International Specialty Conference on Cold-Formed Steel Structures

(1982) - 6th International Specialty Conference on Cold-Formed Steel Structures

Nov 16th, 12:00 AM

Comparison of Methods Predicting Diaphram Behavior

Paul E. Liedtke

Donald R. Sherman

Recommended Citation

Liedtke, Paul E. and Sherman, Donald R., "Comparison of Methods Predicting Diaphram Behavior" (1982). *International Specialty Conference on Cold-Formed Steel Structures*. 1.
https://scholarsmine.mst.edu/isccss/6iccfss/6iccfss-session7/1

COMPARISON OF METHODS PREDICTING DIAPHRAM BEHAVIOR

BY

Paul E. Liedtke[1] and Donald R. Sherman[2]

ABSTRACT

A computer program has been developed to permit the comparison of four analytical predictors of shear diaphragm behavior: the SDI Method, the Triservice Method, the European Method and a method developed at West Virginia University. Inputs to the program include diaphragm dimensions, sheet properties and dimensions, and the properties and arrangements of various types of fasteners. The outputs are the shear strength and stiffness as predicted by the four methods.

In order to provide a basis for comparing the methods to a specific application, a series of tests was conducted on diaphragms with puddle welds as sheet to frame connectors and button punches as sheet to sheet connectors. The number and arrangement of these connectors were varied as well as the span of the diaphragms and the sheet thickness. The experimental strengths and stiffnesses of these diaphragms were compared to predicted behavior using the computer program.

---

[1] Lecturer, Civil Engineering Department, University of Wisconsin-Milwaukee

[2] Professor, Civil Engineering Department, University of Wisconsin-Milwaukee

INTRODUCTION

Shear diaphragms have long been components of structural systems. Diaphragm construction is used to resist lateral loads from wind, blast and seismic forces. As parts of roofs, floors and walls, diaphragms help to control sway and stabalize pin jointed structures by transferring forces to fixed points, lowering stresses and controlling deflections in rigid frames. Diaphragms may also be used as flexural plates to resist gravity loads, as shells (such as folded plates) and as continuous bracing for columns.

Many different materials have been used in diaphragm construction. In light metal building construction, the common diaphragms are composed of corrugated, cold-formed steel sheets attached to one another and to some supporting frame. The characteristics required to evaluate or design diaphragms are their strength and stiffness. Due to complexities in purely theoretical formulations, it has been the practice to determine diaphragm behavior experimentally. However, with the large body of test data, emperical and semi emperical methods of predicting behavior have been developed. The purpose of this work is to compare and contrast four well known methods that can be used to predict the behavior of cold-formed diaphragms.

COMPLICATIONS INVOLVED IN DIAPHRAGM ANALYSIS

Because of their characteristics, corrugated metal diaphragms are difficult to analyze. Although the shearing properties of continuous plates may be better understood, these diaphagms possess some peculiarities of construction which challange classical analysis.

Such diaphragms are made of thin sheets which are corrugated to provide flexural stiffness. Of course, the corrugations complicate in-plane behavior. The individual sheets are connected discretely to each other and to a supporting structure. Therefore, there are, along the seams between sheets and along the ends of the sheets, rather long unfastened regions. These act in a manner similar to slits or holes in continuous material. In addition, many diaphragms have openings for doors, windows, fixtures and other structural and architectural purposes.

Diaphragm analysis is further complicated by the various failure modes which are possible. A stability failure or buckling can occur, limiting the strength of a diaphragm. Research has been conducted to predict the buckling strengths of some diaphragm configurations(3). The results of these investigations show that, while buckling may be a consideration in systems which contain many fasteners spaced closely together, such failure is not of great concern in most common structural systems, where the fasteners are fewer and farther between.

Most often, the failure of a diaphragm is the direct result of the failure at the connections which hold it together. The inadequacy may be in the sheet to sheet connections along the seams between sheets, or in the sheet to structure connections, either along the edge members (parallel to the corrugations) where the direct transfer of shear to the sheets takes place, or along the end beams or intermediate purlins (perpendicular to the corrugations).

Futher, the failure of a connection may be of two types. The deck material surrounding the connector may fail in bearing or tear out. Bearing failure is common around screws as the area in bearing is small hence the stress produced is high. Tear out failure can occur with welds or screws. It happens often around welds which were made with improper contact and amperage and because of the consequent burn through have poor or little attachment to the surrounding deck material.

The other type is the failure of the connector itself. Shearing of a screw may occur because of its relatively small cross sectional area. Welds, on the other hand, may simply pop off under load due to inadequate penetration. Shearing of good welds is not a problem because of their relatively large cross sectional areas and because of the high strength of the weld material. In the button punch connection where lapped material is mechanically crimped together, failure occurs when one dimple rides out of the other causing the sheets to separate and eliminating the shear plane that existed.

METHODS OF DIAPHRAGM ANALYSIS

These complexities have led engineers to develop many methods by which diaphragm behavior, specifically strength and stiffness, can be predicted. Four such methods are briefly discussed here. The reader is advised to consult the appropriate references for more specific information.

Since the late 1940's, full scale testing has been a popular method of diaphragm evaluation in this country. Such experiments give reliable forecasts of a diaphragm's characteristics, but they have their drawbacks. Full scale tests are cumbersome, slow and expensive. Even more detrimental is the fact that a test is limited in scope to a particular configuration. Still, they are the most reliable method of predicting diaphragm behavior in service.

Computer based numerical techniques have been applied to the problem(1). A typical diaphragm's make up - individual elements connected at discrete points - lends itself to the use of finite element methods. Detractors say that the programs are initially expensive, not readily available to every engineer and still too limited in their scope.

Therefore, many designers prefer to use one of the empirical hand calculation techniques that have been developed. These methods are simple and relatively quick to apply and involve varying degrees of approximation. The four methods compared in this paper are those proposed by the Steel Deck Institute, the Triservice Manual, Huang and Luttrell at West Virginia University and the European Recommendations. The following discription gives the development of the methods and, along with Table 1, provides a comparison of the methodology.

