Thesis.

Subject. A Steam Fire Engine House.

Mass. Inst. Tech.
W. E. Chamberlin '77.

The assumed conditions and requirements of the subject of this thesis are as follows:-

There is a suburban town whose business interests are rapidly progressing; so much so, that with the increase in the number of buildings in the business portion of the town, there arises the necessity of having a Steam-Fire-Engine and accommodations for it. Fortunately there exists at the corner of two prominent streets an unoccupied lot of land 40' x 75' upon which the towns-people decide to erect their building.

It is to be two stories high, built of brick with light sandstone trimmings, and the front must be ornamented with the hose-tower.

The following table shows how the different floors are to be occupied:—

Cellar.	First Floor.	Second Floor.
1. Staircase to 1st floor.	1. Staircase to cellar.	1. Six sleeping rooms.
2. Manure cellar.	2. Six stalls.	2. Hay & Grain room.
3. Hose trough.	3. Office.	3. Bath-room.
4. Hose-tower.	4. Hose-tower.	4. Hose-tower.
5. Heater for engine.	5. Room for engine, &c.	5. Parlor.
6. Heating apparatus.	6. Workshop.	6. Battery-room.
7. Coal bins.	7. Staircase to 2nd floor.	7. Staircase to 1st floor.

[It happened that Mr. Beal and I selected the same subject for a thesis; we therefore joined our forces and visited two of the best Cambridge houses and three of the Boston ones, and worked up our plans together. From the captains of the engines we obtained many valuable, and of course practical hints, in accordance with which we designed our plans, yet the result was that our design differs very materially from that of any house we visited.]

PLAN. The plan of the house has been made very simple, being merely a rectangle with the hose-tower on one corner. There is an alley-way behind so that three sides of the building are exposed, the fourth being against the adjacent house. (See perspective view.)

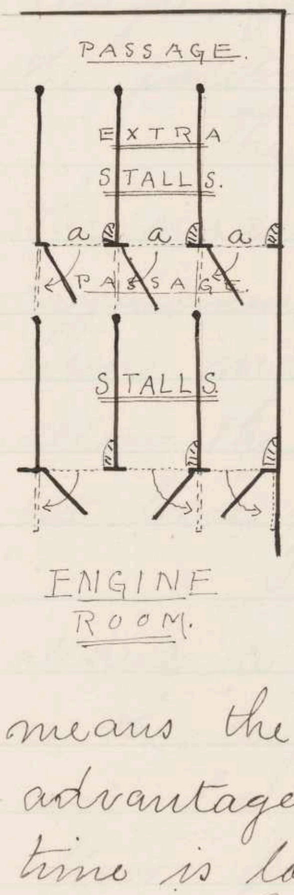
CELLAR. The cellar will be considered first. It extends under the entire building, and is $8\frac{1}{2}'$ high. In one corner, and necessarily under the horses, is the manure cellar, which is enclosed by an 8" brick wall with one door. In the rear, communicating with the alley-way, there is a large basement window through which the refuse may be easily transferred to carts. It is necessary to have this room thoroughly ventilated, and this necessity is met by carrying the ventilating-flue into the heater-flue where there is a continual draft, as it is warm throughout the whole year.

The hose-trough, where the hose is washed upon returning from a fire, must be at least 50 feet long, in order to accommodate a "length" of hose, and 18" by 18" in width and depth. One end of it must rest against the tower, where there is an aperture 2 ft. wide and 4 ft. high, through which the hose is pulled up into the tower where it is left to dry.

The heater consists of a small upright boiler connected with the engine-boiler above by two pipes, by means of which the hot water constantly circulates, and so regulated as to keep up any desired pressure of steam in the engine.

The coal bins should be three in number, one for steamer-coal, one for heater and office grate, and one for the heating apparatus. (By accident I indicated only two on the plan of the cellar.) They have been so located as to cause little inconvenience either in getting in the coal or carrying it to be used.

FIRST FLOOR. - Stalls. - During the greater part of the year only three horses are needed, two for the engine and one for the hose-carriage, but in snowy weather when the going is hard it is necessary to have twice as many, and consequently three extra stalls are required. The permanent stalls always face the engine and are so arranged that the front doors fly open at the stroke of the alarm and the horses immediatly trot out into position. The usual method of arranging the extra stalls, which are generally temporary, is to put them up in some out-of-the-way corner, from which the horses have to be backed out and led by hand. The consequence is that in winter a great deal of time is lost in getting out. To obviate this we have arranged the stalls in a different manner.



The extra stalls have been placed directly behind the others, leaving a passage sufficiently large for cleaning operations. When the stall-doors a, a, a, open they close up the passage and allow the horses in the rear to pass out through the forward stalls. By this means the extra horses have the same advantages as the others, and little or no time is lost.

