x1.50x0.150
Verticals	1L-1.00x1.00x0.109
W2	RB 0.875 Dia.
W3	1L-1.25x1.25x0.109
W4	1L-1.75x1.75x0.155
W5	1L-1.00x1.00x0.109
W6	1L-1.50x1.50x0.123
W7	1L-1.00x1.00x0.109
W8	1L-1.25x1.25x0.133

These two joists supported a concrete slab that was 25 ft. long and 5 ft. wide. The steel deck for this slab had a rib height of 1 in. and was attached to the joists with self tapping screws. The thickness of the concrete slab above the ribs of the deck was 2 ½ in. Properties of the concrete, determined from test cylinders, were 3900 psi for the compressive strength and 149 pcf for the unit weight. The joists rested on a masonry block wall.

This setup was subjected to a point load of 600 lbs. in the middle of the slab. Each joist took half of this load and the measured deflection at the midspan of each joist was 0.02 in. The moment of inertia of the tee-beam of one joist was back calculated from the equation for the deflection of a simply supported beam with a midspan point load, and found to be 303 in^4. In addition to the deflection test, the first natural frequency of this setup was determined from a heel drop test (see Section 4.2.1), and found to be 10.5 Hz.

2.2.2 Setup 2

This setup used two joists which were 300 in. long, 16 in. deep, and spaced 30 in. on center. For both of these joists, L1 was 42 in., L2 was 30 in., L3 was 12 in., L4 was 24 in., and P was 8. Table 2.2 lists the member sizes of these joists.

The two joists supported a concrete slab that was 25 ft. long and 5 ft. wide. The steel deck for this slab had a rib height of 1 in. and was attached to the joists with self tapping screws. The thickness of the concrete slab above the ribs of the deck was 2 ½ in. Concrete for this deck was assumed to have the properties of 4000 psi for the compressive strength and 145 pcf for the unit weight. The joists for this setup were supported on W18x50 girders.

This setup was subjected to a point load of 600 lbs. which was applied to the center of each joist. The joists deflected 0.081 in. at their midspan. The moment of inertia for the tee-beam of one joist was back calculated from the equation for the deflection of a simply supported beam with a midspan point load, and found to be 144 in^4. In addition to the deflection test, the first natural frequency of this setup was determined from a heel drop test, which was 7.5 Hz. To investigate if the girders contributed to the system frequency, they were supported at the third points by hydraulic jacks, and then the system was tested again. The results were the same, so it was concluded that the effect of the girders on the system frequency was negligible (Band 1996).

Table 2.2 Member Sizes for Setup 2 Joists

Member	Size (in.)
Top Chord	2L-1.50x1.50x0.138
Bottom Chord	2L-1.25x1.25x0.133
W2	RB 0.688 Dia.
W3	RB 0.625 Dia.
W4	RB 0.625 Dia.
W5	RB 0.625 Dia.
W6	RB 0.625 Dia.
W7	RB 0.625 Dia.
W8	RB 0.625 Dia.
W9	RB 0.50 Dia.
W10	RB 0.50 Dia.
W11	RB 0.50 Dia.
W12	RB 0.50 Dia.

2.2.3 Setup 3

Setups 3, 4, 5, and 6 were used in a study on the strength of long span composite joists (Gibbings 1991). Setup 3 had one joist which was 672 in. long and 36 in. deep. For this joist, L1 was 42 in., L2 was 42 in., L3 was 42 in., L4 was 84 in., and P was 6. Table 2.3 lists the member sizes of these joists.

The joist supported a concrete slab that was 56 ft. long and 102 in. wide. The steel deck for this slab had a rib height of 3 in. and was attached to the joist with twenty-two 3/4 in. diameter 5 in. long shear studs. The thickness of the concrete slab above the ribs of the deck was 3 in. Properties of the concrete, determined from test cylinders, were 4430 psi for the compressive strength and 147 pcf for the unit weight. The joist was supported in a test frame on large hot rolled girders.

The load applied to this setup was an eight point loading configuration to simulate a distributed load. With a total load of 34 kips, the measured deflection was 1.0 in. The moment of inertia was calculated using the equation for the deflection of a simply supported, uniformly loaded beam. From the above values, the moment of inertia was calculated as 4633 in^4. The frequency for this setup was not determined experimentally, so the moment of inertia calculated was used in Equation (1.1) to obtain a frequency of 3.83 Hz.