The Steel Deck Institute intended its method (7) primarily as a design aid. At the time of its introduction, no purely analytical procedure existed by which diaphragm strength and stiffness could be reliably predicted. In its desire to develop such a method, the Institute initiated a test program at the University of West Virginia. Under the direction of Luttrell, some 160 full scale diaphragm tests were conducted beginning in 1968. The results of these tests led to the equations hereafter referred to as the SDI Method.

The formulas of the SDI Method relate diaphragm behavior to panel geometry, material thickness, deck span and type of connections (especially important are the sidelap connections). Various types of deck profile are dealt with in different equations. Two modes of failure - connector failure and buckling - are considered in two seperate equations for each case of strength. Connections are assumed to be of good quality; values for strengths and stiffnesses of three types of fasteners are internally included and may not be input independently into the equations.

During the 1950's and 1960's, most of the information pertaining to the strength and stiffness characteristics of diaphragms was available only through the manufacturers of diaphragm materials. This information, in the form of equations, was based on test results and was updated periodically when new data were available. In an effort to consolidate these scattered pieces of knowledge, the Triservice Seismic Design Committee developed the equations presented in its document entitled, "Seismic Design for Buildings" (6). These equations were based on all the information available to the Triservice Committee in 1973 at the time of publication.

The Triservice Method, as it will be referred to herein, incorporates the same variables as the SDI Method, although screws are not considered as possible connectors. As with the SDI Method, the specific characteristics of individual fasteners are inherent in the equations. Instead of predicting diaphragm stiffness, the Triservice Committee suggests equations for computing a "Flexibility Factor","F", to be used in conjunction with a table of allowable values provide in the manual. No dimensional values for flexibility or stiffness are generated by the Triservice Method. It should also be noted that the method does not consider buckling as a mode of failure.

As with other methods available at the time, the SDI and Triservice Methods were developed to fit experimental data and were revised on the basis of more data. Still, no purely analytical approch existed. At West Virginia University, Huang and Luttrell (5) undertook an extensive study to arrive at such a method. Published in 1979, it was verified by experiment, but was developed analytically. Their intent was to free diaphragm analysis form its heavy dependence on experiment.

The West Virginia Method (5), as it will be called here, relates a diaphragm's behavior to the behaviors of the individual elements of which it is composed. Panel and sheet geometry, connector frequency and position are again considered, but Huang and Luttrell also deal with the performance and characheristics of the connections themselves (i.e. the connections' strengths and stiffnesses) and with the actions of the flutes, or corrugations, as these individual elements play an important role in the overall behavior of a diaphragm. Huang and Luttrell do not consider the problem of buckling because configurations apt to buckle are, as they put it, "not representative of common civil engineering and construction practices".

The document "European Recommendations for the Stressed Skin Design of Steel Structures" (4) presents a method of diaphragm analysis developed mainly by Bryan. This European Method is similar to the one devised by Huang and Luttrell although the assumed distribution of internal forces is not the same. As in the West Virginia Method, a diaphragm's strength and stiffness are viewed as the sums of the strengths and stiffnesses of its component elements. Further, each element's behavior is dealt with seperately, enabling the user to see how the overall behavior of the diaphragm is affected by one element. It is said of this method that it allows the engineer to see "the weak links in the chain".

The European Method considers failure at seams and at sheet-shear connections (those at the diaphragm's edge, parallel to the corrugations). The strength for any other mode of failure must, according to the recommendations, be 25% higher than the least of the above failure modes' strengths. Buckling is dealt with as a possible failure mode using the equations developed by Easley (3).

Unique to the European Method is its treatment of diaphragms attached on two sides only. These constructions do not possess sheet to structure fasteners along their edges (parallel to the corrugations) hence the external shear forces are transferred to the sheets through the purlin/rafter connections and through the sheet to structure fasteners along the purlins. This is the so called "indirect" case of shear transfer.

EXPERIMENTAL PROGRAM

To facilitate comparison of the numerical results generated by the four methods, tests were conducted on thirty-two diaphragm assemblies. The assemblies consisted of six sheets which were interconnected with button punches and were puddle welded to the framing members and purlins. Variables in the tests were the sheet thickness, deck span and fastener spacings. The test procedure and setup shown in Figure 1 followed the AISI recommendations (2) with the exception that the load application and shear deflection occurred perpendicular to the corrugations. The deck used was manufactured by Vulcraft. The particulars of its profile may be seen in figure 2.

Since the WVA and EUR methods require data for fastener stiffness and strength, shear tests were conducted in a tensile testing machine with the specimens shown in Figure 3. Table 2 gives the strengths and stiffnesses obtained for the welds and button punches. Considerable scatter is evident even with the limited sample size. This reflects the sensitivity of the characteristics of these fasteners to the quality of their installation. Average values were used as inputs to the West Virginia and European Methods.

Welds and button punches were tested two at a time as shown in Figure 2. In the weld tests, samples of deck were welded to 1/4" (6mm) thick plate. The welds were comparable in size to those used in the actual tests - about 3/4" (19mm) apparent diameter. Because of the difficulties encountered in measuring the stiffness of the welds, only their ultimate strength, were found. Stiffness value were interpelated from a plot in reference (5). The plot gives stiffness characteristics of 5/8" (15.9mm) puddle welds made on various thickness of deck material. To use this data, it was multipled by a factor of(5/8)/(3/4)=5/6 to account for the size of the welds actually used.

The button punch tests were conducted using both 20 and 22 gage material. The button punches were made at least 12ins. (0.305m) apart to approximate the actual test conditions. Both strength and stiffness were measured.

RESULTS

All four methods predict strengths in similar units (lbs/ft), but in order to compare the estimates of stiffness, some manipulation is necessary.

