Loading tests on conventional roof constructions: second progress report

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LOADING TESTS ON CONVENTIONAL ROOF CONSTRUCTIONS

(Second Progress Report)

by

A. T. Hansen

Report No. 113

of the

Division of Building Research

Ottawa

December 1956

Preface to Report 113

The results of further laboratory loading tests of conventional timber roof constructions for houses are now reported. The initial work on a W truss design was described in Report No. 77 and further work on rafters and trusses in Report No. 81. A full-scale loading test of a house described in Report No. 62 may also be considered as part of this series since some interesting aspects of roof performance were revealed in that test. In particular it was noted that collar ties became loaded as struts and not in tension. Further consideration is now given to the performance of collar ties in rafter designs of the type studied in Report No. 81.

These investigations of the structural performance of roof components are part of a broad reassessment of the structural design of houses which will be carried out, as circumstances permit, in the interests of improvement and economy in Canadian housing.

Ottawa
December 1956.

N. B. Hutcheon
Assistant Director.

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A. T. Hansen

As a continuation of the investigations of roof frames previously reported in D.B.R. Report No. 81, eighteen additional tests were conducted on conventional roof frames.

The purpose of these additional tests was twofold: to attempt to establish criteria by which unconventional roof frames, such as roof trusses might be evaluated; and to determine the difference in strength between conventional joist-rafter constructions built with 2 by 4 collar ties and those with 1 by 5 collar ties.

Description of Test Structures

All test structures were of the same slope (5/12) and span (24 ft. 0 in.) as those reported in D.B.R. Report No. 81.

These tests were conducted on Type I construction. (See D.B.R. Report No. 81 for sketch and nailing details of this construction.) In all tests 2 by 6 joists were used and all lumber was yard run Eastern spruce.

It was decided to limit this series of tests to Type I construction as field observations have shown this type to be the most commonly used type in practice. Also, it was decided to limit these tests to structures with 2 by 6 and 2 by 4 rafters since it was found that these were among the most common rafter sizes used in practice, with by far the majority being 2 by 6 rafters.

Twelve tests were conducted on structures built with 2 by 6 rafters of which six tests were made with 2 by 4 collar ties and six with 1 by 5 collar ties. Six tests were also conducted on structures built with 2 by 4 rafters and 1 by 5 collar ties.

The nailing for these tests, except for the 1 by 5 collar tie connections, was identical with the nailing described in D.B.R. Report No. 81 for this type of construction.

The 1 by 5 collar ties were fastened to the rafters by four $2\frac{1}{2}$-inch nails at each end. It is difficult to reproduce in these individual tests the proper amount of collar tie stiffening provided by a continuous 1 by 4 strip nailed at right angles to the 1 by 5 collar ties which would be representative of the effect in a complete roof system where many collar ties are involved. (This continuous 1 by 4 strip is required with 1 by 5 collar ties under the National Building Code and CMHC Standards.) It was decided therefore to try to approximate this effect in the following way: the two collar ties were nailed on the outside of the rafters (Fig.5) rather than on the same side, as would normally be the case in practice, and the two collar ties tied together by a 1 by 4 strip at right angles to the collar ties near their centres.

Testing of Test Structures

Test Equipment. - The test equipment consisted of the same arrangement as described in D.B.R. Report No. 81.

Instrumentation. - Some changes in instrumentation were introduced in this series of tests. The rafter deflections were measured at mid-rafter span by means of piano wire strung along the lengths of the rafters. The relative displacement under load of the ceiling joists at the splice at the bearing partition (Fig.4 of D.B.R. Report No. 81) were measured by means of a dial gauge (Fig. 4). The vertical deflection of the ridge of the rafters was measured by hanging an indicator weight from the peak of the assembly and noting its movement on a recording board located directly below.

All other instrumentation was the same as recorded in D.B.R. Report No. 81.

Application of Load. - Application of load and test procedure was the same as reported in D.B.R. Report No. 81.

Recording of Results. - All dial gauge readings were taken to the nearest 0.001 inch and all rafter deflections to the nearest 0.01 inch. The rafter deflections reported in the results are for 40 pounds per square foot snow loading and are the average defelctions of the 4 rafters in the test structure. The results of the tests are given in Tables I and II.

