A COMPARATIVE INVESTIGATION OF TWO BARN TRUSSES

Thesis for the Degree of B. S.

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A Comparative Investigation of Two

Barn Trusses

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Introduction

The earliest barns in this country were crude log buildings that were hewn from trees and constructed by the farmers themselves. The second era of building introduced the country carpenter or practical builder who spent weeks assembling the heavy timbers for the frame before the actual raising took place. Mortice and tenon joints were used, fastened with wooden draw pins. Many of these barns still stand today as evidence of the ability of these men.

It is the purpose of this study to design two types of trusses for a small barn and compare them as to cost of material and storage space.

Construction

The following designs are of a scissors truss and a gambrel truss. The designs have been made using Kidders Handbook and Supplement 6 The Manual of Timber Connector Construction.

The stresses in the members of the trusses were obtained by graphical solution* and are listed in tables 1 and 2 in their respective designs.

The trusses are spaced farther apart than in most barn designs, the most common spacing being two feet on centers. In place of the nailed and bolted joints Teco toothed ring connectors have been used. These connectors may be obtained from the Timber Engineering Company. The assembly of the joint is made by inserting the toothed ring connector between the two members and inserting a special bolt through the hole in the members. A ball bearing washer is then placed over the bolt and a nut turned on with a ratchet wrench thus drawing the two members together forcing the toothed ring connector into the wood. When the two members have been drawn tightly together the special bolt is removed and the regular machine bolt is inserted, tightened up and the joint is completed.

When the trusses are completely assembled they are then raised into place and fastened to the plate. Then the sheathing and roofing job is done, completing the roof.

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*Refer to Figures 3, 5 & 6.

Design of Scissors Truss

In the following design of a scissors truss the stresses were determined by a vertical equivalent wind and snow load + a dead load. This method of loading was used because of the gable type roof which will give approximately equal values to those secured when separate dead and live loading are applied.

This type of truss, which this writer has never seen used in a barn, was used as an experiment and to give a contrast in the comparison of the two trusses.

Design of Truss

One-third Pitch

$$\text{Tan } \theta = \frac{10}{15} = .6667$$

$$\theta = 31^{\circ}\ 41'\ 30''$$

$$L = \sqrt{15^2 + 10^2} = \sqrt{325} = 18.03'$$

Trusses Spaced 4 ft. on Centers

Roof Area = 18.03 x 4 = 72.12 sq. ft.

Equivalent Vertical Wind & Snow Load = 25# / sq. ft.

72.12 x 25 = 1800#

Dead Load --

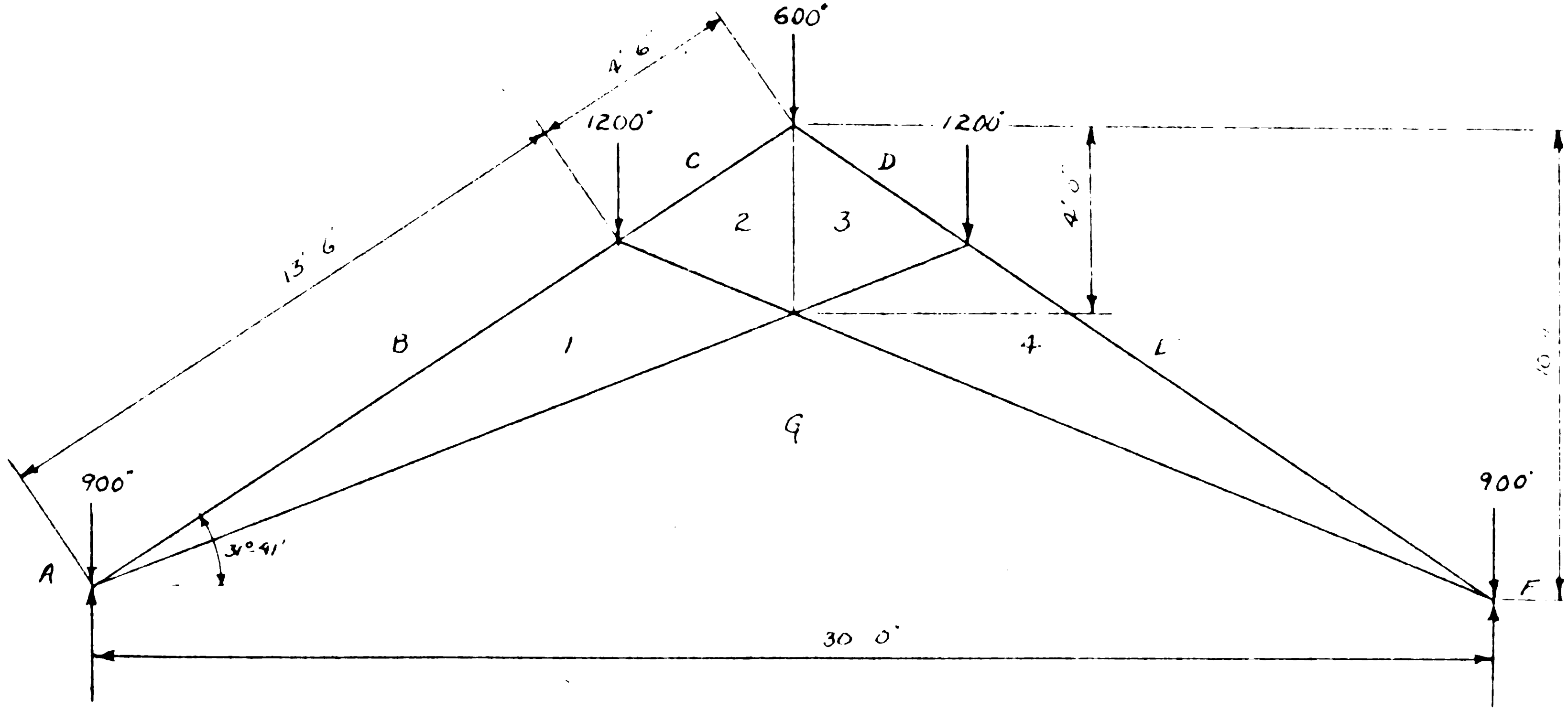
Shingles = 3# / sq. ft.