Figure 4a is an illustration of the test procedure used; Figure 4b is the arrangement assumed by the methods.

The stiffness of the diaphragm can be represented by the expression:

$$G' = \frac{\frac{P}{a}}{\gamma} = \frac{\frac{P}{a}}{\frac{\delta}{b}} = \frac{Pb}{a\Delta}$$

or by:

$$G' = \frac{\frac{V}{b}}{\gamma} = \frac{\frac{V}{b}}{\frac{\Delta}{a}} = \frac{Va}{b\Delta}$$

It is easily seen that these two expressions are equivalent by noting that Pa = Vb (by statics) and that $\gamma = \gamma$ (or more precisely that $\delta/b = \Delta/a$).

Two of the methods predict stiffnesses as ($Va/b\Delta$) and, as illustrated, this poses no problem. The European Method, on the other hand, predicts a flexibility of Δ/V, which can easily be converted to a stiffness of V/Δ. In order to make this stiffness comparable, it must be multiplied by the ratio of the length to the width of the diaphragm, namely a/b. Again, the Triservice Method predicts a Flexibility Factor which is dimensionaless, hence it cannot be compared directly with the values of the other methods.

Tables 3 and 4 contain the strength and stiffness results of the tests and the corresponding predictions of the four methods.

To identify the deck configurations, the following code was used: Diaphragm Depth/Gage of Deck Material/End Welds per Sheet/Spacing of Button Punches (inches). The 12', 14' and 16' (3.66m, 4.27m, 4.88m) diaphragms contained one intermediate purlin and had spans of 6', 7' and 8' (1.83m, 2.13m, 2.44m) respectively. The 15' (4.57m) decks contained two intermediate purlins and spans of 5' (1.52m).

The decks with 4 end welds per sheet had a fastener in every other trough; those with 7 end welds per sheet had one in every trough.

Listed are the experimental results (EXP) and the predictions of the SDI Method (SDI), the Triservice Method (TRI), the West Virginia Method (WVA) and the European Method (EUR).

CONCLUSIONS

The data in Tables 2 and 3 require considerable study to ascertain the dependence of the results on the test variables. As an aid to illustrate the relative trend in the predictions of each method caused by the variation of experimental parameters, the data in Tables 2 and 3 have been normalized in Tables 4 and 5 by dividing abitrarily by the first value in each of the columns for each end weld case.

- The strength estimates of the European Method are consistently the highest. Those of the West Virginia Method are slighty less, though still higher than the others by as much as a factor of three. However, it should be noted that strengths predicted by these methods vary proportionally with connector strength. If the lowest values in Table 2 were used, the predicted strengths would be 5 to 10% lower. The SDI and Triservice methods' predictions are relatively close to one another, but the SDI Method usually gives somewhat higher values.

- The stiffness predictions of the SDI Method are always greater than those of the West Virginia and European Methods. While the estimates of the West Virginia Method are slightly lower than the European Method for the case of end welds in every other trough, its predictions are more than those of the European Method for decks with end welds in every trough.

- Strength and stiffness both increase with thickness. However, strength changes in the SDI Method are influenced to a greater extent than in the other methods. The Triservice Method for stiffness is significantly more sensitive to thickness than the others.

- Diaphragms with more connectors (end welds or seam fasteners) should be stronger and stiffern than those with fewer. Or, in other words, greater connector spacing decreases strength and stiffness. The sensitivity of strength to seam fastener spacing is approximately the same in all methods, but slightly greater in the Triservice Method. Stiffness is only slightly influenced by the number of seam fasteners except in the SDI Method, where it is a significant factor. The number of end welds significantly influences the stiffness in all methods.

- Span is not a strength factor in the SDI Method, but has about the same effect in decreasing strength in the other methods. The effect of span on stiffness is somewhat erratic, with the SDI Method being the only one to predict decreasing stiffness with increasing span.

There is some scatter in the experimental data, especially in the stiffness values. Although these irregularities might be attributed to the quality control exercised in the erection of the tests, it is doubtful that this is their cause. Great care was taken during the construction of the decks - especially in the welding procedure. Though the button punches were of poor quality, this was uniform throughout the tests. Their inadequacies were caused by acknowledged imperfections in the sheets, namely lips that were too short.

- The experimental strengths follow the same trends observed in the predictions. It seems, though, that as span increases, material thickness has a smaller effect on diaphragm strength. In both magnitude of strength and significance of the parameters, the experimental data is best predicted by the Triservice Method.

- Experimental values of stiffness are in the order of those predicted by the West Virginia Method and the European Method although they are more closely predicted by the latter. They are significantly less than those predicted by the SDI Method and can not be compared to the Triservice factors.

APPENDIX-REFERENCES

1. Atrek and Nilson, "Non-Linear Finite Element Analysis of Light Gage steel shear Diaphragms", Structural Engineering Report 363, Cornell University.

2. "Design of Light Gage Steel Diaphragms", American Iron and Steel Institute, 1967.

3. Easley, J.T., "Buckling Formulas for Corrugated Metal Stear Diaphragms", Journal of the Structural Division, ASCE, Volume 101, No. ST7, July, 1975.

4. "European Recommendations for the Stressed Skin Design of Steel Structures", ECCS-XVII-77-i/e, Published by CONSTRADO, NLA Tower, 12 Addiscombe Road, Croydon CR9 3JH, England.

5. Huang and Luttrell, "Theoretical and Physical Approach to Light Gage Steel Shear Diaphgagms", Civil Engineering Report, West Virginia University, Morgantown, West Virginia, December, 1979.

6. "Seismic Design for Buildings", U.S. Army Technical Manual 5-809-10, Department of the Army, Washington, D.C., April 17, 1973.

7. "Tentative Recommendations for the Design of Steel Deck DIaphragms", Steel Deck Institute, 9836 West Roosevely Road, P.O. Box 207, Westchester, Illinois 60153, October 12, 1972.