Table 2.3 Member Sizes for Setup 3 Joist

Member	Size (in.)
Top Chord	2L-2.50x2.50x0.313
Bottom Chord	2L-3.50x3.50x0.313
Verticals	1L-1.50x1.50x0.138
W2	2L-2.00x2.00x0.205
W3	2L-2.50x2.50x0.212
W4	2L-1.75x1.75x0.188
W5	2L-2.00x2.00x0.187
W6	1L-2.00x2.00x0.205
W7	2L-1.50x2.50x0.145
W8	1L-1.50x1.50x0.145
W9	2L-1.50x1.50x0.138

2.2.4 Setup 4

This setup had one joist which was 480 in. long and 16 in. deep. For this joist, L1 was 24 in., L2 was 15 in., L3 was 6 in., L4 was 60 in., and P was 7. Table 2.4 lists the member sizes of these joists.

The joist supported a concrete slab that was 40 ft. long and 81 in. wide. The steel deck for this slab had a rib height of 3 in. and was attached to the joist with sixty-six 3/4 in. diameter 5 in. long shear studs. The thickness of the concrete slab above the ribs of the deck was 3 in. Properties of the concrete, determined from test cylinders, were 4000 psi for the compressive strength and 143 pcf for the unit weight. The joist was supported in a test frame on large hot rolled girders.

The load applied to this setup was similar to that of Setup 3. With a total load of 50 kips, the measured deflection was 1.2 in.. From these values, the moment of inertia was calculated as 2069 in^4. The frequency for this setup was not determined experimentally, so the moment of inertia calculated was used in Equation (1.1) to obtain a frequency of 5.55 Hz.

Table 2.4 Member Sizes for Setup 4 Joist

Member	Size (in.)
Top Chord	2L-3.50x3.50x0.313
Bottom Chord	2L-5.00x5.00x0.438
Verticals	1L-1.00x1.00x0.109
W2	2L-3.00x3.00x0.250
W3	2L-2.00x2.00x0.216
W4	2L-3.00x3.00x0.227
W5	2L-3.00x3.00x0.250
W6	2L-2.50x2.50x0.188
W7	2L-2.50x2.50x0.212
W8	2L-1.50x1.50x0.170
W9	2L-1.75x1.75x0.155
W10	2L-1.50x1.50x0.155

2.2.5 Setup 5

This setup had one joist which was 480 in. long and 14 in. deep. For this joist, L1 was 27 in., L2 was 30 in., L3 was 3 in., L4 was 30 in., and P was 14. Table 2.5 lists the member sizes of these joists.

The joist supported a concrete slab that was 40 ft. long and 81 in. wide. The steel deck for this slab had a rib height of 3 in. and was attached to the joist with thirty-six 3/4 in. diameter 5 in. long shear studs. The thickness of the concrete slab above the ribs of the deck was 3 in. Properties of the concrete, determined from test cylinders, were 4430 psi for the compressive strength and 149 pcf for the unit weight. The joist was supported in a test frame on large hot rolled girders.

The load applied to this setup was similar to that of Setup 3. With a total load of 40 kips, the measured deflection was 1.2 in. From these values, the moment of inertia was calculated as 1655 in^4. The frequency for this setup was not determined experimentally, so the moment of inertia calculated was used in Equation (1.1) to obtain a frequency of 5.20 Hz.

Table 2.5 Member Sizes for Setup 5 Joist

Member	Size (in.)
Top Chord	2L-3.00x3.00x0.313
Bottom Chord	2L-4.00x4.00x0.438
W2	2L-3.00x3.00x0.313
W3	2L-2.00x2.00x0.250
W4	2L-2.00x2.00x0.163
W5	2L-2.00x2.00x0.187
W6	2L-2.00x2.00x0.163
W7	2L-2.00x2.00x0.187
W8	2L-2.00x2.00x0.163
W9	2L-1.75x1.75x0.155
W10	2L-1.50x1.50x0.170
W11	2L-2.00x2.00x0.163
W12	2L-1.25x1.25x0.133
W13	2L-1.25x1.25x0.133
W14	2L-1.00x1.00x0.109
W15	2L-1.25x1.25x0.109
W16	2L-1.00x1.00x0.109
W17	2L-1.25x1.25x0.109

2.2.6 Setup 6

This setup had one joist which was 480 in. long and 20 in. deep. For this joist, L1 was 27 in., L2 was 30 in., L3 was 3 in., L4 was 30 in., and P was 14. Table 2.6 lists the member sizes of these joists.

The joist supported a concrete slab that was 40 ft. long and 81 in. wide. The steel deck for this slab had a rib height of 3 in. and was attached to the joist with thirty-six 3/4 in. diameter 5 in. long shear studs. The thickness of the concrete slab above the ribs of the deck was 3 in. Properties of the concrete, determined from test cylinders, were 5720 psi for the compressive strength and 143 pcf for the unit weight. The joist was supported in a test frame on large hot rolled girders.