Discussion of Results

Deflection Characteristics. - As may be expected, the rafters in the test structures with the 1 by 5 collar ties deflected more under load than those with the 2 by 4 collar ties (Tables I and II). For all tests with Type 1 construction it was observed that the collar ties acted in compression throughout the tests. The 1 by 5 collar ties, being in compression were not able to resist buckling to the same degree as the 2 by 4 collar ties, and therefore did not provide as much support against deflection as did the 2 by 4 collar ties.

Strength Characteristics. - From the average results shown in Table II it may be seen that the choice of collar tie does not have too much influence on the ultimate strength of the structures in these tests.

As explained in D.B.R. Report No. 81 (pages 9 and 10), the rafters of a roof frame structure with a 5/12 slope without collar ties will have a horizontal thrust at the heel of $\frac{1}{2} \times 12/5$ W L, where W = rafter loading in pounds per foot of rafter; and the same structure with collar ties at mid-height will have a horizontal thrust of $\frac{3}{4} \times 12/5$ W L if the collar tie is assumed to be an adequately designed pin-connected member. It may be seen therefore that the effect of the collar tie as a compression member is to increase the horizontal thrust at the heel of the rafter, and the greater the compressive load carried by the collar tie, the greater will be the thrust at the heel of the rafter which will approach a maximum value of $\frac{3}{4} \times 12/5$ W L.

According to this reasoning then, failures due to horizontal rafter thrust should take place at a higher loading for structures with 1 by 5 collar ties than for structures with 2 by 4 collar ties, providing that failure occurs at the same place at the higher loading. This would explain why the average failure of Type I construction with 2 by 4 rafters and 2 by 4 collar ties and tested on roller supports failed at 56 pounds per square foot while the average for 1 by 5 collar ties was 63 pounds per square foot. The difference in failure loads with Type I construction with 2 by 6 rafters and 2 by 4 collar ties and tested on roller supports and those with 1 by 5 collar ties is not so apparent. This is probably due to the fact that with the stiffer rafters, the collar ties do not act to the same degree to withstand compressive loads as with less rigid rafters. Therefore the influence of the type of collar tie on horizontal rafter thrust will not be so marked with the 2 by 6 rafters as with 2 by 4 rafters.

To carry this reasoning through to Types 11 and 111 constructions, (see D.B.R. Report No. 81) it would appear that the use of collar ties, particularly 2 by 4 collar ties, would actually produce weaker structures than if the collar ties were omitted. Again, the result of omitting the collar ties would be considerably more apparent with 2 by 4 rafters than with heavier rafters.

The average range of failure loads for good conventional construction, loaded in a similar manner as for these tests, then, may be expected to vary from 62 to 113 pounds per square foot depending on whether the walls are assumed to give no resistance to outward movement of the rafters or whether the walls are assumed to offer rigid resistance to rafter spread. The true value must lie somewhere between these two extremes. It seems fairly obvious that walls cannot offer perfect rigidity and that the failure load should be considerably less than the 113 pounds per square foot upper limit. It is suggested, therefore, that the value of 100 pounds per square foot would be a reasonable figure to choose as a value that house roofs should be expected to withstand under short-term loading. In the light of tests conducted on Types 11 and 111 constructions (D.B.R. Report No. 81) this value would appear to be considerably on the safe side.

