Static and Ultimate Load Behavior of Cold-formed Steel Joint Residential Floor Systems

R. J. Kudder

P. W. Linehan

J. F. Wiss

STATIC AND ULTIMATE LOAD BEHAVIOR

OF

COLD-FORMED STEEL-JOIST RESIDENTIAL FLOOR SYSTEMS

by

R. J. Kudder, P. W. Linehan and J. F. Wiss*

INTRODUCTION

This paper will discuss the static characteristics of cold-formed steel-joist residential floor systems at design load levels and at ultimate load. These characteristics were determined by physical testing of representative floor systems that were constructed in the laboratory according to the recommended designs of the suppliers of the steel joists. Twelve floor systems of different configurations, including single and double spans, were built and tested.

The structural characteristics of primary interest for this investigation are the behavior, distribution of load, and strength of the floors. The static testing included a single concentrated incremental load at the center of the span, incremental uniform loading to design load, and finally, incremental uniform loading to the ultimate capacity of the floor system. A dynamic testing program, which is discussed in another paper, consisted of determining the natural frequency, dynamic deflections, and damping under vertical impact loadings. It also included measurement of deflections under walking excitation. Finally, test subjects rendered their opinion on the acceptability of the performance of the floor under walking vibration in their home.

---

* Senior Structural Engineer, Senior Engineer, and Principal, respectively Wiss, Janney, Elstner and Associates, Inc.

DESCRIPTION OF FLOOR SYSTEMS

Twelve floor systems were fabricated during the test program. Using seven basic designs, the CFSJ floors were constructed in accordance with the recommendations of the joist supplier. Table 1 describes the structural components and general configuration of the test floors. Table 2 lists the properties of the joists and decking. Each floor is assigned a letter identifying the basic design and a number identifying the floor length. The A1 Floor System, for example, is of basic design A with a floor length of 40 ft (12.19 m). The same floor system was reduced in length to 36 ft (10.97 m) and is designated A2.

Each floor system was fully supported around the entire perimeter on special reinforced concrete forms. The forms also permitted a seal to be developed for vacuum loading during static uniform load tests. Fig. 1 shows typical setups for testing the double-span A and B Series Floor Systems. The center support located midway between exterior headers is a W6X20-wide flange beam. Two screw jacks are used to provide additional support for the beam. After completing tests on the longer span, the shorter floor systems are made by cutting 2 ft (0.61 m) from the floor system at each header end of the floor.

STATIC LOADING TESTS AND RESULTS

Static loading tests within the design load range were performed on the floor systems. These tests included a concentrated load test up to a minimum of 400 lbs (1.78 kN), and a uniform load test up to 40 psf (1.92 kN/m^2). This phase of the program had two objectives: to determine the behavior of the floor systems when subjected to static loading, and to obtain test data for the development of empirical models.

TABLE 1

COMPONENTS AND CONFIGURATION OF TEST FLOORS

Floor Desig.	Floor length (ft)	Joist description	Floor description
A1 A2 A3	40 36 32	9 1/4 x 16 ga on 24-in. centers, 2 cont. 20-ft spans A1, reduced to 18 ft & 16 ft for A2 & A3	3/4-in. T/G Group 1 plywood. Joists continuous over mid-support, additional 5 ft, 5 in. long section of joist centered over midsupport attached back-to-back with full-length joist. One row 18-ga steel strapping, bottom only, each span
B1 B3	40 32	7 1/4 x 16 ga on 16-in. centers, 2 cont. 20-ft spans B1, reduced to 16 ft for B3	5/8-in. T/G Group 2 plywood. Joists lapped 50 in. back-to-back at midsupport
C	40	10 x 12 ga on 24-in. centers, 2 cont. 20-ft spans	28-ga metal centering with 2 in. concrete fill. Joist continuous over midsupport. Welded solid metal bridging at midsupport. Two rows V-bar strapping, top and bottom, in each span
D	32	2 x 10 Douglas Fir wood joists on 16-in. centers, 2 16-ft single spans	5/8-in. T/G Group 1 plywood. Joists lapped 4 in. at midsupport. Solid wood bridging at midsupport and midspan
E1 E2 E3	20 18 16	9 1/4 x 14 ga on 24-in. centers, 20-ft single simple-span, reduced to 18 ft & 16 ft for E2 & E3	3/4-in. T/G Group 1 plywood. One row 18-ga steel strapping, bottom only, at midspan
F	16	8 x 18 ga on 16-in. centers, single simple-span	5/8-in. T/G Group 2 plywood. Two rows steel X bridging screwed to lower flange and upper web
G	16	2 x 10 Douglas Fir wood joists on 16-in. centers, single simple-span	5/8-in. T/G Group 2 plywood. Solid wood bridging at midspan

ATTACHMENT OF FLOOR TO JOIST

Joist	Floor	Method
CFSJ	Plywood	Stelco Joistud Nail, 6 in. o.c. perimeter 10 in. o.c. interior
CFSJ	Concrete	Puddle weld, 12 in. o.c.
Wood	Plywood	8d Common Nails, 6 in. o.c. perimeter 10 in. o.c. interior