The load applied to this setup was similar to that of Setup 3. With a total load of 60 kips, the measured deflection was 1.2 in. From these values, the moment of inertia was calculated as 2483 in^4. The frequency for this setup was not determined experimentally, so the moment of inertia calculated was used in Equation (1.1) to obtain a frequency of 6.35 Hz.

Table 2.6 Member Sizes for Setup 6 Joist

Member	Size (in.)
Top Chord	2L-3.00x3.00x0.313
Bottom Chord	2L-4.00x4.00x0.438
W2	2L-2.50x2.50x0.250
W3	2L-2.00x2.00x0.187
W4	2L-2.00x2.00x0.163
W5	2L-2.00x2.00x0.187
W6	2L-2.00x2.00x0.163
W7	2L-2.00x2.00x0.187
W8	2L-1.50x1.50x0.155
W9	2L-1.75x1.75x0.155
W10	2L-1.50x1.50x0.143
W11	2L-1.50x1.50x0.170
W12	2L-1.25x1.25x0.109
W13	2L-1.25x1.25x0.133
W14	2L-1.00x1.00x0.109
W15	2L-1.25x1.25x0.109
W16	2L-1.00x1.00x0.109
W17	2L-1.25x1.25x0.109

2.3 Description of the Modeling Techniques Evaluated

Following are descriptions of the computer program and the modeling techniques used in this evaluation. The above setups are each modeled using the techniques described below.

2.3.1 Overview of the Computer Program

SAP2000 Plus, from Computers and Structures, Inc. (Wilson and Habibullah 1996), is the computer program used throughout this study. SAP2000 has a fully developed graphical interface, for both the input of the model and interpretation of the results. The graphical input is similar to drawing in a CAD package, which allows quick and accurate input of a model. This program is designed to run on a desktop computer and for use by the typical structural design firm. SAP2000 can also perform dynamic analysis of complex structures. For these reasons, this program was chosen for use in this study.

2.3.2 Description of the Computer Modeling Elements

In this study, only beam and shell finite elements are used. The beam element used in SAP2000 is called the three-dimensional frame element. This element is a two node beam type element with six degrees of freedom at each node. Member and material properties are then assigned to the frame element after its creation in the model (Wilson and Habibullah 1996).

The shell element used in SAP2000 is a four node quadrilateral shell element. This element has six degrees of freedom at each node. The material properties and thickness of the shell are assigned after its creation (Wilson and Habibullah 1996).

Shell elements are usually divided, or meshed, into smaller elements to more accurately model the behavior of the actual structure. For instance, consider a floor which consists of beams and a concrete slab where only one shell element is used to define the concrete slab. This model would not behave as expected, because the shell is only connected to the rest of the model at four nodes. In the model, the floor is connected only to the ends of the two exterior floor beams, where in reality there are many connections. Therefore, the interaction of the shell and the interior floor beams is completely neglected, which is not how the real floor system behaves. Dividing the shell elements into smaller elements improves the interaction of the shell with its connecting elements.

2.3.3 In-Plane Model for the Joist and Slab

For the in-plane model shown in Figure 1.4, the slab and joist are located at the same elevation along a common centroidal axis. The slab is modeled using shell elements, which are assigned the properties of the concrete and the thickness of the concrete slab above the ribs of the steel deck. The joist is modeled using frame elements, which share a line of nodes in the middle of the shell elements. These frame elements have an area equal to the sum of the areas of the top and bottom chord of the joist. The frame elements are assigned a moment of inertia equal to the composite moment of inertia minus the transformed moment of inertia of the slab about its own centroidal axis. The composite moment of inertia is calculated using Equation (1.7), and the moment of inertia of the slab is calculated as the moment of inertia of a rectangle. The computer model automatically adds the two moments of inertia since all of the elements are in the same plane.

2.3.4 Frame Element Model for the Joist and Slab

The model shown in Figure 2.2 uses only frame elements to describe both the joist and the concrete slab. The frame elements for the joist are assigned the area of the chords and the moment of inertia of the joist alone, which is calculated using Equation (1.6). The slab frame elements have a rectangular cross section. To define the width of the slab frame element, the smaller value of the joist spacing, S, or four-tenths of the joist length is used. To define the thickness of the slab frame element, the value of the depth of the concrete above the ribs of the steel deck is used. The frame elements of the beam and the slab are then connected by a series of very stiff frame elements called rigid links.

These rigid links are defined using a high area (100 in^2) and high moment of inertia (10,000 in^4). This rigid link uses a material defined with no weight, no mass, and a high modulus of elasticity (100,000 ksi).

