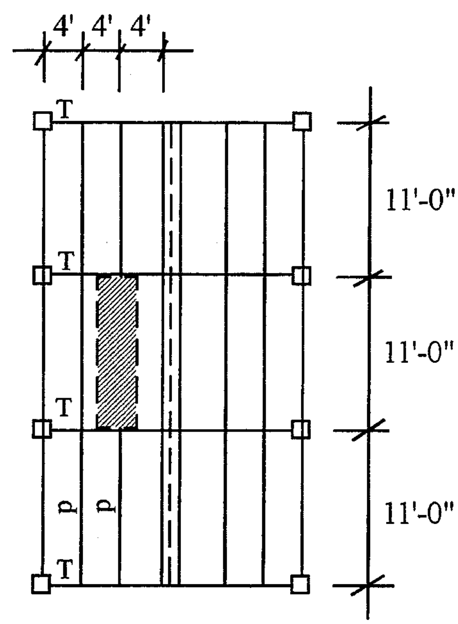
Chapter 3
DESIGN OF PURLINS AND TRUSSES

3.1. DESIGN OF PURLIN

Design of purlin sizes are based on an analysis of bending members as a simple beam. The length of the purlin from truss to truss is taken as the span length needed for the single span, simply supported beam formula. This is a conservative approach as it provides for a larger bending moment than that obtained by true engineering analysis.



Illustrative Example

Let purlin spacing = 4' - 0" C/C

Truss spacing = 11' - 0" C/C

Truss span = 50' - 0"

L. L = 16 psf

Sheathing = 2 psf

Roofing material = 4.5 psf

Use PyinKado. Unit wt. = 60 pcf.

Assume 5" x 2" purlins are used.

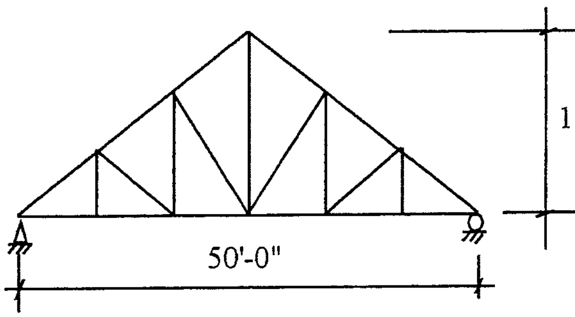
L.L	=	16 x 4 x 11	=	704	Lb
Roofing	=	4.5 x 4 x 11	=	198	Lb
Sheathing	=	2 x 4 x 11	=	88	Lb
Own wt.	=	$\frac{5 \times 2}{144} \times 60 \times 11$	=	45.83	Lb
		W	=	**1035.83**	**Lb**

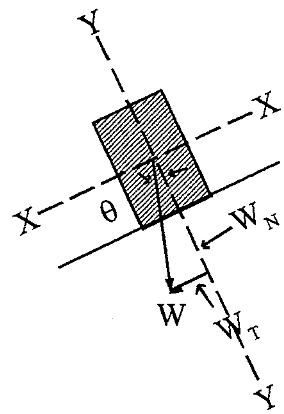
$$\theta = \tan^{-1} \frac{18}{25} = 35.754$$

$$W_N = W \cos\theta = 1035.83 \times \cos 35.754 = 840.61 \text{ Lb}$$

$$W_T = W \sin\theta = 1035.83 \times \sin 35.754 = 605.24 \text{ Lb}$$

$$M_X = \frac{W_N L}{8} = \frac{840.61x(11x12)}{8} = 13870.07 \text{ in-lb}$$





$$Z_x = \frac{1.75 x (4.75)^2}{8} = 6.58 \text{ in}^3$$

$$\sigma_{b_X} = \frac{M_x}{Z_x} = \frac{13870.07}{6.58} = 2107.91 \text{ psi}$$

Similarly,

$$M_y = \frac{W_T L}{8}$$

$$Z_y = \frac{4.75 x (1.75)^2}{6}$$

$$\sigma_{by} = \frac{M_y}{Z_y}$$

If $\sigma_{tot} = \sigma_{bx} + \sigma_{by} \leq$ allowable F_b, OK.