TABLE 2

STRUCTURAL PROPERTIES OF JOISTS AND DECKS OF TEST FLOORS

Joist ** Section Property	Floor System						
	A Series	B Series	C Series	D Series	E Series	F Series	G Series
Thickness (in.)	0.0610	0.0598	0.105	1 1/2	0.0760	0.0478	1 1/2
Depth (in.)	9 1/4	7 1/4	10	9 1/4	9 1/4	8	9 1/4
Mom./Inertia (in.^{4})	9.43	5.34	17.40	98.93	11.61	4.94	98.93
Section Mod. (in.^{3})	2.04	1.45*	3.48	21.39	2.51	1.24	21.39
Area (in.^{2})	0.83	0.71	1.15	13.88	1.03	0.53	13.88
Weight (lb/ft)	3.03	2.4	4.31	2.9	3.73	2.0	2.9
Top flange width (in.)	1.75	1.90	1.625	solid	1.75	1.625	solid
Bottom flange width (in.)	1.875	2.06	1.625	wood	1.875	1.625	wood

* With respect to the top face of the joist, neutral axis 3.576 in. from the top face, 3.674 in. from the bottom face

Total Dead Load, including Deck (psf)	Floor System						
	A Series	B Series	C Series	D Series	E Series	F Series	G Series
	3.7	3.6	23.9	4.0	4.1	3.3	4.0