APPENDIX-NOTATION

a = diaphragm length

b = diaphragm depth

G'= diaphragm shear stiffness

P = diaphragm shear force

V = diaphragm shear force

δ = shear deflection

Δ = shear deflection

γ = shear strain

Table 1 - Comparison of the Factors Considered in the Four Analytical Methods

	VARIABLE	SDI	TRI	WVA	EUR
OVERALL GEOMETRY	Diaphragm Length	✓	✓	✓	✓
	Diaphragm Depth	✓	✓	✓	✓
	Panel Length	✓	✓	✓	✓
	Panel Depth	✓	✓	✓	✓
SHEET GEOMETRY	Type of Deck Profile	✓			
	Surface Condition of Deck Material		✓		
	Gage (Material Thickness)	✓	✓	✓	✓
	Modulus of Elasticity of Deck Material			✓	✓
	Sheet Length	✓	✓	✓	✓
	Sheet Width	✓	✓	✓	
	Height of Sheet		✓	✓	✓
	Length of Top Flange of Corrugation			✓	
	Length of Bottom Flange of Corrugation			✓	
	Length of Web of Corrugation			✓	✓
	Horizontal Projection of Web			✓	✓
	Pitch of Corrugations			✓	✓
	Developed Width of Corrugation			✓	
	Moment of Inertia of Sheet About Horizontal Neutral Axis		✓		
	Moment of Inertia of Sheet About Vertical Neutral Axis		✓		

Table 1 (continued)

	VARIABLE	SDI	TRI	WVA	EUR
FASTENER PROPERTIES AND ARRANGEMENT	Type of End/Purlin Fasteners	✓	c		
	Arrangement of End/Purlin Fasteners	✓	✓	✓	✓
	Strength of End/Purlin Fasteners		d	✓	✓
	Stiffness of End/Purlin Fasteners			✓	✓
	Type of Edge Fasteners	a	a		
	Arrangement of Edge Fasteners	b	b	✓	✓
	Strength of Edge Fasteners		a	a	✓
	Stiffness of Edge Fasteners		a	a	✓
	Type of Seam Fasteners	✓	✓		
	Arrangement of Seam Fasteners	✓		✓	✓
	Strength of Seam Fasteners			✓	✓
	Stiffness of Seam Fasteners			✓	✓
	Stiffness of Purlin/Rafter Connections				✓
MISC.	Cross sectional Area of Purlins				✓
	Modulus of Elasticity of Purlins				✓

a Assumed to be the same as for end/purlin fasteners
b Assumed to be the same as for seam fasteners
c Assumed to be welds
d Incorporated indirectly, through effective length of weld

Table 2 - Fastener Properties

Sheet to Structure: 3/4 in (19.1 mm) Diameter Puddle Welds

On 22 Gage Material

Test No.	Strength k (kN)	Flexibility in/k (mm/kN)
1	3.00 (13.4)	
2	3.30 (14.7)	
Ave.	3.15 (14.0)	0.00583 (0.0333)*

On 20 Gage Material

Test No.	Strength k (kN)	Flexibility in/k (mm/kN)
1	4.16 (18.5)	
2	4.65 (20.7)	
3	4.24 (18.0)	
Ave.	4.35 (19.4)	0.00492 (0.0281)*

Sheet to Sheet: Button Punches

On 22 Gage Material

Test No.	Strength k (kN)	Flexibility in/k (mm/kN)
1	0.365 (1.62)	0.0700 (0.400)
2	0.320 (1.42)	0.7200 (0.411)
3	0.372 (1.65)	0.0560 (0.320)
Ave.	0.352 (1.57)	0.0660 (0.377)

On 20 Gage Material

Test No.	Strength k (kN)	Flexibility in/k (mm/kN)
1	0.440 (1.96)	0.0605 (0.345)
2	0.390 (1.73)	0.0333 (0.190)
3	0.484 (2.15)	0.0643 (0.367)
Ave.	0.438 (1.95)	0.0527 (0.301)

See Reference 5; (0.0070)(5/6)=0.00583, (0.0059)*(5/6)=0.00492

Table 3 - Strength Data lbs/ft (N/mm)