Deflection Check

Allowable max: deflection from AITC $= \frac{L}{120} = \frac{11x12}{120} = 1.10"$

W_{DN} = (wt. of roofing + own wt. + sheathing) x Cos θ

= (198 + 45.83 + 88) x Cos 35.754°

= 269.29 lb

W_{LN} = L.L x Cos θ = 704 x cos 35.754° = 571.32 Lb

$$I = \frac{bd^3}{12} = \frac{1.75 x (4.75)^3}{12} = 15.63 \text{ in}^4$$

$$\Delta_X = \frac{5}{384} \frac{(2W_{DN} + W_{LN})}{EI} L^3$$

Similarly,

$$\Delta_y = \frac{5}{384}\frac{(2W_{DT}+W_{LT})}{EI} L^3$$

If actual $\Delta = \sqrt{(\Delta_x)^2 + (\Delta_y)^2} \leq$ allowable deflection from AITC, OK.

Choose 5" x 2" purlins.

3.2. DESIGN OF ROOF TRUSSES

3.2.1. Selection of Roof Trusses

Architectural style, types of roofing material, methods of support of column framing, and ralative economy are the principal factors influencing a choice among the three basic types of trusses: bowstring, pitched, and flat. In addition, side- and end-wall height and type, roof shape, and bracing requirements must be considered.

Other factors being equal, economy is the prime consideration. Economy is dependent upon efficiency in use of material relative to truss type and proportions and to fabrication labor. Theoretically, the three basic types in order of relative efficiency are bowstring, pitched, and flat.

The function of a truss is to transfer load from point of application to the supports as directly as possible. Thus for a concentrated load at the centerline of a span, a simple "A" frame is the most efficient. Like-wise, if only two equal and symmetrically placed concentrated loads are involved, a truss similar to the queen-post type is the most effcient. In both trusses, the load is transferred to the support directly through the sloping top-chord members without the need for web members.

3.2.1.1. Bowstring Trusses

For more or less uniform loads, which are usually assumed in roof construction, an arch in the shape of a parabola is theoretically the most efficient because direct stress alone is developed in the arch and in the tie member. A parabolic arch has no need for a larger arch section to take care of bending moment, moreover, and no need to introduce web members to lessen the amount of bending. Because most structures must sustain some unbalanced load, however, web members are desirable, and a circular arc is simpler to fabricate than a parabolic one. Thus the widely used bowstring truss has a top chord in a circular arc and sufficient web members to keep top-chord sizes reasonable.

Bowstring trusses are usually analyzed for direct stress as though the top chord were in a straight line between panel points. Top chords may be glued-laminated (Fig. 3.1) to the curvature or may be solid timbers laid to the curved pattern with or without their top surfaces sawed to the curvature (Fig. 3.2). The bending moment due to eccentricity between panel points must be considered both for curved-laminated members and for members sawed to curvature if the centerline of the member does not coincide with the assumed direction of axial stress. If joists are spaced along the top chord, this secondary bending moment may permit the use of smaller member sizes than would a truly segmental, sawed timber top chord. In addition, because of their higher allowable unit stresses, glued-laminated top chords and other glued-laminated members normally permit the use of smaller sizes. They also eliminate or lessen the need for the seasoning maintenance required by some sawed members. Because of the extra labor involved in laminating, however, they may be more expensive than sawed members.

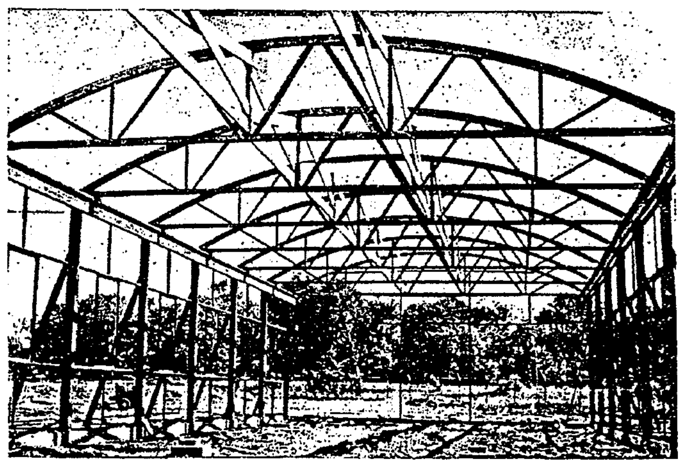


Fig 3-1. Bowstring truss, glued-laminated

Eight 54 ft span trusses spaced 18 ft, 6 in. on centers.

