AN

ICE PLANT

WITH AN

ICE SKATING RINK

BY

RIZK S. KHURI

MAY 1949

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AN
I C E P L A N T
WITH AN
I C E S K A T I N G R I N K

BY

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MAY 1949

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<u>TERMINOLOGY AND ABBREVIATIONS.</u>

A :Area.

B.T.U. :British Thermal Unit is the quantity of heat required to raise the temperature of 1 lb. water 1 Fahrenheit degree.

D : Diameter of pipe in inches.

d : Diameter of pipe in feet.

Enthalpy : Heat content.

Enthalpy (specific) : Heat content per unit weight, B.T.U. /lb.

f : Coefficient of friction of a fluid passing in a pipe.

G.P.M. : Gallons per minute.

H.P. :Horse power.

Humidity ratio : The weight of water vapor per pound of dry air.

h_a : Specific enthalpy of dry air, B.T.U./lb.

h_{as} : $h_s - h_a$ the difference between the enthalpy of moist air at saturation per pound of air, and the specific enthalpy of the dry air itself.

h_f :Pressure drop in feet of fluid.

h_s : Enthalpy of moist air at saturation per pound of dry air.

h_w : Specific enthalpy of condensed water B.T.U. /lb water.

I : Moment of inertia.

R : Reynolds number.

S : Stress per unit area.

W : Weight of fluid in lb. persecond

w : Weight per foot.

INTRODUCTION

Since many design problems and projects were dealt with in connection with the different courses of structures, irrigation architecture etc, , the author found it benefitial to tackle a new subject or field such as the ice plant and the skating rink from which some additional knowledge could be acquired. In this way a more rigid work would be achieved , thus fulfilling a closer approach to thesis requirements.

The ice plant , which is very common , is a sort of a factory for making ice blocks to be used by the public for various purposes during the hot months of the year; whilst the skating rink is a place for recreation and sports where sportsmen can skate on an artificial ice surface during the rest of the year. Thus the machines will be working in summer for the production of ice and in the cold months for the maintainence of the rink. Such a combination will create an economical project. The survival of the project may be ensured by situating it in Jerusalem, Palestine, where snow is very scarce during winter so much so that there is no opportunity for ice skiing or any other ice sports. Further there is will also be a demand for ice during summer for local consumption. Moreover, the influx into Palestine of pilgrims from various parts of the world will very immensely encourage the introduction of such a scheme in the Holy Land, which, to the best of my knowledge and belief, is non-existant in the Near East.

In view of the planning zones of Jerusalem, the selection of a site for a combination of a factory and a place for sports will undoubtedly be confronted with unsurmountable difficulties; for if the structure were to be constituted of the rink only, it would be very easy to have it situated in a residential area. Therefore it is deemed extremely expedient to select a site for it in the interior part of the city as is shown in the situation plan in Plate I.

The plot of land for the project in view lies on the western side of the main road to Bethlehem, and slopes from north to south. The depression at the southern end may be offset by erecting thereat the ice plant in the basement and the rink partly above it and partly above some fill. Motor traffic along the prospective site between the central part of the city and other residential areas offers an ideal means of transport from and to the rink.

P A R T

I

S K A T I N G   R I N K

CHAPTER

I

ARCHITECTURAL COMPOSITION

1. General Description: The ground floor which contains the rink, is composed of the skating hall, a combination of a restaurant and a bar kitchen , a pantry and two toilet rooms for both sexes of the spectators on one side. On the other side are special units for the skators ; namely a room for storing the skates, a room for keeping the clothes of the skators and two toilet rooms for men and women respectively. The two doors leading to the skating hall, one for the skators and one for the spectators, are of the revolving type so as to minimize the heat leakage. Next to each door there is a ticket room, and in between a room for administration.

2. Skating Hall: The size of the ice surface is 185 feet by 85 feet which is a standard[1] one. A space 5 feet wide along the longitudinal edges of the ice surface is provided in which the main pipes can be embedded. A seating system of tables and chairs is introduced instead of benches so that the restaurant can make some profit by offering cold food. The chairs and tables are placed over two platforms to the eastern side of the hall. Each platform is 8 feet and 8 inches wide which is enough for a table of four and leaving a passage way. Each platform is raised 2 feet above the surface infront of it so that the spectators can be able to have a good view

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1."Refrigeration Application " by The American Society of Refrigeration Engineers. page 445 of the skators . For the comfort of the spectators , the design provides parabolic radiators of heat , conveniently located in the wall so as to insure a comfortable warmth by direct radiation , while the quantity of heat they generate is actually much less than their sensible effect.

C H A P T E R

II

STRUCTURAL COMPOSITION

1. Roof: The roof of the various units with the exception of the skating hall, consists of an ordinary reinforced concrete slab at a hight of 13 feet. As to the skating hall, its outside dimensions are 195 feet by 115 feet, and 22 feet high big enough that the problem of economy should be considered in deciding upon the kind of roof. The opinion of Proffesor Yaramian, who is an experienced engineer, has been asked about this matter. He suggested that a steål truss would be the most economical kind of roof for such a span of 114 feet - center to center of bearing - on the basis that he had actually made the calculations for a span of 100 feet not a long time ago, at the beginning of the year 1949, with the conclusion that the steel truss was the best. Since that time, prices of building materials did not undergo a great deal of change, so that the construction of a steel truss is decided upon; and what remains, is the selection of the form and the spacing of the trusses which is discussed under PART III.

The upper surface of the roof consists of asbestos sheets which is a poor conductor of heat and water proof. The bottom of the roof, that is the ceiling, consists of three layers of aluminum sheets, and each two are 2 inches appart. These sheets will render a light ceiling load on the trusses and will conceal all the displeasing elements of the trusses. Around each 3 foot square, vertical projections of aluminum sheets are projecting downward from the ceiling to a depth of 6 inches. Such projections will serve a double purpose. One of the two is to serve as decorative elements, and the second is to obstruct any air movement in the upper part of the skating hall, thus making the air near the ceiling in a state of stagnation to serve as a sort of insulation.

The use of such an aluminum ceiling in public halls, is becoming very common and widely spread in the U.S. of America and a lot of advertisements are published now adays about this subject specially in the architectural magazines, one of which states : "This aluminum louvered ceiling offers eye-pleasing, non-glaring illumination under a striking ceiling. Easy to install - conceals overhead elements.[1]" Aluminum is a bad rediator of heat, hence its use will help in reducing the refrigeration load. Usually it oxidizes as it is exposed to air and moisture, forming a very thin film which increases its resistance to corrosion and preserves its colour. This is advantageous, but being a natural process it takes a long time; and now adays it is done artificially as described in one of the British magazines[2]. The magazine calls the process the "Anodic Oxidation of Aluminum" which is "an electrolytic process for thickening the oxide film present on all aluminum surfaces". The natural thickness of the film which is 0.000013 m.m. is increased by this process into 0.01 m.m.

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1. "The Architectural Record" of January,1949.
2. "Engineering",vol.166 - No. 4313; September 24,1948 which is an illustrated weekly journal.

2. Walls And Floor : The walls of the skating hall are built up of limestone masonry with a concrete backing, celcrete as an insulator and plaster. A thickness of 4 inches of celcrete is extending from the floor to a hightof 7 feet, and 2 inches from that hight up to the ceiling. The thickness of the wall at near the floor consists of:

Limestone and concrete...	12 inches
Celcrete.........................	4 "
Plaster..........................	$\frac{1}{2}$ "
Total thickness of the wall.....	=16$\frac{1}{2}$ inches.

The exterior walls of the other rooms are also built up of limestone masonry and a concrete backing with a total thickness of 12 inches. The partition walls are made up of brick 6 inches thick.

The floor of the skating hall consists of three layers. At the bottom there is a concbete slap 4 inches thick with little reinforcement of steel which are 5/16 inches round bars at 6 inches center to center in both directions so as to provide for any settlement that may occure due to the fill under it and to account for the sbrinkage and cracking of concrete. Above the concrete there is a layer of celcrete 5 inches thick serving as an insulation above which there is a layer of concrete 2 inches thick. On top of all there is a mixture of sand and gravel in whcih the pipes are embedded. To provide for drainage the floor surface is divided longitudinally into two halves inclined towards the walls so that in case some repairs should be made for the pipes due to leakage or the refrigeration process is stopped for some other reason, the melted ice can be drained off easily.

CHAPTER
III
TECHNICAL DESIGN

1. Insulators: The main insulating material for the walls and floor is Celcrete. It has been selected for insulation because of its small thermal conductivity, and for being water proof and fire resisting substance. It is a cellular concrete mass formed by mixing a special foam with a cement solution. It is manufactured in different types of densities . The standard types have got specific gravities of 0.25 , 0.45 and 0.60 . As an insulator it is as good as cork " but has the great advantage of being less expensive , water proof and rot proof[1] ". The type used for the rink has got a density of 500 kg./m^3. with a thermal conductivity of 0.1 k.cal./m^2./m./hr./c. To change its conductivity into the British system, the following procedure will be done.

1 Cal. 1 gr. 1^{o}C.

1 B.T.U. 1 lb. 1^{o}F.

$$1 \text{ B.T.U.} = \frac{1000}{2.2} \times \frac{5}{9} = 252 \text{ cal.} = 0.252 \text{ k.cal.}$$

0.1 k.cal./m^2./m./hr./C^{o}

$$= \frac{0.1}{0.252} \times \frac{1^2}{3.28^2} \times \frac{3.28}{1} \times 12 \times \frac{5}{9}$$

$= 0.806$ B.T.U./ft^2./in./F^{o}/hr.

1."Celcrete" a pamphlet on celcrete produced by the Contracting & Trading Co. Lebanon - Syria .

Windows are made of double glass instead of single glass so as to decrease the conductivity through windows . Radiation of heat is negligable specially by the use of shutters for the windows on the eastern side of the rink which will obstruct the sun's rays. The conductivity of glass is 0.45 B.T.U. /ft.^{2}/hr. [2] based on a minimum air space of $\frac{3}{4}$ inches.

The ceiling is made up of three sheets of aluminum seperated from each other by an air space of 2 inches in thickness. Thus the three sheets of aluminum confine two layers of still air which will be acting as insulators . The conductivity of air for a thickness of 1 inch

= 0.168 B.T.U./hr./ft.^{2} /F^{o} [3]

2."Heating Ventilating Air Conditioning Guid" of 1947 published by the American Society of Heating and Ventilating Engineers page 138 .

3."H.V.A.C. Guide" page 101

2. Coefficients of Heat Leakage: Since conductance is the reciprocal of resistance, the over all coefficient of conductance for various layers of materials can be found by knowing first the total resistance of the materials. The coefficient of conductivity for the different surfaces is found as follows;

(a) Floor :-

Resistance of concrete[4] 4 in.thick $= 4 \times 0.08 = 0.32$

Resistance of celcrete 6 in.thick $= 6 \times \frac{1}{0.806} = 7.45$

Resistance of concrete 2 in.thick $= 2 \times 0.08 = 0.16$

Total resistance $= 7.93$

Conductivity of floor $= \frac{1}{7.93} = 0.126$ B.T.U./ft.^{2}/hr.

