CURRENT DESIGN ASSUMPTIONS FOR DIAPHRAGMS ASSUME SUPPORT CONDITIONS WHICH ARE EITHER SIMPLE SPAN OR FULLY CONTINUOUS. THE BUILDING CODES REQUIRE A DESIGN BASED ON THE HIGHEST VALUES FOR MOMENT AND SHEAR OBTAINED UNDER EITHER OF THESE TWO SUPPORT CONDITIONS.

THE PURPOSE OF THIS INVESTIGATION WAS TO DETERMINE EXPERIMENTALLY THE EFFECTS OF CONTINUITY CONDITIONS ON TIMBER FLOOR DIAPHRAGMS WITH PLYWOOD SHEATHING SUBJECT TO INPLANE LOADS. PREVIOUS TESTING PROGRAMS HAVE EVALUATED SIMPLY-SUPPORTED DIAPHRAGMS SUBJECT TO UNIFORM LOADING; THIS STUDY EVALUATES THE EFFECTS OF OTHER SUPPORT CONDITIONS AND NON-UNIFORM LOADS. STATIC LOADING CONDITIONS USED WERE TO EVALUATE THE RESPONSE OF THE DIAPHRAGM FOR BOTH DEFLECTION AND ULTIMATE STRENGTH. SIX 8 BY 16 FOOT FLOOR DIAPHRAGMS OF RESIDENTIAL CONSTRUCTION WITH THREE DIFFERENT SETS OF BOUNDARY AND LOADING CONDITIONS WERE TESTED IN ACCORDANCE WITH ASTM E72.

THE TESTS DEMONSTRATED THAT: 1) CONTINUITY OVER A RIGID SUPPORT APPARENTLY DOES NOT INCREASE THE UNIT SHEAR RESISTANCE VALUE OF THE DIAPHRAGM; 2) CONCENTRATED LOADS ON THE DIAPHRAGM PRODUCE LOWER LOAD FACTORS THAN MOMENT-EQUIVALENT UNIFORM LOADS AT A GIVEN LOAD LEVEL; 3) THERE IS NOT AN APPARENT DIRECT RELATIONSHIP BETWEEN RELATIVE PANEL DISPLACEMENT AND OVERALL DIAPHRAGM DEFLECTION FOR THE SIZE DIAPHRAGMS TESTED; AND 4) LOCAL PANEL BUCKLING HAS A MINIMAL EFFECT ON OVERALL DIAPHRAGM FAILURE PATTERNS.

1. INTRODUCTION

LATERAL FORCES ON BUILDINGS ARE OFTEN RESISTED BY COMBINATIONS OF END WALLS AND INTERIOR WALLS AT ONE OR MORE LOCATIONS. THE FLOOR DIAPHRAGM BEHAVES LIKE A BEAM WITH SEVERAL WALL SUPPORTS. BUILDING CODES REQUIRE DESIGN BASED ON SUPPORT CONDITIONS WHICH ARE EITHER SIMPLE SPAN (THUS, THE DIAPHRAGM IS FLEXIBLE) OR FULLY CONTINUOUS, AS OVER AN INTERIOR SUPPORT. THE HIGHEST MOMENT AND SHEAR VALUES OBTAINED UNDER EITHER OF THESE CONDITIONS IS REQUIRED FOR DESIGN. THE ACTUAL DIAPHRAGM BEHAVES IN A MANNER SOMEWHAT BETWEEN THESE EXTREMES. THIS RESEARCH IS A PILOT STUDY TO ASSESS THE EFFECT OF CONTINUITY CONDITIONS FOR A TYPICAL RESIDENTIAL CONSTRUCTION SIZE HORIZONTAL WOOD DIAPHRAGM UNDER DIFFERENT LOADING AND BOUNDARY CONDITIONS.

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A comprehensive bibliography (3) and state-of-the-art (2) are available for plywood diaphragms. Design values for plywood diaphragms were developed through tests on large diaphragms (4, 5, 7, 8, 10, 11) which considered the diaphragm as simply supported, flexible elements.

This research used static loading conditions to be compatible with experimental test results of previous research. These tests describe the inplane loading response for deflection and ultimate shear strength with three sets of boundary support and loading conditions:

1) Simple span horizontal diaphragm with the loads and reactions located symmetrically; this condition serves as a control specimen condition for comparison with earlier research.