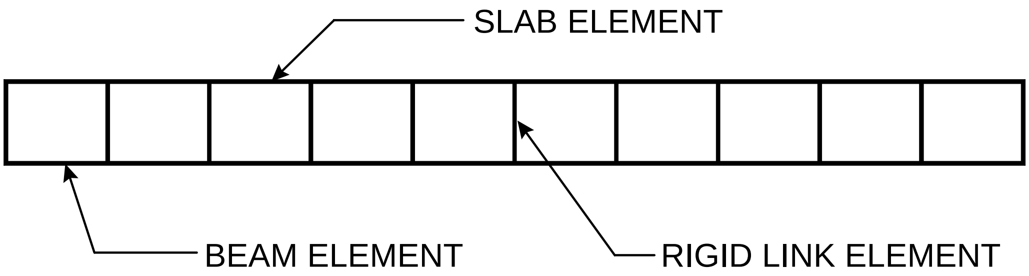

Figure 2.2 Diagram of a Frame Element Model for the Joist and Slab

An alternative to the above model is to replace the frame elements of the slab with shell elements. These elements have the same thickness as the slab's frame elements. The overall dimension of the slab's width and length is modeled using many shell elements, as shown in Figure 1.5. This type of model requires the use of the third dimension, which makes the model more complex. An investigation, as described in Section 2.4, was done to determine if frame elements can be used in place of shell elements to simplify the single joist models.

2.3.5 Full Joist Model With and Without Joint Offsets

The model shown in Figure 1.6 uses frame elements to represent every member of the joist. The bottom chord, top chord, and slab are located at the elevation of their centroidal axes. The two chords are connected by frame elements representing the web members, while the top chord and the slab are connected using rigid link elements as described in Section 2.3.2. All of the properties of the individual members of the joist are needed to define the appropriate frame elements in the model. The full joist model uses joint offsets to model angle web joists more accurately. Joint offsets are described in Section 1.3.2 and shown in Figure 1.7.

2.3.6 Modification of the Concrete Material Properties

To obtain a more accurate result for frequency, the mass of the system must be modeled as accurately as possible. The following equations were developed to calculate an equivalent unit weight and unit mass for the smaller slab cross section to represent the actual weight and mass in the system. These values are used in the models for the weight and mass of the concrete material per unit volume. Equation (3.3) is in units of kips per cubic inch, and Equation (3.4) is in units of kip-sec^2/in^4.

$$w_m = \frac{\left(\frac{\left(d_s + \frac{d_r}{2} \right) w_c}{12} + w_d \right) \left(\frac{12}{d_s} \right)}{1{,}728{,}000} \tag{3.3}$$

$$m_m = w/386.4 \tag{3.4}$$

where w_m is the modified unit weight of concrete, k/in^3; d_s is the thickness of the concrete slab above the ribs of the steel deck, in.; d_r is the height of the ribs in the steel deck, in.; w_c is the nominal unit weight of the concrete; w_d is the weight of the steel deck, psf; and m_m is the modified unit mass of the concrete. The factor 1,728,000 is to convert the unit weight of the concrete from pounds per cubic foot to kips per cubic inch, where 1728 in^3 equals 1 ft^3 and 1000 lbs. equals 1kip.

2.4 Investigation of Frame Elements vs. Shell Elements to Model the Concrete Slab

For all of the models described in Section 2.3, except the in-plane model, fra me or shell elements are used to model the concrete slab. However, it is more advantageous to use frame elements, since these are easier to model and do not require using a three-dimensional model. This results in a simpler computer model which is quicker to modify and analyze. Therefore, a study was done to determine if there was any difference in the behavior of the computer model using frame elements instead of using shell elements to represent the slab.

Another aspect of this study was to determine how many finite elements are needed to obtain a model that behaves as expected. For instance, using one frame element to model an entire beam would result in an inaccurate answer for midspan deflection, since the frame elements in SAP2000 do not have any degrees of freedom between the two ends. Dividing the beam into smaller and smaller elements results in a model behavior which more accurately represents the true behavior of the beam. However, at some point, increasing the number of elements only minimally increases the accuracy of the model. Therefore, this study also determined a minimum number of frame elements needed to model the behavior of a beam.

2.4.1 Description of the Study

For this study, a W16x31 wide flange section 240 in. long was chosen for the beam. The concrete slab used had a total thickness of 5.25 in., of which 2 in. was the steel deck and 3.25 in. was the concrete above the ribs of the deck. Three different slab widths were used to represent a narrow, medium, and wide slab used in the models for the investigations in Chapter 3. These widths were 24 in., 120 in., and 288 in., respectively.