(b) Windows :-

Conductivity of double glass $= 0.45$ B.T.U./ft.^{2}/hr.

(c) Walls :-

Resistance of 12 in. masonry[5] $= \frac{1}{0.58} = 1.73$

Resistance of 4 in. celcrete $= \frac{4}{0.806} = 4.95$

Resistance of $\frac{1}{2}$ in. plaster[6] $= \frac{1 \times 0.13}{2} = 0.065$

Total resistance $= 6.75$

Conductivity of wall $16\frac{1}{2}$ in. thick $= \frac{1}{2\ 6.75}$
$= 0.148$ B.T.U./ft./hr.

Resistance of 12 in. masonry $= 1.73$

Resistance of 2 in. celcrete $= 2.48$

Resistance of $\frac{1}{2}$ in. plaster $= 0.07$

4.28

Conductivity of wall $14\frac{1}{2}$ in. thick $= \frac{1}{4.28}$
$= 0.233$ B.T.U./ft.^{2}/hr.

4."H.V.A.C." page 117
5."H.V.A.C." page 129
6."H.V.A.C." page 118

(d) Roof :- The combined ceiling and roof coefficient between the air under the ceiling and the exterior air outside the roof is given by the formula :[7]

$$U = \frac{U_r \times U_{ce}}{U_r + \frac{U_{ce}}{n}}$$

where U = The combined conductivity coefficient to be used with the ceiling area.

U_r = Conductivity coefficient of the roof.

U_{ce} = Conductivity coefficient of the ceiling.

N = Ratio of the roof area to the ceiling area.

U_r = 0.55[8] (asbestos shingles on wooden sheathing $\frac{25}{32}$ in. thick)

$$U_{ce} = \frac{0.168}{4} = 0.042$$

$$N = \frac{2.24}{2} = 1.12 \quad \text{(roof pitch is } \tfrac{1}{4} \text{)}$$

$$U = \frac{0.55 \times 0.042}{0.55 + \frac{0.042}{1.12}} = \frac{0.0231}{0.55 + 0.038} = 0.039 \text{ B.T.U./ft.}^2\text{/hr. of ceiling area.}$$

3. Inside Temperature : In a cold storage room where the cooling coils are placed near the ceiling , the temperature at any height is naturally kept constant ; because as soon as any heated air rises up for being light , it gets in contact with the coils and cools down . As a reslt all the air inside the room is cooled to the same desired temperature . IN the present case of the rink , it happens that the refrigerating coils are at the floor and not near the ceiling so that the cold air which is heavy will remain by

7. "H.V.A.C." Page 129
8. "H.V.A.C." page 136

gravity at the bottom without any circulation and with the result of having the upper layers of air hotter than those at the bottom.

The temperature of air at the breathing level is kept at 50°F by means of the heat radiators . The breathing level is considered as 7 feet above the ice surface ,. To account for the temperature of air at the ceiling and at some intermediate points between the ceiling and the floor , it is specified[9] that there will be " an increase in temperature of 1 percent per foot of height above the breathing level up to 15 feet , and an addition of $\frac{1}{10}$ of one degree for each foot above 15 feet .

The temperature difference between the breathing level a and the top of the glass which is at 12 feet from the ice surface will be :

$$\frac{50}{100} \times (12-7) = 2.5$$

Temp. at the top of glass = 2.35 + 50 = 52.5° F

$$\frac{50}{100} \times (15-7) = 4.0 \text{ degrees}$$

50.0

Temp. at 15 feet high = 54.0

$$\frac{1}{10} \times (22-15) = 0.7$$

Temp. at the ceiling = 54.7

The temperature of the floor surface with the exterior of the platforms is considered as 32°F. The temperature of the ground under the floor is taken as the average temperature for the whole year and it cannot be related to the air temperature at a certain time due to the lagging of the ground to absorb heat immediately. For at the beginning of winter the ground will be still hot while at the beginning of summer it will be cold. The average temperature for the two years 1943 ,1944 is 16.5°C = 62° F.

9."H.V.A.C. Guide" Page 246

Table I

Temperature Range in Jerusalem [10]

Month	Mean Temp.(C°) 1943	Mean Temp.(C°) 1943 — 5
January	7.5	7.5
February	7.1	9.8
March	8.4	13.0
April	13.0	17.2
May	18.3	18.1
June	20.1	23.2
July	22.4	22.9
August	23.5	23.6
September	22.7	22.8
October	21.6	20.8
November	17.4	14.5
December	12.4	10.4

Table II

Thermodynamic Properties of Moist Air[11]

Fahr. Temp.	Humidity Ratio x 1000	Volume cu.ft./lb.dry air			Enthalpy B.T.U./lb.dry air			Condensed Water Enthalpy
		v_a	v_{as}	v_a	h_a	h_{as}	h_s	h^h_w
44	6.09	12.69	0.12	12.82	10.57	6.58	17.15	12.1
65	13.26	13.22	0.28	13.50	15.61	14.45	30.06	33.11

10."Statistical Abstract of Palestine" of 1944-45 compiled and published by the Department of Statistics.

11."H.V.A.C. Guide" Page 32

4. Load Calculation: The latent heat load required to freeze the ice surface shall not be counted as one to provide for during the sports time because the ice is going to remain continuously on the floor during the skating season. The freezing of ice imposes a load only at the start which amounts to

$$85 \times 185 \times 1/12 \times 57 \ ((65-32) + 144)$$

$$= 74500 \ (33 + 144) = 13300000 \text{ B.T.U.}$$

Letting the freezing of ice take place in 30 hours, the load imposed on the machines per hour = $\frac{13.3 \times 10^6}{30}$ = 445000 B.T.U./hr.

Infiltration through the opening and closing of doors and through cracks in the windows is one of the sources of heat leakage that should be accounted for. But with a large number of people present in the hall for whom there will be a big demand of fresh air by ventilating exceeding that which is entering by infiltration, then load calculations will exclude the infiltration through the doors and windows and will account only for the ventilated air which already includes that through infiltration. The fresh air needed for non-smoking people is 10 cubic feet /min./person[12] and that for smoking people is 15 cubic feet /min./person. Out of the 180 spectators, 100 people are assumed as smokers and the rest with the skaters are non-smokers.

Fresh air for non-smokers	= 10x280	= 2800 cu.ft./min.	
Fresh air for smokers	= 15x100	= 1500 cu.ft./min.	
Total fresh air per minute		= 4300	
" " " " hour	= 4300x60	= 258000 cu.ft./hr.	

12."H.V.A.C. Guide" Page 283

The heat gain from this volume of air will be found as follows:

Temp. of outside air ------------------$65^{o}F$

Relative humidity of outside air -------70%

Average indoor temp. -------------------$44^{o}F$

Relative humidity of inside air --------65%

Humidity ratio at $65^{o}F$ = 0.01326

x 70% = 0.00928 lb.water/lb.air

Humidity ratio at $44^{o}F$ = 0.00609

x 65% = 0.00396 lb.water/lb.air

Condensed water = 0.00532 lb./lb./air

Specific enthalpy of condensed water at $44^{o}F$ = 12.10 B.T.U./lb.w.

Assuming that 50% of this condensed water will fall on the ice surface and freeze, then the heat gain due to moisture

$$= 0.00532 \times 12.1 + \frac{50}{100} \times 0.00532\ (1 \times (44-32) + 144 + (32-31.5)\ 0.504)$$

$$= 0.0644 + 0.00266\ (12 + 144 + 0.252)$$

$$= 0.0644 + 0.416 = 0.4804 \text{ B.T.U./lb.dry air}$$

Enthalpy of moist air at $65^{o}F$, 70% R.H.

$$= 15.614 + 0.7 \times 14.45 = 25.73 \text{ B.T.U./lb.dry air}$$

Enthalpy of moist air at $44^{o}F$, 65% R.H.

$$= 10.57 + 0.65 \times 6.58 = 14.85 \text{ B.T.U./lb.dry air}$$

Difference of enthalpy 25.73-14.85 = 10.88 B.T.U./lb.dry air

Heat gain from the moisture = 0.48

11.36 B.T.U./lb.dry air

$$\text{Total heat produced} = \frac{258000}{13.22+0.7\times0.28} = 218000 \text{ B.T.U./hr.}$$

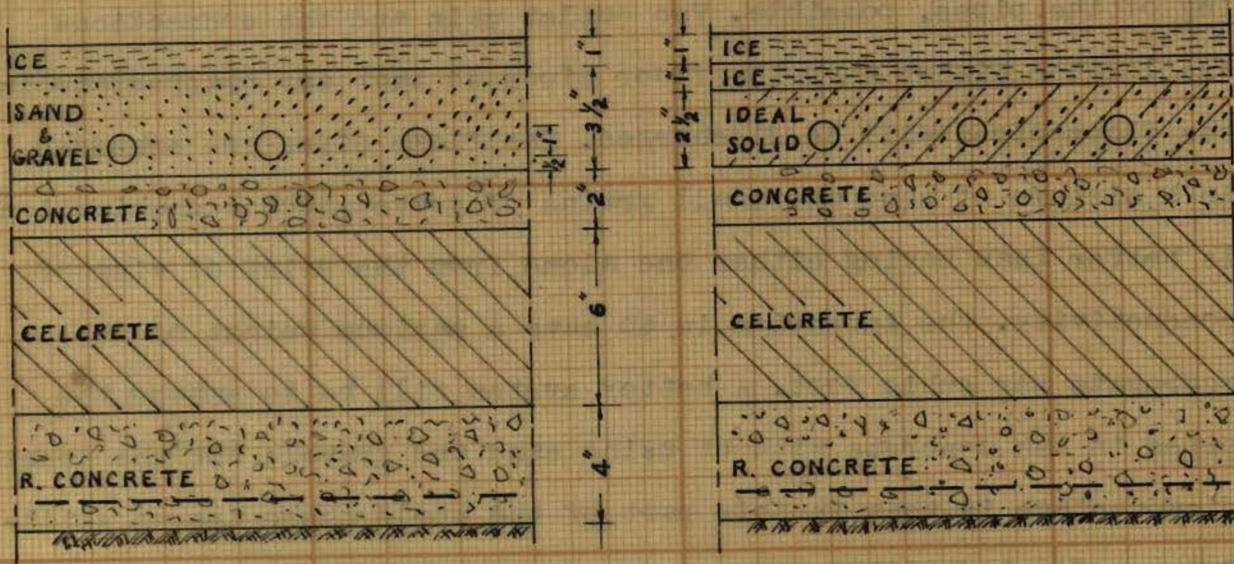
TABLE III

Heat gain due to	Area or No.	Coeffi.	Difference of temp. F^{o}		Heat gain B.T.U./hr
Floor	194 x 95 = 18450 ft.^{2}	0.126	62 - 32	=30	69700
Platform	194 x 17.33 = 3360 ft.^{2}	0.126	62 - 37	=25	10600
Glass windows	16 x 7 x 5 = 560 ft.^{2}	0.45	$65 - \frac{52.5 + 50}{2}$	=13.7	3450
Walls					
From floor up to 7 ft. high	(194 x 2 + 113 x 2)x7)=4298 ft.^{2}	0.148	$65 - \frac{50 + 32}{2}$	=24	15250
From 7ft. to 12ft.	(388 + 226)5 -560 =2510ft^2	0.233	$65 - \frac{52.5 + 50}{2}$	=13.7	8000
From 12 up to 22ft.	(388 + 226)10 = 6140 ft^2	0.233	$65 - \frac{55 + 52.5}{2}$	=11.25	16100
Roof	18450 + 3360 =21810 ft^2	0.039	65 - 55	=10	8520
People active	200	800			160000
People at rest	180	500			90000
Electric lights	15000 watts	3.42			51300
Heaters	15000 watts	3.42			51300
					484220
Ventilation				=	218000
			Total B.T.U./hr.	=	702220
Adding 14% for safety the total refrigeration load				=	800000