** All cold-formed steel-joists are stiffened "C" sections.

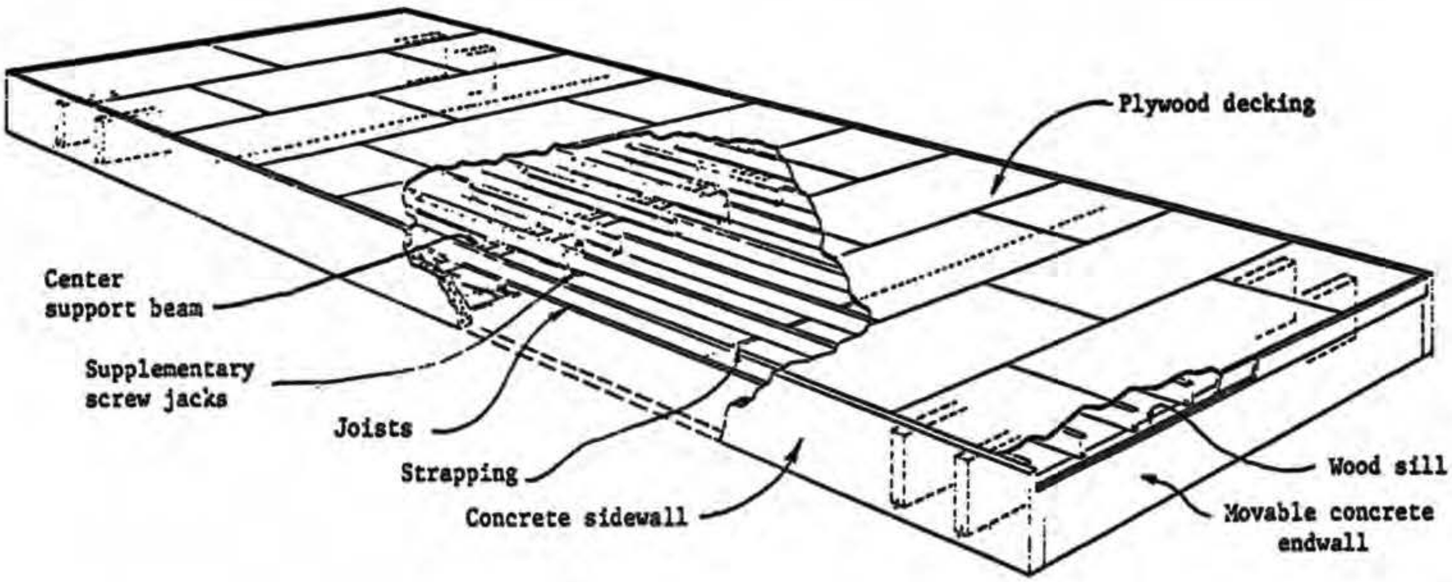


Fig. 1 - Typical test setups for A and B Series Floors

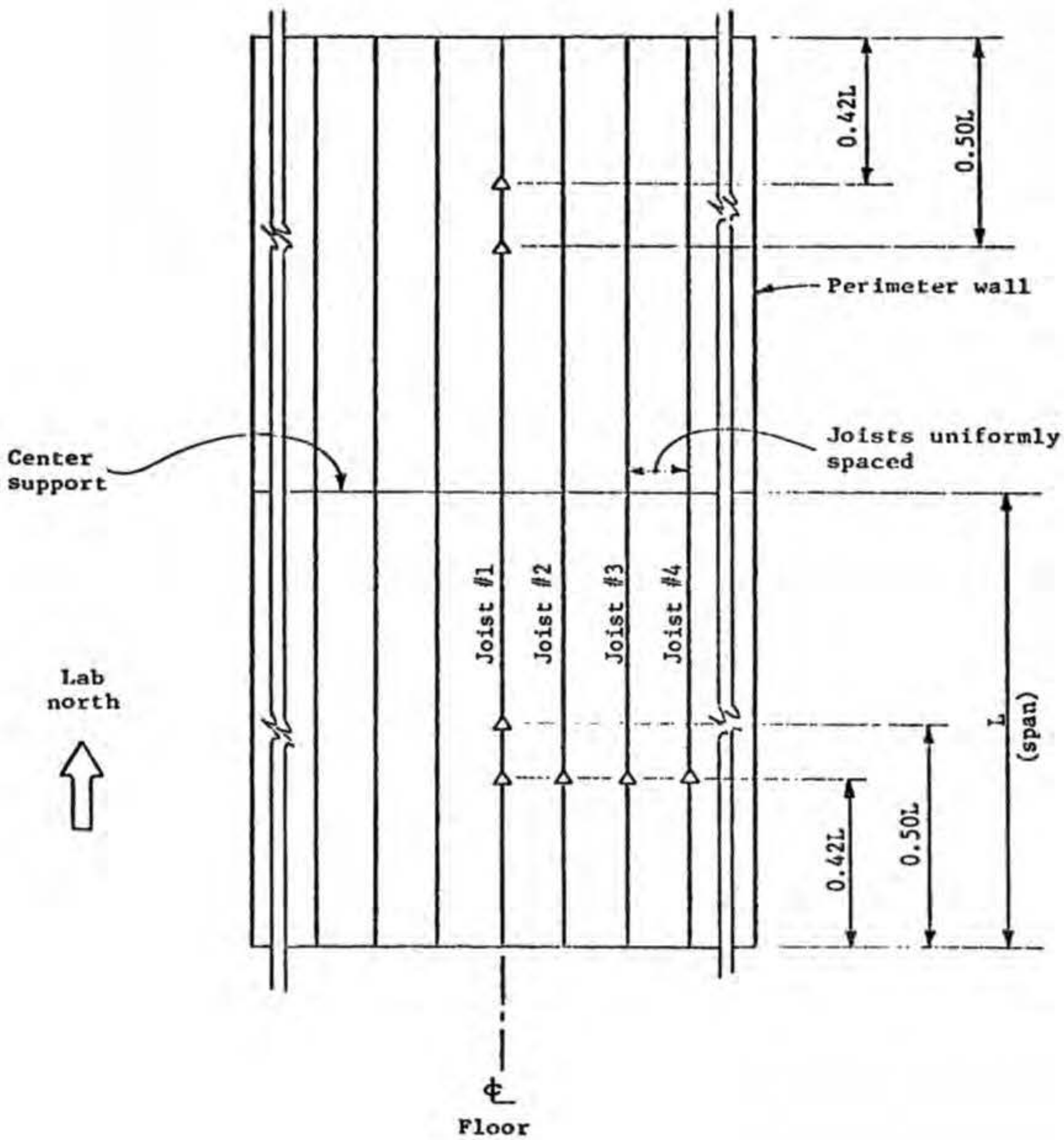
Description of Test Setup and Procedures

Deflection measurements of the joists were recorded using linear potentiometers with a range of 2 in. (5.08 cm) of movement. Overall accuracy of the measurement system is $\pm$ 2 mils (0.051 mm).

The potentiometers were mounted to wooden test stands beneath the floor system. Their spring-loaded movable core was then located in contact with the lower flange of a joist.

The joist deflection profile in the vicinity of the midspan of the floor system was obtained with at least three potentiometers. Fig. 2 shows the typical measurement location. The concentrated load test on double-span floors included an additional measurement at the centerline joist of the unloaded span. The location of the potentiometers for the single-span configuration was at one-half of the span length referenced from the outside headers. For the floors having a double-span configuration, the location of the majority of the potentiometers for the uniform load test was determined after preliminary testing to determine if flexural continuity was developed at the center support. The maximum deflection with a uniform load, for a double-span floor system having continuity at the center support, will occur at 0.42 of the span length (L), referenced from the outside headers. This type of floor system, having continuity when subjected to a concentrated load at one of the midspans, will also exhibit appreciable upward deflection in the adjacent span at the midspan. Thus, the preliminary concentrated load test indicated if significant continuity was developed at the center support and aided in selecting the location of the potentiometers for the uniform load test.

The concentrated load test was performed with the load applications at the center of the span (L/2) for all floor systems, whether it was a single- or double-span system. An 8 x 8 x 1 in. (20.3 x 20.3 x 2.54 cm) steel plate was used throughout



Δ = Typical measurement locations

Fig. 2 - Typical floor plan for double-span floors

the research program as the loading area. Concrete blocks, weighing approximately 43 lbs (191.4 N) each, were then stacked on the steel plate up to a minimum of 400 lbs (1.78 kN) total load.

The uniform load tests were performed by developing a differential vacuum between the underside and the topside of the floor. This technique required that a plastic sheet be placed over the floor system and sealed around the perimeter of the concrete supports. A vacuum blower exhausted the air from the joist side of the floor system.

Test Results

Table 3 summarizes the joist deflection measurements from the static concentrated load tests. The deflection data has been interpolated for a 300-lb (1.34 kN) concentrated load based on the actual deflection at the peak concentrated load, which was at least 400 lbs (1.78 kN). The stiffness of the floors under a concentrated load, also given in this table, is based on the maximum joist deflection of the centerline joist, which was observed during the testing.

Table 3 also contains the joist deflection expressed as a percent of the centerline joist deflection, and percent deflection that was observed in the unloaded adjacent span for those floor systems having a double-span configuration.

Table 4 summarizes the joist deflections which were observed during the 40 psf (1.92 kN/m^2) uniform load test. The minimum span/deflection ratio and the deflection of adjacent joists expressed as a percent of the centerline joist deflection, are also given in this table. Deflections at Joist No. 2, and in some cases Joist No. 3, which are greater than the centerline joist, can be attributed to the location of the butt joints at the 4-ft (1.22 m) end of the plywood sheets used as decking.