Upon returning from a fire the dirty hose is put down cellar and clean hose is reeled on from the tower. It is desirable that this operation should be performed on the hose-carriage side of the house, which is the same as saying that the hose-carriage and hose-tower should be on the same side of the house; this is really the key-note of the whole design, for it fixes, to a great degree the positions of the stairs, stalls, &c.

The stairs, in accordance with the unanimous statement of all the Enginemen whom I have consulted, have been made in one straight run, to allow the men to get down in the quickest time possible.

The large room is 31½' X 35' and allows a free passage for the horses as the engine and hose carriage are each less than five feet wide. The floor pitches slightly towards the front doors, and is caulked to allow the water to run off in washing.

The method of supporting the large area of floor above, without the employment of posts will be spoken of hereafter.

The workshop is used for making small repairs only and therefore does not need to be very large. The one in my design is $8\frac{1}{2}' \times 12\frac{1}{2}'$ which allows for plenty of room although it may appear small.

The room marked "Office" on the plan is a sort of sitting-room and contains a desk where the company-record is kept.

It will be noticed on the 1st floor plan that the outer side of the staircase is a continuation of the line of the tower, so that the room is not broken up.

SECOND FLOOR. The sleeping accommodations for members of the company are not as extensive as in a city engine-house where it is necessary to have what is called a "permanent company" of 13 men. For this town we need rooms for only six men, the remainder of the company being what are termed "call-men". One of the sleeping-rooms has been unavoidably deprived of a window directly out into the air, but the next-best thing has been done by admitting the air through a second window cut in the partition.

The bath-room and battery-room can have no windows; consequently they are lighted by means of a shaft from the roof, a method that suffices for such rooms, as they are only temporarily occupied.

The front of the house is occupied by a parlor, a room where the company holds its monthly meetings, and which is also used as a reception room on occasion of a visit from another company.

The hay and grain room

was obliged to extend as far front as the cribs of the forward stalls, and backwards to the rear wall, in order to take in hay, etc., from the alley-way; hence its irregular shape.

EXTERIOR. - The exterior has been very simply treated, with little carving (mostly confined to the drinking-fountain) Black-brick have been used somewhat; generally to accompany a string-course for the purpose of marking it distinctly.

Unless attention was called to it one would hardly notice that the ridge of the roof is not over the middle pier of the front, and in perspective it is impossible to detect this irregularity. An examination of the plan will show the cause.

In the valley which the roof makes with the wall of the adjoining building, there must be a secondary roof or slant from the middle towards both ends, to throw off the water. The chimney which would appear there has been omitted on the drawings.

CALCULATIONS

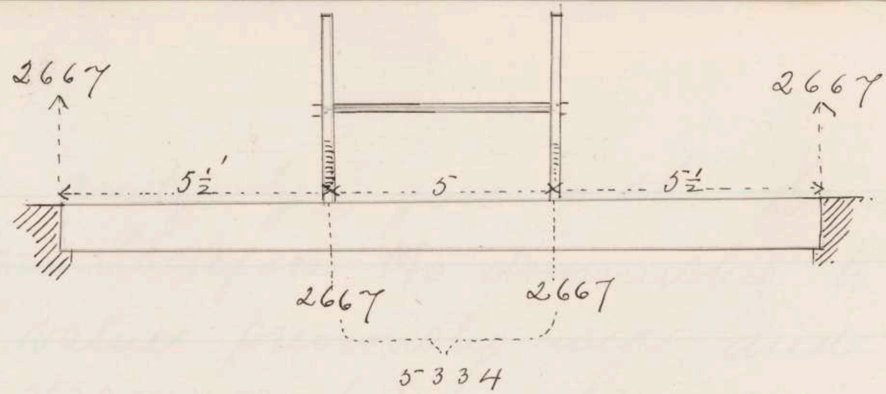
FOR THE CONSTRUCTION.

ENGINE FLOOR. There are brick piers running in the middle of the basement from front to rear; they support a large timber into which the floor joists are framed. Now to find the dimensions of these floor joists.

The weight of the engine (ready for fire) is about 8000 lbs., and according to the Amoskeag Company two-thirds of this of this weight, or 5334 lbs., comes upon the rear wheels which are very nearly five feet apart. When the rear wheels are over a beam the bending moment is as follows:-

$$M_0 = 2667 \times 5\frac{1}{2} = 14668 \text{ ft. lbs.}$$

This must equal $\frac{1}{6} f b h^2$.



(The diagram shows the position of the wheels for the greatest bending moment.)