5. Piping: Trenches, in which the main inlet and outlet pipes are laid, are provided on the sides to make the cleaning of the pipes, possible. The outlet main and the connections are located higher than the floor pipes so that any trapped air in the floor pipes will be discharged. The floor pipes are embedded in a mixture of sand and small grains of gravel.Such a combination is better than having either one alone from the point of view of conductivity. The intention is to have a maximum weight of the aggregate per cubic foot. A better system will be to embedd the pipes in the concrete without using sand and gravel; but the great disadvantage is that in this part of the world there are no skillful men for installing pipes in concrete, in which case it is very possible that some sort of leakage in the pipes may occure due to the inexperience of the workmen and which will be costly to repair.

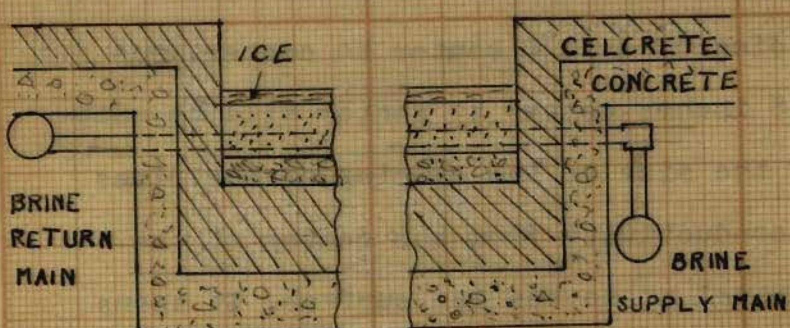
Floor pipes are chosen to be of steel because of their lower initial cost per foot lenght. The usual practice[13] is to use 1 to 1¼ inch pipes at a spacing of 4 to 6 center to center. One inch pipes at a spacing of 5 inches center to center will be adopted. An exact estimation of the size or the spacing of the pipes can be made by knowing the conductivity from the center of the pipe through the sand and gravel up to the ice surface. It seems difficult to find the conductivity of a layer of sand and gravel saturated with water; but if it is imagined that this layer is pressed a little so that a solid, rock like, layer of gravel and sand free of voids and a seperate layer of water are formed, then the conductivity can easily be found. As some contraction or expansion

13."Refrigeration Application"of 1946 page 447

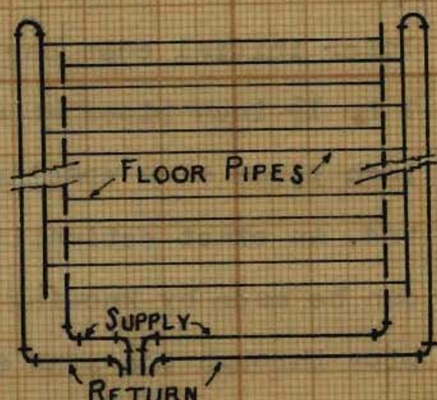


ACTUAL FLOOR SECTION

FLOOR SECTION WITH GRAVEL BEING PRESSED TO A SOLID LAYER



SECTION SHOWING SUPPLY & RETURN PIPES



BALANCED FLOW SYSTEM OF PIPES

may occur in the pipes which extend along the width of the ice surface, then these pipes are not installed in a straight line but a bit curved. The system of distribution of pipes is shown in the figure with alternate pipes having the same main supply and outlet pipes of 4 in. diameter so as to get a more or less uniform cooling at the sides of the ice surface.

The refrigerant circulated in the pipes is the brine of sodium chloride having an average temperature of 15°F, and with a range of temperature difference not more than 2°F between inlet and outlet. Corrosion is prevented by adding a certain percentage of sodium bichromate to the brine, usually 200 lb./1000 cu.ft. sodium chloride brine.

6. Brine Circulation And Pumping Power : Some of the properties of sodium chloride brine are[14] :

Percent of salt by weight --------20

Weight of 1 gallon ---------------9.64 lb.

Weight of 1 cu.ft. ---------------71.76 lb.

Freezing point -------------------6.10° F

Specific heat --------------------0.829

To find the amount of discharge of brine :

Load ---------------800000 B.T.U./hr.

Temp. difference --- 2°F

Wt. of brine circulated $= \dfrac{800000}{1 \times .829 \times 2 \times 60} = 8050$ lb./min.

Vol. " " $= \dfrac{8050}{9.64} = 835$ gal./min.

$= \dfrac{8050}{71.76} = 112.2$ cu. ft./min.

14."Refrigeration and Refrigerating Machinery" Vol. II of The International Library of Technology.

The internal diameter of a pipe of 1 inch nominal size is 1.049 in.[15]

The sum of the section of areas of the floor pipes

$$= \frac{12 \times 185}{5} \times 0.785 \times 1.049^2 = 385 \text{ in.}^2$$

The velocity in the pipes $= \frac{112.2 \times 144}{385} = 42$ ft./min.

$= .70$ ft./sec.

Viscosity of brine at a temp. of 15°F and a density of 71.76 lb./cu.ft. is 3.5 centipoises[16].

Reynolds number[17] $= \frac{22740 \times W}{D \times \text{centipoises}}$

Number of pipes $= \frac{185 \times 12}{5} = 444$

$$W = \frac{8050}{60 \times 444} = .302 \text{ lb./sec.}$$

$$D = 1.049 \text{ inches}$$

$R = \frac{22740 \times 0.302}{1.049 \times 3.5} = 1900$ which is very near to 2000 at which turbulant flow starts and which is very favourable so as to have a greater conductivity than the case with laminar flow.

f[18] $= 0.05$

h_f[19] $= f \frac{L}{d} \times \frac{V^2}{2g}$

Equivalent length of pipe for sudden contraction[20] = 1.5 ft.

" " " " " " enlargement = 2.0 ft.

Head loss $= .05 \times \frac{88.5 \times 12}{1.049} \times \frac{0.70^2}{32.17 \times 2} = .39$ ft. fluid

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15."Refrigerating Data Book" page 179
16."Refrigerating Data Book" page 182
17."Hydraulics " by R.L. Daugherty page 109
18."Refrigerating Data Book " page 177
19."Hydraulics " page 195
20."Refrigerating Data Book " page 293

Flow in one main supply = $\frac{112.2}{2}$ = 56.1 cu.ft./min.

Velocity " " " = $\frac{56.1 \times 144}{4.03^2 \times .785}$ = 635 ft./min.

= 10.6 ft./sec.

$$W = \frac{8050}{60 \times 2} = 67.0 \text{ lb./sec.}$$

$$D = 4.03 \text{ inches}$$

$$R = \frac{22740 \times 67}{4.03 \times 3.5} = 107800$$

$$f = 0.0216$$

Length = 10 + 85 + 185 + 185 + 185 + 10 + 5 = 665 ft.

Equivalent length of 6 elbows[21] 4 in. diameter = 8x6 = 48 ft.

713 ft.

$$h_f = .0216 \times \frac{713 \times 12}{4.03} \times \frac{10.6^2}{64.35} = 79 \text{ ft. fluid}$$

.39

Total h_f - = 79.39

Pressure loss = $\frac{79.39 \times 71.76}{144}$ = 39.5 lb./in^2

The actual pump to be used should have an actual head about 15% greater, to account for pipe defficiency with use. This extra head can be throttled with a gate valve.

$$H.P. = \frac{8050}{60} \times \frac{71.76}{62.4} \times 79.39 \times \frac{1}{550} \times \frac{1}{.75}$$

$$= 29.6 \text{ H.P.}$$

Two pumps will be selected for a total

Head = 39.5 + 15% = 45.5 lb./in^2.

G.P.M. = 835

H.P. = 30

The rest of the machinary will be dealt with under Part II

21. " Refrigerating Data Book " page 283

P A R T

II

I C E   P L A N T

CHAPTER

I

GENERAL CONSIDERATION

1. Composition: The ice plant, small in size as compared to the rink, lies under the southern part of the rink. It is composed of the following:

A machine room

An ice freezing tank

An ice storage room

An office

In addition there is a special tank the purpose of which is to be able to store the brine water of one of the two parts of the ice tank in case of any leakage in the cooling coils instead of wasting it away.

2. Ice Tank: The top of the tank is flush with the general floor of the plant, and it has a wooden cover which not only prevents the rapid transfer of heat from the air to the brine but also prevents the dust and dirt from getting into the ice cans and serves as a floor for the workmen. The sides and the bottom of the tank consist of 4 inches reinforced concrete, an insulation of 6 inches and 2 inches plain concrete. The tank is divided longitudinally into two halves with seperate refrigerating coils for each part; so that in case of having any damage in one of the coil lines or in some part of the tank, then the other half of

the tank will resume its work independently for the production of ice. Angles 3 x 2 $\frac{1}{4}$ are provided at the top of the tank running in both directions to support the wooden covers and the can grids. Some of the standard sizes of ice cans are given in the table below. The ice can of 50 lb. ice cake is selected so as to comform with the size of the ice blocks on the market.

TABLE I[1]

Standard Sizes Of Ice Cans

Size of ice cake pounds	Size of top inches	Size of bottom inches	Inside depth inches	Outside depth inches	Size of band inches
50	8 x 8	$7\frac{1}{2}$x$7\frac{1}{2}$	31	32	$\frac{1}{4}$ x$1\frac{1}{2}$
100	8 x16	$7\frac{1}{4}$x$15\frac{1}{4}$	31	32	$\frac{1}{4}$ x$1\frac{1}{2}$
200	$11\frac{1}{2}$x$22\frac{1}{2}$	$10\frac{1}{2}$x$21\frac{1}{2}$	31	32	$\frac{1}{4}$ x 2
300	$11\frac{1}{2}$x$22\frac{1}{2}$	$10\frac{1}{2}$x$21\frac{1}{2}$	44	45	$\frac{1}{4}$ x 2
400	$11\frac{1}{2}$x$22\frac{1}{2}$	$10\frac{1}{2}$x$21\frac{1}{2}$	57	58	$\frac{1}{2}$ x 2

By comparing column 2 with 3 in the above table, it is concluded that the ice cans are tapered so as to facilitate dumping. The galvanizing on ice cans can be protected by the chromate treatment against corrosion.