TABLE 3

SUMMARY OF VERTICAL DEFLECTIONS
DUE TO A SINGLE 300-LB CONCENTRATED LOAD AT MIDSPAN

Floor System	Joist No. 1 @ 0.50L	Joist No. 1 @ 0.42L	Joist No. 2 @ 0.42L	Joist No. 3 @ 0.42L	Joist No. 4 @ 0.42L	Stiffness (lbs/in.)	Joist No. 1 in unloaded span
A1	0.128	0.128 (100)	0.029 (23)	0.008 (6)		2344	
A2	0.088	0.092 (100)	0.038 (41)	0.004 (4)		3261	
A3	0.078	0.084 (100)	0.028 (33)	0.0002 (-)		3571	(-24)
B1*		0.136 (100)	0.077 (57)	0.029 (21)	0.005 (4)	2192	
B3	0.087	0.089 (100)	0.040 (45)	0.013 (15)		3371	(-19)
C	0.011	0.010 (100)	0.010 (100)	0.0006 (6)		27707	(-17)
			Joist No. 2 @ 0.50L	Joist No. 3 @ 0.50L			
D	0.056 (100)		0.036 (64)	0.020 (36)		5357	(-6)
E1	0.116 (100)		0.53 (46)	0.012 (10)		2586	
E2	0.98 (100)		0.041 (42)	0.008 (8)		3061	
E3	0.075 (100)		0.025 (33)	0.003 (4)		4000	
F	0.126 (100)		0.083 (66)	0.038 (30)		2381	

Note: All deflections are in inches.
Number in parentheses is deflection expressed as a percent of the center joist deflection.

* Deflections for Floor B1 measured at 0.50L

TABLE 4

SUMMARY OF VERTICAL DEFLECTIONS DUE TO A 40-PSF UNIFORM LOAD

Floor System	Joist No. 1 @ 0.50L	Joist No. 1 @ 0.42L	Joist No. 2 @ 0.42L	Joist No. 3 @ 0.42L	Span ÷ Deflection
A1	0.450	0.462 (100)	0.487 (105)	0.441 (95)	493
A2	0.267	0.278 (100)	0.288 (104)	0.268 (96)	750
A3	0.192	0.208 (100)	0.206 (99)	0.184 (88)	923
B3	0.209	0.222 (100)	0.218 (98)	0.224 (101)	864
C	0.127	0.131 (100)	0.127 (97)	0.102 (78)	1832
			Joist No. 2 @ 0.50L	Joist No. 3 @ 0.50L	
D	0.336 (100)		0.343 (102)	0.345 (103)	555
E1	0.828 (100)		0.838 (101)	0.789 (95)	286
E2	0.566 (100)		0.591 (104)	0.549 (97)	365
E3	0.367 (100)		0.394 (107)	0.375 (102)	487
F	0.669 (100)		0.661 (99)	0.657 (98)	287

Note: All deflections are in inches.
Number in parentheses is deflection expressed as a percent of the center joist deflection.

ANALYSIS OF STATIC LOADING TEST DATA

The objective in gathering the data summarized and discussed previously is to use these data in developing a mathematical model which will reasonably predict the static behavior of CFSJ floors under service loads.

Floor Behavior

There are several possible structural mechanisms by which a floor system may respond to loading. Understanding the general behavioral characteristics of the floor system is the essential first step in developing appropriate mathematical models.

Slab action under uniform load - Under a uniform load, a floor system simply supported on four sides can respond as a one-way or a two-way slab. The deflected surface of a one-way slab can best be described by a cylindrical surface with all beams, except possibly the peripheral ones, undergoing approximately the same deflection. In such a case, the slab can be analyzed by isolating a single beam, uninfluenced by adjacent beams. A two-way slab responds more like a plate, with a deflected surface best described by a three-dimensional trigonometric or parabolic surface. If the stiffnesses in the direction of the joists and perpendicular to them are not equal, the floor is called an "orthotropic plate". The joist deflections will decrease toward the perimeter of the floor as the load is carried in two directions to the reactions. In this case, the floor cannot be properly analyzed by isolating a single joist.

The nature of the slab action for the test floors under uniform loading can be established by examining a profile of joist deflections. Table 4 shows the deflection of the center joist and the next two adjacent joists under uniform loading of 40 lbs psf (1.92 kN/m^2). Also shown is the relative deflection of the third joist as a percent of the center joist deflection. The closer this value is to 100%, the closer the deflected floor conforms to a cylindrical surface, and therefore, a one-way slab. The average relative third joist deflection for all of the plywood-deck and cold-formed steel-joist floors is 96.5% with a standard deviation of 4.3%, strongly suggesting that these floor systems are behaving as one-way slabs. This is consistent with current design procedures in which a single joist is isolated for strength calculations. Wood-joist floor systems are also currently designed as one-way slabs, and this is supported by the results for Floor D, in which the third joist deflection is approximately equal to the center joist deflection.

Floor C, with a concrete deck and cold-formed steel joists, had the lowest relative third joist deflection, suggesting two-way slab action under a uniform load. If a half-cycle sinusoidal deflection profile perpendicular to the joists is assumed, the predicted relative displacement for the third joist would be approximately 81%, very close to the 78% measured.

The important point of this discussion is that wood-deck and concrete-deck floors behave differently. Any mathematical model developed for cold-formed steel-joist floors must either account for this fundamental difference in behavior, or alternately, be restricted to only one deck type.

