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FOREWORD

An extensive series of tests on conventional and trussed roof construction used in houses was undertaken to examine the strength of conventional construction and to develop truss designs for Canadian use. Conventional rafter-joist construction of the type built prior to 1962 showed a wide range of strengths, which varied according to type of support, member sizes and joint details. Tests on nailed W truss designs examined the effect on strength and stiffness of variations in roof slope, span, member size, nailing, duration of loading, location of partitions, and cantilevering.

On the basis of this test work, and similar work carried out by the Forest Products Research Branch of the Department of Forestry, performance criteria were developed to assess the suitability of trusses used in houses built under the National Housing Act. These performance requirements are now included in the Housing Standards, Supplement No. 5 to the National Building Code of Canada 1960. In addition, a number of nailed W type truss designs that satisfy these requirements were developed for spans of from 16 to 28 ft (in 2-ft increments) and for roof slopes of 3/12, 4/12 and 5/12. Designs are included for 30, 40 and 50 psf snow load areas.

TRUSSED RAFTERS FOR HOUSES

by

A. T. Hansen

In 1955, the Division of Building Research, National Research Council, in co-operation with the Forest Products Research Branch of the Department of Forestry, undertook an investigation of the strength and deflection characteristics of wood roof trusses. This program has continued at intervals over a period of seven years, during which time a total of about 150 test structures have been examined. This paper outlines the results of that portion of the test program undertaken by the Division of Building Research.

Scope

The original objective was to develop and test truss designs suitable for general use in houses across Canada. To do this it was necessary to have criteria to assess the performance of trusses. It was recognized that those designed according to standard engineering procedures were much stronger and more expensive to build than conventional roof frames. As there appeared to be no need for roof trusses to be stronger than well built conventional roof framing, which has a history of generally satisfactory performance, criteria were established on the basis of an evaluation of different types of these joist and rafter framing systems. These criteria were used first by Central Mortgage and Housing Corporation in accepting trusses for houses built under the National Housing Act and later were incorporated into the Housing Standards (Supplement No. 5 to the National Building Code of Canada 1960).

Most of the work carried out by the Division was concerned with W trusses with nailed plywood gusset plates, although at the beginning of the program a series of comparative tests was carried out on trusses with other types of joint connections including glued, splitring, and bolted joints. These trusses were for the most part modifications of designs developed in the United States. All tests, however, were of an exploratory nature and were meant only as a guide in determining the direction of the truss testing program. The results of these initial tests, therefore, are not included in this paper. On the basis of tests and for practical considerations it was decided to proceed with the development of trusses with nailed plywood gusset plate connections only.

Originally, it had been planned that the trusses should be loaded to failure with short term loading to compare their strength with that of conventional construction. As testing proceeded, however, it was thought advisable to carry out a number of tests with longer term loading in an attempt to correlate the results with those of short term loading. In addition, other aspects of truss performance were investigated. These included the effects of locating partitions beneath trusses and of cantilevering trusses over the supports, as well as the effect on truss performance of varying the nailing and changing the member sizes. Variations in span and slope were also investigated.

Testing Equipment and Procedure

All structures were tested in pairs and sheathed to provide lateral stability. During the early part of the program board sheathing was used, but it did not provide sufficient lateral stability, especially at higher loads. Plywood sheathing was used instead in most of the later tests and provided sufficient restraint to prevent lateral buckling without additional bracing.

Short term roof loads were applied with eight equally spaced hydraulic tension jacks anchored to the floor, and located at the panel quarter points mid-way between the pair of trusses or rafters (Figure 12). The weight of the test assembly approximated the dead weight of the roof covering so that the reported loads are those over and above the dead weight of roof shingles and sheathing.

For the longer term loading tests roof loads were applied with concrete blocks stacked to prevent arching action between the units (Figure 13). In all cases a ceiling load equivalent to 10 lb/sq ft was applied to the lower chords with weights located at the quarter points of each panel.

In most cases deflections were measured at each panel point and mid-way between for both the upper and lower chords. Deflections were measured with piano wire weighted at one end and stretched along the chord members. Conventional joist and rafter assemblies were tested both on fixed end supports bolted rigidly to the floor to resist outward thrust and on roller supports. The former represented walls that could effectively resist lateral thrust; the latter, walls that could not resist lateral thrust. The joists were also supported at centre-span near the splice (Figure 1).

Exploratory tests indicated that the type of end support did not have an important affect on truss performance. Most of the trusses, therefore, were simply supported on 2 x 4 plates resting directly on concrete blocks during the tests.

Loading Procedure

In the first series, trusses and traditional framing assemblies were loaded with a 10 psf ceiling load and 40 psf roof load applied in increments. The roof load was removed to record the recovery characteristics, based on deflections caused by roof load only, and then re-applied in increments until failure. Loads were applied 5 minutes before deflections were recorded.

During the latter part of the program this procedure was modified slightly. After application of a 10 psf ceiling load, the trusses were loaded in increments up to a load corresponding to the snow load anticipated for the truss. This load was maintained for one hour and deflections were recorded after both 5 minutes and one hour. The roof load was then increased in increments to twice the anticipated snow load and maintained for 24 hours, after which the loads were increased in increments until failure occurred.

A number of fairly long term tests were conducted in which structures were loaded for one month, then unloaded and allowed to recover for another month. In two cases the structures were reloaded for 2 weeks. The deflections were recorded in every case 5 minutes after load application or removal and at increasing time intervals thereafter.

Tests to determine the effect of truss deflections on the partitions beneath them were of the short term type. In these cases the trusses were loaded in increments. After each increment of loading the bottom chord of the truss was raised to a position of zero deflection at a point where a partition was assumed to be. The load at this location was then measured with proving rings and the over-all truss deflections recorded. This procedure was repeated at several positions along the bottom chord for each increment of loading.

Tests to determine the effect of cantilevering trusses were also short term, and the same general test procedure was followed as for simply supported trusses, except that the cantilevered portion was loaded with a uniform loading (Figure 11).

Types of Structures Tested

The conventional roof constructions tested are shown in Figures 1 and 2. The nailing at the joints conformed to the requirements of the 1953 edition of the National Building Code and the 1958 Housing Standards. Where there were no specific requirements for some details, nailing considered to represent good building practice was used. It is worth noting that the nailing specified in both the Code and the Standards was considerably superior to nailing observed in actual constructions across the country (according to a survey made prior to the test program).

Since this series of tests on conventional construction was carried out, further investigations of conventional roof structures have been undertaken as a separate research program to determine the effect of nailing, roof slope and span length on the performance of conventional construction. This work falls outside the scope of this paper, however, and will be reported separately by others.

The truss designs tested were developed more or less on an ad hoc design basis and were modified through tests to provide, as stated earlier, trusses at least as strong as well-built conventional construction and reasonable deflection characteristics.

No. 1 spruce was used for all tests on conventional joist-rafter assemblies and for most truss tests. Some trusses, however, were made of construction grade Douglas fir. Member size for the top and bottom chords was generally 2 x 4 in. but this was increased in a number of cases to 2 x 5 or 2 x 6 in. for additional strength or to obtain comparative test results.

The number of nails in the earlier tests was based on a design roof load of 35 lb/sq ft and a ceiling load of 10 lb/sq ft. The allowable lateral load per 3 in. nail was assumed to be 102 lb in double shear with spruce and 156 lb for Douglas fir. The allowable lateral load for $2\frac{1}{2}$-in. nails in spruce was assumed to be 43 lb/nail in single shear. The designs determined on this basis are shown in Figures 3 to 5, inclusive. In later tests the number of nails was reduced to two thirds and one half the original nailing to determine the effect of nail reduction on over-all strength and stiffness of the assembly.

Results of Tests

A summary of results of short term tests on conventional construction is shown in Table I. Table II summarizes the results of the first series of short term tests on trusses, Table III, the later series. As mentioned earlier, the test procedure in this later series had been slightly revised. The test results are shown on the basis of 16-in. spacings for conventional construction and 24-in. spacings for trusses. Except as indicated in Table II the results in Tables I to III are based on an average of three tests (six roof frames) in each case.

The curves in Figure 6 show the effect of roof slope on the deflection characteristic of trusses with similar spans and main member sizes.

Figure 7 shows the effect of span length on trusses having equal roof slopes and main member sizes.

Figure 8 illustrates the effect of increasing the main member sizes on the deflection of trusses.

The variation in truss stiffness caused by variations in nailing are illustrated by the curves in Figure 9.

Figure 10 shows a typical over-all deflection pattern of a truss simply supported at each end, the deflection pattern of the same truss having a partition located at various positions beneath the lower chord. The loads measured at each partition location are also shown in Figure 10.

The results of tests shown in Figures 6 to 11 inclusive are based on short term tests on spruce trusses. The test results illustrated in Figures 6, 7 and 9 are based on the average of three tests (6 trusses) in all cases. Those shown in Figures 8, 10 and 11 are based on a single test (two trusses), except as otherwise noted in Figure 8.

The results of long term tests on conventional joist and rafter construction are shown in Table IV and are based on single tests of the type of construction shown in Figure 1. The summary of long term test results on trusses is shown in Table V, and is based on single tests (two trusses) of the design shown in Figure 3.