Sheathing = 4# / sq. ft.

Rafters = 1.3# / sq. ft.

Total = 8.3# / sq. ft.

Dead Load = 72.12 x 8.3 = 600#



LINE DIAGRAM

FIG 1

SCALE 1" = 8'-0"

K.L.W 10 10 42

Load Distribution

$\frac{4.5}{18} \times 2400 = 600\#$ on Surface C

$\frac{13.5}{18} \times 2400 = 1800\#$ on Surface B

$R_1 = R_2 = 2400\#$

Load at Joint A, B, 1, G $= \frac{1800}{2} = 900\#$

Load at Joint B, C, 1, 2 $= \frac{1800}{2} + \frac{600}{2} = 1200\#$

Load at Joint C, D, 2, 3 $= \left(\frac{600}{2}\right) 2 = 600\#$

Refer to Figure 1

Stresses As Scaled From Figure 2

Member	Character of Stress	Stress	Size of Member
B,1; E,4	Compression	8520	2 x 8"
C,2; D,3	Compression	5145	2 x 8"
G,1; G,4	Tension	5820	2 x 6"
1,2; 3,4	Compression	1200	2 x 6"
2,3	Tension	5180	2 x 10"

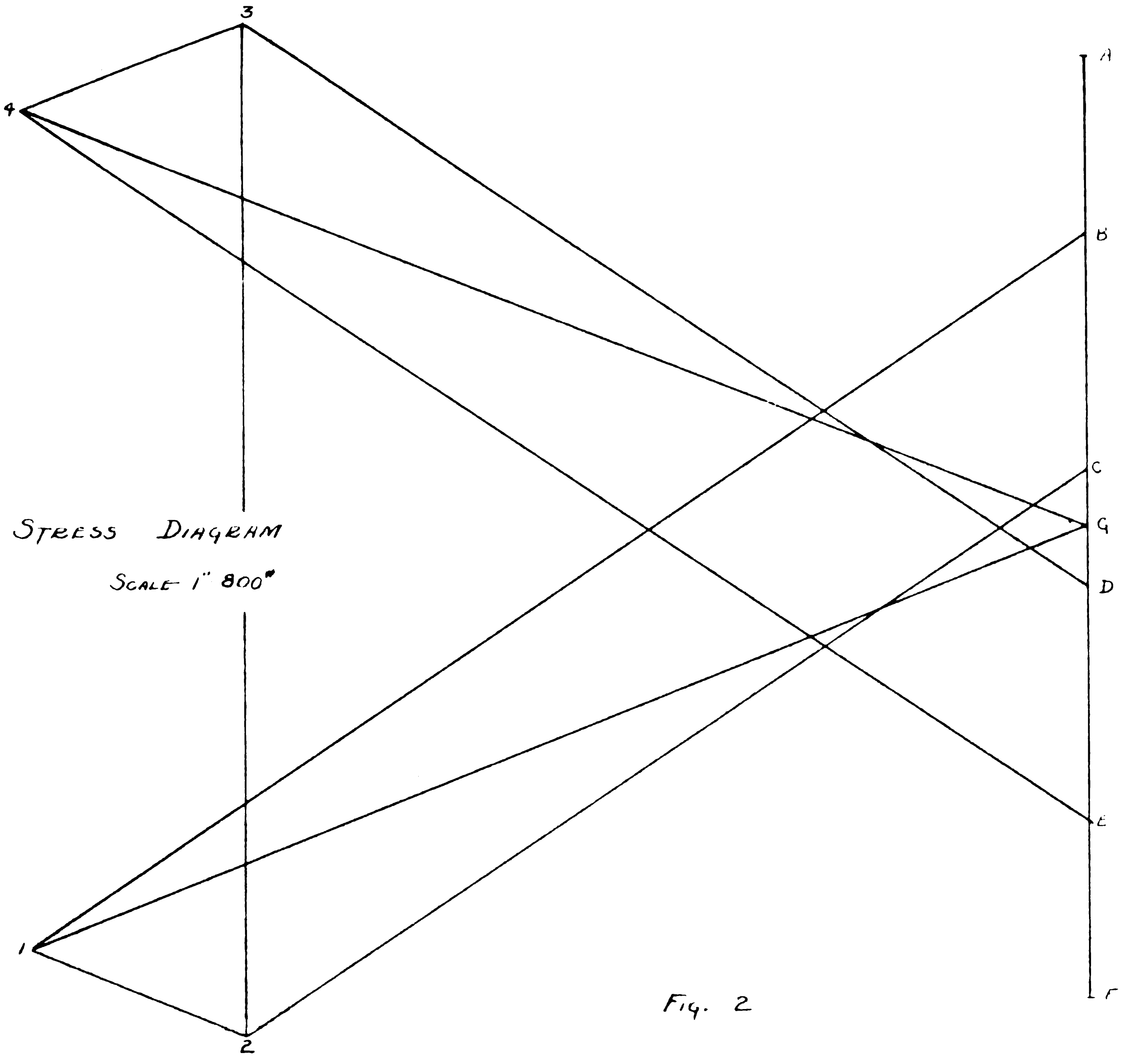


Fig. 2

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Design of Members

Southern Yellow Pine   Number 1 Common Grade

Allowable ----

Compressive Stress - 1000# per Square Inch
Tensile Stress - 1200# per Square Inch

Stresses taken from Kidders Handbook

Member B,1; E,4

In Compression $\frac{6520}{1000}$ = 6.52 square inch area required

$\frac{l}{d}$ Ratio = $\frac{13.5}{6''}$ x 12 = 27

Use 2" x 6" Timber   Actual Area = 8.94 square inch

Member C,2; D,1

Use same size as B,1 for balance & continuity in upper chord.

Member G,1; G,4

In Tension $\frac{5820}{1200}$ = 4.85 square inches required

Use 2" x 6" Member

Member 1,2; 2,3

Use same size as for G,1 for balance and continuity.

Member 2,3

$\frac{5120}{1200}$ = 4.4 square inch required

Use 2" x 10" Member to provide room for Connector Spacing.

Stud Design

Column Formula = $P_{CR} = \dfrac{\pi^2 EI}{4\ L^2}$