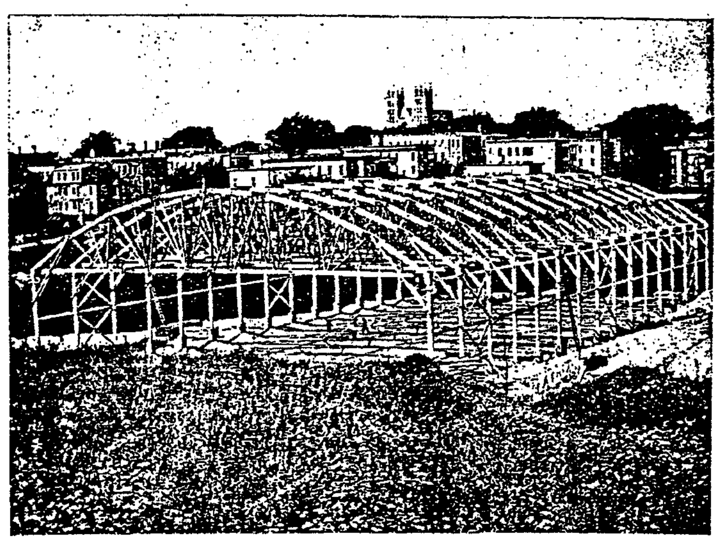


Fig 3-2. Bowstring truss, segmental

Sixteen 130 ft span trusses for a skating rink

Top chords that have been mechanically laminated with nails, bolts, or both are sometimes used for bowstring trusses. Although their efficiency is less than that of a glued-laminated member or a sawed member of the same size, they are suitable for use if the amount of nailing has been designed or sepcified on the basis of experience to provide the required strength of the built-up section. The section will usually be larger than that needed for a glued-laminated member, but it will also be more suitable for field lamination.

A bowstring truss may be built up to provide the appearance of either a flat or a pitched truss and thus is probably the most flexible of all truss types. For such constructions, proper lateral bracing should be provided for that portion of the curved top chord which lacks direct lateral support from the roof framing. (see Fig 3.3)

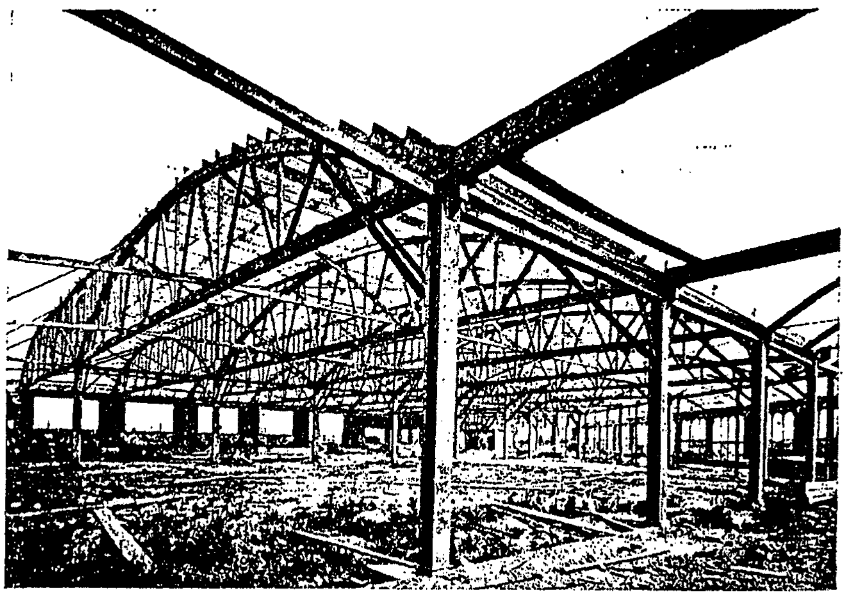


Fig. 3-3. Bowstring truss, built-ups

Eighteen 76 ft span trusses , one 72 ft truss, one 68-ft truss.

3.2.1.2. Pitched Trusses

Pitched trusses (fig. 3.4) have some of the theoretical advantages of bowstrings in that a portion of the load is transferred to the supports directly through the top- chord members and need not be carried through the web members. For average spans, the top chords of pitched trusses have the economic advantage of permitting the use of sawed timber without special sawing or fitting to curvature, and of being simple to lay out and fabricate. Web-member and other connections are also simple, as a rule. Like those in a bowstring truss, they are much less complicated than flat-truss connections.