Composite beam behavior - The best way to determine the extent of composite behavior is to accurately locate the neutral axis using strain gages. An alternate method is to compare measured deflections with calculated deflections in which composite action is assumed. This comparison can only be made for one-way slabs under uniform loading, thus eliminating questions as to lateral distribution or two-way slab action. Table 5 shows the predicted deflection of the floor systems

TABLE 5

COMPARISON OF MEASURED AND PREDICTED DEFLECTION FOR STATIC 40PSF UNIFORM LOAD

Floor Ident.	Vertical displacement of center joist (in.)		
		Predicted	
	Measured	Composite	Noncomposite
A1	.462	.254	.437
A2	.278	.167	.287
A3	.208	.104	.179
B1	No data	.377	.515
B3	.209	.155	.211
D	.336	.289	.468
E1	.828	.526	.855
E2	.566	.345	.561
E3	.367	.216	.350
F	.669	.378	.549
G	No data	.304	.468

which behave as a one-way slab under a 40 lbs psf (1.92 kN/m^2) uniform load, based on a composite and noncomposite moment of inertia, and considering a single isolated joist. For these calculations, the following equations were used:

For single-span joists:

$$\Delta = \frac{5Wl^3}{384EI} \tag{1}$$

For double-span joists (except Floor D):

$$\Delta = \frac{Wl^3}{185EI} \tag{2}$$

in which: Δ = deflection (in.)

W = total joist load (lbs)

l = span (in.)

E = modulus of elasticity of joist (psi)

I = moment of inertia of joist (in.^{4})

The table reveals that an assumption of noncomposite action provides a better estimate of observed deflection for all of the floor systems acting as one-way slabs, except for Floor D. For Floor D, which consists of wood joists and a plywood deck, an assumption of full composite action leads to an underestimate of deflection, while an assumption of noncomposite action leads to an overestimate of deflection. The actual behavior is somewhere between the two. This is consistent with the idea of a "slip modulus" between wood joists and a wood deck recently developed by Vanderbilt (1974).

The floors with plywood decks and cold-formed steel joists are best modeled as noncomposite systems for uniform static loads.

Floor C, with a concrete deck, has been excluded in this discussion because it behaves as a two-way slab. A simple comparison, such as the one above, will not lead to a valid conclusion.

Continuity at intermediate supports - If a beam over an intermediate support is capable of developing a moment at that support, the beam is said to possess "continuity". The presence of continuity can be established in many ways. For a two-span system, a load on one side of the intermediate support, causing a downward deflection on the loaded side, will cause an upward deflection on the adjacent unloaded span. Another method is to compare a measured deflection with a calculated deflection in which continuity is assumed. This comparison was implicit in the calculated deflections shown in Table 5. Continuity was assumed for all of the double-span cold-formed steel-joist floors. Together with an assumption of noncomposite action, the assumption of continuity led to reasonable estimates of the observed deflections.

The presence of continuity for Floor D, the double-span wood-joist system, cannot be determined directly from the comparisons in Table 5 because of the important effect of partial composite action. It would be impossible to separate the two effects in a single comparison. To determine the presence of continuity in this floor system, the interaction between the spans was investigated. A downward concentrated load in one span led to a downward deflection in that span, and an upward deflection of only 6% in the adjacent span, as was shown in Table 3. There is very little interaction between the spans, and continuity is not present for all practical purposes. In performing the calculations for Table 5, Floor D was therefore considered as a single-span floor.

Summary of general behavior of test floors under uniform load - Cold-formed steel-joist floor systems with plywood decks generally behave as noncomposite one-way slabs. When detailed similar to the test floors, they provide continuity at intermediate supports.

Cold-formed steel-joist floor systems with concrete decks generally behave as two-way slabs. They also probably exhibit composite behavior, although this cannot be conclusively established by this study.

Wood-joist floor systems with plywood decks generally behave as partially composite one-way slabs. When detailed similar to Floor D, two-span wood-joist floors do not provide continuity at the intermediate support.

The response of the test floors to uniform static loading was discussed in the previous section in establishing the general behavior of the floors. Traditional methods of analysis are adequate for predicting the response of cold-formed steel-joist floors with plywood decks under uniformly distributed static loading with the following behavioral constraints: one-way slab action; noncomposite beam action; and continuity at supports where appropriately detailed. Fig. 3 shows the comparison between the calculated and measured deflections under a 40-psf (1.92 kN/m^2) uniformly distributed load. The agreement is satisfactory and does not require additional statistical analysis.

Concentrated Static Loading

It has been established that cold-formed steel-joist and plywood-deck floor systems behave essentially as a one-way, noncomposite slab. When the floor is subjected to a single concentrated load, there is a lateral distribution of the load between the loaded joist and adjacent joists. This is demonstrated by the data in Table 3. The measured deflections indicate that the joists adjacent to the loaded centerline joist are responding to the load, and therefore contributing to the overall stiffness of the floor system. This is due to strain compatibility requirements in the vicinity of the loaded joist, and should not be attributed to orthotropic plate behavior. The measured deflections decrease more rapidly with distance from the load than would be expected for a two-way slab or an orthotropic plate.