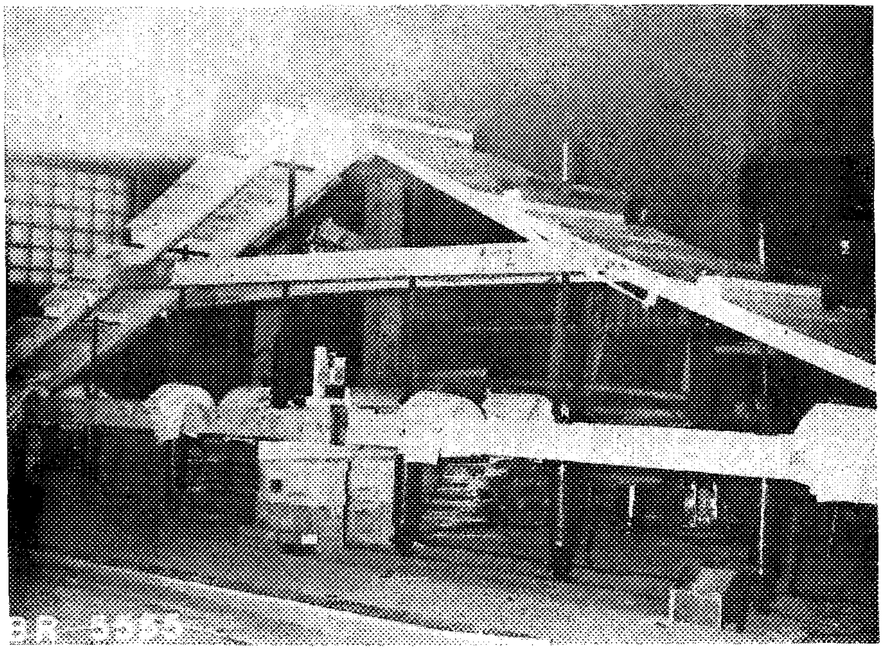

Fig. 1

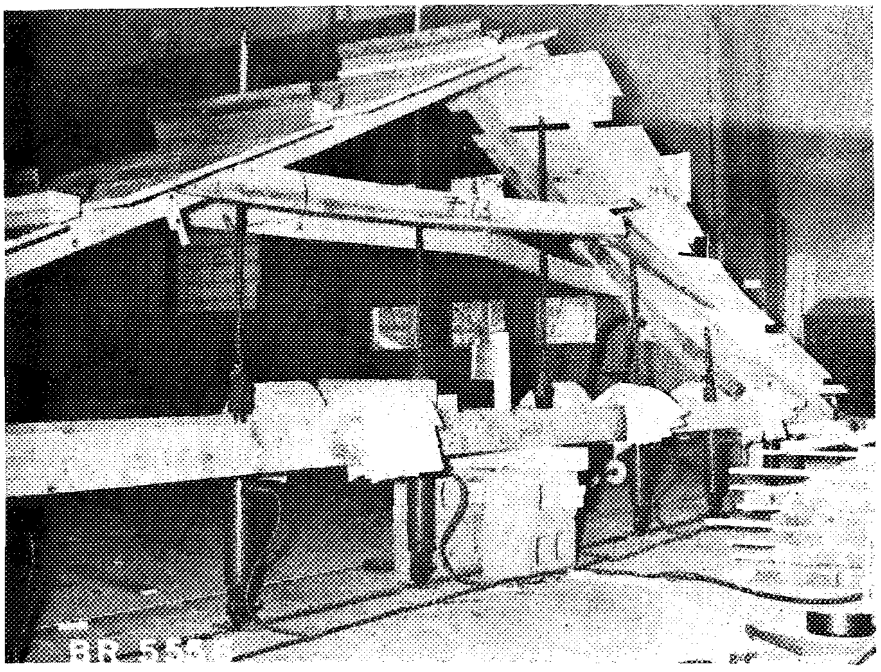

Fig. 2

Failure in Type I construction with 2 x 4 rafters and 1 x 5 collar ties with fixed end supports. Collar ties broke after considerable lateral buckling, after which the rafters broke.