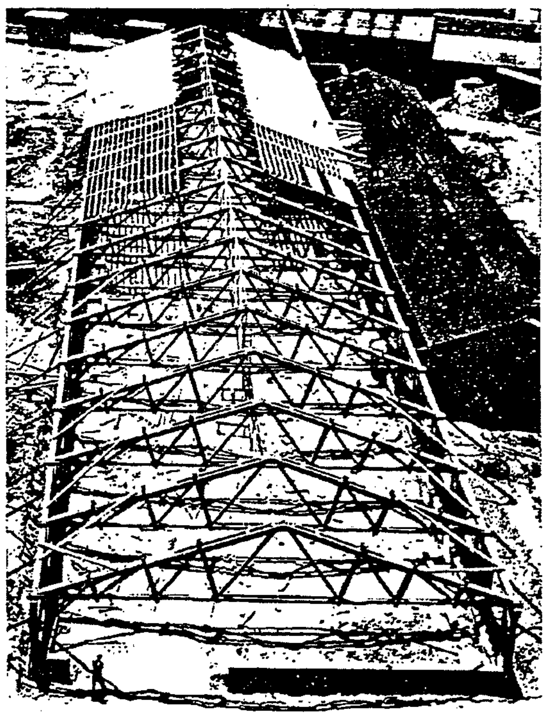


Fig. 3-4. Pitched Truss

Eighteen 64 ft span Belgian trusses.

3.2.1.3. Flat Trusses

Flat trusses (Fig. 3.5) are less efficient than either the pitched or bowstring type. They are preferable only if a relatively flat roof surface, particularly on with multiple spans, is desired. For lateral-bracing and column connections, they have the advantage of providing a bracing effect, because both the top and bottom chords may be attached to the columns. For usual truss proportions, their web-member stresses will be considerably greater than those for pitched or bowstring trusses and their web connections more complicated and expensive.

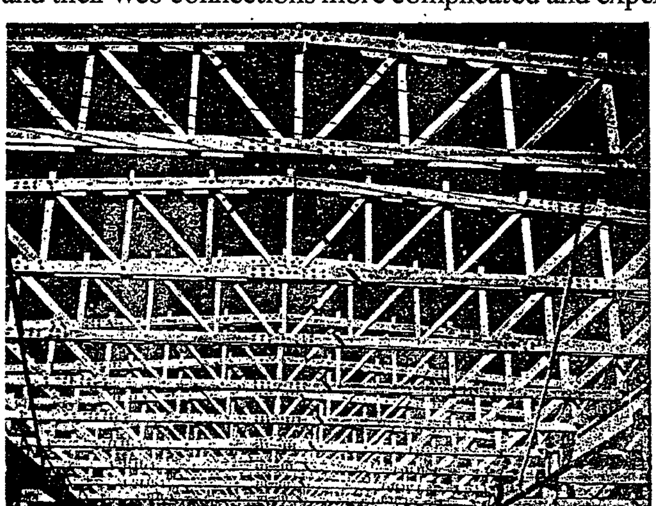


Fig 3-5. Flat Pratt truss

3.2.1.4. Raised-chord Trusses

Raised-chord trusses(Fig.3.6) are trusses with the center portion of the bottom chords raised substaintially above the level of supports. They are frequently used for reasons of appearance or added clearance. Typical examples are crescent trusses of a bowstring type, the so-called cambered or raised-bottom-chord pitched trusses employing Howe, Pratt, or Fink web systems, and scissors trusses. Unless these trusses are analyzed as arches and fixity or resistance to horizontal thrust provided accordingly at the support, the effective depth-to-span ratios of simple trusses should be maintained.

A raised-chord truss, particularly one with spans, longer than 50ft, should be analyzed for the thrust on the walls induced by deflection, and the walls or columns designed accordingly. Otherwise special bearing details or wall framing should be provided to relieve the thrust .

If a truss is supported by masonry, thrust due to deflection may be minimized by means of slotted anchorage connections. Roller supports at one bearing are not common except in large spans where more positive free movement is considered necessary. Provision for deflection thrust relief is most important at the time of erection; later the truss wil have stabilized substaintially. If maximum vertical live load and wind are assumed not to occur at the same time, moreover, the normal provision for wind loads on the supports is often considered adequate for vertical load deformation thrust.

Fig 3-6. Scissors Truss

Span of 33 ft, 6½ in., 12 ft spacing; 45-deg roof slope; 30-deg bottom-chord slope.

For trusses supported on free-standing columns with masonry side walls, it is well to allow clearance for lateral deflection between column and wall at the time of erection. After original lateral movement, the connections between column and wall may be tightened. Required clearance may be determined by deflection calculations, but it is frequently rather arbitrarily chosen on the basis of experience.

3.2.1.5. Special Trusses

There are many other types of trusses as well as combinations of the standard types that offer special advantages for special conditions. In general, the same recommendations for proportions, spacing, and other design details continue to apply. Typical combinations are bowstring-flat (Fig. 3.7a) and pitched-flat trusses (Fig. 3.7b) of a two-span width, which provide drainage to outside walls. Combinations of Pratt and Howe web systems are frequently used with flat trusses. Special types include the common saw-tooth truss, cantilevered trusses, and inverted trusses.