DISCUSSION OF TEST RESULTS

Conventional Construction

Conventional roof frames that were tested showed an extremely wide range of failure loads from 18 to 125 lb/sq ft, depending on the heel joint details, size of rafter and fixation of the end supports. When tested on roller supports, they were 12 per cent stronger with 2 x 6 rafters and 59 per cent stronger with 2 x 8 rafters than with 2 x 4 rafters (Figure 1), even though failures occurred for the most part at the same location (heel joint or centre joist splices). In the case of the construction shown in Figure 2, assemblies made with 2 x 8 rafters were over $2\frac{1}{2}$ times as strong as those with 2 x 4 rafters, even though the nailing was the same; all failures occurred at the heel joints. This increase in strength with rafter size is probably due in part to the fact that the stiffer the rafter, the less the collar beam will contribute to the outward thrust of the rafter.

In practice, the most common type of construction is that shown in Figure 1 with 2 x 6 rafters. This type had failure loads of between 62 and 113 lb/sq ft depending on whether the supports were on rollers or were fixed so that they could not move outwards. Normally, the exterior walls of a house would provide little resistance to rafter spread and the failure load in practice would probably be closer to a value of 62 lb/sq ft. It may be of interest to note that nailing requirements for roof framing in Canada have been upgraded somewhat since these tests were carried out, so that present requirements as outlined in the 1963 Housing Standards should ensure a minimum failure load of about 70 lb/sq ft for conventional framing built in snow load areas of 50 lb/sq ft or more. These failure loads, of course, refer to short term loading tests; for longer duration loading the failure load might be considerably lower.

Performance Criteria

Conventional framing, constructed in accordance with requirements in the 1953 edition of the National Building Code, has been used for a number of years with few if any reported failures. It seems reasonable, therefore, to use past experience with conventional construction in establishing an acceptable standard of performance for truss construction. It also seems reasonable to relate the performance standard to the design snow load for the area in which the truss is to be used, so that a uniform factor of safety can be established across the country. The performance criteria for trusses in the 1963 edition of the Housing Standards is a reasonable attempt to achieve these goals. The criteria require that a truss be able to withstand at least twice the design roof load plus the ceiling load for 24 hr, and that it must not deflect more than 1/360 of the span under the full design load after 1 hr. These criteria ensure that truss construction will be at least as strong as good conventional roof framing.

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Trusses

The truss results reported in Table III are based on tests conducted in the light of these performance criteria, whereas the truss tests reported in Table II were conducted before these criteria had been developed. Because of the large number of tests on trusses, however, there are sufficient data available on the factors affecting strength and deflection to permit assessment of the truss results in Table II.

Effect of Truss Slope

The effect of roof slope on truss deflections is shown in Figure 6, which indicates the average mid-span deflection for 28-ft span spruce trusses with similar size main members and nailing calculated for the same design load. At a deflection of 1/360 of the span, the roof load plus the ceiling load (10 psf) was 48 psf for a truss slope of 3/12, 71 psf for a slope of 4/12 and 96 psf for a slope of 5/12.

Under a roof load of 50 psf, 3/12 slope trusses deflected 0.95 in., 4/12 slope trusses about 0.65 in., and 5/12 slope trusses 0.45 in., even though the load per nail was approximately the same in all cases. This can be explained by the fact that the deflection caused by a given amount of nail slip at the joints and the deflection caused by axial strains in the members is increased as the slope is decreased.

The average failure load for these trusses was 107 psf for a slope of 3/12, 131 and 135 psf for a slope of 4/12, and 145 psf for a slope of 5/12. This means that 4/12 slope trusses were about 25 per cent stronger and 5/12 slope trusses about 35 per cent stronger than 3/12 slope trusses.

Effect of Truss Span

Figure 7 shows the effect of truss span on truss deflection. All trusses in this case are spruce with a slope of 4/12 and nailing calculated to support the same design loads. A roof load of 71 psf was required to cause a deflection equal to 1/360 of the span for the 28-ft truss; loads of 84 psf for the 26-ft span, and 87 psf for the 24-ft span were required to produce the same deflection ratio. That is, at a deflection of 1/360 of the span the 26-ft trusses supported 18 per cent more roof load and the 24-ft trusses about 23 per cent more roof load than the 28-ft span trusses. These values indicate a trend towards stiffer trusses in terms of the deflection to span ratio with the shorter spans.

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The failure load for 28-ft trusses was 131 lb/sq ft; for 26-ft trusses it was 130 lb/sq ft; and for 24-ft trusses it was 165 lb/sq ft.

Truss Member Sizes

The deflection curves in Figure 8 show the relative effect of member sizes on deflection characteristics and strength. These curves show the mid-span deflection of 28-ft span, 4/12 slope spruce trusses with identical nailing. Although these curves are in most instances based on a single test (two trusses) the results indicate a trend, showing an increase in stiffness by substituting 2 x 6 chord members for 2 x 4 members. The roof load necessary to cause a deflection of 1/360 of the span, for example, is about 68 psf if 2 x 4 members are used throughout, 79 psf if 2 x 6 top chords are used, 81 psf if 2 x 6 bottom chords are used, and 102 psf if 2 x 6 top and bottom chords are used. Bottom chords of 2 x 6 seem to contribute more in reducing deflections than 2 x 6 top chords at roof loads below 90 psf, but the reverse seems true at loads above 90 psf.

The failure load was 135 psf for trusses made entirely of 2 x 4's, and increased only to 140 psf if 2 x 6 bottom chords were used. When 2 x 6 top chords were used, however, the failure load was increased to 171 psf, and if 2 x 6 chords were used both top and bottom the failure load was increased only to 176 lb/sq ft. This pattern of increase is understandable when one considers that the failures in trusses with 2 x 4 top chords occurred when the top chord broke in bending. When 2 x 6 top chords were used failure occurred in one instance at the centre splice in a member containing dry rot, and in the other case by lateral instability of the structure.

The same pattern of behaviour may be seen in the results listed in Table III, where the failure load for 28-ft span 3/12 slope trusses was increased from 107 to 184 psf if 2 x 6 top chords were substituted for 2 x 4's, even though the nailing was the same. This change also reduced the deflection from 0.95 to 0.75 in. (about 21 per cent less) at a 50 psf roof load.

Nailing

As may be seen in Figure 9, deflection is considerably influenced by the nailing. Figure 9 is based on tests of 28-ft span 4/12 slope spruce trusses. At a deflection equal to 1/360 of the span the roof load was 71 psf when full nailing was used, 55 psf when it was reduced by one third, and 44 psf when it was reduced by one half. In other words, when the nailing was reduced 33 per cent, the roof load carrying capacity at a deflection of 1/360 of the span was reduced by only 23 per cent; and at a 50 per cent reduction the roof load causing this deflection was reduced by only 38 per cent.

The failure load for these trusses with full nailing was 131 lb/sq ft (Table II); at two-thirds nailing it was 105 psf (Table III), or about 80 per cent of value for full nailing; at one-half nailing it was 87 lb/sq ft (Table III), or about 66 per cent of strength with full nailing. It is of interest to note that the trusses did not fail at the joints, even at one-half nailing; failure was invariably structural - in the chord members. It must be assumed, therefore, that the reduction in load-carrying capacity was caused by an increase in total stresses resulting from the greater distortion of the truss with reduced nailing.

Duration of Loading

The deflection of trusses under a relatively long term loading may be seen in Table V for various roof loads. The percentage increase in deflection after a given time interval was fairly constant and relatively independent of the applied load. The average increase in deflection after one hour of loading was 6 per cent; after one day, 26 per cent; after one week, 55 per cent; and after one month, 97 per cent. During this series of tests trusses subjected to an 80 psf roof load collapsed due to lateral instability after 12 days, and those subjected to 60 psf roof load collapsed after 22 days for the same reason. These failures were not considered true failures, however, because the same trusses installed in a house roof would receive considerably more lateral restraint than was provided in this test for only one pair of trusses sheathed with 1 x 6 board sheathing. The remaining trusses continued to show deflection recovery for one month after the loads had been removed.

Location of Partitions

It has been common practice among some authorities to consider partitions located beneath trusses as non-load bearing. Although to the author's knowledge this has not caused any difficulties, tests indicate that trusses deflecting under load can exert considerable force on a partition restraining this deflection (Figure 10). At a 40 psf roof load and 10 psf ceiling load, for example, this load has been measured at 440 lb/truss if the partition is located at the centre of the span, 1800 lb/truss if the partition is located at the junction of the diagonal members, and 240 lb/truss if it is located mid-way between the end panel points. These values are for a 26-ft span, 4/12 slope spruce truss of the type shown in Figure 4.

If the partition yields, these loads will, of course, be reduced, but the amount of yielding to eliminate load should equal the truss deflection at the location of the partition when the truss is simply supported at the ends only. There is a possibility, therefore, that if openings in partitions are framed as non-load bearing some damage to the wall finish may result if trusses are subjected to substantial snow loads. There is no question of structural collapse, however, because the load is reduced as the partition yields.

Cantilevering of Trusses

The cantilevering of roof trusses (originally designed to be end supported) in such a way that the support on the cantilevered end lies between two end panel points can lower the ultimate strength of a truss. This cantilevering may also cause a reversal of stress in the web members on the cantilevered side as well as the cantilevered portions of the chord members. Further work seems to be required in developing a standard detail for cantilevering trusses originally designed to be end supported. The method used here, whereby the chord members on the cantilevered end were increased from 2 x 4 to 2 x 6 and a vertical strut wedged between top and bottom chords, was not adequate to develop strength equal to that of the end supported trusses with similar nailing. Figure 11 shows the results of three tests on cantilevered trusses in which the support on the cantilevered end was located mid-way between panel points and a 2 x 4 strut was wedged between the top and bottom chords at the support. In Figure 11(a) the trusses were of the same type as those shown in Figure 3, except that the top chord members on the cantilevered side were 2 x 6 and the nailing was reduced to 2/3, the nailing shown in Figure 3. The long diagonal (1 in. thick) began to buckle in compression at fairly low loading and finally broke before a total roof load of 80 psf had been reached, at about the same time as the top and bottom chords broke at the cantilevering support. A truss with similar nailing using 2 x 4 top chords and supported at the ends would have a failure load of approximately 105 lb/sq ft (Table III).