The two computer models used were the frame element model for the beam and slab (see Section 2.3.4 and Figure 2.1), and the frame element model for the beam with a shell element model for the slab (see Figure 1.5). In all, six different cases were developed and used. Each case started with two frame elements representing the beam, with the slab divided in a similar fashion. When the slab was composed of frame elements, the number of frame elements matched the number of the elements modeling the beam. When the slab was composed of shell elements, the number of divisions parallel to the beam were the same as the number of elements modeling the beam. However, the shell had to be divided along the middle of its width to be able to attach to the rigid links which then attached to the beam, as shown in Figure 1.5.

Each case was analyzed to determine the first natural frequency of the system, measured in Hz. The elements in the model were then divided in two, new rigid links were added, and the model analyzed again, as shown in Figure 2.3. This continued until the beam was divided into 64 elements. Beyond this point, the models became very large and took a great deal of time to analyze, while the change in the predicted frequency was minimal.

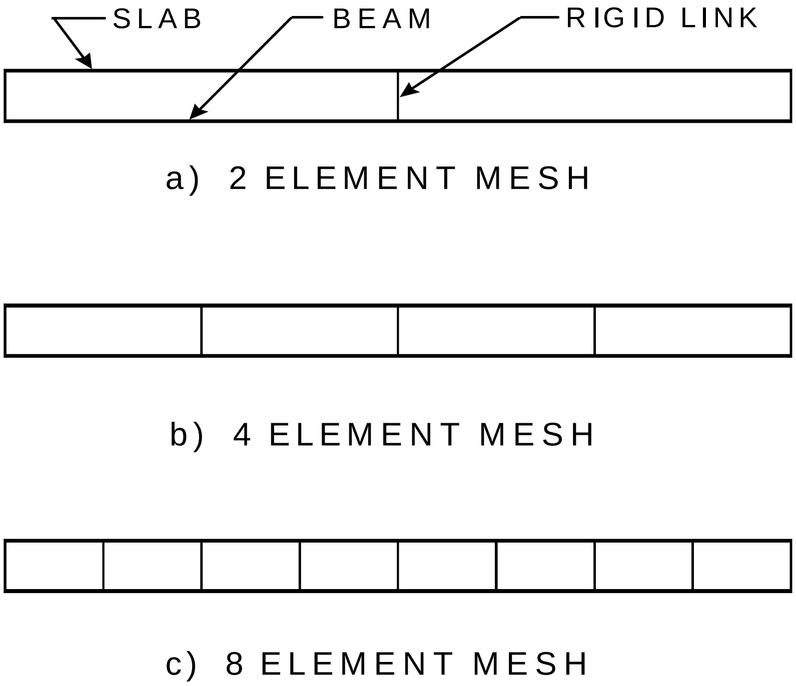

Figure 2.3 Definition of Mesh Refinement

2.4.2 Results of the Study

The results for all six cases are presented in Tables 2.7, 2.8, and 2.9. Each table represents a particular slab width. The column labeled "Mesh" indicates the number of elements that the beam was divided into for that row of data. The column labeled "Shell" indicates that the model used shell elements to represent the slab, whereas the column labeled "Frame" indicates that the model used frame elements to represent the slab, The ratio of the frequencies found from these two models is given in the final column to indicate how close the two model types are to each other. A ratio less than unity indicates that the model using frame elements is stiffer than the model using shell elements.

Table 2.7 Data for the 24 in. Wide Slab

	Frequency, Hz		
Mesh	Shell	Frame	Ratio (S/F)
2	21.48	21.45	1.001
4	24.32	24.27	1.002
8	25.05	25.02	1.001
16	25.28	25.37	0.996
32	25.39	25.59	0.992
64	25.51	25.78	0.990

Table 2.8 Data for the 120 in. Wide Slab

	Frequency, Hz		
Mesh	Shell	Frame	Ratio (S/F)
2	10.5	11.82	0.888
4	12.5	14.01	0.892
8	13.89	14.72	0.944
16	14.39	15.09	0.954
32	14.53	15.33	0.948
64	14.65	15.43	0.949

Table 2.9 Data for the 288 in. Wide Slab

	Frequency, Hz		
Mesh	Shell	Frame	Ratio (S/F)
2	3.61	8.25	0.438
4	6.58	9.79	0.672
8	8.7	10.3	0.845
16	9.54	10.56	0.903
32	9.82	10.68	0.919
64	9.95	10.72	0.928

Figures 2.4, 2.5, and 2.6 graphically represent the data in Tables 2.7, 2.8 and 2.9, respectively. These graphs plot the frequency of the shell and frame slab element models against the number of elements used to analyze the model.