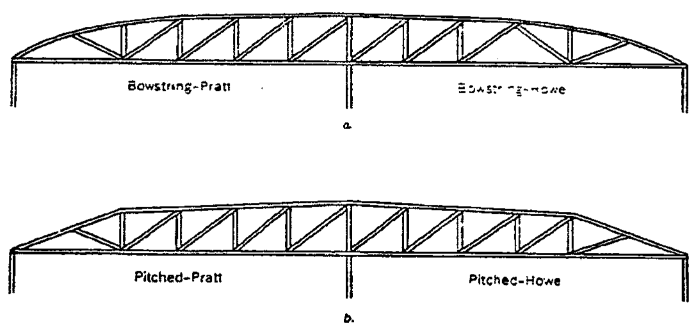


Fig. 3-7. Combinations of truss types

Indeterminate structures, such as rigid frames or continuous trusses, are not frequently used in timber. Such trusses frequently present erection problems that increase costs more than the savings made in materials.

3.2.2. Maximum roof truss span

3.2.2.1. Economic factors

The maximum economical span of any given type of timber truss will vary with the material available, loading conditions, spacing, type of truss, ratio of labor to material cost, and fabrication methods.

3.2.2.2. Pitched and flat roof trusses

Pitched and flat roof trusses with average loading and spacing of 15 to 20 ft are infrequently used for spans in excess of 80 ft. Economical spans are usually limited by the available sizes and lengths of solid sawed or glued-laminated timber and by the potential capacity of the web-member connections. If loading and spacing are smaller, larger spans may be constructed with the same relative member sizes and joint details.

3.2.2.3. Bowstring roof trusses

Bowstring trusses are economical in spans up to 250 ft or more. Bowstring trusses using glued-laminated members are usually shop-fabricated and are not recommended for field fabrication unless competent supervision is provided and essentially the same quality control is exercised as required under shop conditions. As many fabricators have standardized on the bowstring type, it may profitably be considered as an alternative even though original designs may call for a flat or pitched type truss.

3.2.2.4. Light roof trusses

Light trusses, such as trussed rafters of 2 to 4 ft spacing, are recommended for spans up to about 50ft (see Fig3.8). They can be built for longer spans, but a heavy truss with larger spacing may be more economical for this purpose and may even be so for spans under 50 ft.

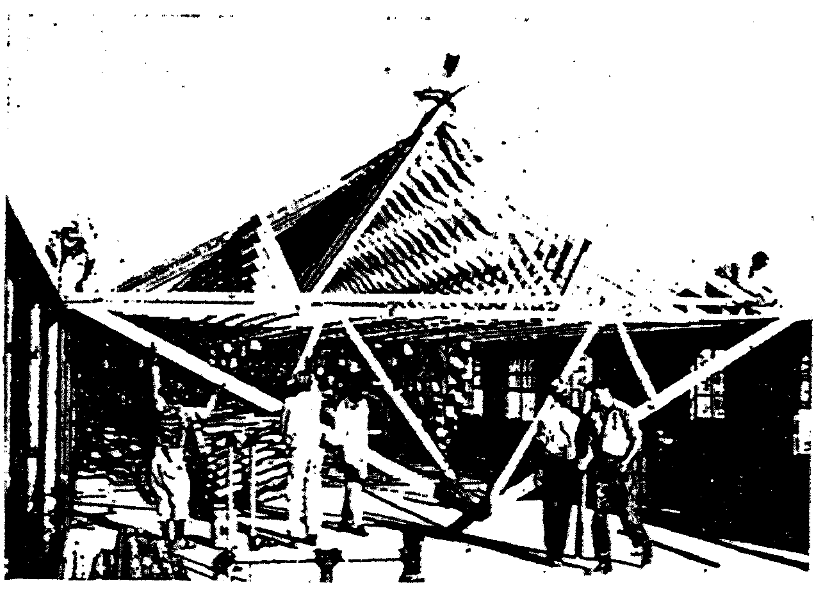


Fig. 3-8. Triangular trussed rafters

Trussed rafters are particularly require small, readily available pieces of lumber, their joints are simple to fabricate, and completed units are light enough in weight to be handled and erected without special equipment.

3.2.3. Truss proportions

3.2.3.1. Truss proportions

If economy, deflection, and secondary stresses due to deflection are disregarded, trusses may theoretically be built to almost any proportions. An understanding of the interrelated factors that contribute to performance and economy will aid the designer in selecting the best system.