DECK*	EXP	SDI	TRI	WVA	EUR
15/22/7/12	432 (6.30)	394 (5.75)	465 (6.79)	1589 (23.4)	1594 (23.3)
15/22/7/24	391 (5.71)	371 (5.41)	422 (6.16)	1449 (21.0)	1472 (21.5)
15/20/7/12	613 (8.95)	756 (11.0)	715 (10.4)	2147 (31.3)	2124 (31.0)
15/20/7/24	566 (8.26)	706 (10.3)	663 (9.68)	1971 (28.8)	1984 (29.0)
12/22/7/12	467 (6.82)	394 (5.75)	401 (5.85)	1461 (21.3)	1513 (22.1)
12/22/7/24	378 (5.52)	360 (5.25)	347 (5.06)	1285 (18.8)	1362 (19.9)
12/20/7/12	598 (8.73)	756 (11.0)	609 (8.89)	1969 (28.7)	2015 (29.4)
12/20/7/24	573 (8.36)	681 (9.94)	544 (7.94)	1750 (25.5)	1839 (26.8)
14/22/7/12	430 (6.28)	394 (5.75)	356 (5.20)	1276 (18.6)	1342 (19.6)
14/22/7/24	404 (5.90)	348 (5.08)	294 (4.29)	1075 (15.7)	1168 (17.0)
14/20/7/12	556 (8.11)	756 (11.0)	534 (7.79)	1715 (25.0)	1780 (26.0)
14/20/7/24	547 (7.98)	655 (9.56)	460 (6.71)	1464 (21.4)	1576 (23.0)
16/22/7/12	384 (5.60)	394 (5.75)	322 (4.70)	1139 (16.6)	1214 (17.7)
16/22/7/24	368 (5.37)	360 (5.25)	268 (3.91)	963 (14.1)	1058 (15.4)
16/20/7/12	396 (5.78)	756 (11.0)	478 (6.98)	1524 (22.2)	1605 (23.4)
16/20/7/24	351 (5.12)	681 (9.94)	413 (6.03)	1305 (19.0)	1421 (20.7)
15/22/4/12	329 (4.80)	394 (5.75)	349 (5.09)	1199 (17.5)	1271 (18.5)
15/22/4/24	384 (5.60)	371 (5.41)	306 (4.47)	1075 (15.7)	1134 (16.6)
15/20/4/12	377 (5.50)	535 (7.81)	530 (7.73)	1616 (23.6)	1701 (24.8)
15/20/4/24	379 (5.53)	499 (7.28)	479 (6.99)	1456 (21.3)	1533 (22.4)
12/22/4/12	267 (3.90)	394 (5.75)	307 (4.48)	1111 (16.2)	1213 (17.7)
12/22/4/24	240 (3.50)	360 (5.25)	253 (3.69)	935 (13.6)	1042 (15.2)
12/20/4/12	364 (5.31)	535 (7.81)	459 (6.70)	1468 (21.7)	1622 (23.7)
12/20/4/24	371 (5.41)	481 (7.02)	395 (5.76)	1267 (18.5)	1411 (20.6)
14/22/4/12	256 (3.74)	394 (5.75)	277 (4.04)	976 (14.2)	1089 (15.9)
14/22/4/24	210 (3.06)	348 (5.08)	215 (3.14)	775 (11.3)	893 (13.0)
14/20/4/12	364 (5.31)	535 (7.81)	409 (5.97)	1300 (19.0)	1451 (21.2)
14/20/4/24	376 (5.49)	464 (6.77)	335 (4.89)	1050 (15.3)	1210 (17.7)
16/22/4/12	251 (3.66)	394 (5.75)	254 (3.71)	876 (12.8)	996 (14.5)
16/22/4/24	211 (3.08)	360 (5.25)	200 (2.92)	700 (10.2)	824 (12.0)
16/20/4/12	264 (3.85)	535 (7.81)	371 (5.41)	1162 (17.0)	1324 (19.3)
16/20/4/24	258 (3.77)	481 (7.02)	306 (4.47)	942 (13.8)	1111 (16.2)

*w/x/y/z

w=diaphragm depth

x=gage

y=end welds per sheet

z=spacing of button punches (in)

Table 4 - Stiffness Data k/in (kN/mm)
(Flexibility Factor for Triservices Method)

DECK*	EXP	SDI	TRI#	WVA	EUR$
15/22/7/12	54.7 (9.59)	164 (28.7)	53.8	63.5 (11.1)	33.8 (5.93)
15/22/7/24	32.9 (5.76)	117 (20.5)	54.5	61.0 (10.7)	32.5 (5.69)
15/20/7/12	57.6 (10.1)	177 (31.0)	33.0	84.8 (14.9)	48.5 (8.49)
15/20/7/24	52.6 (9.21)	136 (23.8)	33.4	80.9 (14.2)	46.2 (8.09)
12/22/7/12	42.7 (7.48)	182 (31.9)	66.0	53.9 (9.44)	24.8 (4.33)
12/22/7/24	39.9 (6.99)	92.4 (16.2)	67.3	51.3 (8.98)	23.9 (4.19)
12/20/7/12	101 (17.7)	201 (35.2)	40.4	73.4 (12.9)	36.0 (6.30)
12/20/7/24	60.9 (10.7)	117 (20.5)	41.1	63.9 (11.2)	34.2 (5.99)
14/22/7/12	37.0 (6.49)	170 (29.8)	53.9	56.1 (9.82)	27.3 (4.77)
14/22/7/24	37.8 (6.62)	79.2 (13.9)	61.2	52.1 (9.12)	25.6 (4.48)
14/20/7/12	60.2 (10.5)	185 (32.4)	36.8	75.4 (13.2)	39.1 (6.84)
14/20/7/24	74.7 (13.1)	100 (17.5)	38.0	69.2 (12.1)	36.1 (6.33)
16/22/7/12	33.0 (5.78)	158 (27.7)	54.4	57.5 (10.1)	29.3 (5.12)
16/22/7/24	39.3 (6.88)	98.5 (17.3)	56.5	53.3 (9.33)	27.5 (4.81)
16/20/7/12	46.7 (8.18)	170 (29.8)	34.3	76.4 (13.4)	41.6 (7.29)
16/20/7/24	43.2 (7.57)	116 (20.3)	35.6	70.0 (12.3)	38.5 (6.74)
15/22/4/12	8.60 (1.51)	81.9 (14.3)	188	14.2 (2.49)	8.32 (1.46)
15/22/4/24	8.92 (1.56)	58.7 (10.3)	189	14.0 (2.45)	8.21 (1.44)
15/20/4/12	12.3 (2.15)	88.6 (10.3)	111	21.3 (3.73)	12.7 (2.23)
15/20/4/24	10.1 (1.77)	67.8 (11.9)	112	20.9 (3.66)	12.5 (2.19)
12/22/4/12	7.23 (1.27)	90.8 (15.9)	234	10.7 (1.87)	5.78 (1.01)
12/22/4/24	6.12 (1.07)	46.2 (8.09)	235	10.5 (1.84)	5.70 (1.00)
12/20/4/12	11.1 (1.94)	100 (17.5)	138	16.3 (2.85)	8.91 (1.56)
12/20/4/24	11.2 (1.96)	58.6 (10.3)	139	16.0 (2.80)	8.76 (1.53)
14/22/4/12	7.71 (1.35)	84.9 (14.9)	203	12.1 (2.12)	6.63 (1.16)
14/22/4/24	8.79 (1.54)	39.6 (6.93)	206	11.8 (2.07)	6.49 (1.14)
14/20/4/12	16.7 (2.92)	92.3 (16.2)	120	18.3 (3.20)	10.2 (1.78)
14/20/4/24	15.3 (2.68)	50.2 (8.79)	122	17.6 (3.08)	9.90 (1.73)
16/22/4/12	9.48 (1.66)	79.1 (13.9)	180	13.4 (2.35)	7.46 (1.31)
16/22/4/24	8.69 (1.52)	49.3 (8.63)	183	13.0 (2.28)	7.28 (1.27)
16/20/4/12	12.7 (2.22)	85.0 (14.9)	108	20.1 (3.52)	11.4 (1.99)
16/20/4/24	12.4 (2.17)	58.2 (10.2)	110	19.3 (3.38)	11.1 (1.94)