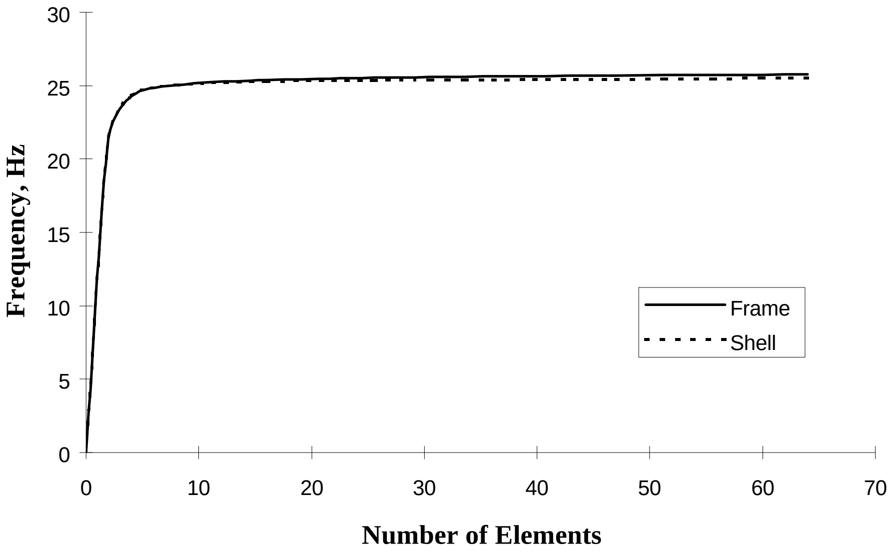

Figure 2.4 Effect of Mesh Refinement on System Frequency for 24 in. Wide Slab

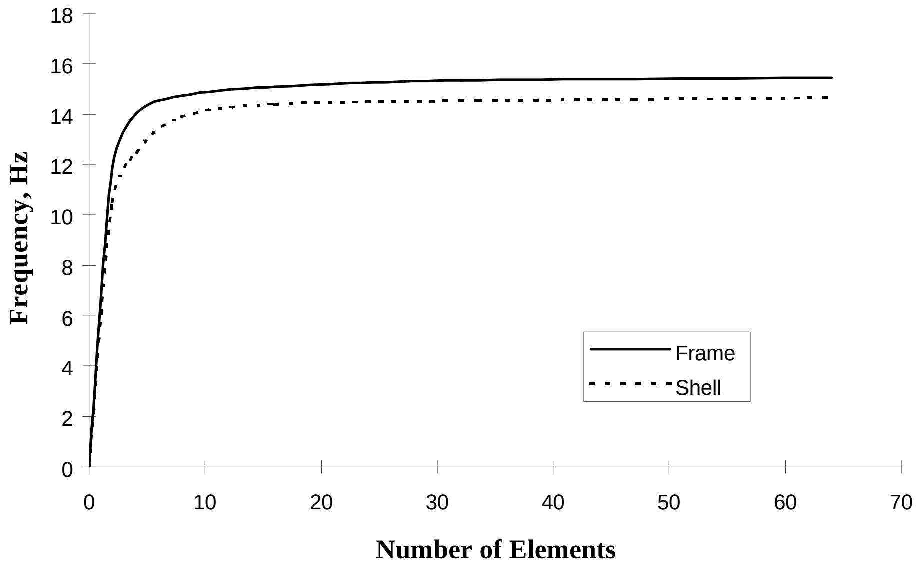

Figure 2.5 Effect of Mesh Refinement on System Frequency for 120 in. Wide Slab

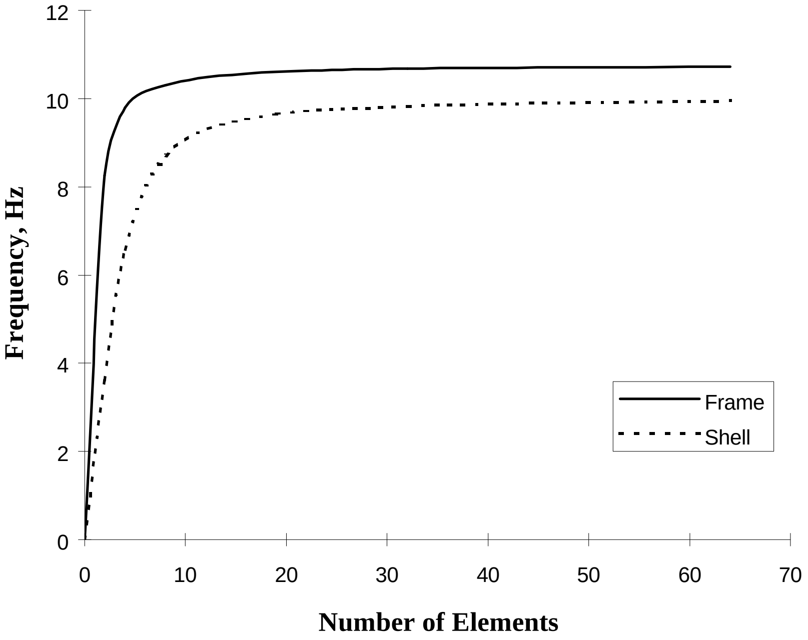

Figure 2.6 Effect of Mesh Refinement on System Frequency for 288 in. Wide Slab

2.4.3 Analysis of Results

From Table 2.7, it can be seen that the frame element and shell elements give very similar answers for frequency for a narrow, 24 in. wide slab. For the wide slabs, 120 in. and 288 in., Tables 2.8 and 2.9 show that the agreement is not as close as in Table 2.7. However, as the number of elements increase, the values become closer to each other. In all three tables, once 16 elements are used to model the system, the value for the frequency has no more than a 10% difference between the frame model and the shell model. This indicates that with an appropriate number of elements, frame elements can be used to model a concrete slab as well as shell elements.

The only difference between the three tables is the width of the slab being modeled. As the slab increases in width, the frequencies obtained from the frame model and the shell model are not as close as for the previous slab width. An explanation for this behavior is the aspect ratio of the slab. The aspect ratio is defined as the length of the slab divided by the width of the slab. In Table 2.7, this ratio is 10, in Table 2.8 this ratio is 2, and in Table 2.9 this ratio is 0.833. It can be seen from Tables 2.7, 2.8 and 2.9 that almost all of the values for frequency from the shell element models are lower than the values obtained from the frame element models. The only difference for a particular case between the two models is the way the slab is modeled. If one examines the variables in the equation for frequency, Equation (1.1), one can see that the values for mass, length, and modulus of elasticity are the same between the models. This leaves the moment of inertia as the only parameter changing between the models. From Equation (1.1), it can be seen that if the moment of inertia is decreased, the system frequency is decreased. This behavior is exactly what can be observed in the above tables. The frame element is completely rigid across the width of the element. The shell element is divided across its width, which introduces more degrees of freedom into the system. This creates a system that is not as stiff as that created by the frame elements. The aspect ratio of the slab can be used to quantify this principle. In actual floors, if the beams are spaced close together compared to their length, giving a high aspect