P_{CR} = Critical Load

E = 1,800,000

I = Smallest Moment of Inertia

L = Length of Column = 10 feet

$$P_{CR} = \frac{3.14^2 \times 1,800,000 \times 32}{4 \times 120^2} = 8750 \qquad I = \frac{bh^3}{12} = \frac{6 \times 4^3}{12} = \underline{32}$$

P_{CR} = 8750# Allowable Actual = 2400

$\dfrac{l}{d} = \dfrac{10 \times 12}{4} = 30$

For studding use 2-3" x 8" members nailed together with a plate consisting of 2-2" x 8" member nailed together.

$$\frac{2400\#}{1000} = 3.4 \text{ square inch area required}$$

Size of studs gives added strength and a good foundation for plate and trusses.

Joint Design

Refer to Figure 8 for Connector Arrangement.

Gable Joint

Allowable stress per Connector = 2680#

Maximum stress = 5150#

Use 3 - 4" toothed ring connectors

Use 3 - 3/4" bolts 8" long

Use 2 plywood gusset plates 18" x 18" x 1"

Joint 1,2 3 C

Maximum load = 6520 - 5145 = 1375 lbs.

1-4" Toothed Ring Connector = 3560#

Use 1-4" Toothed Ring Connector

Use 1-3/4" Bolt 8" long

Joint 1,2,3,4 G

Maximum load = 5820 + 1200 = 7020#

1-4" Toothed Ring Connector =2230#

1-2 5/8 Toothed Ring Connector = 450#

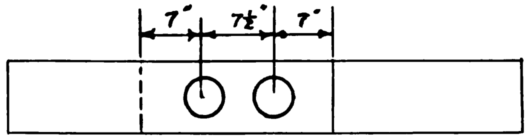
2680#

Increase basic connector values 33% for wind load stress   2680 x 1.33 = 3560# per connector

Use 4-2 5/8" toothed ring connectors placed concentrically inside 4-4" toothed ring connector

Use 2-1" bolts 8" long.

Splice Design for member G,1; G,4



Load = 5320

Required 3 - 2 x 8" x 12' boards

Use 2-4" tooth ring connectors

2 - 3/4" bolt 8" long

Allowable stress per connector = 3820#

Design of Heel Joint

Maximum Stress = 5620

Angle between members = 8° 52'