3. Miscellaneous

(a) Brine agitator: It is a kind of a propeller introduced for the sake of having a uniform freezing effect in the tank. When the ice cans are filled with water, the brine surrounding them becomes warm , while the brine in contact with the coils is cold. So in order to facilitate the transfer of heat the brine is stirred by means of the agitator, with the result of having a uniform temperature.

(b) Cranes: In small plants ice cans are lifted by cranes with hand hoists. But as the present plant is a big one, then an electric motor hoist which can handle four cans at a time is used for each half of the tank.

(c) Dip tanks: The cans lifted by the crane are carried to a dip tank in which they are submerged under water until the ice blocks float up in the can. Such a process is called thawing. The dip tank water is kept at not over $70^{o}F$ in order to avoid the stressing and cracking of ice.

(d) Ice dumps: An ice dump is a sort of a cradle supported on pivots and consisting of a front, bottom and side end box. After the ice thaws from the cans, they are raised and shifted to the dumps, so that by some mechanical means the latter are tipped quickly into a position for the ice to slide out. The pitch for the dumps and ice run is 1 inch per foot.

(e) Can filler: It is a device for filling the ice cans with water to the required amount and then stopping automatically.

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1. "Refrigeration and Refrigeration Machinery " Vol.II of the International Library of Technology.

CHAPTER

II

TECHNICAL DESIGN

1. Load Calculations: In order to make use of the full capacity of the machines, the ice plant is designed for an amount of ice such that the total load will be approximately equal to that got from the skating rink. To begin with, an amount of ice of 45 tons per day is reasonable enough to produce. The major part of the load will be due to the freezing of ice and the rest is due to some minor losses from the tank and the storage room. The temperature inside the storage room is kept at $25^{\circ}F$. The temperature at which the brine should be kept,

$$t = 32 - \frac{583.1\ a^2}{nW}$$ [1]

where a = thickness of block

n = number of cans /ton ice produced in 24 hrs.

w = weight of cake, lb.

$$t = 32 - \frac{583.1 \times 64}{40 \times 50} = 32 - 18.7 = 13^{\circ}F$$

The time for freezing is expressed by

$$x = \frac{7a^2}{32-t}$$ [2]

$$= \frac{7 \times 64}{32-13} = 23.6 \text{ hr.}$$

1." Refrigeration Applications " page 431
2." " " " 431

The load due to the different sources will be found as follows:

Freezing of ice, 45 tons/day

90000(1x(75-32) +144+(32-25)x0.5)

= 90000(43+144+3.5)

= 17130000 B.T.U./24hr. = 715000 B.T.U./hr.

Losses from the ice tank 41x32x3 ft.

Walls = 2(42+32) x 3 = 444ft.^{2}

Floor = 42 x 32 = 1344

1788 ft.^{2}

x .126(62-13) = 11050 B.T.U./hr.

2 in. wooden cover = 1344x0.39(75-13) = 32550 B.T.U./hr.

Agitator 5 H.P.

5 x 3000 = 15000 B.T.U./hr.

Storage room 25x24x10 ft.

Walls = (25+24) x 10 = 490 ft.^{2}

x .128(75-25) = 3140 B.T.U./hr.

x .109(62-25) = 1980 B.T.U./hr.

Ceiling = 25x24x.126(75-25) = 3780 B.T.U./hr.

Floor = 25x24x.126(62-25) = 2800 B.T.U./hr.

Door opening and infiltration

Number of air changes[3] for a volume of 6000 cu.ft. is 6.5 per 24 hr.

Heat removed in cooling to storage temp.

= 2.05 B.T.U./cu.ft.

$6000 \times 2.05 \times \frac{6.5}{24}$ = 3300 B.T.U./hr.

Workmen, 2

2 x 750 = 1500 B.T.U./hr.

Forward = 790100 B.T.U./hr

Light 120 watts

120 x 3.42 = 410 B.T.U./h r

Total load = 790510 B.T.U./hr

For safety, the refrigerating load = 800000 B.T.U./hr

Refrigeration capacity = 66.7 tons

2. Brine circulation and cooling coils:

On the basis of circulation $7\frac{1}{2}$ B.T.U./gal.per ^{o}F [4], then the volume of brine circulated,

$$V = \frac{800000}{7.5 \times 1 \times 60} = 1780 \text{ gal/min}$$

$$= 238 \text{ cu.ft/min.}$$

At a suction temperature of ammonia of 7^{o}F and brine 13^{o}F, the surface area of $1\frac{1}{4}$ in. coolers required

$$= \frac{800000}{6 \times 50} = 2670 \text{ ft}^2.$$

$$\text{Length} = \frac{2670 \times 12}{1.38 \times 3.1416} = 7400 \text{ ft.}$$

= 3700 ft. each half of the tank

Pipes are extending in vertical planes across the flow of brine at 2.5 inches center to center.

$$\text{Length of each set of pipes} = 4 \times \frac{3 \times 12}{2.5} = 53 \text{ ft.}$$

Length of distributors = 7

60 ft.

$$\text{Number of sets} = \frac{3700}{60} = 61$$

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3. "Refrigeration Data Book " page 170
4. " Refrigeration Applications " page 436

3. Refrigeration equipment.

Condenser:Since the supply of water in Jerusalem is to a certain extent limited and insufficient, then some kind of condenser should be selected by means of which a minimum amount of water is wanted. An evaporative condenser is selected not because it " has only one purpose - to save water! "[5] but also it occupies small space as compared to cooling towers. For a load of 800000 B.T.U./hr. a Trane evaporative condenser will be selected having a [6]

Unit no.------------KN - 1516

Capacity------------801000 B.T.U./hr.

Water required------2 C.P.M.

Compressors:Two compressors are provided instead of having a single compressor of the same capacity of 800000 B.T.U./hr. having ammonia as the refrigerant. Special concrete base foundations are constructed on which the machines are mounted. An extra base is made for a third compressor to be installed in the future as a reserve , as it is not advisable to invest more capital during the initial stages of the scheme.

Suitable valves and connecting pipes for suction and liquid lines are selected.

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5. "Evaporative Condenssor", Trane Bulletin DS - 350 March 1946 page 2
6. " Evaporative Condenssor", Trane Bulletin DS - 350 March 1946 page 10

PART

III

ROOF TRUSS

CHAPTER I

ECONOMICAL CONSIDERATION

1. Form of truss: It has been a difficult problem to choose the type of truss for such an unusual span of 114 feet. Would it have been a factory, then columns could have been inserted so as to shorten the span. But to preserve the beauty of the skating hall and to prevent any obstruction infront of the spectators, the columns were of no use. Such a span of 114 feet could be satisfied by an arch form of truss, which would be light and might reduce the wind pressure specially the suction effect on the leeward side. Due to lack of information about the dynamic effect of the wind on such a structure, it has not been adopted; and a compound fink truss, as shown below, has been selected.

2. Available data:

Span of truss -----114 feet c. to c.

Kind of truss -----Compound fink

Roofing -----------Asbestos[1] shingles @6.0 lb/ft.^{2}

Sheathing ---------Yellow pine[2] 25/32 in.@2.74 lb/ft.^{2}

Joists ------------Yellow pine 2 feet c. to c.

Snow[3] load --------20 lb/ft.^{2}

Wind pressure -----30 lb/ft.^{2} on a vertical surface

Wt. of ceiling ----2.0 lb/ft.^{2} (assumed)

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1. "Structural Design In Steel" by T.C. Shedd p. 397
2. "Structural Design In Steel" by T.C. Shedd p. 373
3. Maximum snow fall in Jerusalem is 2 ft. high, x 10 lb/ft.^{3} = 20 lb/ft.^{2} The specific weight of snow is taken from the "Competitive Design Of Steel Structures" by P. Russel & G.D.

3. Economical Spacing of Trusses: In designing the roof of a building, the spacing of trusses is an important factor to be considered. If the space between each two trusses is large, the purlins will be heavy; but the number of trusses for the entire roof will be less. In such a condition there is on the one hand an increase in the weight of steel on the part of the purlins, whilst on the other hand there is a decrease in the number of trusses, thus a saving in the weight of steel and in the shop work is effectd, which means a saving in the cost. The opposite condition will happen if the spacing is decreased. To strike a balance with the minimum cost of purlins and trusses, the following five different spacings are tried for the 194 foot length of roof.

(a) 13 spacings @ 14.92 ft. = 194 ft.

Design of purlins:

Shingles --------6.00 lb./ft.^{2}

Sheathing -------2.74 " "

Joists ----------1.70 " "

½ Snow load -----10.00 " "

20.44 lb/ft.^{2}

x 7.96 = 163 lb/ft.

Assumed weight of purlins = 15 " "

178 lb/ft.

178 x 1/2.24 = 80 lb/ft. parallel to the roof

178 x 2/2.24 = 160 lb/ft. perpendicular to the roof

Winds load 22.3 x 7.96 = 177 lb/ft. " " "

337 lb/ft. " " "

$M_p = -1/10 \times 80 \times (\frac{14.92}{3})^2 \times 12 = 2400$ in.-lb. (2 sag rods)

$M_n = 1/8 \times 337 \times 14.92^2 \times 12 = 113800$ in.-lb.

Assumed $S = 22 \times S/2$ Where one flange is resisting the moment around the Y-Y axis of the purlins.

$I/c = \frac{113800}{20000} + \frac{2400 \times 22}{20000} = 5.69 + 2.64 = 8.33$ in.^{3}

9 in. [@ 13.4 lb./ft. $I/c = 10.50$ in.^{3}

The weight of the truss can be estimated approximately by the "Sutherland & Bowman" formula:

$$W = \left[\tfrac{1}{2}(L-50)^2 + (L-20)\left(18 + \frac{8(W+P)}{100\,C}\right)\right]\left(\frac{16000}{20000}\right)$$

Where,

W = Weight of truss in pounds.

L = Span of truss in feet.

C = Total length of top chord in feet.

P = Total vertical load carried by the truss in pounds exclusive of its own weight and including; roofing, sheathing, joists, purlins, bracing & snow.

In this case,

$L = 114$ ft.

$C = 127.4$ ft.