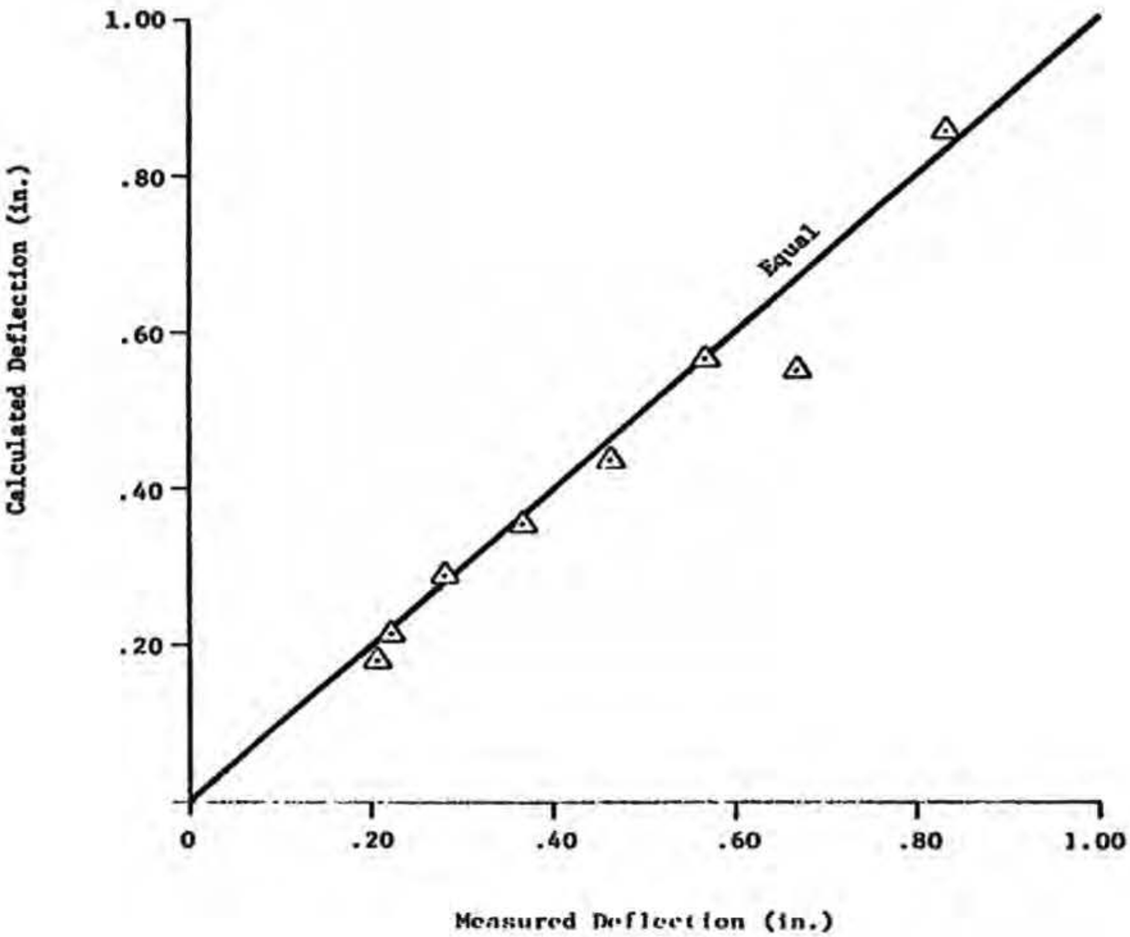


Fig. 3 - Calculated vs measured deflection of cold-formed steel-joist and plywood-deck floors under 40psf uniformly distributed static loading

A mathematical model for predicting the joist deflection due to a single concentrated load must account for this lateral distribution. One concept for a model views the entire floor as an orthotropic plate, leading perhaps to an "equivalent number of fully effective joists". Another model concept empirically predicts an equivalent number of fully effective joists. Both models involve the concept of an equivalent number of fully effective joists. This implies that the floor system responds to load with less deflection than would be predicted by considering the stiffness of a single joist. It can be a useful concept to account for orthotropic plate behavior or simple lateral distribution of load. It indicates how many single, fully effective joists, acting together with the load equally divided between them, should be ASSUMED so that the predicted deflections will match the measured deflection. This is a convenient mathematical device and is not the actual number of joists in a floor responding to the load.

The idea of modeling a floor system as an orthotropic plate has been successful for concrete deck floors (Galambos, 1974, and McCormick, 1974). It is also a very promising model for Floor C of this study, which has a concrete deck. Although cold-formed steel-joist floors with plywood decks are not orthotropic plates, the floor characteristics which determine the properties of an equivalent orthotropic plate could be useful in developing an empirical model.

A review of the classical structural mechanics relationships for flexure, and building code requirements governing residential floor systems, indicates that the following parameters should be considered: joist spacing (S) and span (L); thickness of floor deck (t); material properties of joist and slab; support conditions; section properties of joist and slab; and span-to-depth (L/d) ratio of the joist.

Using multiple linear regression analysis, these parameters are investigated individually and in various combinations to construct an empirical model to predict the number of fully effective joists. The dependent variable in these regression analyses is an "observed" number of fully effective joists. This is determined by first calculating the deflection of a single noncomposite joist subject to a midspan concentrated load, assuming continuity where appropriate. The formulas used for CFSJ/plywood-deck floors are:

for single spans:

$$\Delta = 0.0208 \frac{PL^3}{EI} \quad (3)$$

and for double spans:

$$\Delta = 0.0150 \frac{PL^3}{EI} \quad (4)$$

in which: P = midspan concentrated load (lbs)

This calculated deflection for a single joist is then divided by the measured floor deflection, creating the ratio:

$$N_{stat} = \frac{\text{Calculated deflection for one joist}}{\text{Measured floor deflection}} \quad (5)$$

A concentrated load of 300 lbs (1.34 kN) is assumed, and the measured deflections at this load are the ones reported in Table 3, and also used in the regression analysis. The load-deflection curves indicate that the floor systems behave linearly under a concentrated load within this range, so the value of N_{stat} is independent of the load at which it is calculated.

Since N_{stat} is a dimensionless number, the first step in the regression analysis is to combine floor system properties into nondimensional parameters. In forming these parameters, properties which affect the stiffness of the deck and the stiffness of the joist are selected. The individual properties of interest are shown in the table below, together with their mean, standard deviations and linear correlations with N_{stat}. Only floors with cold-formed steel joists and plywood decks are considered.