1 tooth ring 4" = 3820

1 tooth ring 2 5/8" = 355

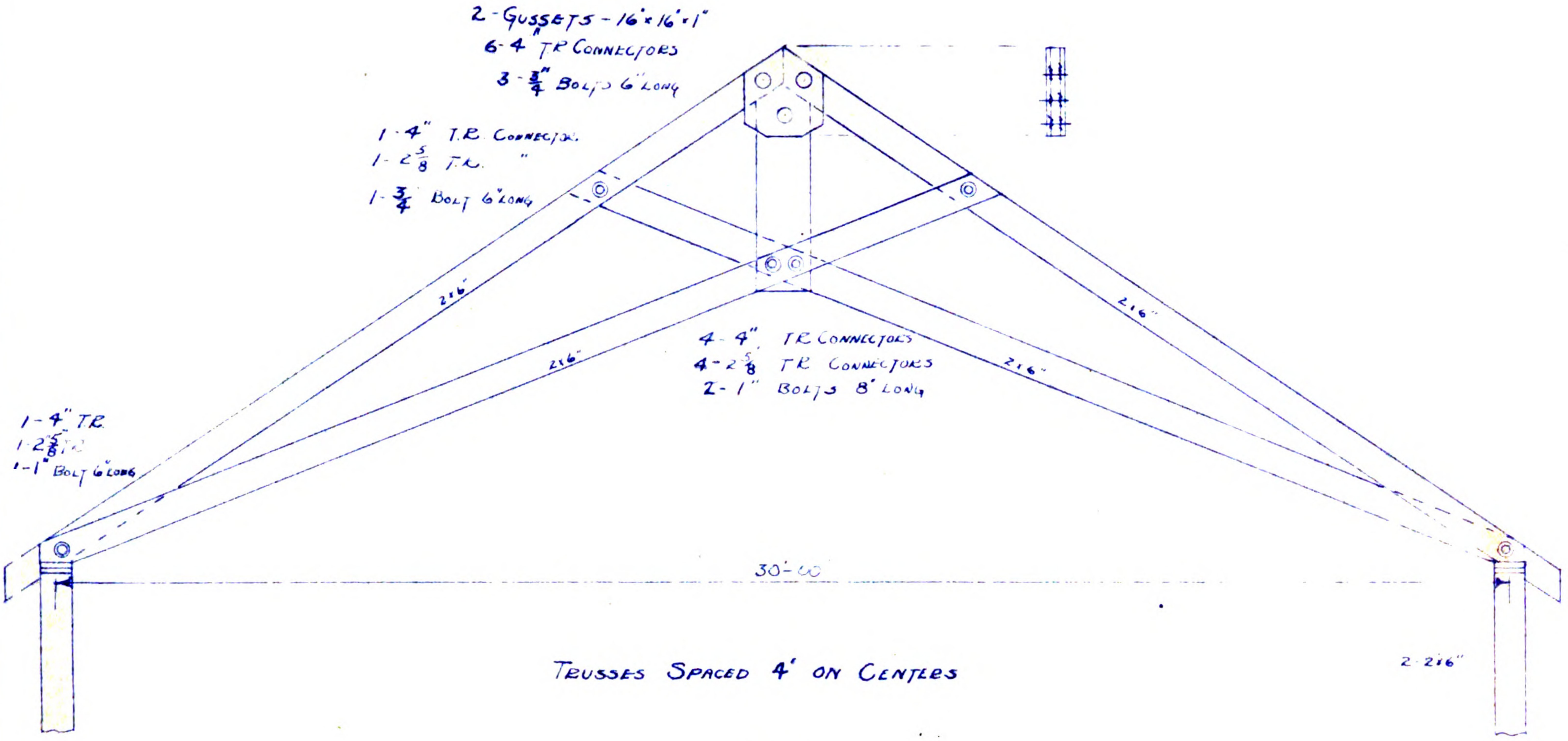
4175

An 33% increase in connector values may be made due to wind load and a 7% increase due to increased size of bolt

4175 x 1.33 x 1.01 = 5350#

Use 1-2 5/8" toothed ring connector placed concentrically inside 1-4" toothed ring connector