$W = 7300$ lb. (assumed)

$P = 20.44 + 22.3 \times \frac{2}{2.24} = 40.44$ lb/ft.^{2}

bracing $= 3L/400 = 0.86$

ceiling $= \underline{2.00}$

43.30 lb/ ft.^{2}

$43.30 \times 127.4 \times 15 = 82800$

purlins $13.4 \times 18 \times 14.92 = 3600$

$82800 + 3600 = 86400$ lb.

$$W = \left[\tfrac{1}{2}(114-50)^2 + (114-20)\left(18 + \frac{8(7300 + 86400)}{100 \times 127.4}\right) \right] \times 0.8$$

$$= \left[2050 + 7210 \right] \times 0.8 = 7400 \text{ lb.} \quad \text{wt. of truss.}$$

Wt. of purlins $= 3600 \times 13 = 46800$ lb.

@ L.L. 0.27 = 12750 Lebanese pounds

Wt. of trusses $= 7400 \times 12 = 88900$ lb.

@ L.L. 0.59 = 52600 " "

Total cost of purlins & trusses = 65350 " "

(b) 12 spacings @ 16.17 ft. = 194ft.

Assumed weight of purlin = 15.0 lb./ft.

D.L. + $\frac{1}{2}$ S.L. = 163.0 " "

178.0 lb/ft.

178 x 1/2.24 = 80 lb/ft. parallel to the roof

178 x 2/2.24 = 160 lb/ft.normal to the roof

Wind load = 177 " " " " "

337

$M_p = 1/10 \times 80 \times \frac{(16.17)^2}{3} \times 12 = 2780$ in.-lb.

$M_n = 1/8 \times 337 \times 16.17^2 \times 12 = 132000$ in.-lb.

Assumed S = 22 x s/2

$I/c = \frac{132000}{20000} + \frac{2780 \times 22}{20000} = 6.6 + 3.06 = 9.66$ in.^{3} required

9 in. /@ 15.0 lb. $I/c = 11.30$ in.^{3} supplied

C = 127.4 ft.

P = 43.3 x 127.4 x 16.17 + 18 x 16.17 x 15 = 89200 + 4370 = 93570 lb.

$W = [\frac{1}{2} (114 - 50)^2 + (114 - 20)(18 + \frac{8(7700 + 93570)}{127.4})] \times 0.8$

= (2050 + 7670) x 0.8 = 7776 lb. wt. of truss.

Wt.of purlins = 4370 x 12 = 52400 lb.
@ LL.0.27 = 14300 Lebanese Pounds.

Wt.of trusses = 7776 x 11 = 85500 lb.
@ LL.0.59 = 50600 " "

Total cost of purlins and trusses = 64900 " "

(c) 11 spacings @ 17.64 ft. = 194 ft.

Assumed wt. of perlin = 15.30lb/ft.

D.L. + ½ S.L. = 163.00 lb./ft.

178.30 lb/ft.

178.30 x 1/2.24 = 80 lb/ft. parallel to the roof

178.30 x 2/2.24 = 160 lb/ft. normal to the roof

Wind load = 177 " " " " "

337 lb/ft. " " " "

$M_p = 1/10 \times 80 \times \left(\frac{17.64}{3}\right)^2 \times 12 = 3320$ in.-lb.

$M_n = 1/8 \times 337 \times 17.64^2 \times 12 = 157000$ in.-lb.

Assumed S = 22 x s/2.

$I/c = \frac{157000}{20000} + \frac{3320 \times 22}{20000} = 7.85 + 3.65 = 11.50$ $in.^3$ required

10 in. ⌐@ 15.3 lb/ft. $I/c = 13.40$ $in.^3$ supplied

C = 127.4 ft.

P = 43.3 x 127.4 x 17.64 + 18 x 15.3 x 17.64 = 97200 + 4860 = 102060.

$W = \left[\tfrac{1}{2}(114 - 50)^2 + (114 - 20)\left(18 + \frac{8(8300 + 102060)}{127.4}\right)\right] \times 0.8$

= (2050 + 8210) x 0.8 = 8200 lb. wt. of truss.

Wt. of purlins = 4860 x 11 = 53460 lb.

@ LL. 0.27 = 14600 Lebanese Pounds.

Wt. of trusses = 8200 x 10 = 82000 lb.

@ LL. 0.59 = 48500 " "

Total cost of purlins and trusses = 63100 " "

(d) 10 spacings @ 19.4 ft. = 194 ft.

Assumed weight of purlin = 20.0 lb/ft.

D.L. + ½ S.L. = <u>163.0 lb/ft.</u>

183.0 lb/ft. vertical

183.0 x 1/2.24 = 81.8 lb/ft. parallel to the roof

183.0 x 2/2.24 = 163.6 lb/ft. normal to the roof

Wind load = <u>177.0</u> " " " " "

340.6 " " " " "

$M_p = 1/10 \times 81.8 \times \left(\frac{19.4}{3}\right)^2 \times 12 = 4100$ in.-lb.

$M_n = 1/8 \times 340.6 \times 19.4^2 \times 12 = 192000$ in.-lb.

Assumed S = 24 x s/2

$I/c = \frac{192000}{20000} + \frac{4100 \times 24}{20000} = 9.6 + 4.92 = 14.52$ in.^{3} required

10 in. ⌐@ 20 lb/ft. I/c = 15.70 in.^{3} supplied

W = 8700 lb. (assumed)

C = 127.4 ft.

P = 43.3 x 127.4 x 19.4 + 18 x 19.4 x 20 = 107000 + 6990 = 113990 lb.

$W = \left[\tfrac{1}{2}(114-50)^2 + (114-20)\left(18 + \frac{8(8700 + 113990)}{127.4}\right)\right] \times 0.8$

= (2050 + 8925) x 0.8 = 8780 lb. wt. of truss.

Wt. of purlins = 6990 x 10 = 69900 lb.

@ LL% 0.27 = 19100 Lebanese Pounds

Wt. of trusses = 8780 x 9 = 79020 lb.

@ LL. 0.59 = <u>46700</u> " "

Total cost of prulins and trusses = 65800 " "

(e) 9 spacings @ 21.55 ft. = 194 ft.

Assumed weight of purlins = 20.0 lb/ft.

D.L. + $\frac{1}{2}$ S.L. = 163.0 lb/ft.

183.0 lb/ft. vertical

183.0 x 1/2.24 = 81.8 lb/ft. parallel to the roof

183.0 x 2/2.24 = 163.6 lb/ft. normal to the roof

Wind load = 177.0 " " " " "

340.6 " " " " "

$M_p = 1/10 \times 81.8 \times \left(\frac{21.55}{3} \right)^2 \times 12 = 5050$ in.-lb.

$M_n = 1/8 \times 340.6 \times 21.55^2 \times 12 = 236000$ in.-lb.

Assumed S = 25 x s/2

$I/c = \frac{236000}{20000} + \frac{5050 \times 25}{20000} = 11.8 + 6.31 = 18.11$ in.^{3} required

12 in. [@ 20.7 lb/ft. $I/c = 21.40$ in.^{3} supplied

W = 10000 lb. (assumed)

C = 127.4 ft.

P = 43.3 x 127.4 x 21.55 + 18 x 21.55 x 20.7 = 118900 + 8020 = 126920

$W = \left[\frac{1}{2} (114-50)^2 + (114-20)\left(18 + \frac{8(10000 + 126920)}{127.4}\right) \right] \times 0.8$

= (2050 + 9760) x 0.8 = 9450 lb. wt. of truss.

Wt. of purlins = 8020 x 9 = 72180 lb.
@ LL. 0.27 = 19700 Lebanese Pounds

Wt. of trusses = 9450 x 8 = 75600 lb.
@ LL 0.59 = 44700 " "

Total cost of purlins and trusses = 64400 " "

The third trial with 11 spacings @ 17.64 ft. gave the most economical condition for which the design of the sag rods will follow:

$D.L. + S.L. = 30.44\ lb/ft.^2$

$\times 63.7 \times \frac{17.64}{3} = 11400$ lb.

Wt. of perlins $= 15.3 \times \frac{17.64}{3} \times 8 = 720$

12120 lb. vertical

$12120 \times 1/2.24 = 5420$ lb. parallel to the roof

$\text{Area} = \frac{5420}{18000} = 0.3\ in.^2$

Minimum[4] size of sag rods used is 5/8 in. round bars

Therefore 5/8 in. round bars are adopted.

Wt./ft. = 1.043 lb/ft.

Total weight of sag rods on each truss = 266 lb.

4. " Ketchum's Structural Engineers Handbook", by Ketchum, page 36.

CHAPTER II

STRESSES

1. Dead and Snow Load: The dead load includes the weight of the joists which have not been designed yet. To account for their weight, their design will follow:

Shingles.	6.00	lb./ft.^{2}	
Sheathing	2.74	"	"
Equivalent load of snow & wind... ..	24.00	"	"
Assumed weight of joists.	2.00	"	"
	34.74	"	"

$M = 2/8 \times 34.74 \times (63.7/8)^2 \times 12 = 6630$ in.lb.

$I/c = M/S = \frac{6630}{1000} = 6.63$ in.^{3}

Wooden joists 2 in. x 8 in. at 3.39 lb/ft. 24 in. C.to C.are used

Therefore the panel load will be:

Shingles.	6.00	lb./ft.^{2}	
Sheathing	2.74	"	"
Joists...	1.70	"	"
Bracing..	0.86	"	"
Details..	2.00	"	"
	13.30		

x 127.4 x 17.64 =	30000
Purlins.. ... ... =	4860
Sag rods. ... ... =	270
Wt. of truss. ... ... =	8200
	43330 lb.

The panel dead load = $\frac{43330}{16}$ = 2700 lb. = 2.70 kips.

The panel snow load = 20 x $\frac{127.4}{16}$ x 17.64= 2.81 "

The coefficients of stresses for all the members due to a unit panel load will be calculated below, referring to fig 1. :-

Sin. of the slope angle = 0.447

Cos. " " " " = 0.895

Joint L_0

$L_0U_1 = \frac{7.5}{.447}$ = 16.8 kip compression.

L_0L_1 = 7.5 x 2 = 15.0 kip tension.

Joint U_2

U_1L_1 = 1.0 x 0.895 = 0.895 kip compression.

U_1U_2 = 16.8 - 1.0 x 0.895 = 16.35 kip compression.

Joint L_2

L_1U_2 = (0.895 x 0.895) $\frac{35.6}{28.5}$ = 1.0 kip tension.

L_1L_2 = 15.0 - 0.895 x 0.447 - $\frac{21.4}{35.6}$ x 1.0 = 14.0 kip tension.

Section 1 - 1

$M_{u4} = \frac{28.5}{2} L_2L_4 + 3 \times \frac{57}{4} \times 1 - 7.5 \times \frac{57}{2} = 0$

$L_2L_4 = \frac{213.8 - 42.75}{14.25}$ = 12.00 kip tension.

$M_{L_0} = 1/2.24 \times L_3U_4 \times \frac{63.7}{2} - \frac{3 \times 57}{4}$

$L_3U_4 = \frac{42.75 \times 2.24}{31.9}$ = + 3.0 kip tension.