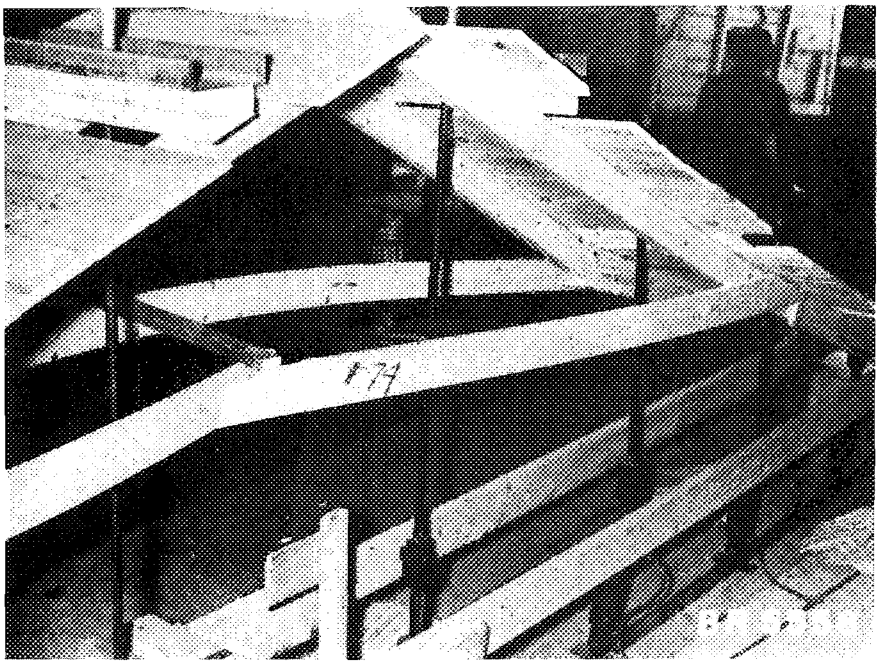

Fig. 3

Failure in Type I construction with 2 x 4 rafters and 1 x 5 collar ties with fixed end supports. Collar ties broke after considerable lateral buckling, after which the rafters broke.

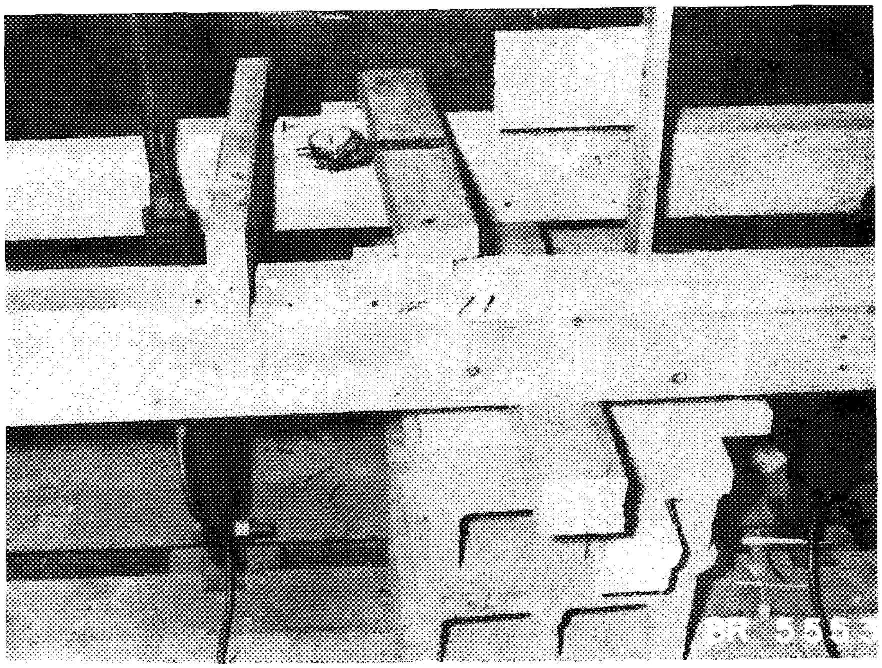

Fig. 4

Method used for measuring relative movement between joists at partition splice due to applied load. Photograph taken after this splice failed in test 71.

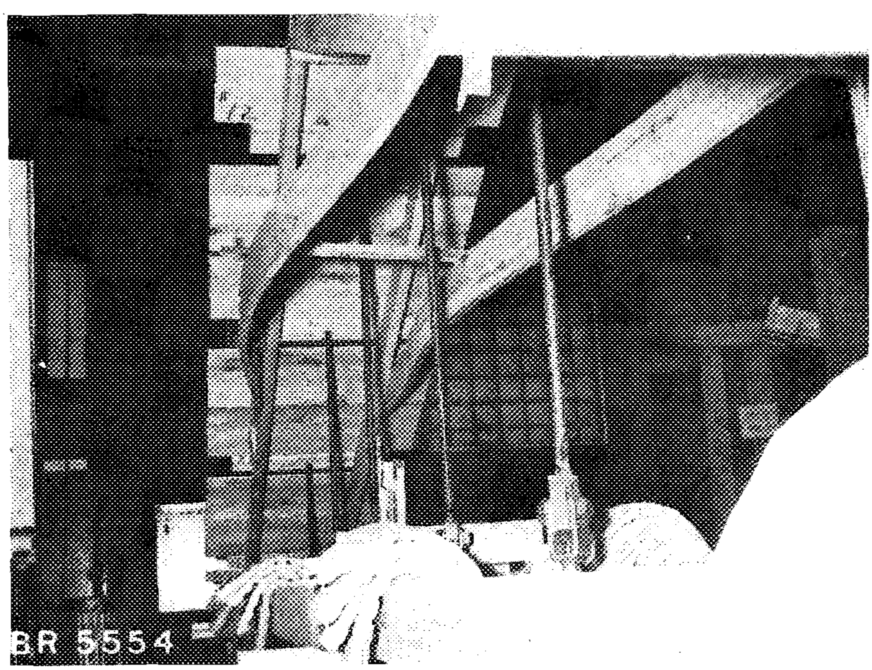

Fig. 5

Lateral buckling in the 1 x 5 collar ties with 2 x 4 rafters at a 40 p.s.f. applied snow load. This photograph also indicates the method of collar tie application.