ratio, then the slab between the beams acts like a wide, rigid beam. However, if the distance between the beams is large compared to their length, resulting in a low aspect ratio, the slab acts less like a wide beam and more like a shell. For the cases that were modeled in Chapter 3, the smallest slab aspect ratio is 2.5. From Table 2.8, the frame element model was within 5% of the shell element model for a slab aspect ratio of 2. Therefore, frame elements are used throughout this study to model the slab single joist, concrete slab tee-beams.

The second aspect of this investigation was to determine how many elements a beam should be divided into for an accurate result. The term “accurate result” means that the values the analysis returns have converged, so increasing the number of elements will not change the values obtained from the analysis. Figures 2.4, 2.5, and 2.6 show the increase in the value for frequency when plotted against the number of elements used to obtain a certain value. All three graphs start with a large change in the values for frequency as elements are added, but at around 10 elements the values begin to converge and stay constant. This fact is indicated by the nearly horizontal line in Figures 2.4, 2.5 and 2.6. For the frame element cases (the solid line in Figures 2.4, 2.5 and 2.6), the value for frequency changes very little after the model has been divided into eight elements. For all three slab widths, the value of the frequency obtained from 64 elements within 4% of the value obtained from eight elements. Therefore, at least eight elements are required for an accurate model.

2.5 Evaluation of Different Computer Models for Steel Joist-Concrete Slab Systems

An investigation was done to determine which of the computer models described in Section 2.3 would best predict the true behavior of the six setups described in Section 2.2. A description of the study, presentation of the results, and analysis of the results now are presented.

2.5.1 Description of the Study

Each of the six setups described in Section 2.2 was modeled four ways: the in-plane method (Model A), the frame to frame method (Model B), the full joist model without joint offsets with a frame element slab (Model C), and the full joist model with joint offsets with a frame element slab (Model D). All of the models used at least eight elements to define the beam. Both frequency and centerline deflection were used to track the behavior between the models. The results are also compared to the experimentally determined values for the setups as described in Section 2.2. From this comparison, a model was selected based on which method best predicted the experimental values.