Trusses in Figure 11(b) and (c) were similar to the design in Figure 4, except that 2 x 6 top and bottom chord members were used on the cantilevered end. These trusses had failure loads of 80 and 100 lb/sq ft and failure occurred on the cantilevered end with the breaking of the top and bottom chords in bending at the support. A similar truss with 2 x 4 members throughout should have a failure load of 135 psf when supported at the ends (Table II).

Application of Results

This test program has shown that if the design load per nail and the member sizes are constant the results of tests on trusses of a given span and roof slope may be conservatively applied to shorter spans and steeper slopes without the necessity for further tests to develop truss designs of at least equal performance. The number of nails, also, can be safely reduced in proportion to the roof load, or more conservatively still, in proportion to the total load (roof plus ceiling), so that if a given design is proof tested for adequacy in a given snow load area, the nailing may safely be reduced in proportion to the total load to develop designs for trusses for areas with lower snow loads.

As mentioned previously, the results of the tests in Table II are for short term tests only and were determined before accepted performance criteria had been developed. However, on the basis of the test results shown in Tables III and V, one may attempt to assess the performance of the trusses in Table II in relation to these performance criteria.

The precise relationship between the maximum load that can be carried by a truss over a 24-hour period as compared to the short term failure load is difficult to establish without extensive testing. Some use can, however, be made of the data in Table III, showing the maximum proof load carried by the trusses, and the corresponding failure loads when the trusses were tested to destruction. The 24-hour proof loads shown in Table III are not necessarily the largest 24-hour load that could have been carried, however, since the 24-hour proof loads were applied only in 20 psf increments.

In examining the results of Table III, it can be seen that the ratio of the 24-hour proof load to the short term failure load was 0.76 for 28-ft span 4/12 slope trusses with 2/3 the nailing shown in Figure 3. In applying this ratio to the measured failure loads shown in Table II to predict the maximum 24-hour proof loading that can be carried, the results should be on the conservative side. By multiplying this ratio by the failure loads in Table II, it can be shown that all but two trusses would support a 24-hour proof loading of 100 psf; and that of these two the weakest truss should be able to withstand a 24-hour proof loading of 97 psf. A 97 psf proof load should be acceptable for snow load areas of 48.5 lb/sq ft. Considering that the 0.76 factor may be slightly low (in view of the 20 psf increment of proof loading) it would seem reasonable for all practical purposes to consider all trusses in Table II as meeting the performance requirement of supporting twice the design snow load of 50 psf for 24 hours.

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With regard to the requirements for limiting deflection, it may be seen from Table V that an increase in deflection after one hour of loading should not be more than about 6 per cent. If this increase in deflection is applied to the deflections shown in Table II for 50 psf roof loads, the deflections would still be well within the limit of 1/360 of the span. It would appear reasonable to conclude therefore that the trusses in Table II must meet the accepted performance criteria for trusses for a 50 psf snow load.

On the basis of these considerations three nailing schedules have been prepared to provide truss designs to cover a range of spans, slopes and snow loads to satisfy the performance requirements established in the 1963 Housing Standards. Table VI is a nailing schedule for 4/12 and 5/12 slope spruce trusses with spans of from 16 to 28 ft and snow loads of 30, 40 and 50 psf for the type of truss shown in Figure 3.

Table VII is similar except that it applies to the type of truss shown in Figure 4. Table VIII is the nailing schedule for 3/12 slope spruce trusses of the type shown in Figure 5. In this case the spans also range from 16 to 28 ft and nailing is determined for 30, 40 and 50 psf snow loads.

Conclusions

1. Conventional constructions built prior to the introduction of the 1962 and 1963 Housing Standards show a wide range of load carrying capacities, some of which are as low as 18 psf under a short term loading.

2. The criteria of acceptable performance states that roof trusses must withstand twice the design snow load for 24 hours and must not deflect more than 1/360 of the span under design load after one hour. It provides for roofs that are considerably stronger than most conventionally framed roofs.

3. The stiffness of trusses with members of similar size and nailed joints designed for the same load is increased as the slope is increased or as the span is decreased.

4. Increasing the member sizes from 2 x 4 to 2 x 6 in the top or bottom chords increases the stiffness and strength of trusses. Increase in strength is most marked when the top chord members are increased in size.

5. Truss stiffness is decreased as the nailing is decreased. If the number of nails is reduced by a certain percentage, the load required

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to cause equal deflection will be decreased by a smaller percentage.

6. Truss strength is dependent to some extent upon truss stiffness. If trusses of similar member size and geometry, but with joints designed for different loadings, are tested to failure and failure occurs in the members and not at the joints, the stiffer trusses will have higher failure loads.

7. The percentage increase in truss deflections over an extended period of time seems largely unrelated to the magnitude of the load. For trusses made with 2 x 4 members, the increase in deflection is about 6 per cent after one hour, 26 per cent after one day, 55 per cent after one week, and 97 per cent after one month.

8. Contrary to popular conception, partitions located beneath trusses can be subjected to loads in excess of those born by partitions located beneath framed roofs.

9. Cantilevering of trusses beyond their designed end support so that it is located between panel points can seriously weaken them.

10. The roof truss designs developed on the basis of this test program meet the above criteria of acceptable performance (which has since been incorporated into the Housing Standards) and should provide roofs of adequate performance in those snow load areas for which they were developed.

Acknowledgment

Work on roof trusses undertaken by the Division of Building Research has been developed jointly with the Forest Products Research Branch. Their co-operation in these studies is very much appreciated.

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TABLE I

SUMMARY OF RESULTS OF SHORT TERM TESTS ON CONVENTIONAL CONSTRUCTIONS WITH SPRUCE JOISTS AND RAFTERS SPACED 16 in. O. C.

Type of Construction	Rafter Size in.	Collar Tie Size in.	Type of End Supports	Ultimate* Roof Load (psf)
See Figure 1	2 x 4	2 x 4	Rollers	56
	2 x 4	2 x 4	Fixed	72
	2 x 6	1 x 5	Rollers	63
	2 x 6	1 x 5	Fixed	113
	2 x 6	2 x 4	Rollers	62
	2 x 6	2 x 4	Fixed	108
	2 x 8	2 x 4	Rollers	89
	2 x 8	2 x 4	Fixed	125
See Figure 2	2 x 4	2 x 4	Rollers	18
	2 x 4	2 x 4	Fixed	18
	2 x 8	2 x 4	Rollers	46
	2 x 8	2 x 4	Fixed	46

* In addition to 10 psf ceiling load

TABLE II

CONDENSED SUMMARY OF RESULTS OF SHORT TERM TESTS ON NAILED W TRUSSES SPACED 24 in. O. C.

Type of Truss	Span ft	Slope	Upper Chord Size in.	Lower Chord Size in.	Lower Chord Deflection Ratio for 40 psf Roof Load*	Percentage of Recovery after 40 psf Roof Load Removed	Lower Chord Deflection Ratio for 50 psf Roof Load*	Failure Load* (psf)
Spruce (see Figure 3)	24	5/12	2 x 4	2 x 4	1/910	69	1/740	163
	24	4/12	2 x 4	2 x 4	1/820	78	1/670	165
	26	5/12	2 x 4	2 x 4	1/870	69	1/720	143
	26	4/12	2 x 4	2 x 4	1/800	75	1/660	130
	28	5/12	2 x 4	2 x 4	1/890	72	1/740	145
	28	4/12	2 x 4	2 x 4	1/600	71	1/500	131
	28	4/12	2 x 5	2 x 4	1/690	77	1/570	142
Spruce (see Figure 4)	26	4/12	2 x 4	2 x 4	1/610	71	1/500	127
	28	4/12	2 x 4	2 x 4	1/610	70	1/510	135
	28	4/12	2 x 6	2 x 4	1/650	73	1/550	171**
	28	4/12	2 x 4	2 x 6	1/800	79	1/650	140**
	28	4/12	2 x 6	2 x 6	1/1030	79	1/840	176**
Douglas Fir (see Figure 4)	26	4/12	2 x 4	2 x 4	1/650	66	1/520	136
	28	4/12	2 x 4	2 x 4	1/590	74	1/470	117

* In addition to 10 psf ceiling load

** Based on one test only

TABLE III

SHORT TERM TESTS ON TRUSSES TO DETERMINE ACCEPTABILITY FOR VARIOUS SNOW LOAD AREAS. TRUSSES SPACED 24 in. O. C.