3.2.3.2. Depth-to-span ratio

Certain ratios of effective depth to span are recommended as being satisfactory on the basis of experience. The larger the span, the more desirable it is to use deeper trusses. Although trusses of less depth than these may be acceptable, special attention should then be given to the possibility of greater deflection and secondary stresses. Deflection in trusses of less-than-average depth may be held to a minimum by the following practices: (1)conservative design,(2) the use of low or intermediate grades of material, (3) the use of a minimum number of chord splices (by employing the longest available lengths), (4) the use of fastenings with the smallest deformation, and (5) the use of as few panels as possible. Stiffer members are also obtained, and therefore less deflection for a given load.

It is recommended that the top chord of a bowstring truss be fabricated with a radius about equal to the span. The suggested effective depth-to-span ratio is between 1:6 and 1:8. A radius equal to the span will give a ratio slightly larger than the suggested minimum.

For pitched trusses, an effective depth-to-span ratio between 1:5 and 1:6 is recommended, and a minimum of not less than 1:7 unless special consideration is given to deflection . Much deeper trusses may be used for the sake of appearance, such as for the steeply pitched roofs popular in churches.

For flat trusses, a minimum depth-to-span ratio between 1:8 and 1:10 is recommended, the deeper trusses being preferred for the longer spans. Roofs should have a minimum slope of ¼ in. per ft for proper drainage, although steeper slopes are often desirable. Flat roofs with no slope for drianage are not recommended unless provision is made in the design for possible accumulation of water due to a stopped drain or natural deflection. Drains on flat roofs should be located at the low points. These are at the center of the span if the truss is built flat.

In longer spans, secondary deflection stresses are probably more important. As these stresses are not capable of exact computation, the larger depth-to-span ratios should be used for trusses employing such spans. Deflection of free-span trusses is usually well within acceptable limits, even that for plaster, but care should be taken to see that the natural deflection does not interfere with auxiliary framing. Suspended ceilings are often desirable. Ample clearance should be provided between trusses and so-called nonbearing partitions or plate glass windows. Provision should also be made for adjustment in the level of the hingers if there is a possibility that deflection may interfere with the proper operation of truss-suspended doors or machinery.

3.2.3.3. Number of panels

It is desirable to use as few truss panels as the use of reasonable member sizes will allow. This practice will mean fewer members to handle, fewer joints to fabricate and assemble, and theoretically improved performance. The number of panels usually should be determined by reasonable top-chord sizes rather than by any fixed formula. For materail of 2 to 4 in. thickness, desirable panel length will usually be in the range of 6 to 10 ft. Thus, a symmetrical truss of 30 ft span would probably have four panels whereas a 40 ft truss might have either four or six, and an 80 ft truss eight or ten.

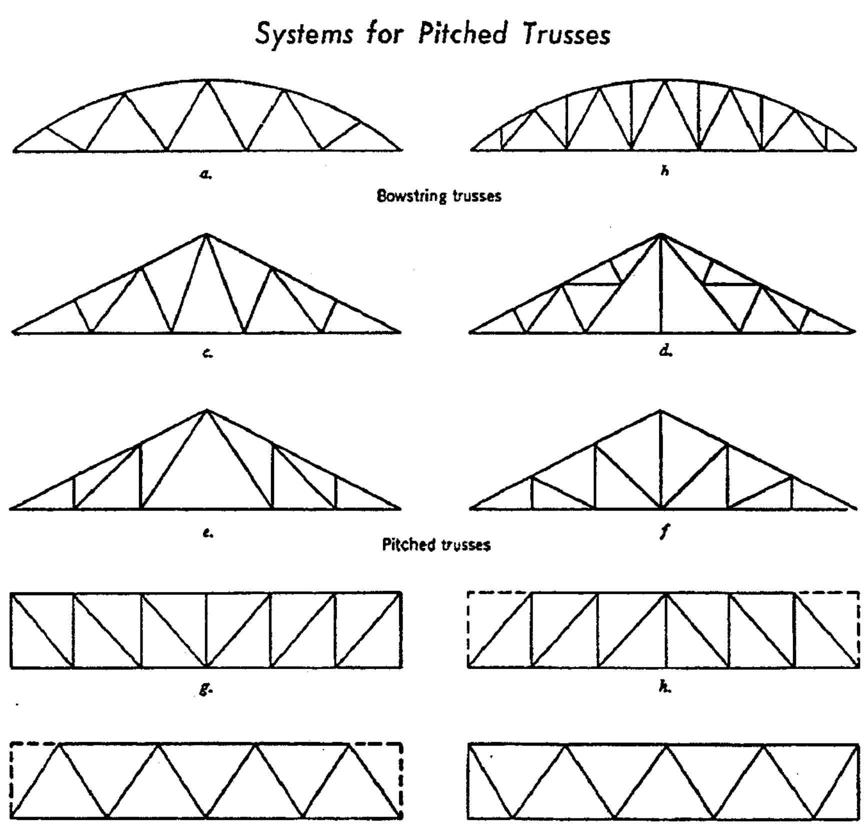


Figure 3-9. Truss types and web-member systems.