TABLE I

SUMMARY OF RESULTS

Test No.	Type of Const-ruction	Rafter Size	Collar Tie Size	Type of end Supports	Measurements at 40 p.s.f. Snow Load			Type of Failure	Ultimate Snow Load (p.s.f.)
					Mid Span of Rafters	Ridge Deflection	Joist Splice Displacement		
56	Type I	2"x6"	1"x5"	Rollers	.34"	.42"	.146"	see Fig.3, Report 81	65
57	Type I	2"x6"	1"x5"	Rollers	.37"	.56"	.246"	see Fig.3, Report 81	59
58	Type I	2"x6"	1"x5"	Rollers	.49"	.40"	.103"	see Fig.3, Report 81	64
60	Type I	2"x6"	1"x5"	Fixed	.24"	.19"	.037"	see Fig.6, Report 81	108
61	Type I	2"x6"	1"x5"	Fixed	.25"	.12"	.014"	see Fig.6, Report 81	110
62	Type I	2"x6"	1"x5"	Fixed	.19"	.14"	.026"	see Fig.6, Report 81	120
63	Type I	2"x6"	2"x4"	Rollers	.20"	.23"	.065"	see Fig.9, Report 81	67
64	Type I	2"x6"	2"x4"	Rollers	.24"	.34"	.150"	see Fig.3, Report 81	60
65	Type I	2"x6"	2"x4"	Rollers	.18"	.31"	.109"	see Fig.3, Report 81	60
66	Type I	2"x6"	2"x4"	Fixed	.17"	.15"	.029"	see Fig.6, Report 81	105
67	Type I	2"x6"	2"x4"	Fixed	.11"	.15"	.032"	see Fig.6, Report 81	110
68	Type I	2"x6"	2"x4"	Fixed	.15"	.18"	.041"	see Fig.6, Report 81	110
69	Type I	2"x4"	1"x5"	Rollers	.84"	.77"	.134"	see Fig.3, Report 81	63
70	Type I	2"x4"	1"x5"	Rollers	.57"	.46"	.143"	see Fig.3, Report 81	65
71	Type I	2"x4"	1"x5"	Rollers	.72"	.49"	.139"	see Fig.3, Report 81	60
72	Type I	2"x4"	1"x5"	Fixed	.60"	.22"	.017"	see Fig. 1	75
73	Type I	2"x4"	1"x5"	Fixed	1.31"	.22"	.013"	see Fig. 2	70
74	Type I	2"x4"	1"x5"	Fixed	.94"	.22"	.017"	see Fig. 3	75

TABLE II

CONDENSED SUMMARY OF RESULTS

Type of Constr-uction	Rafter Size	Collar Tie Size	Type of End Supports	Measurements at 40 p.s.f. Snow Load				Ultimate Snow Load (p.s.f.)
				Deflections of Mid Span of Rafters		Ridge Deflection	Displacement of Joists at Splice	
				Ins.	Deflection Ratio			
Type I	2"x6"	1"x5"	Rollers	.43	1/390	.46"	.165"	63
Type I	2"x6"	1"x5"	Fixed	.23	1/680	.15"	.026"	113
Type I	2"x6"	2"x4"	Rollers	.21	1/740	.29"	.108"	62
Type I	2"x6"	2"x4"	Fixed	.14	1/1110	.16"	.034"	108
Type II	2"x4"	1"x5"	Rollers	.71	1/220	.57"	.139"	63
Type II	2"x4"	1"x5"	Fixed	.95	1/160	.22"	.016"	73
Type II *	2"x4"	2"x4"	Rollers	.69	1/230	.93"	----	56
Type II *	2"x4"	2"x4"	Fixed	.56	1/280	.26"	----	72

* Results taken from Report No. 81 and included in this summary for comparison.