$M_o = \frac{1}{6} f b h^2 = \frac{1}{6} 1000 . b . 12 . 12$ assuming $h = 12''$ and $f = 1000$ for spruce.

Reducing M_o to inch pounds we have

$14668 \times 12 = \frac{1}{6} . 1000 . b . 12 . 12 .$

whence $b = 7.334''$

or assuming $b = 3''$ we get $h = 18''+$

These values are evidently too large and the reason is that no account has been taken of the flooring which consists of a 2" planking matched, and covered with 1" hard pine; this gives a very stiff floor which greatly distributes the weight. Therefore I have assumed that if the floor joists are 15" apart on centres and the rear wheels are directly over one beam, $\frac{1}{4}$ of the load is transmitted to each adjacent beam and only $\frac{1}{2}$ goes to the beam below. Therefore M_0 diminishes to $\frac{1}{2}$ the value previously used, and we have $7334 \times 12 = \frac{1}{6} \cdot 1000 \cdot 3 \cdot h^2$ assuming $b = 3''$, whence $h = 13''+$; call it $14''$.

Consequently we have a beam $3'' \times 14'' \times 16'$ of spruce, spaced $15''$ on centres. This is a trifle stronger than those commonly used.

The hose-carriage (seldom weighing as much as 4000 lbs.) does not need so strong a floor, but it is well to make it so, as there might be occasion for the engine and hose-carriage to change places, from some cause or other.

PARLOR FLOOR. The floor-beams of the parlor run lengthwise with the building, with one end resting on the front wall and the other supported upon the lower chord of the trussed partition

(See figure, page 16.) The beams are of spruce and spaced 14" on centres. Therefore each running foot of beam supports $\frac{14}{12}$ of a foot of flooring. Assuming the weight on the floor (including weight of floor itself) to be 90 lbs. pr. sq. ft., the weight supported by each beam is $\frac{14}{12}$ of $90 \times 16 = 1680$ lbs.

Using formula:–

$$h = \sqrt{\frac{W L}{108 b}}$$ (given by Mr. Hoyt.)

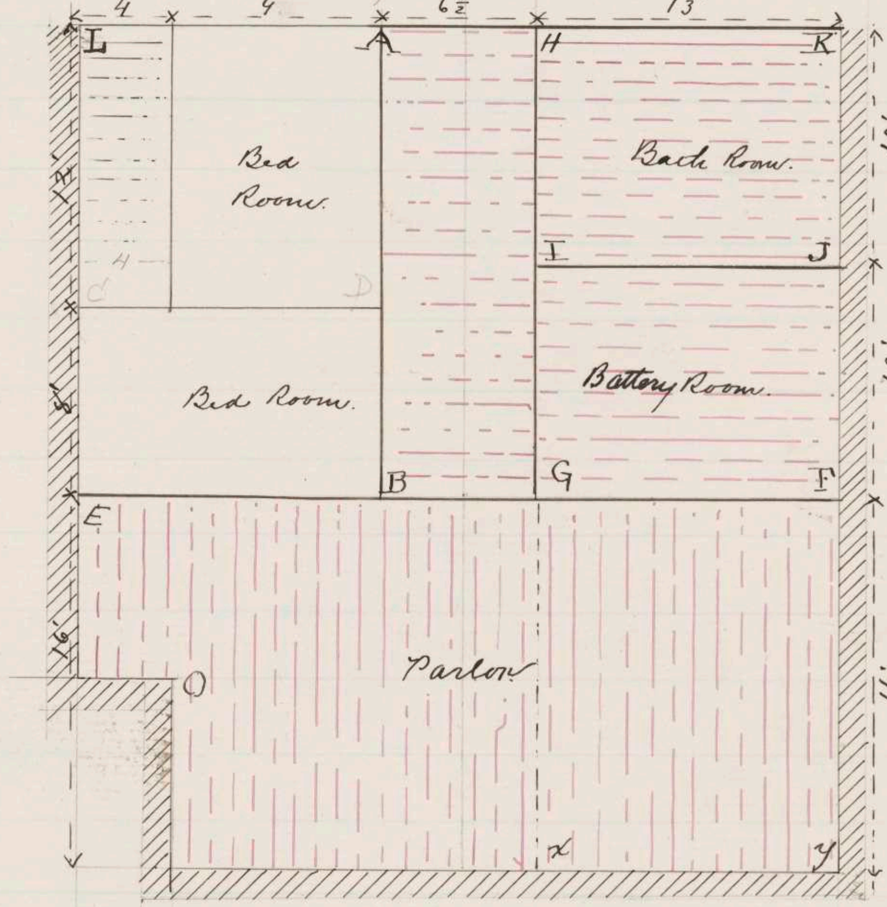
and assuming $b = 2"$

we get $h = \sqrt{\frac{1680 \times 16}{108 \times 2}} = \sqrt{125} = 11"+$

call it 12". Then the floor beams are $2" \times 12" \times 16'$.