3.2.4. Roof construction systems

Only two basic systems of roof construction need be considered in truss design. One applies roofloads to the truss only at the panel points; the other applies them either continuously, as with plank roofing; or at intervals along the top, as with joints. The former system produces only direct stress in the chord member; the latter introduces bending as well as direct stress.

In terms of lumber alone, joints closely spaced along the chords or purlins placed at and between panel points are more economical than purlins placed only at the panel points because the latter require heavier plank roofing or rafters and sheathing. However, labor costs are less if purlins and planking are used instead of closely spaced joists because there are fewer pieces to handle and fewer points at which the planking must be nailed. Thick planks of the lighter species of wood, with special tongues and grooves, are sometimes applied directly to the top chords in palce of joists or purlins. They are probably the least expensive to install from a labor standpoint. Plank roofing and heavy purlins offer improved fire resistance, as do all heavy truss members compared to thinner or lighter members. Purlins used at panel points do not introduce appreciable bending in the top chord. They may therefore be desirable as a means of keeping chord sizes resonable, particularly for larger spans, heavier loadings, and for flat, pitched, or other straight-chord trusses.

3.2.5. Roof-truss spacing

There are no fixed rules for spacing trusses in buildings. Spacing may be affected by roof framing, wall construction, size of material available, loading conditions, and the column spacing desired for material handling or traffic. In general, the greater the spacing, the more ecomnomical the construction., and the longer the span, the more desirable the greater spacing. Spacing limits are set by the purlin or joists sizes available for framing between trusses. Spacing is often more or less arbitrarily chosen because of its suitability for a particular roof and wall construction or building function. For example, if masonry walls are used, a truss spacing is frequently selected that will fit the pilaster spacing required for the lateral support of the walls. If roof sheathing material is to be applied directly to the trusses without auxiliary framing-in order to save the labor of placing the purlins-the spacing might vary from, say, 2 ft with 1-in. sheathing, to 7 to 9 ft, with 2 in. plank, or to still greater dimensions with heavier plank. If joists or purlins are used between trusses, the spacing might be determind by economical and available joints sizes although common usage would probably call for a spacing in the range of 14 to 20 ft. If spacing exceeds 20 ft, the availability of required sizes and lengths should definitely be considered. If spacing is desired that is greater than that suitable for sawed purlins, either glued-laminated purlins or trussed purlins may be used instead.

3.2.6. Purlins truss

If the spacing of trusses requires longer purlins than are commercially avilable, purlins trusses are frequently used. Their design is similar to that of any simple truss. If purlin trusses are inclined from the vertical, that is , if they do not have their top and bottom, chords in the same vertical plane, as when used on pitched trusses, it is important that bracing be provided to keep the bottom chords in proper position.

3.2.7. Roof -truss bracing and anchorage

Bracing and anchorage is necessary to hold trusses and truss members in proper position so that they can resist vertical loads as well as lateral loads such as wind, impact, or earthquake. Although roof framing will usually serve as lateral bracing for the top-chord members , it is important that adequate lateral supports be provided for the bottom-chord members (see Fig3.10), and also that consideration be given to the possible need for vertical-sway bracing between top and bottom chords of adjacent trusses (see (Fig. 3.11). Horizontal cross-bracing is sometimes required in the plane of either the top and bottom chord, particularly in long buildings in which the diaphragm action of the roof framing is not adequate for end-wall forces, or in which side-wall loads are resisted by end walls or intermediate bracing such as cross walls. The latter situation arises if each truss and its support are not designed as a bent to resist the lateral load.

Trusses must be securely anchored to properly designed walls or columns and columns in turn anchored to foundations. Unless some other provision made for lateral loads on the side walls and on the vertical projection of the roof-such as for diaphragm action in walls and roof sheathing- lateral resistance should be provided in the column members by means of knee braces or fixity at the column base. The bracing should be designed and detailed with the same care as the truss itself and not left to the judgment of the contractor.