Use 1-1" bolt 8" long

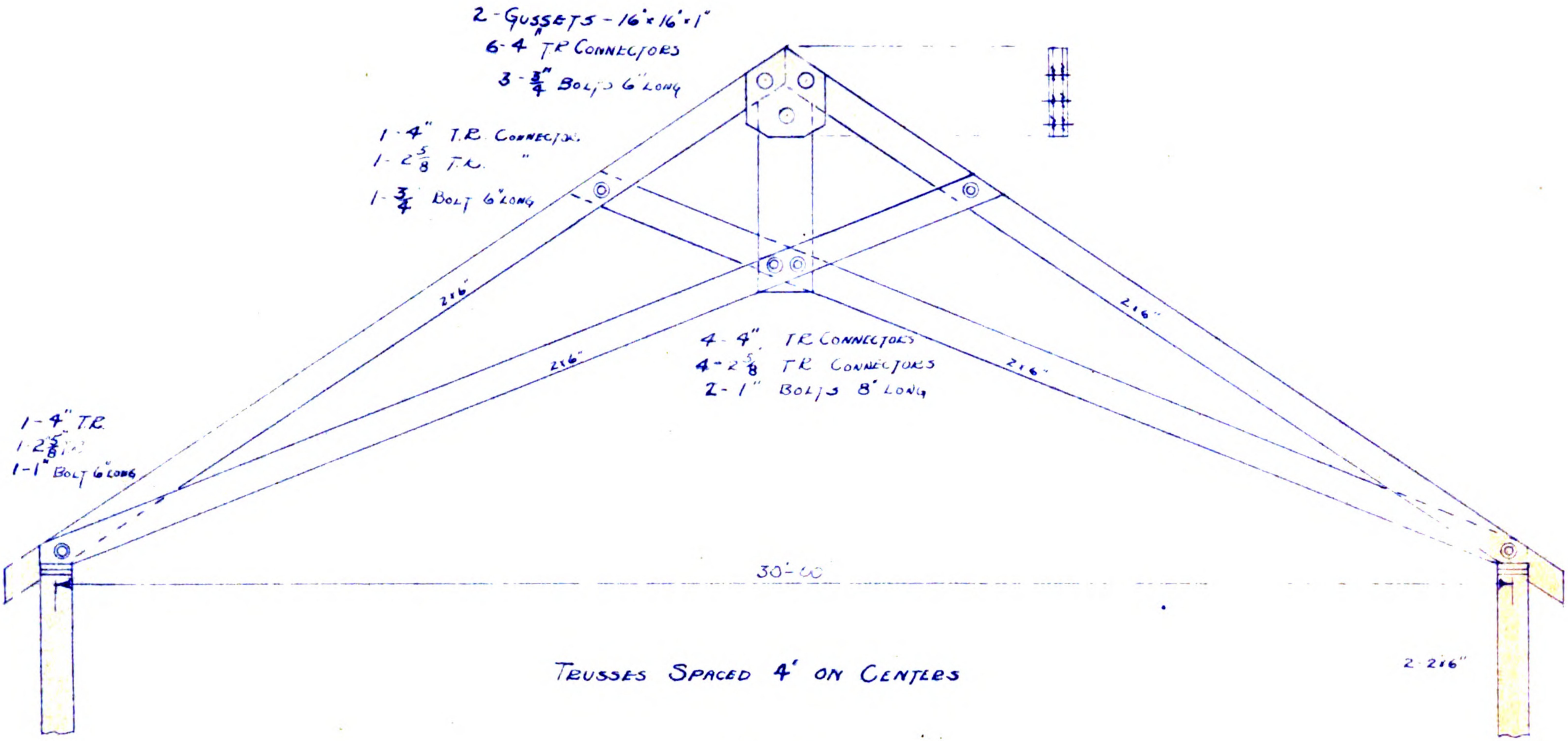


TRUSSES SPACED 4' ON CENTERS

FIG. 3

SCALE- 1" = 3'0"

R.E.W. 11-25-42



Trusses Spaced 4' on Centers

Fig. 3

Scale- 1" = 3'0"

B.E.W. 11-23-42

Heel Connection

Horizontal Force Outward = 6520 x cos 31° 41' =

= 6520 x .8509 = 5540#

Horizontal Force Inward = 5820 x cos 21° 49'

= 5820 x .9284 = 5400#

Horizontal reaction a heel joint

= 5540 - 5400 = 140#

Allowable load per lineal inch of penetration for

16 d nails = 38#

2" penetration

$$\text{No.} = \frac{140}{76} = 1.86 \text{ nails}$$

Toenail truss to plate using 4 16 d nails

Cost Estimate

Lumber

2 - 2" x 6" x 20' = 40 board feet

4 - 2" x 6" x 12' = 48 board feet

1 - 2" x 10" x 4' = 4 board feet

SUM 92 board feet

10% waste = 10 board feet

Total 102 board feet

Cost of Lumber = $54.00 / 1000 board feet

Cost per Truss = 102 x $.054 = $5.50

Cost of Gussets = .50

$6.00 per Truss

Roof Area = 2(18 x 42) = 1510 board feet

$\frac{1510}{1000}$ x $54 = $81.50 Cost of Sheathing

Shingles

$\frac{1510}{100}$ x $7.00 = $105.70 cost of shingles

Hardware

4 - 2 5/8" toothed ring connectors

14 - 4" toothed ring connectors

4 - 1" bolts 8" long

11 - 3/4" bolts 8" long

30 plate washer 3½ x 3½ x 3/8

Cost of Hardware

Cost of connectors	=	18 x 12½	=	$2.25
Cost of bolts	=	15 x 10	=	1.50
Cost of washers	=	30 x 10	=	3.00
Total Cost of Hardware			=	$6.75

Cost of Trusses = 11 x $8.00	=	$88.00
Cost of Sheathing	=	81.50
Cost of Shingles	=	105.70
Cost of Hardware = 11x$6.75	=	74.25
		$387.45 = Total cost of roof

Storage Space

Barn 30 feet x 40 feet

2 - Mows 30 feet x 14 feet with 12 foot drive floor

Under Truss

Area - 2 (15 x 3) = 90 square feet

2 (30 x 14' mows) 2520 Cu. Ft. Storage space
Allowable space for storage of 1 ton of loose hay = 500 cu. ft.

$\frac{2520}{500}$ = 5.1 ton maximum storage under roof

Due to difficulty in packing hay in close to rafters, probably storage would be 1 ton less until hay has had time to settle. Additional hay may be stored at the rate of .84 tons per foot of depth below the plate.