*w/x/y/z w=diaphragm depth y=end welds per sheet
x=gage z=spacing of button punches (in)
#Flexibility Factor, not in comparable units
$Method's prediction multiplied by the factor (a/b)

Table 5 - Normalized Strength Data

DECK*	SPAN (ft)	EXP	SDI	TRI	WVA	EUR
15/22/7/12	5	1	1	1	1	1
15/22/7/24		0.91	0.94	0.91	0.91	0.92
15/20/7/12		1.42	1.92	1.54	1.35	1.33
15/20/7/24		1.31	1.79	1.43	1.24	1.24
12/22/7/12	6	1.08	1.00	0.86	0.92	0.95
12/22/7/24		0.88	0.91	0.75	0.81	0.85
12/20/7/12		1.38	1.92	1.31	1.24	1.26
12/20/7/24		1.33	1.73	1.17	1.10	1.15
14/22/7/12	7	1.00	1.00	0.77	0.80	0.84
14/22/7/24		0.94	0.88	0.63	0.68	0.73
14/20/7/12		1.29	1.92	1.15	1.08	1.12
14/20/7/24		1.27	1.66	0.99	0.92	0.99
16/22/7/12	8	0.89	1.00	0.69	0.72	0.76
16/22/7/24		0.85	0.91	0.58	0.61	0.66
16/20/7/12		0.92	1.92	1.03	0.96	1.01
16/20/7/24		0.81	1.73	0.89	0.82	0.89
15/22/4/12	5	1	1	1	1	1
15/22/4/24		1.17	0.94	0.88	0.90	0.89
15/20/4/12		1.15	1.36	1.52	1.35	1.34
15/20/4/24		1.15	1.27	1.37	1.21	1.21
12/22/4/12	6	0.81	1.00	0.88	0.93	0.95
12/22/4/24		0.73	0.91	0.72	0.78	0.82
12/20/4/12		1.11	1.36	1.32	1.24	1.28
12/20/4/24		1.13	1.22	1.13	1.06	1.11
14/22/4/12	7	0.78	1.00	0.79	0.81	0.86
14/22/4/24		0.64	0.88	0.62	0.65	0.70
14/20/4/12		1.11	1.36	1.17	1.08	1.14
14/20/4/24		1.14	1.18	0.96	0.88	0.95
16/22/4/12	8	0.76	1.00	0.73	0.73	0.78
16/22/4/24		0.64	0.91	0.57	0.58	0.65
16/20/4/12		0.80	1.36	1.06	0.97	1.04
16/20/4/24		0.78	1.22	0.88	0.79	0.87

*w/x/y/z
w=diaphragm depth
x=gage
y=end welds per sheet
z=spacing of button punches (in)

Table 6 - Normalized Stiffness Data

DECK*	SPAN (ft)	EXP	SDI	TRI	WVA	EUR
15/22/7/12	5	1	1	1	1	1
15/22/7/24		0.60	0.71	0.99	0.96	0.96
15/20/7/12		1.05	1.08	1.63	1.34	1.43
15/20/7/24		0.96	0.83	1.61	1.27	1.37
12/22/7/12	6	0.78	1.11	0.82	0.85	0.73
12/22/7/24		0.73	0.56	0.80	0.81	0.71
12/20/7/12		1.85	1.23	1.33	1.16	1.07
12/20/7/24		1.11	0.71	1.31	1.01	1.01
14/22/7/12	7	0.68	1.04	0.91	0.88	0.81
14/22/7/24		0.69	0.48	0.88	0.82	0.76
14/20/7/12		1.10	1.13	1.46	1.19	1.16
14/20/7/24		1.37	0.61	1.42	1.09	1.07
16/22/7/12	8	0.60	0.96	0.99	0.91	0.87
16/22/7/24		0.72	0.60	0.95	0.84	0.81
16/20/7/12		0.85	1.04	1.57	1.20	1.23
16/20/7/24		0.79	0.71	1.51	1.10	1.14
15/22/4/12	5	1	1	1	1	1
15/22/4/24		1.04	0.72	0.99	0.99	0.99
15/20/4/12		1.43	1.08	1.69	1.50	1.53
15/20/4/24		1.17	0.83	1.68	1.47	1.50
12/22/4/12	6	0.84	1.11	0.80	0.75	0.69
12/22/4/24		0.71	0.56	0.80	0.74	0.69
12/20/4/12		1.29	1.22	1.36	1.15	1.07
12/20/4/24		1.30	0.72	1.35	1.13	1.05
14/22/4/12	7	0.90	1.04	0.93	0.85	0.80
14/22/4/24		1.02	0.48	0.91	0.83	0.78
14/20/4/12		1.94	1.13	1.57	1.29	1.23
14/20/4/24		1.78	0.61	1.54	1.24	1.19
16/22/4/12	8	1.10	0.97	1.04	0.94	0.90
16/22/4/24		1.01	0.60	1.03	0.92	0.88
16/20/4/12		1.48	1.04	1.74	1.42	1.37
16/20/4/24		1.44	0.71	1.71	1.36	1.33

*w/x/y/z w=diaphragm depth y=end welds per sheet
x=gage z=spacing of button punches (in)