2.5.2 Results of the Study

The results of the study are given in Tables 2.10 and 2.11. These tables give the results of each model for each setup, and also the experimental value for reference. In Table 2.10, the parameter measured is centerline deflection. Each setup had a different loading applied, as described in Section 2.2 for the setups. The computer models were loaded exactly the same, and the model’s centerline deflection was recorded, as shown in Table 2.10. For Table 2.11, the parameter measured is the first natural frequency. The experimentally obtained frequencies are also given for reference. For both tables, the columns headed A, B, C, and D refer to the model type described in Section 2.5.1, and the column headed ‘Exp.’ is the experimental value.

Table 2.10 Centerline Deflection of Test Setups

	Centerline Deflection, in.				
Setup	A	B	C	D	Exp.
1	0.009	0.009	0.014	0.015	0.02
2	0.083	0.056	0.071	0.078	0.081
3	1.15	0.75	1.02	1.03	1.0
4	1.73	1.14	1.2	1.2	1.2
5	2.2	1.42	1.44	1.48	1.2
6	1.65	1.19	1.2	1.22	1.2

Table 2.11 First Natural Frequency of Test Setups

	Frequency, Hz.				
Setup	A	B	C	D	Exp.
1	15.4	15.6	12.9	12.6	10.5
2	7.59	9.18	8.24	8.02	7.5
3	3.57	4.4	3.81	3.8	3.83
4	4.61	5.6	5.56	5.57	5.5
5	3.84	4.76	4.76	4.7	5.2
6	5.42	6.34	6.37	6.32	6.35

2.5.3 Analysis of the Results

Using the values in Tables 2.10 and 2.11, each model was compared to the experimental value as the ratio of the model result divided by the experimental result. The average and standard deviation (SD) of these ratios were then calculated. This information is shown in Table 2.12 for the deflection results of Table 2.10, and Table 2.13 gives this information for the frequency results of Table 2.11.

Table 2.12 Ratios of Model Result to Experimental Result for Deflection Results

Setup	A/Exp.	B/Exp.	C/Exp.	D/Exp.
1	0.45	0.45	0.70	0.75
2	1.02	0.69	0.88	0.96
3	1.15	0.75	1.02	1.03
4	1.44	0.95	1.00	1.00
5	1.83	1.18	1.20	1.23
6	1.38	0.99	1.00	1.02
Average:	1.212	0.836	0.966	0.999
SD:	0.425	0.236	0.152	0.141

Table 2.13 Ratios of Model Result to Experimental Result for Frequency Results

Setup	A/Exp.	B/Exp.	C/Exp.	D/Exp.
1	1.47	1.49	1.23	1.20
2	1.01	1.22	1.10	1.07
3	0.93	1.15	0.99	0.99
4	0.84	1.02	1.01	1.01
5	0.74	0.92	0.92	0.90
6	0.85	1.00	1.00	1.00
Average:	0.973	1.132	1.042	1.029
SD:	0.236	0.188	0.099	0.091

From Tables 2.12 and 2.13, a few observations can be made. First, Setup 1 did not give good results with any model for deflection or frequency. This setup was built several years prior to the study from which these results were obtained. In that time, the setup was moved around several times, and the bond between the concrete slab and the deck may have broken. This broken bond could have caused the setup to act completely non-composite, even though very little composite action is needed when frequency is measured. Similarly, Setup 5 did not give good results for deflection for unknown reasons.

The general trend of how the models predict measured behavior are the same for all setups. From Tables 2.12 and 2.13, it is seen that Model A had the most disagreement with the experimental values, since this model has the largest standard deviation in its ratios. Each model after Model A had progressively better results. This fact is shown by the smaller standard deviations of the ratios for the other models. Models C and D were the best in predicting the experimental values, with Model D just slightly better than Model C. These trends are the same in both Tables 2.12 and 2.13. Since Model D has the smallest standard deviation of its ratios, it was selected for use in the remaining studies of this research.

2.6 Conclusions

The studies in this chapter investigated three aspects of the computer modeling of steel joist-concrete slab tee-beams for stiffness and first natural frequency. These aspects are: determine if frame elements can be used to model the concrete slab, determine the number of frame elements are needed to accurately model the behavior of a beam, and select the type of computer model that is the best at predicting the actual behavior of steel joist-concrete slab tee-beams. Following are the conclusions to these studies:

1. Frame elements can model shell elements for the concrete slab, as long as the aspect ratio of the slab is not less than 2.

2. To accurately model a beam, at least eight finite elements should be used. Above this number, little change is noticed in the results for deflection and frequency of the beam.

3. Models C and D were the best in predicting the experimental values of the setups. Thus, for the remaining studies in this research, Models C and D will be used. These two models are both full joist models (see Figure 1.6). Model D is used exclusively in the study in Chapter 3, while both Models C and D are used in the study in Chapter 4.