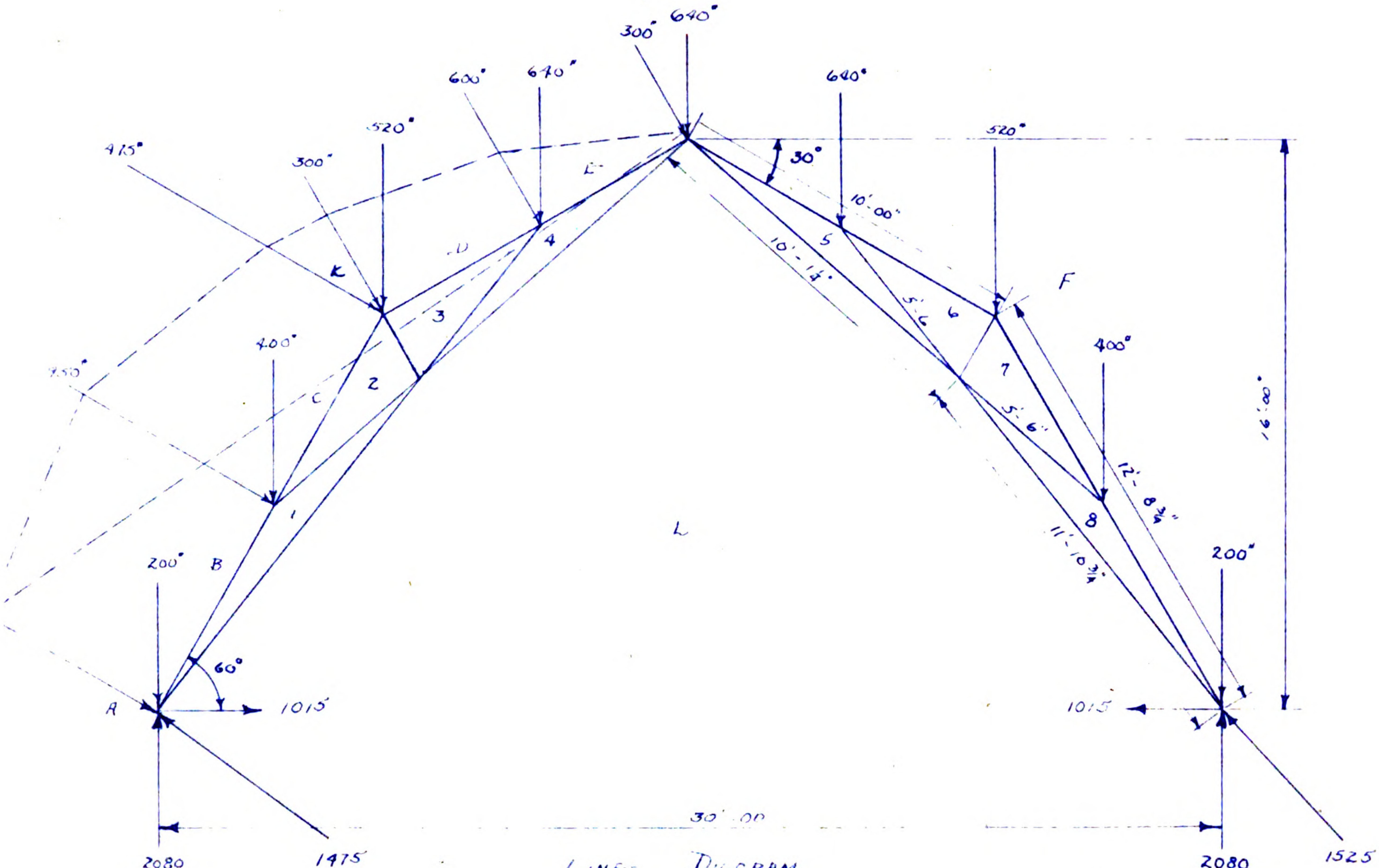
30' x 14 x 1 = 420 cu. ft.

$\frac{42}{50}$ = .84 tons per mow

Design of Gambrel Truss

In the design of a gambrel truss, the truss should approximate an inverted catenary curve to give the best placement of materials for arch construction. If, therefore, the joints of the gambrel fall on or near the curve, the best roof truss will probably result.

Common practice says, however, that this first rafter is set at approximately 60° to the horizontal and the second rafter is set at approximately 30° to the horizontal. Thus in the following design, the values of 60° and 30°, respectively, were used.



LINE DIAGRAM

FIG 4

SCALE 1"=4'-0"

B.E.W. 11-25-42

Design

Trusses spaced 5 feet on centers

60° Pitch Wind Load 30#/sq. ft.

Dead Load

Snow Load = 2.5# / sq. ft.

Roof Truss= 3.0# / sq. ft.

Shingles = 3.0# / sq. ft.

Sheathing = 4.0# / sq. ft.

Total =12.5# / sq. ft.

Area = 12.7 x 5 = 63.5 sq. ft.

Wind Load = 63.5 x 30 = 1900#

Dead Load = 63.5 x 12.5 = 795#

30° Pitch Wind Load 24#/sq. ft.

Dead Load

Snow Load = 15.0# / sq. ft.

Roof Truss= 3.5# / sq. ft.

Shingles = 3.0# / sq. ft.

Sheathing = 4.0# / sq.ft.

Total = 25.5# / sq. ft.

Area = 10 x 5 = 50 sq. ft.

Wind Load = 50 x 24 = 1200#

Dead Load = 25.5 x 50 = 1220#

Table 2. Stresses as Scaled from Figures

Member	Dead Load Stress	Live Load Stress Windward	Live Load Stress Leeward	Worst Combination	Size of Members
B,1	-2545	-6840	+870	-9,385	2" x 8"
C,2	-1582	-3550	+370	-5,132	2" x 8"
D,3	-1105	-3630	+750	-4,735	2" x 8"
E,4	-2130	-[illegible]	+750	-3,520	2" x 8"
12	- 643	-2880	-0-	-3,520	2" x 8"
23	+ 345	+1210	-430	+1,555	2" x 8"
34	-1505	-2730	-0-	-4,235	2" x 8"
1,L	+ 410	+6750	+2,390	+9,140	2" x 8"
4,L	+1170	+5150	-2,270	+7,320	2" x 8"

* + Designates Tensile Stress; - Designates Compressive Stress

Stress Diagram Dead

Design of Members

Southern Yellow Pine Number 1 Common Grade

Allowable

Compressive Stress = 1000# per sq. ft.