Linear Correlation of Floor Properties with N_{stat}

Property	Mean	Standard Deviation	Linear Correl. with N_{stat}
L	213.333	22.271	0.288
S	21.333	4.000	-0.839
d	8.667	0.901	-0.846
t_{deck}	0.708	0.063	-0.839
ε	0.237	0.014	-0.869

The stiffness ratio, ε is the ratio of stiffness perpendicular to the joists, presumably the subordinate stiffness, divided by the stiffness in the direction of the joists, presumably the dominant stiffness. It is calculated as follows:

$$\varepsilon = \left(\frac{t^3 S}{12nI}\right)^{1/4} \qquad (6)$$

in which: t = deck thickness (in.)

I = moment of inertia of the joist (in.^{4})

S = joist spacing (in.)

n = ratio of modulus of elasticity of joist divided by modulus of elasticity of the deck

There is an important observation to be made in the above table. The deck thickness and joist spacing both have exactly the same linear correlation coefficient with N_{stat}. This results from S and t being perfectly correlated to each other. For the representative floor systems in this study, a change in the deck thickness is associated with a change in joist spacing, such that they are linearly related to each other. This means that S and t are virtually interchangeable in any regression analysis. More important, this relationship leads to a very narrow range of ε, which has a standard deviation of only 6% of its mean. In addition to its narrow range, ε is also highly correlated to joist depth d.

For the development of a versatile model for predicting the lateral distribution of concentrated loads, as wide a range of ε as possible would be desirable.

The table also shows similar correlations for t with N_{stat} and d with N_{stat}. Analysis shows that t and d are very highly correlated to each other, and by implication, so are S and d. As in the previous discussion, two very important floor properties are highly correlated to each other. This will lead to models severely limited in their range of application. The net effect of this strong intercorrelation between important independent variables reduces the sensitivity of the regression analysis to changes in the floor system, and limits its range of application to floors similar to the test floors.

The dimensionless parameters formed from the floor system properties are evaluated using multiple linear regression analysis. The more promising models are summarized below.

Summary of Mathematical Models for N_{stat}

Model No.	Equation	Standard error of estimate	Fit r^2	Maximum error in %
1	$0.180 + 0.184\ (L/S)$	.143	.909	13.9
2	$1.460 + 2.139 \times 10^{-4}\ (L^3/S^2d)$	.188	.843	16.8
3	$1.024 + 4.027 \times 10^{-3}\ (L^2/Sd)$	.183	.851	16.4
4	$-0.248 + 0.962\ (L/S)\varepsilon$	.199	.823	22.2
5	$0.952\ (L/d)^{.711}\ \varepsilon^{-2.100}$	.030 (log)	.916 (log)	8.0
6	$1.084\ (L/S)^{.670}\ \varepsilon^{-1.155}$	.030 (log)	.915 (log)	9.0

In evaluating the models discussed above, and all of the alternative models, an effort was made to minimize the number of independent variables since there are only nine pieces of data to work with.

Because of the intercorrelations discussed above, and the problems created by them, Model 1 is proposed as the appropriate predictor for N_{stat}. It is the simplest model, and does not contain correlated independent variables, although it does not lead to the lowest standard error of estimate or the lowest percent error. Fig. 4 shows the comparison between measured and calculated values of N_{stat} using this relationship.

The recommended model should only be considered appropriate for floor systems with properties within the range of the test floors. Fortunately, this population represents current construction practices using cold-formed steel joists for residential floors.

ULTIMATE LOAD TESTS AND RESULTS

The last test performed on each series of floor systems was an ultimate static load test, using a uniformly distributed load. This test, performed on the A3, B3, C, D, E3 and F Floor Systems, had two purposes: to determine the ultimate load capacity of the floor systems, which are considered representative of residential type of construction; and to determine the behavior of the floor systems, including the failure modes, when each system is loaded beyond the design load to its ultimate capacity.

Description of the Test Setups

The vacuum loading test setup for the uniform load testing in the elastic range was also used for the ultimate load testing of each floor system. A profile