Type of Truss	Span	Slope	Upper Chord Size	Lower Chord Size	Lower chord deflection ratios after 1-hr loading				Max. roof load sustained for 24 hr* (psf)	Average failure load* (psf)
					30 psf Roof Load*	40 psf Roof Load*	50 psf Roof Load*	60 psf Roof Load*		
Spruce (see Figure 5)	28	3/12	2 x 4	2 x 4	-	1/415	-	-	80	107
	28	3/12	2 x 6	2 x 4	-	-	-	1/390	120	184
Spruce (see Note 1 below)	28	4/12	2 x 4	2 x 4	1/510	-	-	-	60	87
Spruce (see Note 2 below)	28	4/12	2 x 4	2 x 4	-	1/470	-	-	80	105

Note 1 - Trusses similar to those in Figure 3 except that the number of nails was reduced to 50 per cent of the number shown in Figure 3

Note 2 - Trusses similar to those in Figure 3 except that the number of nails was reduced to 2/3 of the number shown in Figure 3

* In addition to 10 psf ceiling load

TABLE IV

SUMMARY OF LONG TERM TESTS ON CONVENTIONAL CONSTRUCTION
(24-ft SPAN, 5/12 SLOPE, 2 x 6 SPRUCE RAFTERS
AND JOISTS SPACED 16 in. O. C. (FIGURE 1))
TESTED ON ROLLER SUPPORTS

Loading Phase	Applied Roof Load (psf)	Joist Splice Separation (in.)					Peak Deflections (in.)					Mid-span Rafter Deflections, Perpendicular to Slope (in.)				
		5 Min.	1 Hour	1 Day	1 Week	1 Month	5 Min.	1 Hour	1 Day	1 Week	1 Month	5 Min.	1 Hour	1 Day	1 Week	1 Month
First application of long term roof and ceiling load	20	0.037	0.039	0.050	0.067	0.109	0.12	0.13	0.16	0.23	0.35	0.08	0.08	0.10	0.14	0.19
	40	0.109	0.116	0.144	0.233	0.384	0.39	0.43	0.55	0.77	1.09	0.22	0.24	0.30	0.43	0.63
Roof loads and ceiling loads removed	0*	0.060	0.059	0.057	0.048	0.047	0.20	0.20	0.20	0.19	0.19	0.10	0.10	0.09	0.09	0.08
	0**	0.319	0.316	0.312	0.310	0.303	0.82	0.81	0.80	0.78	0.78	0.42	0.40	0.39	0.38	0.35

* Structure originally loaded with 20 psf roof load

** Structure originally loaded with 40 psf roof load

TABLE V

SUMMARY OF LONG TERM TRUSS TESTS (26-ft SPAN, 4/12 SLOPE SPRUCE TRUSSES SPACED 24 in. O. C. OF DESIGN SHOWN IN FIGURE 3 WITH 2 x 4 TOP AND BOTTOM CHORDS)

Loading Phase	Applied Roof Loads (psf)	MID SPAN DEFLECTIONS OF LOWER CHORDS									
		5 Minutes		1 Hour		1 Day		1 Week		1 Month	
		In.		In.	Percentage Increase over 5-min Deflections	In.	Percentage Increase over 5-min Deflections	In.	Percentage Increase over 5-min Deflections	In.	Percentage Increase over 5-min Deflections
First application of long term roof loads and ceiling loads	20	0. 30		0. 315	5	0. 385	28	0. 48	60	0. 60	100
	40	0. 55		0. 58	5	0. 68	24	0. 83	51	1. 06	93
	60	0. 795		0. 84	6	0. 985	24	1. 19	50	***	
	80	1. 12		1. 21	8	1. 42	27	1. 755	57	****	
Roof loads and ceiling loads removed		In.	Percentage Recovery	In.	Percentage Recovery	In.	Percentage Recovery	In.	Percentage Recovery	In.	Percentage Recovery
	*	0. 335	44	0. 32	47	0. 295	51	0. 265	56	0. 25	58
	**	0. 505	52	0. 49	54	0. 445	58	0. 39	63	0. 35	67
Second application of long term roof loads and ceiling loads		In.	Percentage of Original 1-mo Deflections	In.	Percentage of Original 1-mo Deflections	In.	Percentage of Original 1-mo Deflections	In.	Percentage of Original 1-mo Deflections	In.	Percentage of Original 1-mo Deflections
	20	0. 525	88	0. 545	91	0. 555	93	0. 58	97	---	---
	40	0. 905	85	0. 915	86	0. 94	89	1. 00	94	---	---

* Trusses originally loaded with 20 psf roof load

** Trusses originally loaded with 40 psf roof load

*** Structure collapsed due to lateral instability after 22 days

**** Structure collapsed due to lateral instability after 12 days.

TABLE VI

NUMBER OF NAILS REQUIRED AT VARIOUS JOINTS FOR DIFFERENT SNOW LOAD AREAS. TRUSS DESIGNS IN FIGURE 3 SPACED 24 in. O. C. SPRUCE - 2 x 4 TOP AND BOTTOM CHORDS

Snow load area	Slope	Span		Joint location (see Figure 3)				
		ft	in.	1 3-in. nails	2 3-in. nails	3 $2\frac{1}{2}$-in. nails	4 $2\frac{1}{2}$-in. nails	5 3-in. nails
30 psf	4/12	16	4	9	8	5	5	5
		18	4	10	9	5	6	6
		20	4	11	10	5.	7	7
		22	4	12	11	5	7	7
		24	4	13	12	5	8	8
		26	4	14	13	5	9	9
		28	4	15	14	5	9	9
30 psf	5/12	16	4	7	7	5	5	5
		18	4	8	7	5	6	5
		20	4	9	8	5	6	6
		22	4	10	9	5	7	6
		24	4	10	10	5	8	7
		26	4	11	10	5	8	7
		28	4	12	11	5	9	8
40 psf	4/12	16	4	12	11	5	7	7
		18	4	13	12	5	8	8
		20	4	15	13	5	9	9
		22	4	16	14	5	10	10
		24	4	17	16	5	11	11
		26	4	19	17	5	11	11
		28	4	20	18	5	12	12
40 psf	5/12	16	4	10	9	5	7	6
		18	4	11	10	5	8	7
		20	4	12	11	5	8	8
		22	4	13	12	5	9	8
		24	4	14	13	5	10	9
		26	4	15	14	5	11	10
		28	4	16	15	5	12	10
50 psf	4/12	16	4	17	16	5	11	11
		18	4	19	18	5	12	12
		20	4	21	20	5	13	13
		22	4	23	21	5	14	14
		24	4	25	23	5	16	16
		26	4	27	25	5	17	17
		28	4	29	27	5	18	18
50 psf	5/12	16	4	14	13	5	10	9
		18	4	16	14	5	11	10
		20	4	17	16	5	12	11
		22	4	19	17	5	14	12
		24	4	20	19	5	15	13
		26	4	22	20	5	16	14
		28	4	24	22	5	17	15

TABLE VII

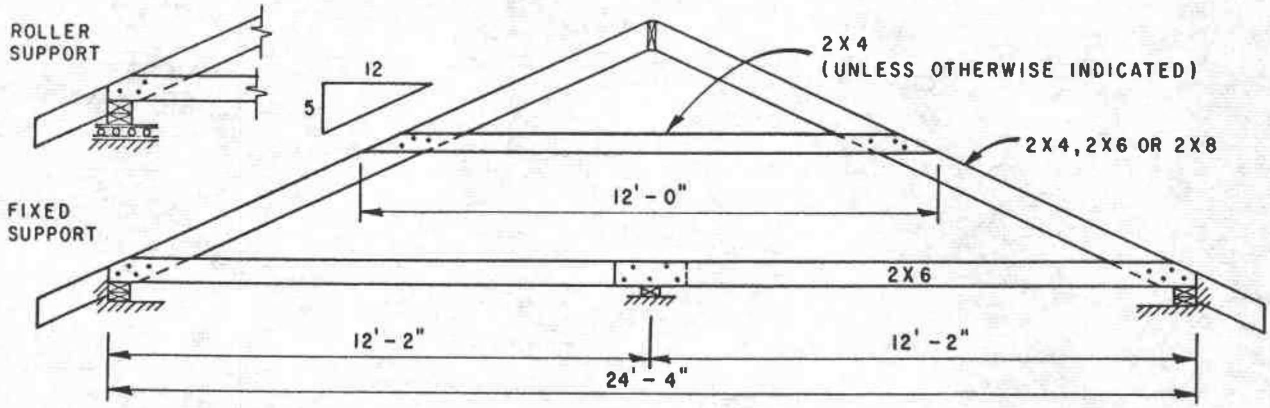
NUMBER OF 3-in. NAILS REQUIRED AT VARIOUS JOINTS FOR DIFFERENT SNOW LOAD AREAS. TRUSS DESIGN IN FIGURE 4 SPACED 24 in. O. C. SPRUCE - 2 x 4 TOP AND BOTTOM CHORDS