Tensile Stress = 1200# per sq. ft.

Stresses taken from Kidders Handbook

Member B,1

$$\frac{l}{d} = \frac{8.55 \times 3}{2} = 9.55$$

$$A = \frac{[illegible]}{1000} = 9.33 \text{ sq. in. area required.}$$

Use 2" x 8" Member actual area = 12.2 sq. in.

Members C,2 - D,3 - E,4 will be constructed of 2" x 8" lumber also to maintain continuity in the upper chord of truss. Members are safe as all compressive stresses are smaller than for B,1.

Member L,1

$$A = \frac{9140}{1200} = 7.62 \text{ sq. in. required}$$

Use 2" x 8" member Actual Area = 12.2 sq. in.

Member L,4

Use same size as for L,1 to maintain continuity and aid in ease of construction.

Members 1,2 - 3,4

$$A = \frac{[illegible]}{1000} = 4.29 \text{ sq. in. required}$$

2" x 8" member will be used as L,1,3,4 and L,4 1,2 are continuous members.

Member 2,3

Area = $\frac{1505}{1200}$ = 1.2 sq. ft. required

Use 2" x 6" member to supply ample room for constructions.

Studding Design

Dead Load Reaction = 2080

Maximum Live Load Reaction = $\underline{1110}$

3190 = Total Load per Stud

$P_{CR} = \frac{\pi^2 EI}{4l^2} = \frac{3.14^2 \times 1.6 \times 10^6 \times 32}{4 \times 120^2} = 8750$

4" x 6" member

$I = \frac{bh^3}{12} = \frac{6 \times 4^3}{12}$

$I = 32$

$\frac{l}{d} = \frac{10 \times 12}{4} = 30$

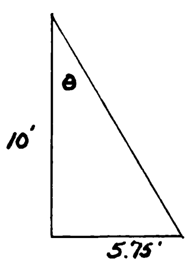
Use 2 - 2" x 6" pieces 10 feet long nailed together, with a plate consisting of 2-2" x 6" members nailed together.

Studs to be placed 5 feet on centers.

Ties

Maximum Horizontal Force on 2 Trusses = 3045 + 3570

= 6615#



$\sin\theta = \frac{6615}{X}$ $X = \frac{6615}{\sin\theta}$

$X = \frac{6615}{.5} = 13230\#$

Area $\frac{13230}{1200}$ = 11.01 sq. in. required

Use 2" x 6" member 12 feet long attached to both end trusses and the second truss from either end to resist the horizontal thrust.

Joint Designs

Gable Joint

Values taken from Manual of Timber Connector Construction. Supplement Number 3.

$V_{L,4} = 8560 \times \sin 30^{\circ} = 4280\#$

$V_{4,L} = 7320 \times \sin 41^{\circ}30' = \underline{4850\#}$

Difference = 590 x 2 = 1180# force downward

Use 6 - 4" Toothed Ring Connectors

3 - 3/4" Bolts 8" long

Use piece of 2" x 12" board 18" long bolted to each side of truss at gable to act as gusset.

Joint 2,C,D,3

$V_{D,3} = -4765 \times \sin 30^{\circ} = 4765 \times .5 = 2383\#$

$V_{2,3} = -1555 \times \sin 60^{\circ} = 1555 \times .866 = \underline{1350\#}$

3732# downward

$V_{3,C} = -5532 \times \sin 60^{\circ} = 5532 \times .866 = \underline{4850\#}$ upward

1118# vertical force

$H_{D,3} = 4765 \times \cos 30^{\circ} = 4765 \times .866 = 4130\#$

$H_{2,3} = 1555 \times \cos 60^{\circ} = 1555 \times .5 = 778\#$ 4130

$H_{C,2} = 5532 \times \cos 60^{\circ} = 5532 \times .5 = \underline{2766\#}$ $\underline{3544}$

3544# 586# outward

Use 6 - 4" Toothed Ring Connectors

3 - 3/4" Bolts 8" long

2 - Gussets 18" x 18" x 1" are required.

Joint D,2 4,3 Angle between members = 31° 30'

Maximum Load = 4280#

1 - 4" Toothed Ring = 3375

1-2 5/8"Toothed Ring = 525

3900

33% Increase Due to Wind Load Stress

3900 x 1.33 = 5180#

Use 1 - 2 5/8" Toothed Ring placed concentrically inside

1 - 4" Toothed Ring

1 - 3/4" Bolt 8" long.

Joint B,1,2,C Angles between members = 18°30'

Maximum Load = 3350#

1 - 4" Toothed Ring = 3375

1-2 5/8" Toothed Ring = 525

3900

Use 1 - 2 5/8" Toothed Ring Connector placed concentrically inside 4 Toothed Ring

1 - 3/4" Bolt 8" long.

Joint L,2,3,4L Angle between members 2,3 and 3,4 = 30°

Angle between members 3,4 and 4L = 10°

Maximum Stress = 13,438#

Angle 30°	Angle 10°
1—4" Toothed Ring = 2890#	2-4" Toothed Ring = 4800#
1-5/8" Toothed Ring = 450#	2-2 5/8"Toothed Ring= 900#
3340#	5700#

Joint 1,2,3,4L con't.