The bracing requirements here suggested are minimums, and are not dependent on actual lateral-load analysis or on local code requirements. Vertical cross-bracing should be installed at the bottom chord at the location of the vertical bracing and be continuous from end

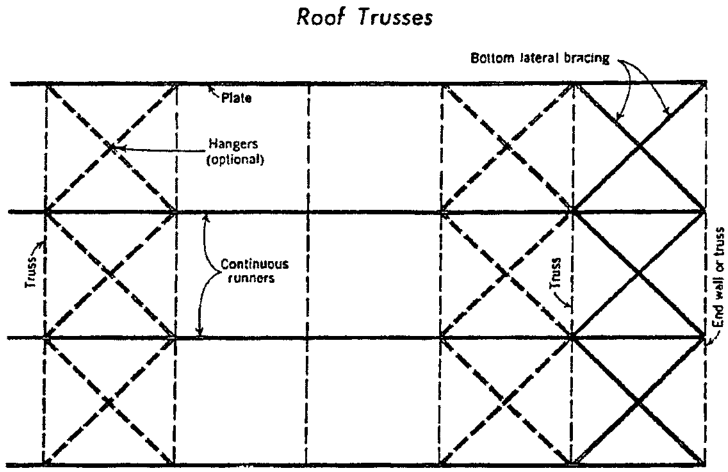


Fig. 3-10. Bottom latral bracing

If required, bottom lateral bracing usually appears in same sections as vertical sway bracing. Members are fastened to truss or to horizontal runners and plate. Wood members may be used, or steel rods. Hangers *may be used from roof framing to eliminate sag in members.* Continuous runners *run full length of building . They may be nearly square, solid members or built up in "T" ,"U", or "I" shapes. They are fasten to bottom chord or web members near chord.* Built-up runners *should be spiked and bolted together. For* top lateral bracing , *diagonal roof sheathing well applied to joists or purlins-with these in turn securely fastened to the truss-is usually sufficient. Sometimes., however, bracing similar to bottom lateral bracing should be applied in the plane of the top chords.*

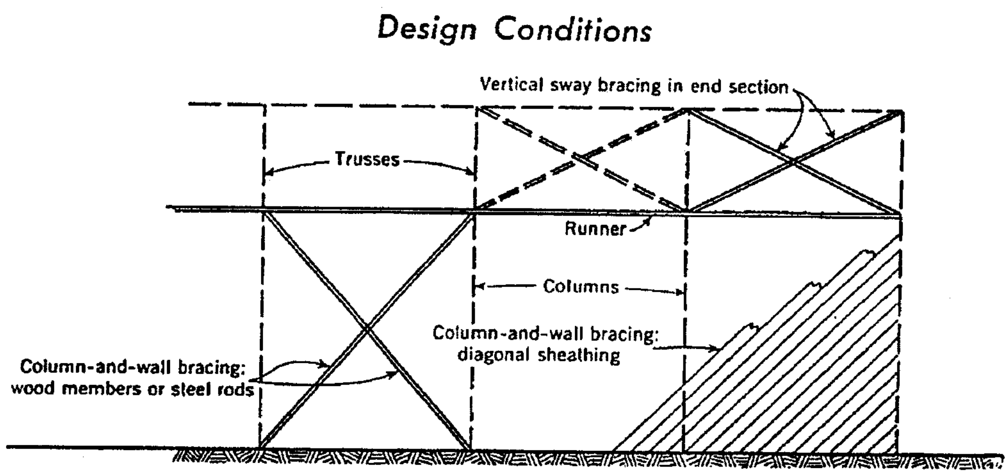


Fig. 3-11. Vertical sway bracing and wall-and-column bracing

Vertical sway bracing *is to be used in end section as a minimum, possibly two sections at each end and near midspan for long buildings. It consists of wood members or steel rods fastened to the truss, roof structure, or runners.* Column-and-wall bracing *should be used where possible. it may consist of diagonal sheathing with studs or girts, let-in braing, or cross-bracing. Crossing may be of wood members or steel rods.*

wall to end wall Such struts and cross-bracing should be adequate for a minimum horizontal compression load of 10 percent of the bottom-chord stress The 10 percent may be distributed in ratio to the number of lines of cross-bracing and proportion to the number of cross-braces in each line if additional bays in excess of the minimum are provided. Positive fastenings, such as bolts, lag screws, or timber connectors, should be provided. Special precautions should be taken to provide adequate bracing of trusses during and after erection and until the permanent bracing system and roof sheathing are installed.

Illustrative example of design of roof trusses are shown in Design Project.