Snow load area	Slope	Span		Joint location (see Figure 4)					
		ft	in.	1	2	3	4	5	6
30 psf	4/12	16	4	9	8	2	3	3	5
		18	4	10	9	2	3	4	6
		20	4	11	10	2	3	4	7
		22	4	12	11	2	4	4	7
		24	4	13	12	3	4	5	8
		26	4	14	13	3	4	5	9
		28	4	15	14	3	4	5	9
30 psf	5/12	16	4	7	7	2	2	3	5
		18	4	8	7	2	3	3	5
		20	4	9	8	2	3	4	6
		22	4	10	9	2	3	4	6
		24	4	10	10	2	3	4	7
		26	4	11	10	3	4	5	7
		28	4	12	11	3	4	5	8
40 psf	4/12	16	4	12	11	2	4	4	7
		18	4	13	12	3	4	5	8
		20	4	15	13	3	4	5	9
		22	4	16	14	3	5	6	10
		24	4	17	16	4	5	6	11
		26	4	19	17	4	6	7	11
		28	4	20	18	4	6	7	12
40 psf	5/12	16	4	10	9	2	3	4	6
		18	4	11	10	3	4	4	7
		20	4	12	11	3	4	5	8
		22	4	13	12	3	4	5	8
		24	4	14	13	3	4	6	9
		26	4	15	14	4	5	6	10
		28	4	16	15	4	5	6	10
50 psf	4/12	16	4	17	16	3	5	6	11
		18	4	19	18	4	5	7	12
		20	4	21	20	4	6	7	13
		22	4	23	21	4	7	8	14
		24	4	25	23	5	7	9	16
		26	4	27	25	5	8	10	17
		28	4	29	27	5	8	10	18
50 psf	5/12	16	4	14	13	3	4	5	9
		18	4	16	14	4	5	6	10
		20	4	17	16	4	5	7	11
		22	4	19	17	4	6	7	12
		24	4	20	19	4	6	8	13
		26	4	22	20	5	7	9	14
		28	4	24	22	5	7	9	15

TABLE VIII

NUMBER OF 3-in. NAILS REQUIRED AT VARIOUS JOINTS FOR DIFFERENT SNOW LOAD AREAS. TRUSS DESIGN IN FIGURE 5 SPACED 24 in. O. C. SPRUCE - 2 x 4 LOWER CHORDS

Snow load area	Span		Joint location (see Figure 5)					
	ft	in.	1	2	3	4	5	6
30 psf (2 x 4 top chord)	16	4	17	17	3	6	6	11
	18	4	19	19	3	6	6	13
	20	4	22	21	4	7	7	14
	22	4	23	23	4	7	7	15
	24	4	26	25	4	8	8	17
	26	4	28	27	5	9	9	18
	28	4	30	29	5	9	9	19
30 psf (2 x 6 top chord)	16	4	12	12	3	4	4	8
	18	4	14	13	3	4	4	9
	20	4	16	15	3	5	5	10
	22	4	17	17	3	5	5	11
	24	4	18	18	3	6	6	12
	26	4	20	20	4	7	7	13
	28	4	21	21	4	7	7	14
40 psf (2 x 4 top chord)	16	4	21	21	4	7	7	14
	18	4	24	23	4	7	7	16
	20	4	27	26	5	8	8	17
	22	4	29	29	5	9	9	19
	24	4	32	31	5	10	10	21
	26	4	35	34	6	11	11	23
	28	4	37	36	6	11	11	24
40 psf (2 x 6 top chord)	16	4	15	15	3	5	5	10
	18	4	17	17	3	5	5	11
	20	4	19	19	4	6	6	12
	22	4	21	21	4	7	7	14
	24	4	23	22	4	7	7	15
	26	4	25	24	5	8	8	17
	28	4	27	26	5	8	8	17
50 psf (2 x 6 top chord)	16	4	18	18	4	6	6	12
	18	4	21	20	4	6	6	14
	20	4	23	22	5	7	7	15
	22	4	25	25	5	8	8	16
	24	4	28	27	5	9	9	18
	26	4	30	29	5	10	10	20
	28	4	32	31	5	10	10	21



LUMBER - CLA No. 1 SPRUCE
NAILS - $3\frac{1}{2}$" COMMON
3 NAILS JOIST TO RAFTER
3 NAILS JOIST TO JOIST AT CENTER
2 TOE NAILS EACH END OF EACH JOIST TO PLATE
3 TOE NAILS EACH RAFTER TO PLATE
3 NAILS EACH END OF COLLAR TIE TO RAFTER

FIGURE 1 TYPE I CONVENTIONAL CONSTRUCTION SPACED 16" O.C.

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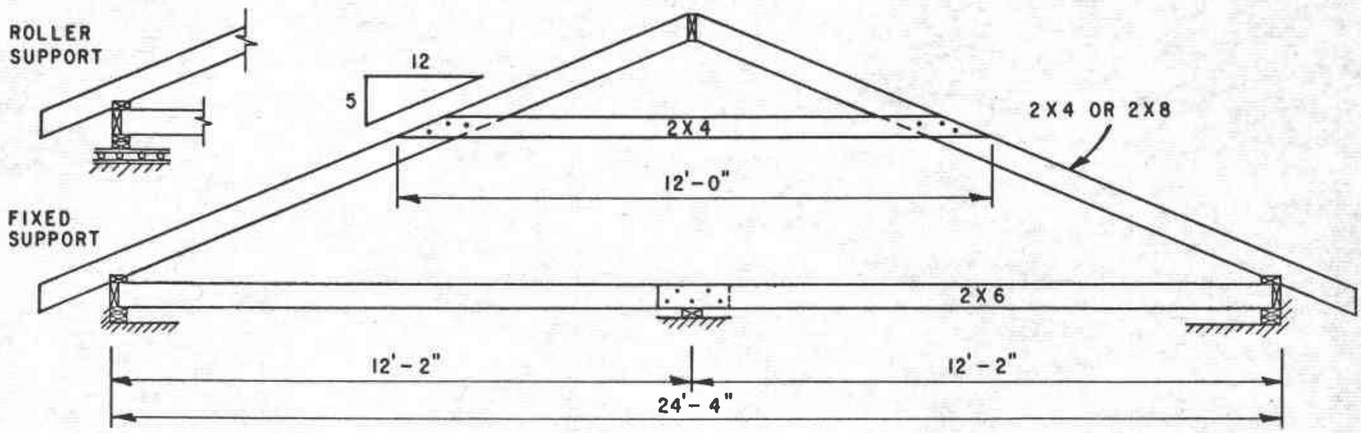
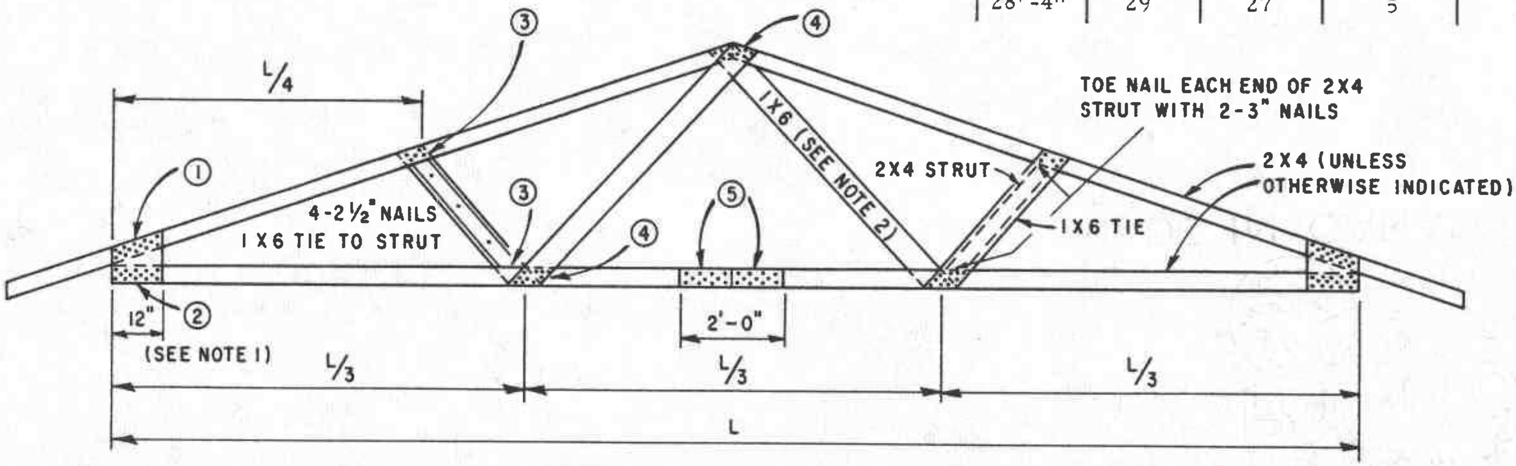


LUMBER - CLA No. 1 SPRUCE
NAILS - 3 - $3\frac{1}{2}$" JOIST TO JOIST AT CENTER
3 - $3\frac{1}{2}$" COLLAR TIE TO RAFTER
2 - 4" HEADER TO END OF JOIST
1 - 4" RAFTER PLATE TO JOIST
1 - 4" RAFTER PLATE TO HEADER
3 - $3\frac{1}{2}$" RAFTER TO RAFTER PLATE (TOE NAILED)
2 - $3\frac{1}{2}$" JOIST TO JOIST PLATE (TOE NAILED)

FIGURE 2 TYPE II CONVENTIONAL CONSTRUCTION SPACED 16" O.C.

BR 2958-2

SLOPE	SPAN	NO. OF NAILS				
		1	2	3	4	5
		3" nails	3" nails	$2\frac{1}{2}$" nails	$2\frac{1}{2}$" nails	3" nails
5/12	24'-4"	20	19	5	15	13
	26'-4"	22	20	5	16	14
	28'-4"	24	22	5	17	15
4/12	24'-4"	25	23	5	16	16
	26'-4"	27	25	5	17	17
	28'-4"	29	27	5	18	18



LUMBER - CLA No. 1 SPRUCE
PLYWOOD - $\frac{1}{2}$" SHEATHING GRADE DOUGLAS FIR, BOTH SIDES
NAILS - $2\frac{1}{2}$" AND 3" COMMON - UNCLINCHED

NOTE 1
16" PLATE USED WHEN No. OF NAILS FOR 1 AND 2 EXCEEDED 20

NOTE 2
1 x 8 DIAGONALS USED WHEN NO. OF NAILS FOR 4 EXCEEDED 12

FIGURE 3 NAILED W TRUSS SPACED 24" O.C.