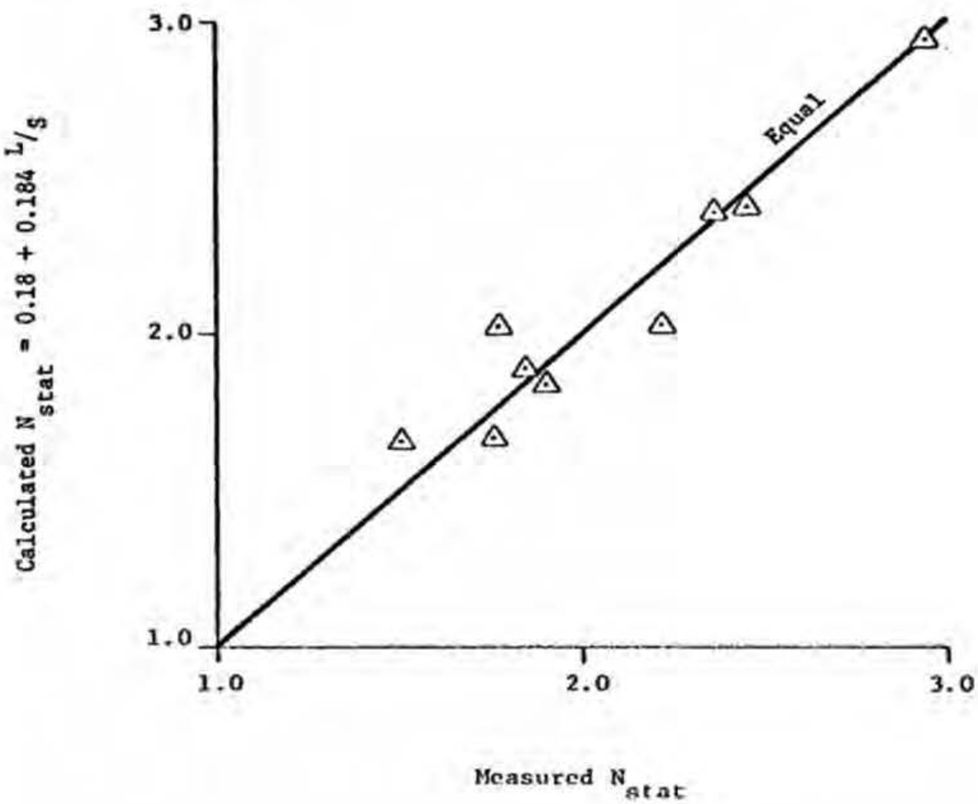


Fig. 4 - Calculated vs measured N_{stat} for cold-formed steel-joist floors with plywood decks

of the deflections of the joists was obtained using linear potentiometers. Linear scales, mounted on the floor surface and read with a transit, were also used in the event that the deflections exceeded the capacity of the potentiometers.

The uniform load was applied to the floor in increments of 5.2 psf (249 N/m^2) up to 66 psf (3.16 kN/m^2). The load was then removed and the residual deflections were recorded. Incremental loading was then resumed until the ultimate capacity of the floor was reached.

Test Results

Table 6 gives the observed residual deflection of Joist No. 1 and the ultimate load capacity of each floor system. The floor systems exhibited several types of failure modes. These include a buckling of the compression flange of the joist at the midspan, a web crippling and buckling at the two-span supports, or single-span end supports. These types of failure modes, as well as others, are summarized in Table 6.

CONCLUSIONS AND RECOMMENDATIONS

The twelve floor systems investigated in this study have been tested to determine their behavior under static uniform and concentrated loads, and the ultimate load capacity. The span length of the floor was varied so that the effect of this parameter could also be studied.

The static uniform load tests showed that CFSJ floors with nailed plywood decks should be considered as one-way noncomposite slabs. Proper detailing will lead to continuity in multiple-span floors, thus reducing deflections. The CFSJ floor with a concrete deck behaved more like a two-way slab. The wood-joist plywood-deck floor responded to static uniform loading as a one-way, partially

TABLE 6

SUMMARY OF ULTIMATE LOAD TEST RESULTS

Floor system	Span (ft)	Ultimate capacity (psf)	Residual joist deflection after 66 psf load		Observed failure modes
			Deflection	Location	
A3	16	135.2	No data		Flange buckling and web crippling at midsupport, distress of the midsupport 2 x 4 sill plates (approx. 1/16-in. deflection), buckling of compression flange of the joists at the midspan.
B3	16	236.3	0.012	0.5L	Not an ultimate load. Test terminated because of test setup failure. No evidence of distress to the joists after removing plywood deck.
C	20	248.6	0.009	0.42L	Buckling and crippling of joists at mid-support, weld failures between joists and steel bridging at the midsupport, buckling of the compression flange of the joists at midspan, weld failures which are used to fasten the corregated deck to the joists.
D	16	213.2	0.029	0.5L	Diagonal tear and cracks developing from the lower face of the joists (tension face) at midspan.
E3	16	161.2	0.013	0.5L	Buckling of the compression flange of the joists at the midspan.
F	16	109.2	0.216	0.5L	Buckling of the compression flange of joists at the midspan, web buckling/crippling failure mode of the joists at the header supports, distress of the bridging in the form of buckling and failure at the connection to the joists.

Note: All deflections are in inches.

composite slab. The usual detailing for multiple-span wood-joist floors did not lead to continuity at the intermediate support.

All of the floors tested displayed a lateral distribution of concentrated load. An empirical relationship for calculating the equivalent number of fully effective joists for predicting deflection due to a concentrated load has been developed for CFSJ plywood-deck floors.

The residual deflections after imposing a load of 66 psf were insignificant, except for Floor F. In general, the cold-formed steel joists failed by flange buckling in the positive moment area, and by web buckling and web crippling at the supports.

The static structural characteristics of CFSJ floors have been studied and discussed. Empirical relationships for floors with properties within the range of parameters of the test floor have been developed.

ACKNOWLEDGEMENTS

This research project was sponsored by the Task Group on Commercial and Residential Applications of Cold-Formed Steel Members, Engineering Subcommittee of the Sheet Committees of the American Iron and Steel Institute, under the chairmanship of Mr. Karl Klippstein. The Task Group has provided guidance and assistance in the testing program and the interpretation of the results.

Appreciation is also expressed for the assistance of Mr. Robert Hannen, Mr. Richard Kotlarz, and to the WJE staff who served as test subjects.

REFERENCES

Galambos, T. V., "Vibration of Steel-Joist Concrete-Slab Floors", Steel Joist Institute, Technical Publication No. 5, 1974

McCormick, M. M., "Office Floor Vibration Design Criteria and Tests", Melbourne Research Laboratories, Melbourne, Australia, February, 1974

Vanderbilt, M. D., Goodman, J. R., and Criswell, M. E., "Service and Overload Behavior of Wood-Joist Floor Systems", Journal of the Structural Division ASCE, Vol. 100, No. ST4, Proc. Paper 10274, January, 1974