TRUSSED PARTITION. (See figure, page 16.) As it would be very inconvenient to have passage in the engine-room obstructed by posts, we are obliged to seek other means for the support of the floor above.

To solve this problem I have



[Dotted red-lines indicate the direction of the floor-joists.] [All doors etc. have been omitted in the calculations and on the diagram.]

put a truss within the partition E.F and have framed the timbers AB and HG into it, so that it is the centre of support of the whole floor LKyO.

The truss occupies the whole height of the partition (12 ft.) In the following calculations the right-hand side of the flooring has been considered as it is a little simpler than the other and the difference is hardly appreciable.

We allow 90 lbs pr. sq. ft. for the weight of the parlor floor and its load. Weight of floor (not deducting re-entering angle of tower) = $32\frac{1}{2} \times 16 \times 90 = 46800$ lbs. One-half this weight is uniformly distributed along E.F

	ABGH	weighs	11700 lbs.
	GFKH	"	23400
Partition	IJ	"	3432 (22 lbs pr. sq. ft.)
"	HG	"	5280 " "
"	E.F	"	8580

$\frac{1}{4}$ of ABGH is transferred to the point G
$\frac{1}{4}$ " GFKH " " " " " "
$\frac{1}{4}$ " IJ " " " " " "
$\frac{1}{2}$ " HG " " " " " "
∴ 12273 lbs " " " " " "

For the uniformly distributed load we have $\frac{1}{2}$ wt of parlor floor = 23400
and the weight of EF = 8580
31980

9594 lbs " of this acts downwards at G
6396 " " " " " " F

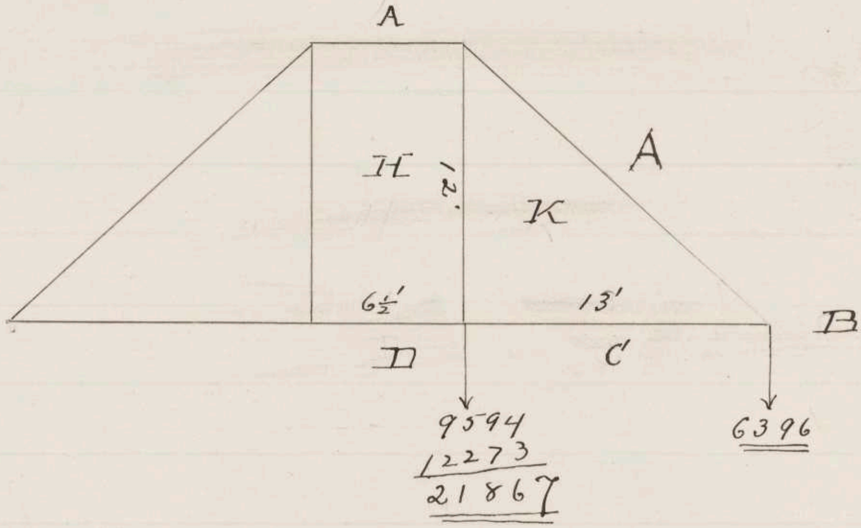
Therefore the total downward pressure at G is 9594 + 12273 = 21867 lbs.
(See figure, next page.)