BR 2958-3

SPRUCE TRUSS

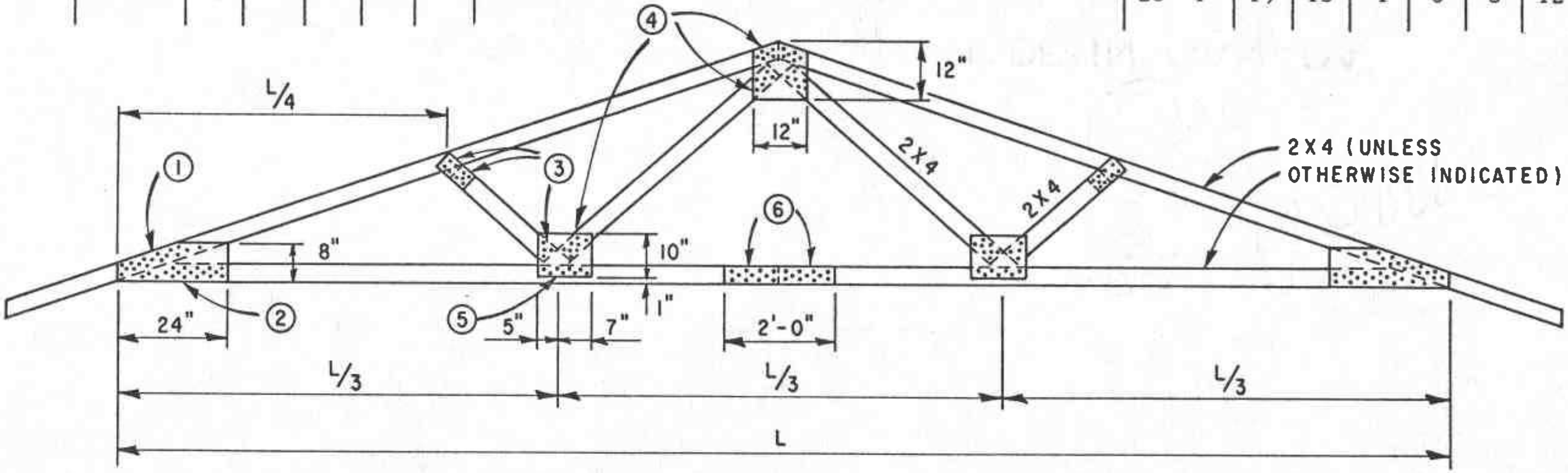
NAILING SCHEDULE

SLOPE	SPAN "L"	NUMBER OF NAILS 1	2	3	4	5	6
4/12	26'-4"	27	25	5	8	10	17
	28'-4"	29	27	5	8	10	18

DOUGLAS FIR TRUSS

NAILING SCHEDULE

SLOPE	SPAN "L"	NUMBER OF NAILS 1	2	3	4	5	6
4/12	26'-4"	18	17	4	5	7	11
	28'-4"	19	18	4	6	8	12



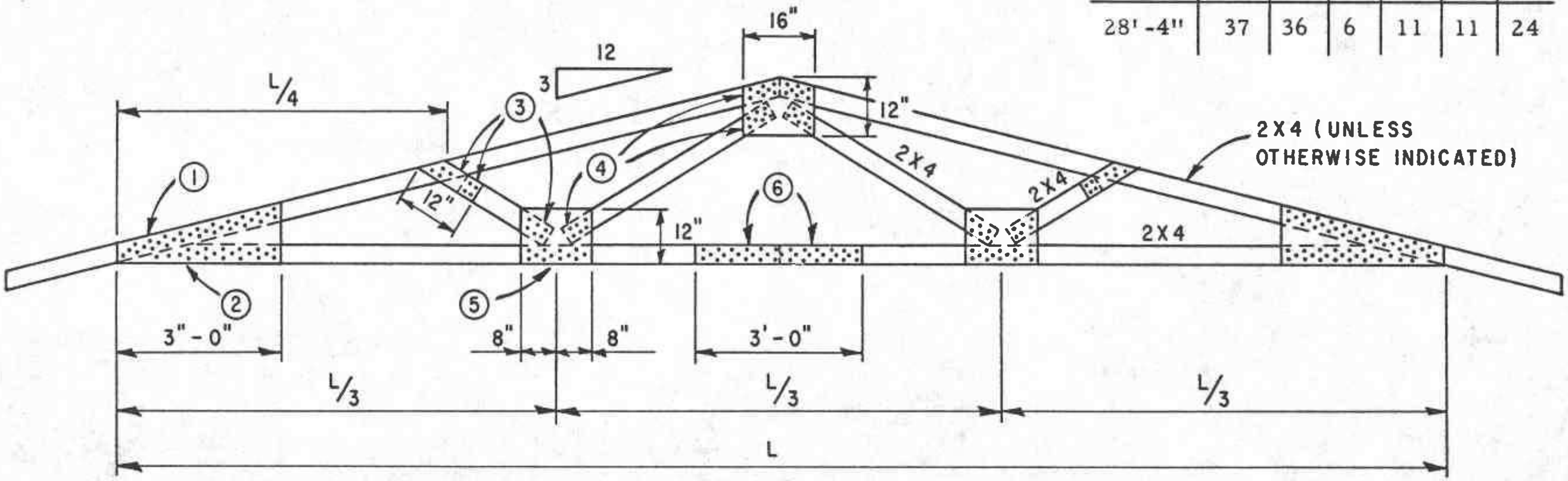
LUMBER - CLA No. 1 SPRUCE OR CONST. GRADE DOUGLAS FIR
PLYWOOD - ½" SHEATHING GRADE DOUGLAS FIR, BOTH SIDES
NAILS - 3" COMMON, UNCLINCHED

FIGURE 4 NAILED W TRUSS SPACED 24" O.C.

AR 2958-4

NAILING SCHEDULE

SPAN "L"	NUMBER OF NAILS					
	1	2	3	4	5	6
28'-4"	37	36	6	11	11	24



LUMBER - CLA No. 1 SPRUCE
PLYWOOD - ½" SHEATHING GRADE DOUGLAS FIR, BOTH SIDES
NAILS - 3" COMMON, UNCLINCHED

FIGURE 5 NAILED W TRUSS FOR 3/12 SLOPE 24" O.C.

BR 2958-5

P.C

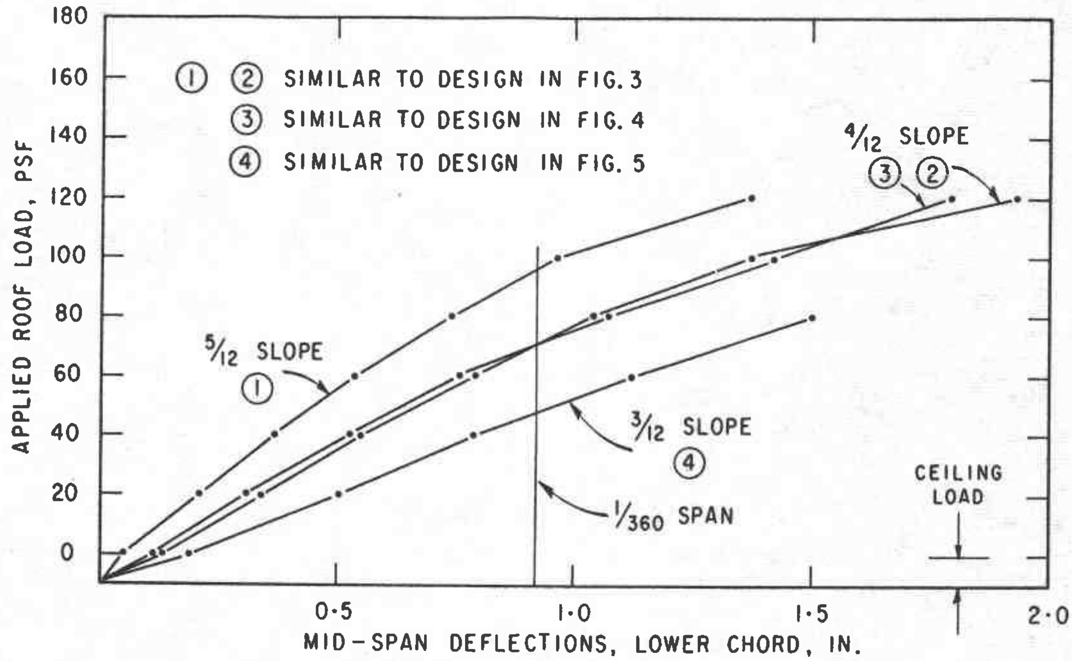


FIGURE 6

DEFLECTION CURVES FOR 28' SPAN, SPRUCE TRUSSES WITH 2X4 UPPER AND LOWER CHORDS WITH NAILING CALCULATED FOR SIMILAR LOADINGS