2) Cantilever horizontal diaphragm which are resisted by two rigid supports with the diaphragm extending over one of the supports; the loads and reactions are located symmetrically on opposite sides of the diaphragm.

3) Cantilever horizontal diaphragm as above but with loads and reactions located asymmetrically on opposite sides of the diaphragm; this loading results in inplane torsional behavior.

Two specimens were tested for each of the three conditions. These two specimens differed only in that the long dimension of the plywood sheathing was perpendicular to the applied loads in one specimen and parallel to the applied loads in the other specimen. The detailed results of these tests and their implications for design practice are discussed in this study. Reference 9 presents a more detailed presentation of the results.

2. TEST METHODS AND PROCEDURES

Six 8 by 16 foot horizontal plywood diaphragms were constructed as shown in Figure 1. Tests 1 and 2 were simple span specimens loaded at the third points with reaction points at the ends of the diaphragm (Figure 2). Tests 3 and 4 were cantilever diaphragms, loaded 1 1/2-inches from the end of the cantilever and at a point six feet from the non-cantilever end on the same side. Tests 3 and 4 reaction points were located at the non-cantilevered end of the opposite long side from the loads and at a point 4 feet 2 inches from the cantilevered end of the opposite side (Figure 2). Tests 5 and 6 were cantilevered diaphragms loaded 1 1/2-inches from the end of the cantilever on one end of the long side of the diaphragm and at a point six feet from the non-cantilevered end on the opposite side of the diaphragm. Reaction points for Tests 5 and 6 were located at one end of the same side on which the cantilevered end load was placed and at a point 4 feet 2 inches from the cantilevered end of the opposite side (Figure 2).

Test Specimens 1 and 2, 3 and 4, and 5 and 6, respectively, taken as pairs, differ only in the orientation of the plywood sheathing. While Specimens 1 and 2 have the same framing pattern, the plywood sheathing in Specimen 1 is oriented so that the continuous panel joint is perpendicular to the applied loads. In Specimen 2, the plywood sheathing is oriented so that the continuous panel joints are parallel to the applied loads—contrary to code recommendations but necessary to make comparisons to Specimen 1. The same is true for Specimens 3 and 4, and 5 and 6, respectively. Thus, each set of two specimens corresponds to only one loading condition, and each of the two members of the set differs from the other only in the orientation of the plywood sheathing.
The plywood sheathing used was Structural I, 4 X 8 foot sheets, 3/8"

thick, C–C, Exterior Grade, 24/0. The sheathing was fastened to the sub-

framing members with 8d common nails spaced at 4 inches around the perimeter of

the diaphragm, at 6 inches along panel edges and at 12 inches over interior

joists inside the panel boundaries. This conforms to a design load level of

320 lbs/ft per the Uniform Building Code (6).

The minimum edge distance for the 8d common nails in the sheathing was 1/2

inch. Nails were driven on a slant to avoid splitting of the joists and block-

ing. The gap distance between panels was 1/8 inch.

The sub-framing material was 2 inch X 8 inch, No. 1 Dense Dried Southern

Pine, pressure treated. The No. 1 Dense was selected to minimize the effect of

knots normally found in timber testing. Only treated material was readily

available in No. 1 Dense and, thus, was used. The perimeter chords of the

diaphragms were two, 2 inch X 8 inch members laid horizontally and nailed

together with 12d common nails at 4 inch spacing along the perimeter except for

the middle 8 feet of the long sides where 8 inch spacing was used.

Vertical framing consisted of five 16 foot lengths of 2 inch X 8 inch

joists, placed in the long direction of the diaphragm, perpendicular to the

intended direction of the loads and reactions. Blocking consisted of 2 inch X

8 inch sections toe-nailed to the joists. Intervals for placement of the

blocking were: a) standard blocking at ends and at 4 feet on center and b)

"load support" blocking immediately in line with the applied points loads. The

load support blocking location varied with the loading conditions for the

individual tests. All wood framing was assembled and tested at between 10 and

14.5 percent moisture content.

Test procedures were based on ASTM E72, "Standard Methods of Conducting

Strength Tests of Panels for Building Construction" (1) and the methods de-

tailed in the 1966 APA Report (10). Since one of the purposes of the test was

to determine the load–deformation curves for the different loading conditions

and panel orientations, considerable care was taken to insure a large number of

readings of both loads and deflections. At each load level, the load was

maintained for five (5) minutes prior to recording diaphragm deflections and

moving to the next higher load level. Load increments were such that a load

rating of less than 300 plf/minute was maintained. Load increments were con-

tinued until ultimate which is defined as the incapacity of the diaphragm to

carry more load.