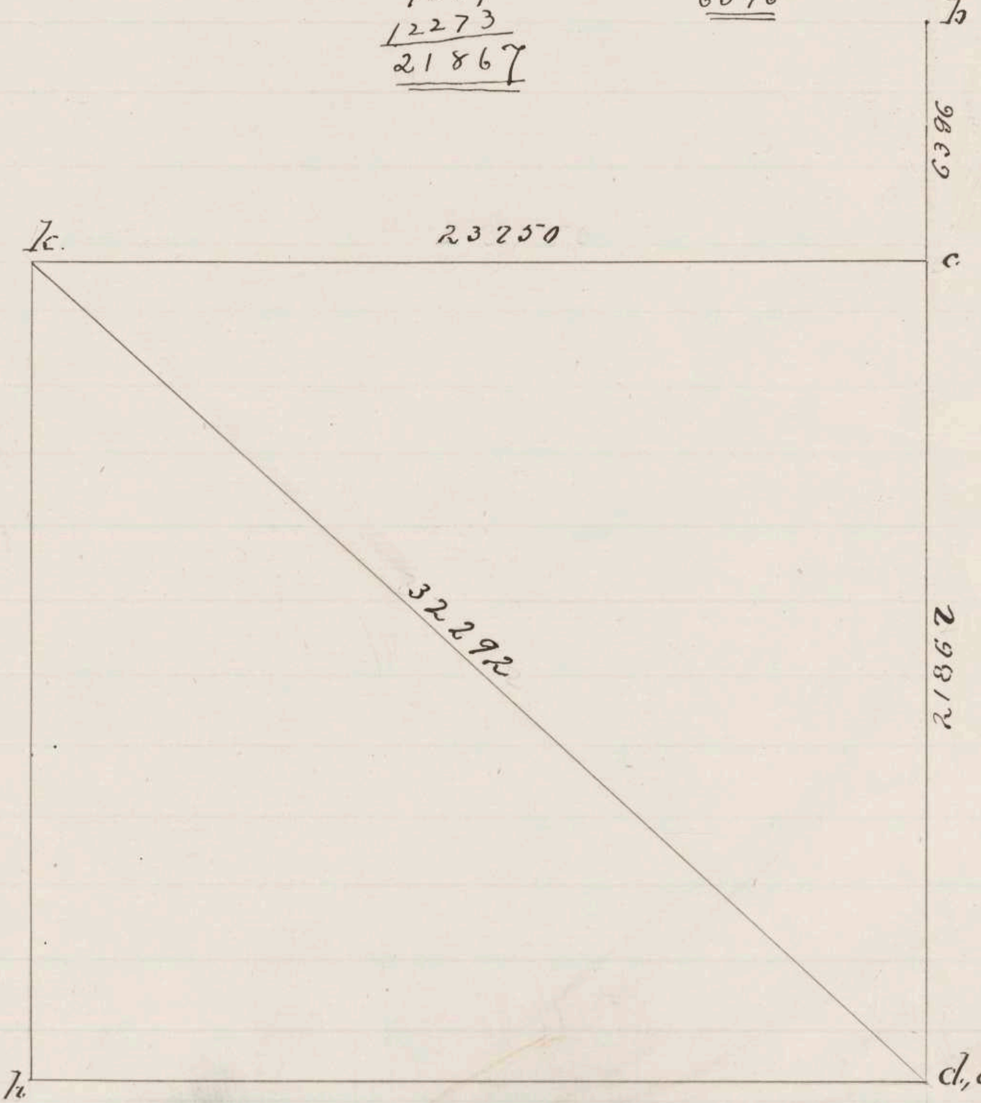
Now to find the dimensions of the different members.

Strain on tie-rod H.K (see figure) = 21867. Taking 10000 lbs. pr. sq. in. as the safe load for wrought iron, the area must be $\frac{21867}{10000} = 2.1867 = \pi r^2$ whence $r = .834$ $\therefore$ $d = 1.6+$ = diam. of tie-rod.

Strain on KC or HD is 23750. Calling $\frac{10000}{6}$ the safe load (tension) for spruce, the required section is

$$\frac{23750}{10000} \times 6 = 14.25''$$





Scale of truss: $\frac{1}{8}$" = 1'   Scale of strain-diagram: 1" = 5000 lbs.

But this beam is also subject to a transverse strain from the flooring of the parlor. We will assume the depth as 12"; then the width $= \frac{14.25}{12} = 1.19"$

The part of the floor which affects the beam is GFxy (see figure, page 16) and this weighs 18720 lbs one half of which is distributed over the beam. It appears that the weight of the partition itself should come in here, but a great deal of the part above the strut KA is carried by it down to the wall and most of what is left acts very near the tie rod, so that considering everything (e.g. the large allowance of 90 lbs. pr. sq. ft. which we have used) we may leave the partition out of the question.

$$M_0 = \frac{1}{6} f b h^2 = \frac{Wl}{8}$$

$$= \frac{9360 . 13 . 12}{8} = \frac{1}{6} . 1000 . b . 12 . 12$$

$$\therefore b = \frac{9360 . 13 . 12 . 6}{8 . 1000 . 12 . 12} = 7.6"+$$

2

This added to 1.19" gives 8.79"
Call it 9" Then the beam is 9"×12".

The upper chord AH supports no extra weight and is merely in compression. As it is held firmly by the studding no account need be made of its buckling.

$\frac{8000}{6}$ = safe load pr. sq. in. for compression. Necessary section = $\frac{23750}{8000} \times 6$ = 18" Call it 20" and use a 4"×5" timber.

The strut KA is also prevented from buckling by the studding so its necessary section is $\frac{32292}{8000} \times 6$ = 24"+ and a 4"×6" timber may be used. This is the same width as the upper chord, so that the joint is easily made.

Roof Truss.