AR 2958-6

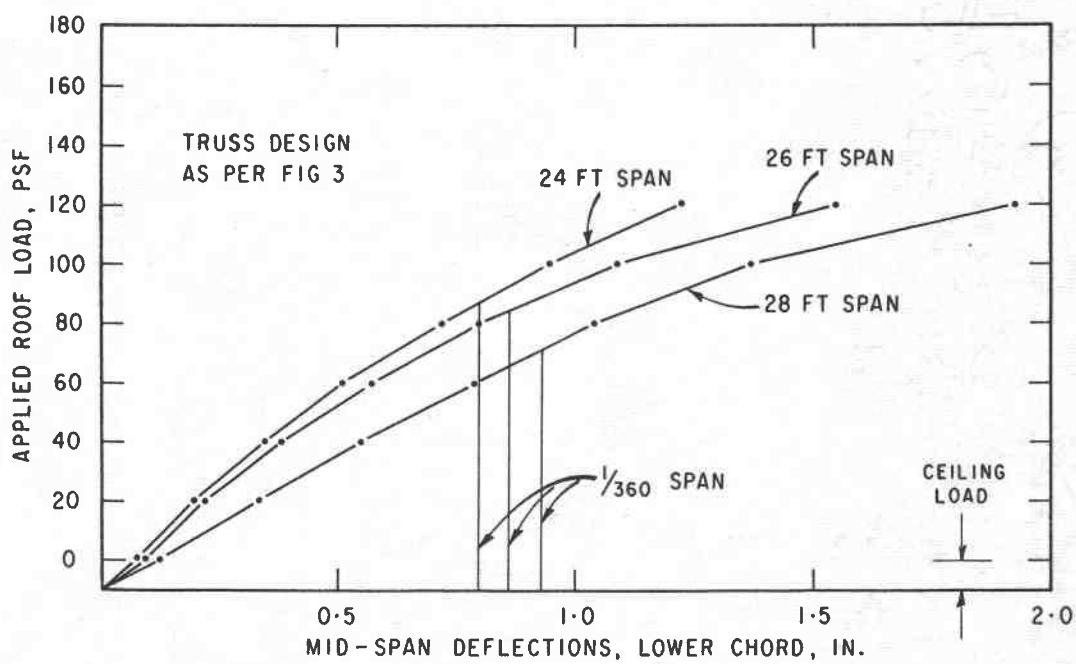
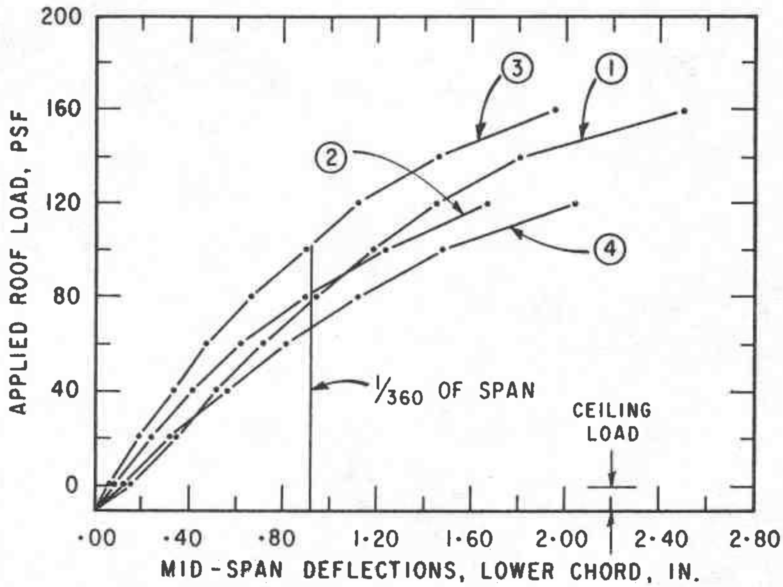


FIGURE 7

DEFLECTION CURVES FOR 4/12 SLOPE, SPRUCE TRUSSES WITH 2X4 UPPER AND LOWER CHORDS WITH NAILING CALCULATED FOR SIMILAR LOADING

AR 2958-7

p. C



LEGEND

1	2" X 6" TOP CHORDS 2" X 4" BOTTOM CHORDS	(ONE TEST ONLY)
2	2" X 4" TOP CHORDS 2" X 6" BOTTOM CHORDS	(ONE TEST ONLY)
3	2" X 6" TOP CHORDS 2" X 6" BOTTOM CHORDS	(ONE TEST ONLY)
4	2" X 4" TOP CHORDS 2" X 4" BOTTOM CHORDS	(AVG OF 3 TESTS)

FIGURE 8

LOAD VS DEFLECTION CURVES 28' SPAN, SPRUCE TRUSSES 4/12 SLOPE, (DESIGN SIMILAR TO FIG 4) FOR DIFFERENT MEMBER SIZES BUT SIMILAR NAILING

BR 2958-8

P. C

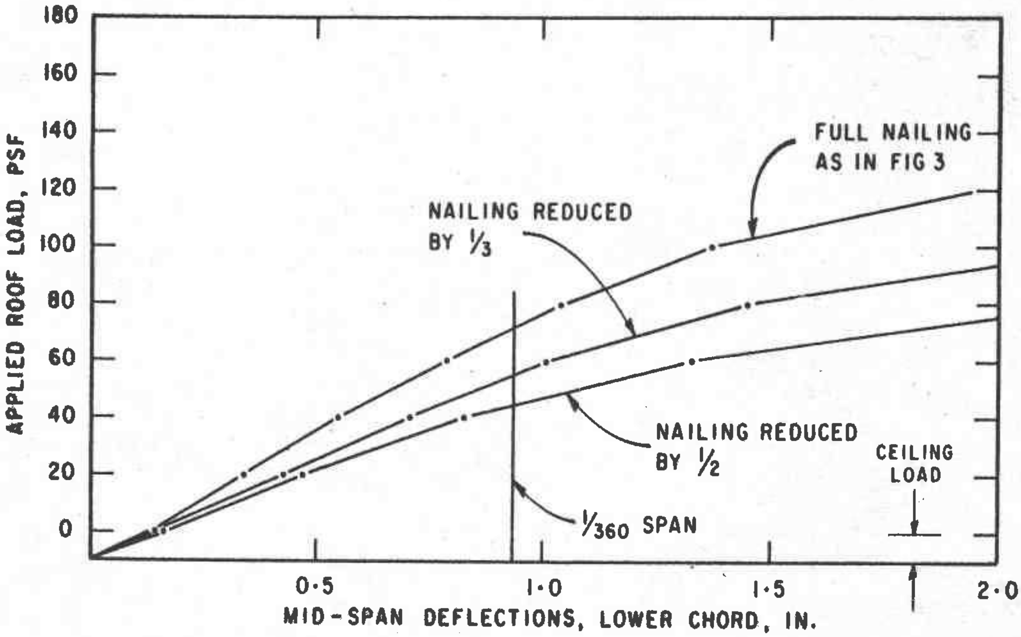
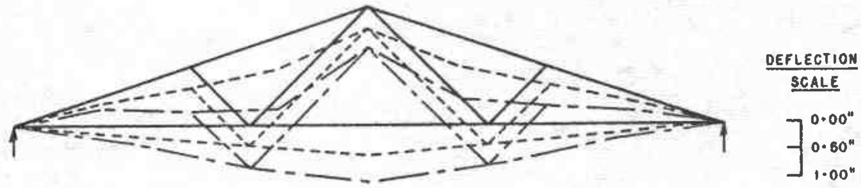


FIGURE 9

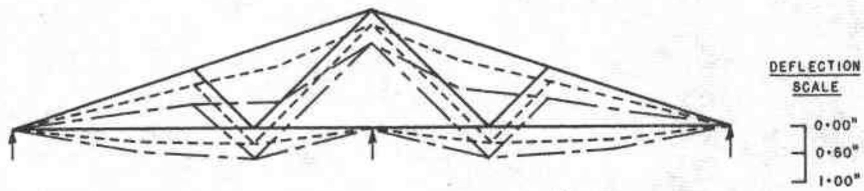
DEFLECTION CURVES FOR SPRUCE TRUSSES WITH VARIATIONS IN NAILING 28' SPAN, 4/12 SLOPE (FIG 3) 2X4 UPPER AND LOWER CHORDS

BR 2998-9

P.C.

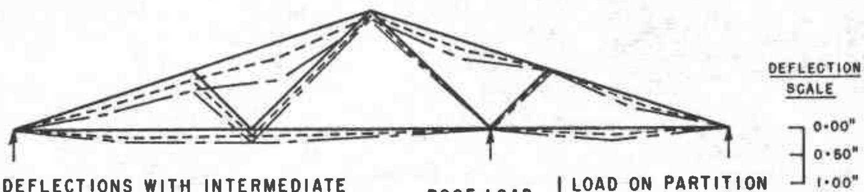


TRUSS DEFLECTIONS WITHOUT INTERMEDIATE SUPPORTS



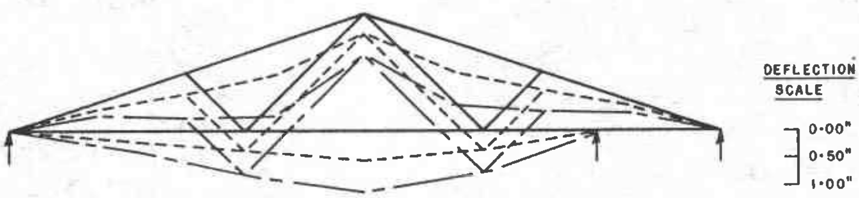
TRUSS DEFLECTIONS WITH INTERMEDIATE SUPPORT LOCATED AT MID SPAN OF THE LOWER CHORD