If stresses are due largely to wind load values, they may be increased by 33%.

Stresses may be raised 20% in smaller connectors due to increased size of bolt from 1/2" to 3/4".

(3340 + 90 + 5700 + 180) = 9310#

9310 x 1.33 12,400# Low

If bolt size be increased to 1" diameter load capacity of connectors may be increased 7%.

12,400 x 1.07 = 13,400

Use 6-2 5/8" Toothed Ring Connectors placed concentrically inside 6-4" Toothed Ring Connectors

Use 3 - 1" bolts 8" long

2 - 2" x 8" x 7" Filler blocks required as shown in Figure 7.

Heel Joint Angle Between members = 9° 30'

Stress in B1 = -2335#

Stress in 1L = -2140#

2 5/8" = $\frac{2235}{4}$ = 558

4" = 3650

3 3/8" = 3150

Total 7358

Due to Stress being caused largely by wind loads values may be increased 33%.

7358 x 1.33 = 9800#

Use 1-2 5/8" Toothed Ring Connector placed concentrically inside a 4" Toothed Ring Connector also 1 - 3 5/8" Toothed Ring connector spaced 6" on centers from 4" Connector.

Use 2 - 3/4" bolts 8" long.

Horizontal Force = 948#

Holding power of 30 d nails = 44" per inch of penetration.

3" x 44 = 132# per nail

$$\text{No.} = \frac{948}{132} = 7.18 \text{ nails required}$$

Toenail truss to plate using 8 - 30 d nails.

Cost Estimate

Lumber

2 - 2" x 8" x 14' = 37.3 board feet

2 - 2" x 8" x 10' = 26.6 board feet

2 - 2" x 8" x 16' = 43.5 board feet

2 - 2" x 8" x 18' = 47.3 board feet

1 - 2" x 8" x 2' = 2.7 board feet

Sum = 156.8

10% Waste = 15.7

172.5 board feet

Lumber = $54.00 per 1000 board feet

$$\text{Cost} = 172.5 \times \frac{54}{1000} = \$9.30 \text{ per Truss}$$

Cost of Gussets = 1.00

$10.30 Total Cost per Truss

Sheathing

Area = 12.7 x 42 = 533

10 x 42 = 420

953 x 2 = 1906 board feet of Sheathing

$\frac{1906}{1000}$ x 54 = \$103.00 Cost of Sheathing

Shingles

$\frac{1906}{100}$ x \$7.00 = \$133.42 Cost of Shingles

Hardware

18 -- 2 5/8" Toothed Ring Connectors

8 -- 3 3/8" Toothed Ring Connectors

30 -- 4" Toothed Ring Connectors

4 -- 1" Bolts 8" long

12 -- 3/4" Bolts 8" long

6 -- 3/4" Bolts 8" long

42 -- Plate Washer 3 1/2 x 3 1/2 x 3/8

Cost of Hardware

Cost of Connectors = 58 x 12 1/2 = \$7.25

Cost of Bolts = 22 x 10 = 2.20

Cost of Washers = 42 x 10 = 4.20

\$13.65 Total cost of Hardware

Total Cost

Cost of Trusses = 9 x 10.30 = \$92.70

Cost of Sheathing = 103.00

Cost of Shingles = 133.42

Cost of Hardware = 9 x 13 = 122.85

\$451.97 Total Cost of Entire Roof

Storage Space Under Truss

Barn 30' x 40'

Mows = 2 - 30 x 14

With 12' Drive Floor

15 x 8 x 2 = 240 square feet.

240 x 2(14) = 6725 cubic feet

$\frac{6725}{500}$ = 13.45 ton of hay under roof

Additional Hay in Mow at the rate of .84 tons per foot depth of Mow

30 x 14 x 1 = 420 cubic feet

$\frac{420}{500}$ = .84 ton per mow.

Comparisons and Conclusions

Storage under Gamorel Truss = 13.45 Tons

Storage under Scissors Truss = 5.1 Tons

Difference = 8.35 Tons

Cost of Gamorel Truss = $452.00

Cost of Scissors Truss = 327.00

Difference = $125.00

Cost per ton of storage space for Gamorel Truss $= \frac{452}{13.45} = \$33.60$

Cost per ton of storage space for Scissors Truss $= \frac{327}{5.1} = \$64.20$

Difference = $30.60

From the above figures, it is evident that the Scissors Truss is the cheaper of the two to construct. Due, however, to the space that is taken up by the members in the top of the truss, the storage space afforded by this truss is very poor. This type of truss would be more useful in a building where roof storage would not be so keenly needed.

The Gambrel Truss is by far the more practical to build, because, for a slightly higher initial cost, a storage space nearly three times as great as the Scissors Truss is acquired. This type truss as is borne out by the figures is about one-half cheaper to build per ton of storage space. A great number of variations of this type of truss is used in barn roof construction because of the fact that it leaves a clear mow space.

A greater storage could be had on this Scissors Truss by increasing the pitch, but it would not nearly approach that which is afforded by the Gambrel type of truss.

It is the evident conclusion of this report, that the Gambrel Truss is by far the best type of truss for a potential builder to select.

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