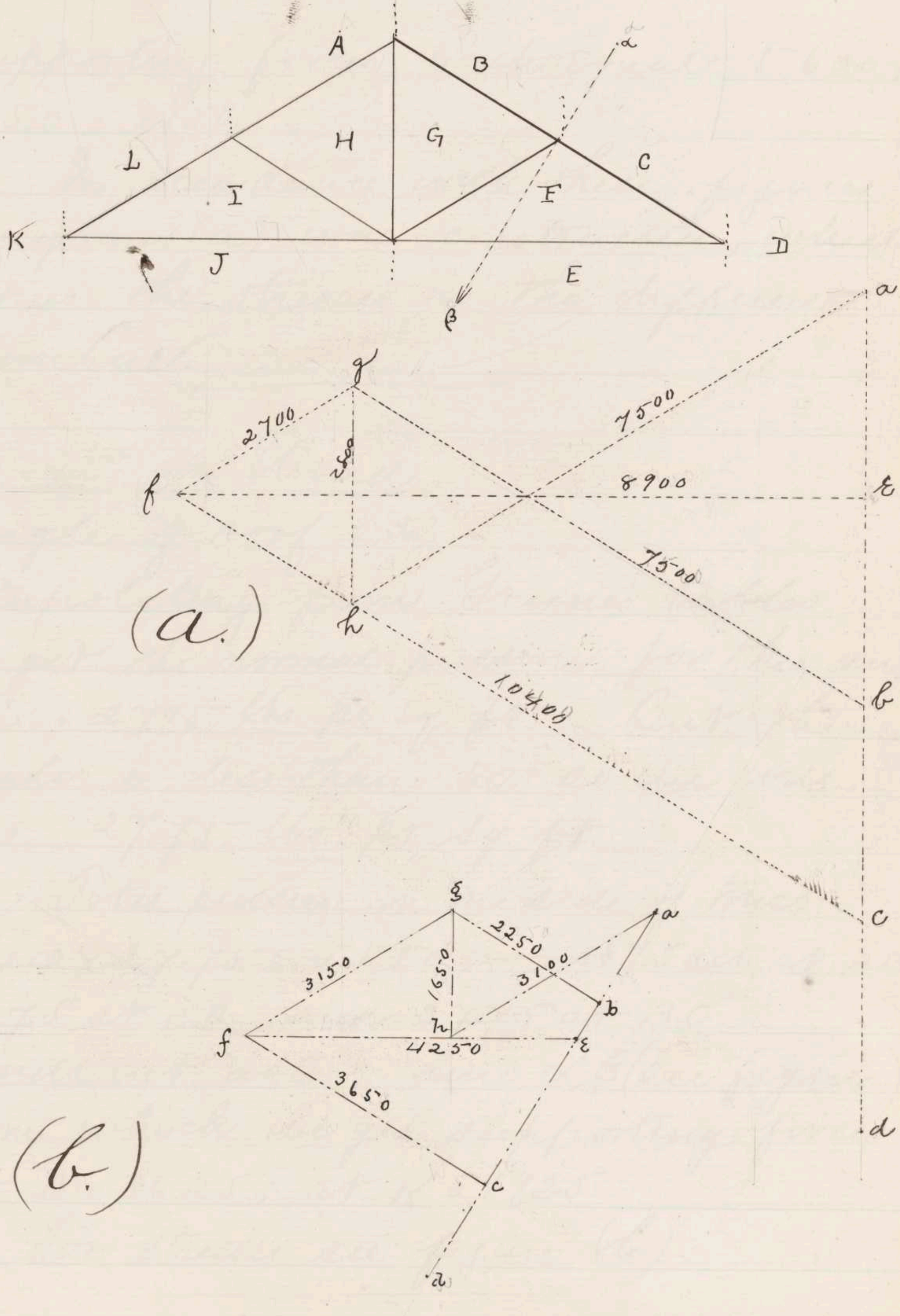
×

The trusses are 10' apart, with a span of 34'.
Let 28 lbs. pr. sq. ft. be used as the total steady load (wt. of truss, snow, slates. &c.)
Slant is 20 ft. long.

20 × 10 = 200 sq. ft. on each rafter
200 × 28 = 5600 lbs = load on each rafter
This may be considered as uniformly distributed by the purlins.

1400 lbs is supported at CI (page 23)
2800 " " " BC
2800 " (1400 from each side) " AB.