ROOF LOAD	LOAD ON PARTITION (PER TRUSS)
40 PSF	440 LB
80 PSF	750 LB



TRUSS DEFLECTIONS WITH INTERMEDIATE SUPPORT LOCATED BENEATH DIAGONAL MEMBERS

ROOF LOAD	LOAD ON PARTITION (PER TRUSS)
40 PSF	1800 LB
80 PSF	2900 LB



TRUSS DEFLECTIONS WITH INTERMEDIATE SUPPORT LOCATED 4'-4" FROM ONE END

ROOF LOAD	LOAD ON PARTITION (PER TRUSS)
40 PSF	240 LB
80 PSF	410 LB

NOTE
ROOF LOADS ARE IN ADDITION TO 10 PSF CEILING LOAD

LEGEND

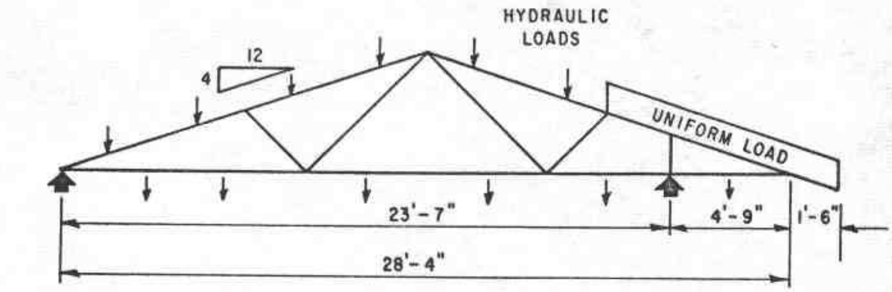
——— SHAPE OF TRUSS BEFORE APPLICATION OF LOAD

- - - - AFTER APPLICATION OF 40 PSF ROOF LOAD AND 10 PSF CEILING LOAD

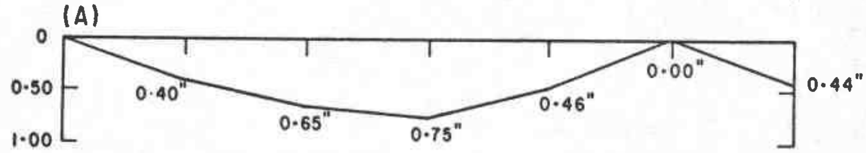
—- - — AFTER APPLICATION OF 80 PSF ROOF LOAD AND 10 PSF CEILING LOAD

FIGURE 10
DEFLECTION PATTERNS FOR 26'. SPAN, 4/12 SLOPE, SPRUCE TRUSSES, 2X4 TOP AND BOTTOM CHORDS (FIG 4) FOR VARIOUS PARTITION LOCATIONS

BR 2958-10

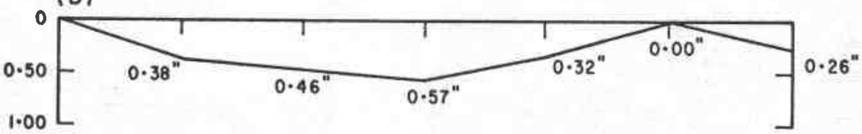


(A)



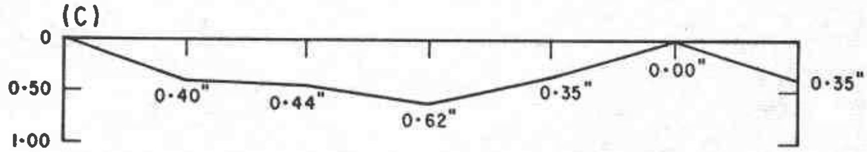
TRUSS DESIGNS SIMILAR TO FIG. 3 EXCEPT 2 x 6 TOP CHORD USED ON CANTILEVERED END, AND NAILING REDUCED BY 1/3. BOTTOM CHORD DEFLECTIONS AT 40 PSF ROOF LOAD AND 10 PSF CEILING LOAD ONE HOUR AFTER LOADING. DEFLECTION OF OVERHANG - 0.44", DEFLECTION RATIO BETWEEN SUPPORTS = 1/377, FAILURE LOAD - LESS THAN 80 PSF ROOF LOAD.

(B)



TRUSS DESIGNS SIMILAR TO FIG. 4, EXCEPT 2 x 6 TOP AND BOTTOM CHORDS USED ON CANTILEVERED END. BOTTOM CHORD DEFLECTIONS AT 50 PSF ROOF LOAD AND 10 PSF CEILING LOAD AFTER ONE HOUR LOADING. DEFLECTION OF OVERHANG - 0.26", DEFLECTION RATIO BETWEEN SUPPORTS = 1/497, FAILURE LOAD - 100 PSF ROOF LOAD AFTER 45 MIN LOADING.

(C)



TRUSS DESIGNS SIMILAR TO FIG. 4 EXCEPT 2 x 6 TOP AND BOTTOM CHORD USED ON CANTILEVERED END. BOTTOM CHORD DELFECTIONS AT 50 PSF ROOF LOAD AND 10 PSF CEILING LOAD AFTER ONE HOUR LOADING. DEFLECTION OF OVERHANG - 0.35", DEFLECTION RATIO BETWEEN SUPPORTS = 1/456, FAILURE LOAD - 80 PSF ROOF LOAD AFTER 6 MIN LOADING.

FIGURE 11

BOTTOM CHORD DEFLECTIONS FOR CANTILEVERED SPRUCE TRUSSES 4/12 SLOPE, 28' SPAN, 2X4 TOP AND BOTTOM CHORDS ON THE END OPPOSITE CANTILEVERED END

BR 2958-11

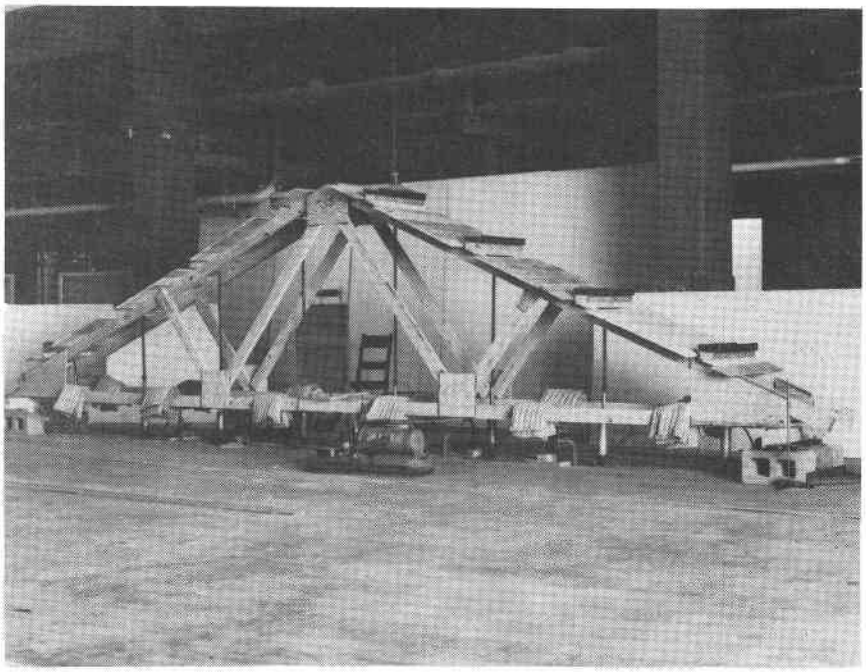


Figure 12 General arrangement for typical short term tests

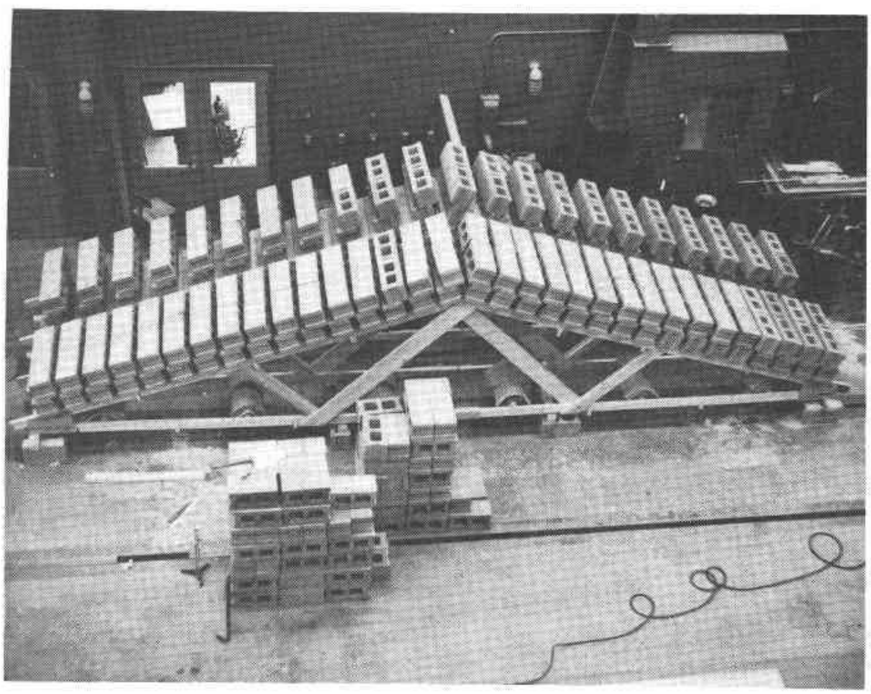


Figure 13 Long term tests using concrete blocks