3. TEST RESULTS AND ANALYSIS

The results of Tests 1 through 6 are summarized in Table 1. The load

factors (ultimate load/allowable load) for the control specimens are on the

order of 2, with the highest unit shear for Test 5—a test in which continuity

over a single support was present and in which the loads were applied from

opposite sides of the diaphragm. The failure modes for Tests 2, 4 and 6 were

virtually identical, thus, indicating the importance of the orientation of the

continuous plywood panel joint location relative to the direction of appli-

cation of the loads.

Particular attention is made to the ultimate strength of Test 5 since an

edge joist failed rather than failure in the plywood. The principal signi-

ficance of this failure mode is that the diaphragm could possibly have sus-

tained even higher unit shears in this loading and panel configuration if the
sub-frame joist had not split. The failure was basically a result of difficulties experienced with the travel distance for applying the loads to the diaphragm and not with the actual diaphragm itself. The deflected shapes of the individual diaphragms at ultimate load (solid line) and recovery (dashed line) are shown in Figure 2.

A comparison of the load factors obtained in these tests with the results of the 1966 APA tests (10) cannot be made since the APA tests used a different loading condition and construction criteria.

The results of Test 5 show the importance of panel orientation and the relationship of the applied loads to the line of the continuous panel joint. This condition, in accord with the requirements of standard building codes, has been a part of the design process for some time. Its importance for the tests reported here is that the shear resistance to inplane torsion was seen to be directly a function of panel orientation. Extensive panel buckling took place in Test 5, but this buckling did not result in early failure of the specimen. The orientation of the panels increased the torsional resistance of the diaphragm. This resistance was notably different from the resistance in Test 6, where the continuous panel joint was parallel to the direction of the applied loads.

4. CONCLUSIONS

The purpose of this investigation was to determine the effects of continuity conditions on timber diaphragms with plywood sheathing subject to inplane loads. This is an important concern in the design of floor and roof diaphragms for low-rise timber and composite structures subject to lateral forces. Current design assumes support conditions for diaphragms which are either simple span, considering the diaphragm to be fully flexible, or fully continuous, as over an interior support. This method requires a design based on the highest values for moment and shear obtained under either of these two conditions.

The research reported herein used static loading conditions for determining the deflection and ultimate strength of six 8 by 16 foot horizontal diaphragms under three sets of boundary and loading conditions.

The results of these tests demonstrate that:

1) Continuity over a rigid support apparently does not increase the unit shear values which can be resisted by the diaphragm, thus, justifying current design assumptions.

2) Concentrated loads on the diaphragm produce lower load factors than moment-equivalent uniform loads for a given load level.

3) There is not an apparent direct relationship between relative panel displacement and overall diaphragm deflection for the size diaphragms tested.

4) Local panel buckling has a minimal effect on overall diaphragm failure patterns.

ACKNOWLEDGEMENTS

The research reported herein was made possible by funding from The Forest Products Laboratory, Department of Agriculture, United States Government.
REFERENCES


9.) THOMAS, D. J., "Effects of Continuity Conditions on Timber Diaphragms with Plywood Sheathing," a thesis submitted to the Graduate School of Vanderbilt University in partial fulfillment of the requirements for the Master of Science Degree, December, 1982.


### TABLE 1
SUMMARY OF TEST RESULTS

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Simple Span</th>
<th></th>
<th>Cantilever Span</th>
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<tr>
<td></td>
<td>Symmetric Loads &amp; Reactions</td>
<td></td>
<td>Symmetric Loads &amp; Reactions</td>
<td></td>
<td>Assymmetric Loads &amp; Reaction</td>
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<tr>
<td>Max. Load/Point (lbs)</td>
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<td>Max. Deflection (inches)</td>
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<td>Design Deflection (inches)</td>
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<td>2:1</td>
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<tr>
<td>Ultimate Defl./Design Defl.</td>
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<td>7.00</td>
<td>10.60</td>
<td>3.98</td>
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<td>Failure Mode</td>
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<td>Plywood Slip &amp; Nail Pull Through</td>
<td>Plywood Slip &amp; Nail Pull Through</td>
<td>Plywood Slip &amp; Nail Pull Through</td>
<td>Edge Joist Split</td>
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Figure 1. Plywood Diaphragm Construction