To the horizontal tie is suspended the ceiling weighing 15 lbs pr. sq. ft.
Wt on FE = 17 × 10 × 15 = 2550
∴ 2550 lb. is supported at JE (1275 from each side) and 1275 at DE.
Wt at JE is transferred up to AB.
Total wt at AB = 2800 + 2500 = 5350
" " " BC = 2800
" " " IC = 1400 + 1275 = 2675


A
B
C
D
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F
G
H
I
J
K
L
α
β
a
b
c
d
e
f
g
h
2700
2800
7500
8900
7500
10400
(a.)
2250
3150
1650
3100
4250
3650
(b.)

Supporting forces each equal 5600 + 2550 = 8150

In accordance with these figures diagram (a) was constructed, which shows the stresses in the different members.

Wind.

Angle of roof = 32° –
Interpolating from Greene's tables we get the normal pressure for this angle = 27.95 lbs. pr. sq. ft. But the angle is less than 32° so we will use 27.75 lbs. pr. sq. ft.

Total pressure on one side of truss = 20 × 10 × 27.75 = 5550; 1387.5 acts at AB 1387.5 at CD and 2775 at BC.
Resultant acts in line LB (see figure) from which we get supporting forces at D = 3625; at K = 1925

For stresses see figure (b)

Summing up of stresses and calculation of sizes of members. –

FC. $10400 + 3650 = 14050$. There is no danger of buckling as the purlins hold it in place. It is merely in direct compression for which $\frac{8000}{6}$ is the safe load pr. sq. in.

$$14050 \div \frac{6}{8000} = 10\tfrac{1}{2}^{\square''} \text{ necessary section}$$
(let $b = 5''$ and $h\ 2''$)

There is also the bending action to be resisted from load and wind. This normal component of the 28 lb load is about 24 lbs ∴ bending wt. pr. sq. ft. $= 24 + 27.75 = 51.75$; $\frac{WL}{8} = \frac{1}{6} f b h^2$

$$10.10.\frac{207}{4}.\frac{10.12}{8} = \frac{1}{6}.\frac{8000}{6}.bh^2;\ bh^2 = 350$$

as above let $b = 5''$ ∴ $h = \sqrt{\frac{350}{5}} = \sqrt{70} = 8''+$

The two h's added together give 10"+ $b = 5''$ Therefore FC must be 5"×10".

GB would probably be of the same size in practice, though it is not needed.

GF has nothing to steady it. Therefore we use a diffrent formular.

$$F_s = \frac{fA}{1 + a\frac{l^2}{h^2}}$$

{ s = factor of safety
f = 7200 (given in Greene.)
A = necessary section.
h = smallest dimension in inches (assumed.)
l = length in inches.
a = $\frac{1}{250}$ (given) }

$$5850 \times 6 =$$

$$\frac{7200A}{1 + \frac{1}{250}\cdot\frac{10.12.12}{3.3}} = \frac{7200A}{\frac{34}{25}}$$

A = 13"+ neces. section.

Use a 3" X 5" beam, or a 4" x 4", which would be more convenient.

HG. Stress = 2800 + 1650 = 4450

From the rit of flooring there is a stress of 2550. Total stress = 7000 lbs.

Safe load pr. sq. in. = 10000 lbs. (wrôt iron.)

Necessary section of bar = $\frac{7}{10}$ of an inch

$\pi r^2 = \frac{7}{10}$" ∴ r = .47"+ ∴ diameter .94"

Call it 1"

FE.. Stress = 8900 + 4250 = 13150

$\frac{10000}{6}$ = safe load pr. sq. in. (tension)

$\therefore 13150 \times \frac{6}{10000} = 8''-$ = necessary section

But the wt. of the ceiling also affects this member. {In the above section (8") let us call $h = 10''$; then $b = \frac{8}{10}''$}