U_3U_4 = (7.3 - 3 + $\frac{28.5}{35.6}$ x 3) 2.24 = - 15.43

Joint U_3

U_3L_3 = 1.0 x 0.895 = 0.895 kip compression

U_2U_3 = 15.47 + 1.0 x 0.447 = 15.88 kip compression.

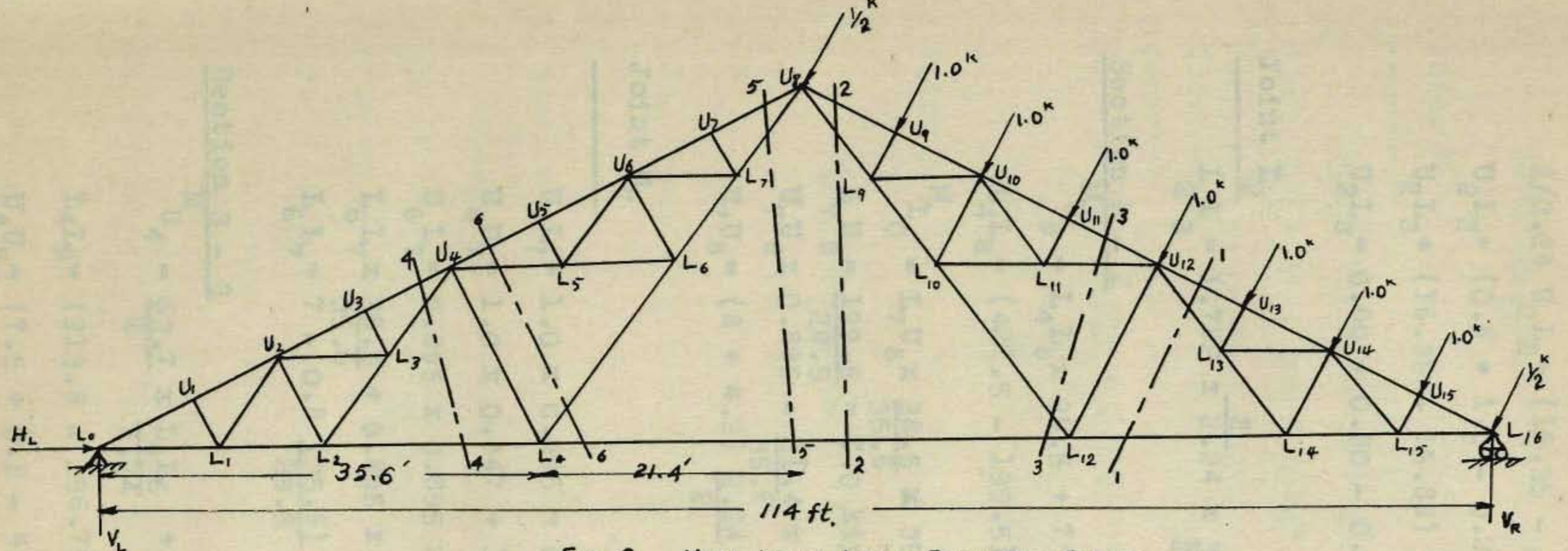

FIG. 3 UNIT WIND LOAD FROM THE RIGHT

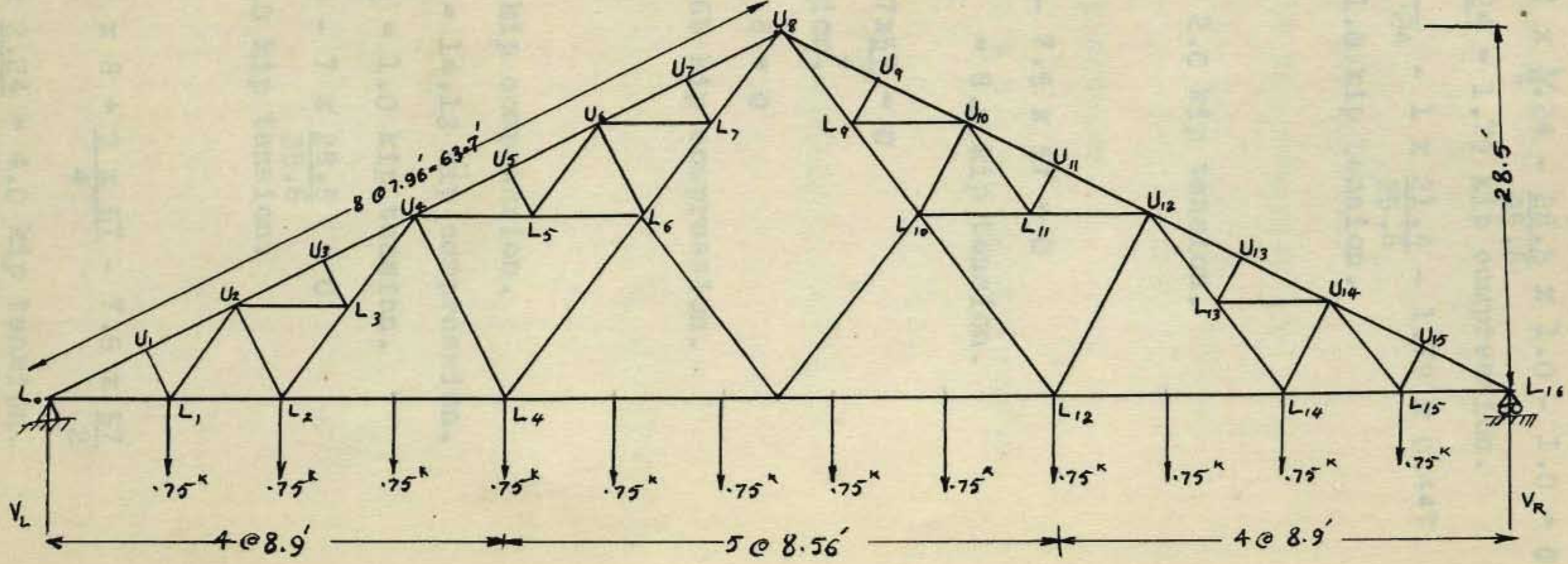

FIG. 4 CEILING LOAD

Joint U_2

$$2/2.24\ U_2L_2 + (16.35 - 15.88) \times 1/2.24 - \frac{28.5}{35.6} \times 1.0 - 1.0 = 0$$

$$U_2L_2 = (0.8 + 1.0 - 0.21)\ \frac{2.24}{2} = 1.79 \text{ kip compression.}$$

$$U_2L_3 + (16.35 - 15.88) \times \frac{2}{2.24} - 1 \times \frac{21.4}{35.6} - 1.79 \times 0.447$$

$$U_2L_3 = 0.60 + 0.80 - 0.40 = 1.0 \text{ kip tension.}$$

Joint L_2

$$L_2L_3 = 1.782 \times \frac{2}{2.24} \times \frac{35.6}{28.5} = 2.0 \text{ kip tension.}$$

Section 2 - 2

$$M_{U_8} = L_4L_8 \times 28.5 + 7 \times \frac{57}{2} - 7.5 \times 57 = 0$$

$$L_4L_8 = (427.5 - 199.5)\ \frac{1}{28.5} = 8.0 \text{ kip tension.}$$

$$M_{L_0} = L_7U_8 \times \frac{28.5}{35.6} \times 35.6 - 7 \times \frac{57}{2} = 0$$

$$L_7U_8 = \frac{199.5}{28.5} = 7.0 \text{ kip tension.}$$

$$U_7U_8 \times 0.895 - \frac{21.4}{35.6} \times 7.0 - 8 = 0$$

$$U_7U_8 = (8 + 4.2)\ \frac{2.24}{2} = 13.68 \text{ kip compression.}$$

Joint U_7

$$U_7L_7 = 1.0 \times 0.895 = 0.895 \text{ kip compression.}$$

$$U_6U_7 = 1.0 \times 0.447 + 13.68 = 14.13 \text{ kip compression.}$$

$$U_6L_7 = 0.895 \times 0.895 \times \frac{35.6}{28.5} = 1.0 \text{ kip tension.}$$

$$L_6L_7 \times \frac{28.5}{35.6} + 0.895 \times 0.895 - 7 \times \frac{28.5}{35.6} = 0$$

$$L_6L_7 = 7 - 0.8\ \frac{(35.6)}{29.5} = 6.0 \text{ kip tension.}$$

Section 3 - 3

$$M_{U_4} = \frac{63.7}{2} \times \frac{L_4L_6}{2.24} + \frac{28.5}{2} \times 8 + \frac{3 \times 57}{4} - 7.5 \times \frac{57}{2}$$

$$L_4L_6 = (213.8 - 156.75)\ 2 \times \frac{2.24}{63.7} = 4.0 \text{ kip tension.}$$

$$U_4U_5 = (7.5 + 3.2 - 4)\ 2.24 = 15.0 \text{ kip compression.}$$

$$U_4L_5 = 15.0 \times 0.895 - 0.6 \times 4 - 8 = 3.0 \text{ kip tension.}$$

Joint L_4

$L_4U_4 = \frac{0.8 \times 4}{0.895} = 3.58$ kip compression.

Joint U_5

$U_5L_5 = 1.0 \times 0.895 = 0.895$ kip compression.

$U_5U_6 = 15 - 1.0 \times 0.447 = 14.55$ kip compression.

Joint L_5

$L_5U_6 = \frac{0.895 \times 0.895}{0.8} = 1.0$ kip tension.

$L_5L_6 = 3 - 0.895 \times 0.447 - 1.0 \times 0.6 = 2.0$ kip tension.

Joint L_6

$U_6L_6 = \frac{0.8 \times 2.0}{0.895} = 1.79$ kip compression.

Wind Load : It is usually designated as a certain pressure per unit area on a surface normal to its motion which is usually vertical. The normal pressure of the wind on the surface of a pitched roof, is given by Duchemin's formula[1] :

$$P_n = P \times \frac{2 \sin \theta}{1 + \sin^2 \theta}$$

where

P_n = Normal pressure on the roof.

P = Normal pressure on a vertical plane.

θ = Slope angle of the roof.

$$P_n = 30 \times \frac{2 \times 0.447}{1 + 0.447^2} = 22.4 \text{ lb/ft}^2.$$

$$\text{Panel Load} = 22.4 \times \frac{63.7}{8} \times 17.64 = 3.15 \text{ kip.}$$

While some suction takes place on the leeward side, yet in practice designers do not provide for it in their calculations due to lack of information about its intensity. Other than this, the location of the building is in a depression where no severe wind can take place and produce suctions; and in addition, the roofing materials are fixed in such a way so as not to resist a great amount of suction with the result of having the truss stand in place against such a suction effect which will be trying to lift it up from its place. The coefficients of stresses for all the members due to a unit panel load with the wind coming from the left side in one case and from the right in another, will be calculated below referring to fig.2 in the first case and to fig. 3 in the second.

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1. "Structural Design In Steel", by T.C. Shedd, Page 370.