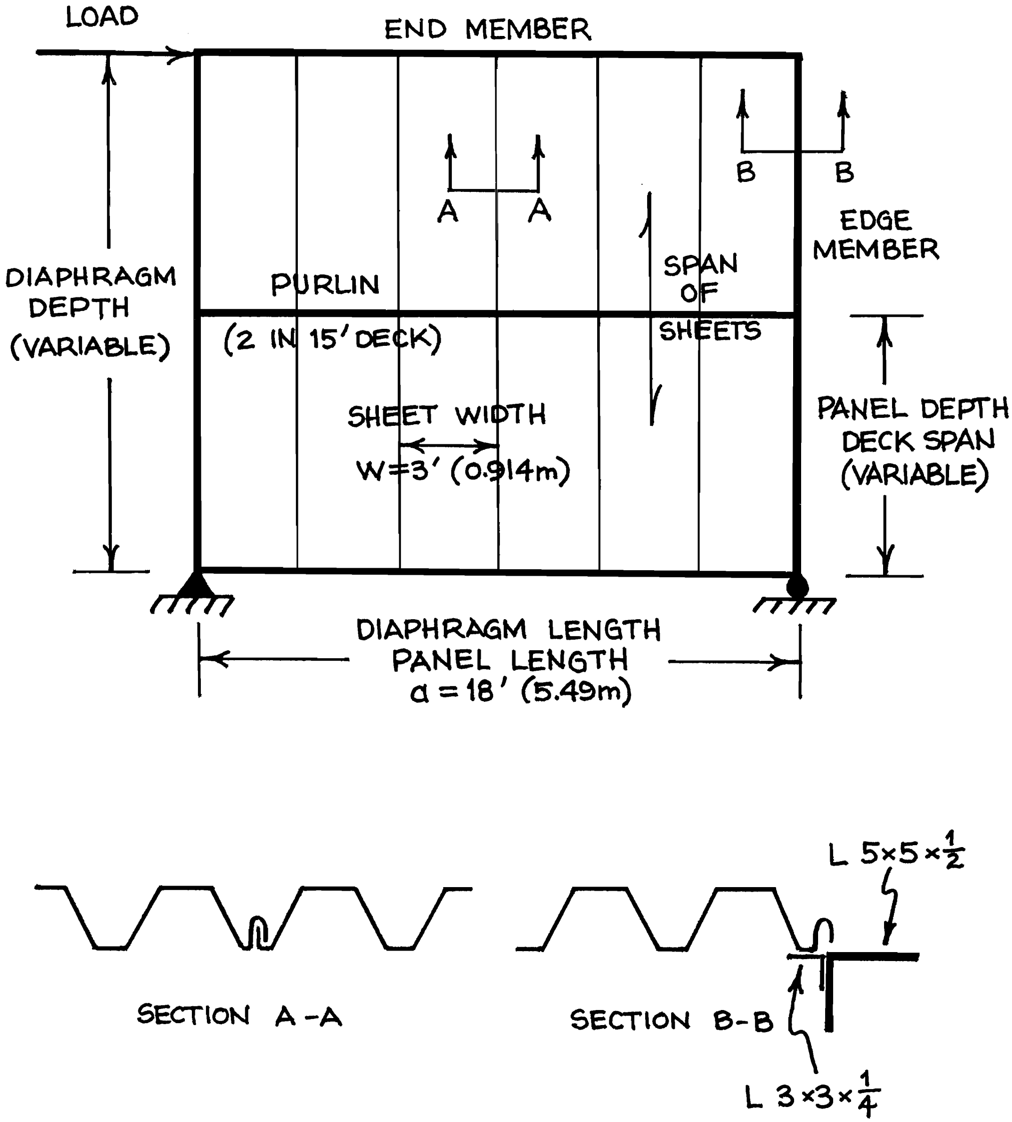


FIG. 1
TEST SET-UP

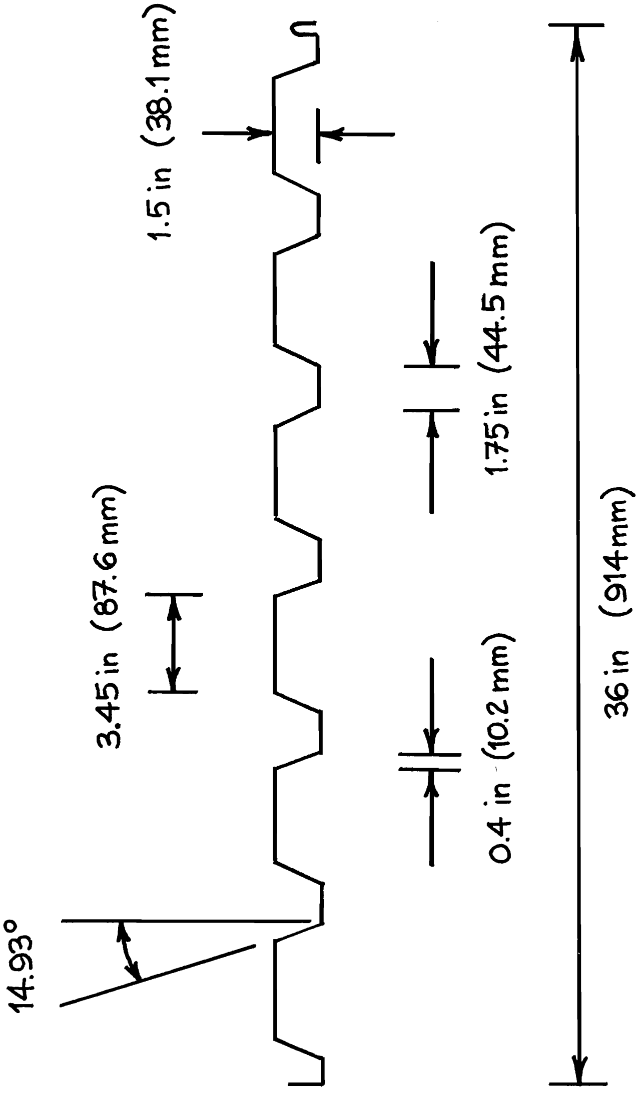
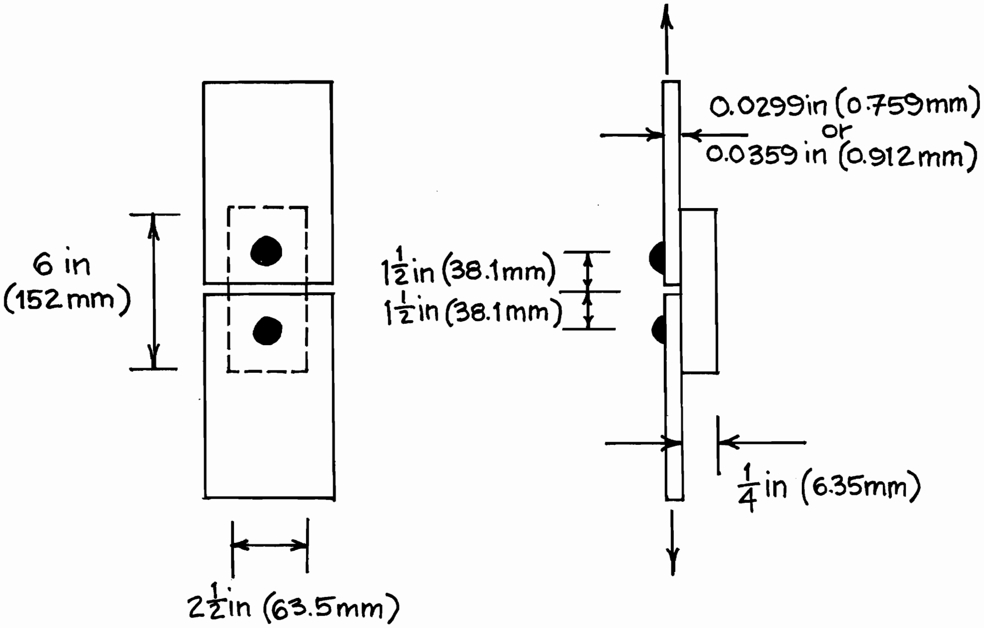
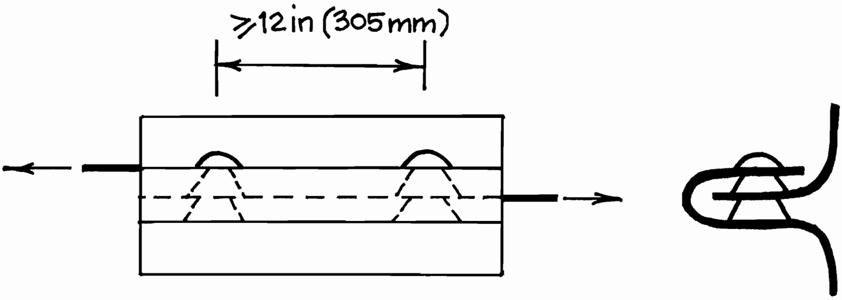