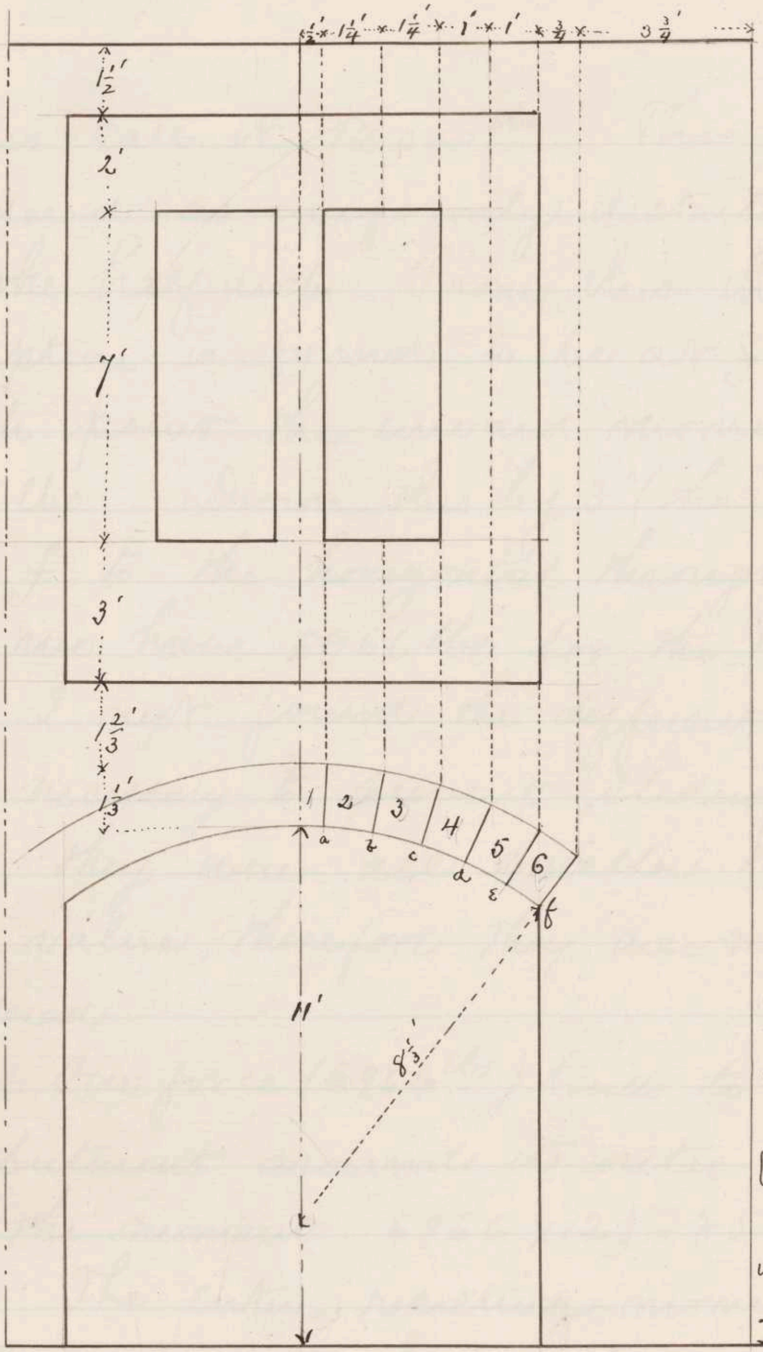
$\frac{1}{6} f b h^2 = M_0 = \frac{Wl}{8}$; $\frac{6 . 2550 . 17 . 12}{1000 . 8} = bh^2$ (using 1000 for spruce.)

$bh^2 = 390$ As above let $h = 10''$ then

$b = 4''-$ This value of b added to the one above $= \frac{8}{10} + 4 = 4\frac{8}{10}''$, and $h = 10''$

Call the timber 5"×10".

THE ARCH.



Assume wt of wall; 130 lbs pr. cu. ft.

Depth of key-stone $= \sqrt{.12\,r} =$

$\sqrt{\frac{12}{100}\cdot\frac{25}{3}} = 1'$

I have made it 16" (two bricks)

	lbs.		lbs.		lbs.
Wt. over 1 =	1700	Wt. of 1 =	100	Total	1800
" " 2 =	867	" " 2 =	267		1134
" " 3 =	920	" " 3 =	270		1190
" " 4 =	2550	" " 4 =	231		2781
" " 5 =	2622	" " 5 =	250		2872
" " 6 =	2177	" " 6 =	200		2377
				Grand Total	12144

Let us call it 12000 lbs. This has been considered as uniformly distributed over the half-arch. From this the joint of rupture is found to be at f, around which point the inward moment is 20900 lbs. Divide this by 3' (the distance from f to the horizontal through the crown) and we have 6966 lbs for the thrust P.

I next found the different values of P necessary to prevent sliding at the joints; they were all smaller than the above value, therefore they are not to be considered.

Our force (6966 lbs) tends to overturn the abutment around its outer edge, X. with the moment $6966 \times 12\frac{1}{3} = 85914$

The entire resisting moment of the abutment and half-arch (with superincumbent wall) about the outer edge of the base = 109568. This exceeds the outward moment and therefore the arch will stand.

This does not leave so great a margin for safety as might be desired yet I feel confident that the arch is perfectly safe. The adhesive power of the mortar strengthens it greatly, but it has not been considered. The corner also is strengthened by the side wall, and consequently more resistance to outward rotation is offered than has been used in the calculation.

All these minor points being considered, there is left no room for doubt as to the stability of the arch. In fact, there seems to be no need of calculating such a small arch, as a glance at the drawings will show.

W. E. Chamberlin

Cambridgeport,

May 13, 1877.