Wind from the Left

$V_R = 8 \times \frac{63.7}{2} \times \frac{1}{114} = 2.24$ kips.

$V_L = 8 \times 2/2.24 - 2.24 = 4.92$ kips.

$H_L = 8 \times 1/2;24 = 3.58$

Joint L_o

$L_oU_1 = (4.92 - 0.5 \times 2/2.24) \times 2.24 = 10.0$ kips compression.

$L_oL_1 = 3.58 + 10 \times 2/2.24 - 0.5 \times 1/2.24 = 12.316$.

Joint U_1

$U_1L_1 = 1.0$ kips compression.

$U_1U_2 = 10.0$ kips compression.

Joint L_1

$L_1U_2 = \frac{0.895}{0.80} \times 1.0 = 1.12$

$L_1L_2 = 12.32 - \frac{1.0}{2.24} - 0.6 \times 1 = 12 = 11.20$ kips tension.

Section 1 - 1

$M_{U_4} = \frac{28.5}{2} L_2L_4 + \frac{3 \times 63.7}{4} + \frac{1}{2} \times \frac{63.7}{2} - 4.92 \times \frac{57}{2} - 3.58 \times \frac{28.5}{2} = 0$

$L_2L_4 = 4.92 \times 2 + 3.58 - \frac{2 \times 63.7}{28.5} = 8.95$ kips tension.

$M_{L_0} = 0.8\, L_3U_4 \times \frac{35.6}{2} - 3 \times 7.96 \times 2 = 0$

$L_3U_4 = 3.36$ kips tension.

$U_3U_4 = (8.95 + 0.6 \times 3.36 - 3.58 + 3.5/2.24) \times 2.24/2$

$U_3U_4 = 8.25 + 1.75 = 10.0$ kips compression.

Joint U_3

$U_3L_3 = 1.0$ kips compression.

$U_3U_2 = 10.0$ kips compression.

Joint L_3

$U_2L_3 = (2/2.24 \times 1.0) \times 1/0.8 = 1.12$ kips tension.

$L_2L_3 = 3.36 - 0.447 - 1.12 \times 0.6 = 2.24$ kips tension.

Joint L_2

$U_2L_2 = (0.8 \times 2.24)\ 2.24/2 = 2.0$ kips compression.

Section 2 - 2

$$M_{U_8} = L_4L_8 \times 28.5 + 7 \times \frac{63.7}{2} + \tfrac{1}{2} \times 63.7 - 3.58 \times 28.5 - 4.92 \times 57$$

$L_4L_8 = (280.5 - 254.8)1/28.5 + 3.58 = 4.48$ kips tension.

$$M_{L_0} = 0.8\ L_7U_8 \times 35.6 - 7 \times \frac{63.7}{2}$$

$L_7U_8 = 7.88$ kip tension.

$$M_{L_4} = U_7U_8 \times \frac{63.7}{4} - 4.92 \times 35.6 + \tfrac{1}{2} \times \frac{63.7}{2}$$

$$U_7U_8 = \frac{35.6 \times 4.92 \times 4}{63.7} - 1 = 11.0 - 1.0 = 10.0 \text{ kips comp.}$$

Joint U_7

$U_7L_7 = 1.0$ kip compression.

$U_6U_7 = 10.0$ kip compression.

Joint L_7

$U_6L_7 = 2/2.24 \times 1/0.8 = 1.12$ kip tension.

$L_6L_7 = 7.83 - 0.447 - 0.6 \times 1.12 = 6.71$ kip tension.

Section 3 - 3

$$M_{U_4} = 1/2.24\ L_4L_6 \times \frac{63.7}{2} + \frac{28.5}{2} \times 4.48 - \frac{28.5}{2} \times 3.58 - 28.5 \times 4.92 + 3 \times \frac{63.7}{4} + \frac{63.7}{4}$$

$L_4L_6 = 4.48$ kip tension.

$$M_{U_8} = \frac{28.5}{2} U_4L_5 + (4.48 - 3.58)\ 28.5 + \frac{5.5}{8} \times 63.7 \times 4 + \tfrac{1}{2} \times 63.7 - 4.92 \times 57 = 0$$

$U_4L_5 = (280.8 - 207)\ 2/28.5 - 1.8 = 3.36$ kip tension.

$U_4U_5 = (4.92 + 0.8 \times 4.48 - 4.5 \times 2/2.24) \times 2.24 = 10$ kips comp.

$U_4U_5 = (4.92 + 0.8 \times 4.48 - 4.5 \times 2/2.24) \times 2.24$

$U_4U_5 = 19.0 - 9.0 = 10.0$ kip compression.

Joint L_4

$U_4L_4 = (0.8 \times 4.48) \frac{2.24}{2} = 4.0$ kip compression.

Joint U_5

$U_5L_5 = 1.0$ kip comp.

$U_5U_6 = 10.0$ kip comp.

Joint L_5

$L_5U_6 = (0.895 \times 1.0) \times \frac{1}{0.8} = 1.12$ kip ten.

$L_5L_6 = 3.36 - 0.447 - 1.12 \times 0.6 = 2.24$ kip ten.

Joint L_6

$U_6L_6 = (0.8 \times 2.24) \frac{2.24}{2} = 2.0$ kip comp.

Joint L_{16}

$U_{15}L_{16} = 2.24 \times 2.24 = 5.0$ kip comp.

$L_{15}L_{16} = 2 \times 2.24 = 4.48$ kip ten.

Joint U_{15}

$U_{14}U_{15} = 5.0$ comp. kips.

$U_{15}L_{15} = 0$ kips.

Section 4 - 4

$M_{U_{12}} = 2.24 \times 28.5 - 14.25\ L_{12}L_{14} = 0$

$L_{12}L_{14} = 4.48$ kip ten.

$M_{L_{16}} = U_{12}L_{13} = 0$ kip.

$U_{12}U_{13}$ = 2.24 x 2.24 = 5.0 kip comp.

Joint U_{13}

$U_{13}L_{13}$ = 0 kip.

$U_{13}U_{14}$ = 5.0 kip comp.

Joint L_{13}

$L_{13}U_{14}$ = 0 kip.

$L_{13}L_{14}$ = 0 kip.

Joint L_{14}

$L_{14}U_{14}$ = 0 kip.

Section 5 - 5

M_{U_8} = 2.24 x 57 - L_8L_{12} x 28.5

L_8L_{12} = 4.48 kip ten.

$M_{L_{16}}$ = U_8L_9 = 0 kip.

U_8U_9 = 2.24 x 2.24 = 5.0 kip. comp.

Joint U_9

L_9U_9 = o kip.

U_9U_{10} = 5.0 kips comp.

Joint L_9

L_9U_{10} = 0 kips.

L_9L_{10} = 0 kips.

Section 6 - 6

$M_{U_8} = L_{11}U_{12} \times 14.25 + 2.24 \times 57 - 28.5 \times 4.48$

$L_{11}U_{12} =$ 0 kips.

$M_{L_{12}} = U_{11}U_{12} \times \frac{63.7}{4} - 2.24 \times 35.6 = 0$

$U_{11}U_{12} =$ 5.0 kips comp.

Joint U_{11}

$U_{11}U_{11} =$ 0 kips.

$U_{11}U_{10} =$ 5.0 kip. comp.

Joint L_{11}

$U_{10}L_{11} =$ 0 kips.

$L_{10}L_{11} =$ 0 kips.

Joint L_{10}

$U_{10}L_{10} =$ 0 kips.

$L_{10}L_{12} =$ 0 kips.

Joint L_{12}

$L_{12}U_{12} =$ 0 kips.

Wind From The Right (fig.3.)

$V_L = 8 \times \frac{63.7}{2} \times \frac{1}{114} = 2.24$ kip.

$V_R = 8 \times 2/2.24 - 2.24 = 4.92$ kips.

$H_L = 3.58$

Joint L_{16}

$U_{15}L_{16} = (4.92 - 0.5 \times 0.895)\ 2.24 = 11.0 - 1.0 = 10.0$ kip. comp.

$L_{15}L_{16} = 0.895 \times 10 - 0.5 \times 0.447 = 8.73$ kips. tension.