FIG. 2
DECK PROFILE



a) WELDS



b) BUTTON PUNCHES

FIG. 3
FASTENER TESTS

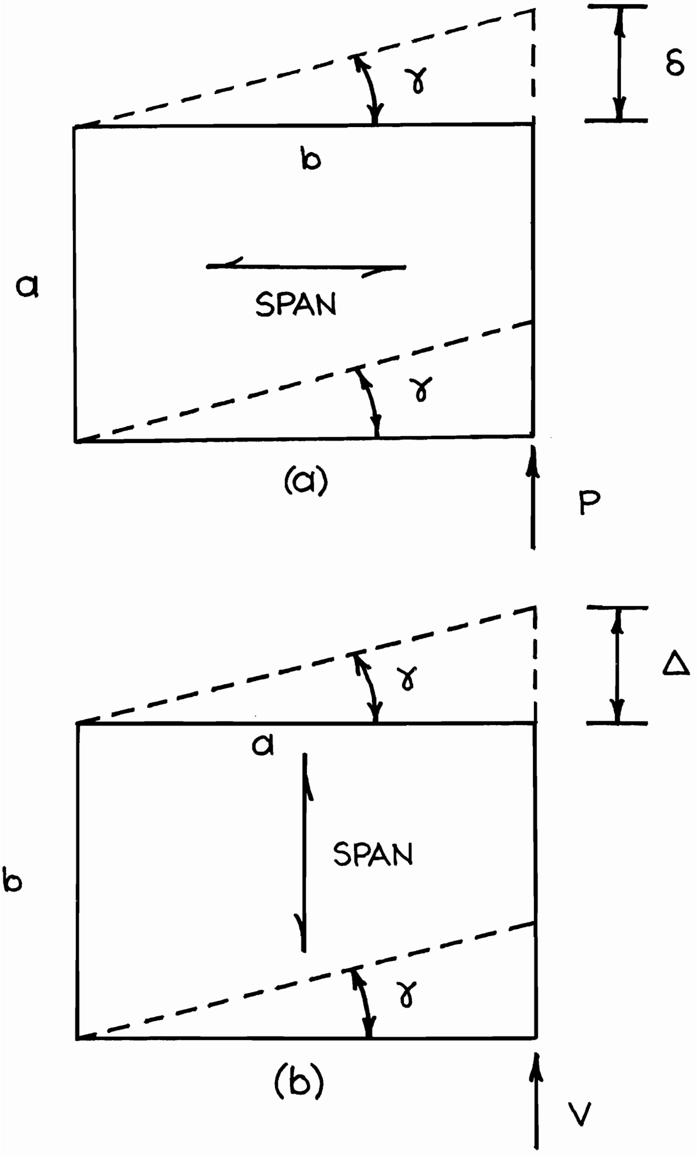


FIG. 4
POSSIBLE DECK CONFIGURATIONS