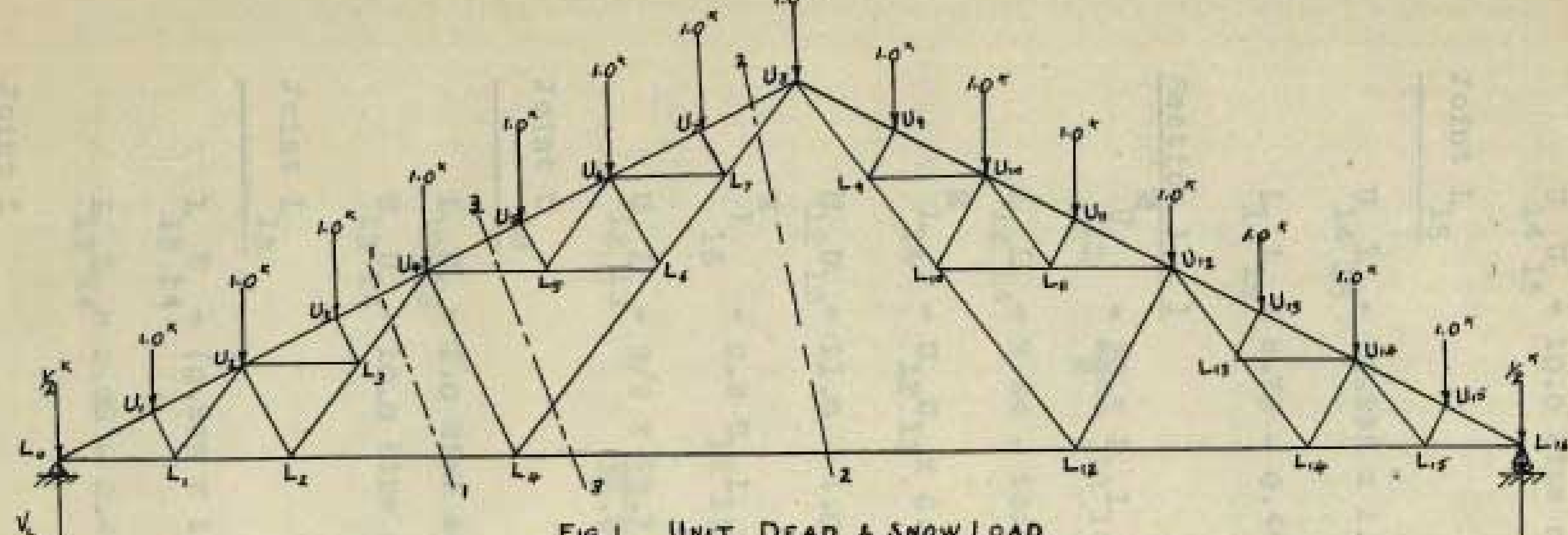

FIG. 1 UNIT DEAD & SNOW LOAD

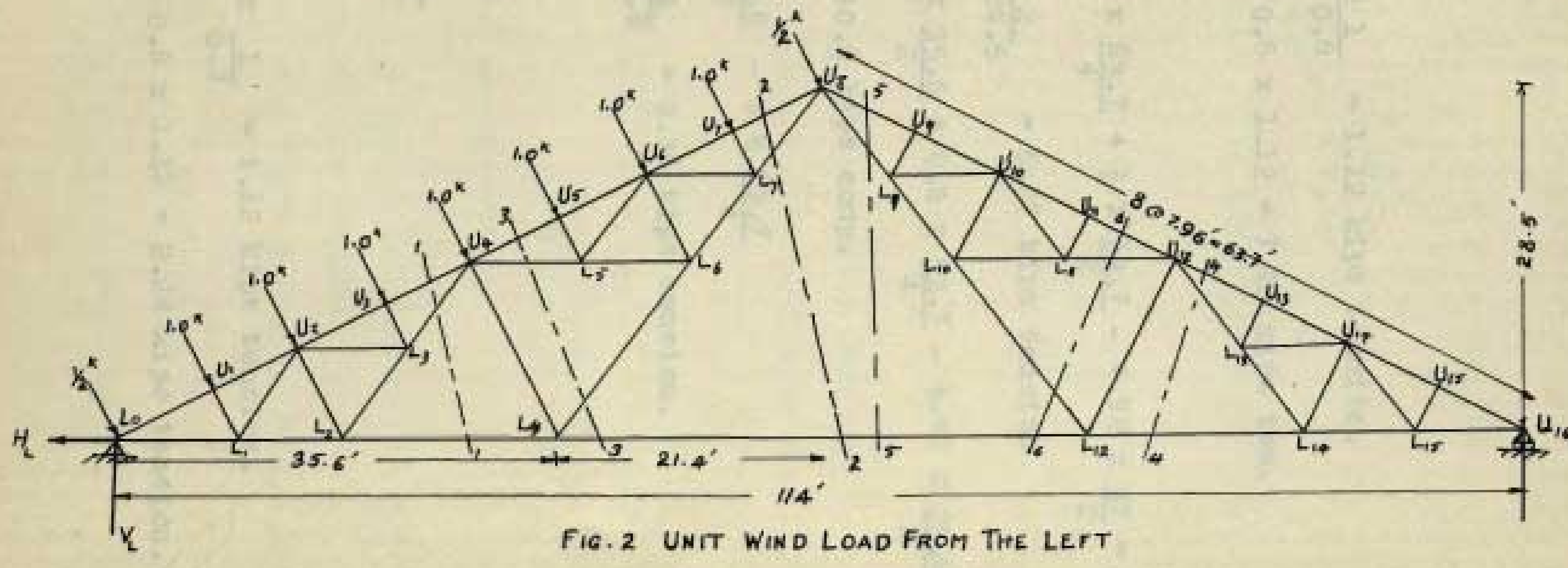

FIG. 2 UNIT WIND LOAD FROM THE LEFT

Joint U_{15}

$U_{15}L_{15}$ = 1.0 kips comp.

$U_{14}U_{15}$ = 10.0 kips comp.

Joint L_{15}

$U_{14}L_{15} = (0.895 \times 1.0) \times \frac{1}{0.8}$ = 1.12 kips tension.

$L_{14}L_{15} = 8.73 - 0.447 - 0.6 \times 1.12 = 7.62$ kips ten.

Section 1 - 1

$M_{U_{12}} = \frac{28.5}{2} L_{12}L_{14} + 3 \times \frac{63.7}{4} + \frac{1}{2} \times \frac{63.7}{2} - 4.92 \times \frac{57}{2} = 0$

$L_{12}L_{14} = 9.84 - 63.7 \times \frac{2}{28.5}$ = 5.37 kips tension.

$M_{L_{14}} = U_{12}U_{13} \times 0.447 \times \frac{35.6}{2} + 0.5 \times \frac{63.7}{4} - 4.92 \times \frac{35.6}{2}$

$U_{12}U_{13} = 11.0 - 1.0$ = 10.0 kips comp.

$M_{L_{16}} = 0.8\, U_{12}L_{13} \times \frac{35.6}{2} - 3 \times \frac{63.7}{4}$

$U_{12}L_{13} = 3/2 \times \frac{63.7}{35.6} \times \frac{1}{0.8}$ = 3.36 kips tension.

Joint U_{13}

$L_{13}U_{13}$ = 1.0 kips comp.

$U_{13}U_{14}$ = 10.0 kips comp.

Joint L_{13}

$L_{13}U_{14} = (0.895 \times 1.0) \times \frac{1}{0.8}$ = 1.12 kips tension.

$L_{13}L_{14} = 3.36 - 0.447 - 0.6 \times 1.12 = 2.24$ kips tension.

Joint L_{14}

$L_{14}U_{14} = \frac{0.8 \times 2.24}{0.895} = 2.0$

Section 2 - 2

$$M_{U_8} = 28.5\,L_8 L_{12} + 7 \times \frac{63.7}{2} + \tfrac{1}{2} \times 63.7 - 4.92 \times 57$$

$$L_8 L_{12} = 9.84 - \frac{63.7}{28.5} \times \frac{8}{2} = 0.9 \text{ kips tension.}$$

$$M_{L_{16}} = 0.8\,U_8L_9 \times 35.6 - 7 \times \frac{63.7}{2}$$

$$U_8 L_9 = 7/2 \times \frac{63.7}{35.6} \times \frac{1}{0.8} = 7.83$$

$$U_8 U_9 = (4.92 + 0.8 \times 7.83 - 7.5 \times 0.895) \times 2.24 = 10.0 \text{ kip.comp.}$$

Joint U_9

$$U_9 L_9 = 1.0 \text{ kips comp.}$$

$$U_9 U_{10} = 10.0 \text{ kips comp.}$$

Joint L_9

$$L_9 U_{10} = (0.895 \times 1.0) \times \frac{1}{0.8} = 1.12 \text{ kips tension.}$$

$$L_9 L_{10} = 7.83 - 0.447 - 0.6 \times 1.12 = 6.71 \text{ kips tension.}$$

Section 3 - 3

$$M_{U_{12}} = L_{10}L_{12} \times 0.447 \times \frac{63.7}{2} + 3 \times \frac{63.7}{4} + \tfrac{1}{2} \times \frac{63.7}{2} - 4.92 \times \frac{57}{2} + 0.9 \times \frac{28.5}{2}$$

$$L_{10} L_{12} = 9.85 - 5.37 = 4.48 \text{ kips ten.}$$

$$M_{L_{16}} = L_{11} U_{12} \times \frac{28.5}{2} + 3 \times \frac{63.7}{4} + 1 \times \frac{63.7}{2} - 0.8 \times 4.48 \times 35.6$$

$$L_{11} U_{12} = 8.95 - 5.59 = 3.36 \text{ kips tension.}$$

$$U_{11} U_{12} = (4.92 + 0.8 \times 4.48 - 4.5 \times 0.895)2.24 = 10.0 \text{ kips comp.}$$

Joint L_{12}

$$L_{12} U_{12} = (0.8 \times 4.48) \times \frac{1}{0.895} = 4.0 \text{ kips. comp.}$$

Joint U_{11}

$L_{11}U_{11} = 1.0$ kips comp.

$U_{10}U_{11} = 10.0$ kips comp.

Joint L_{11}

$U_{10}L_{11} = \frac{0.895}{0.80} = 1.12$ kips tension.

$L_{10}L_{11} = 3.36 - 0.447 - 0.6 \times 1.12 = 2.24$ kips tension.

Joint L_{10}

$L_{10}U_{10} = \frac{0.8 \times 2.24}{0.895} = 2.0$ kips.

Joint L_0

$L_0U_1 = 2.24 \times 2.24 = 5.0$ kips.

$L_0L_1 = 5.0 \times 0.895 - 3.58 = 0.9$ kips tension.

Joint U_1

$U_1L_1 = 0$ kips.

$U_1U_2 = 5.0$ kips comp.

Joint L_1

$L_1U_2 = 0$

$L_1L_2 = 0.9$

Section 4 - 4

$M_{L_0} = L_3U_4 = 0$

$L_3U_4 = 0$ kips.

$U_3U_4 = 2.24 \times 2.24 = 5.0$ kips comp.

$L_2L_4 = 5.0 \times 0.895 - 3.58 = 0.90$ kip tension.

Joint U_3

$U_3L_3 = 0$ kips.

$U_3U_2 = 5.0$ kips comp.

Joint L_3

$U_2L_3 = 0$ kips.

$L_2L_3 = 0$ kips.

Joint L_2

$U_2L_2 = 0$

Section 5 - 5

$M_{L_0} = L_7U_8 = 0$

$L_7U_8 = 0$ kips.

$U_7U_8 = 2.24 \times 2.24 = 5.0$ kips.

$L_4L_8 = 0.895 \times 5 - 3.58 = 0.9$ kips tension.

Joint U_7

$U_7L_7 = 0$ kips.

$U_7U_6 = 5.0$ kips comp.

Joint L_7

$U_6L_7 = 0$ kips

$L_6L_7 = 0$ kips.

Section 6 - 6

$M_{U_8} = U_4L_5 \times \frac{28.5}{2} + 0.9 \times 28.5 + 3.58 \times 28.5 - 2.24 \times 57.$

$U_4L_5 = 0$

$M_{L_0} = L_4L_6 = 0$

$L_4L_6 = 0$

$U_4U_5 = 2.24 \times 2.24 = 5.0$ kips comp.

Joint L_4

$U_4L_4 = 0$ kips.

Joint U_5

U_5L_5 = 0 kips.

U_5U_6 = 5.0 kips comp.

Joint L_5

L_5U_6 = o kips.

L_5L_6 = 0 kips.

Joint L_6

U_6L_6 = 0 kips.

3. Ceiling Load: The ceiling consists of three layers of aluminum sheets, and each is 1.0 m.m. thick, seperated from each other by wooden pieces 2 in. deep and 1 in. wide, running around every 3 foot square. The whole thing is supported by wooden rafters above it. The rafters are extending in the longitudinal direction of the rink and are supported by the lower chords of the trusses. The exact ceiling load can be estimated after designing the rafters below.

Wt. of aluminum = 165 lb/ft.^{3}

Wt. of 1 mm. sheet= $\frac{165}{12} \times \frac{1}{25.4}$ = 0.541 lb/ft.^{2}

Three layers aluminum = 3 x 0.541 = 1.62 lb/ft.^{2}

6 " alumin.projection= $\frac{1 \times 0.541 \times 6}{9}$ = 0.36 " "

2(2 in x 1 in.)tember= $\frac{0.82 \times 6}{9}$ = $\underline{0.55}$ " "

2.53 lb/ft.^{2}

2.53 x 8.9 = 22.5 lb/ft.

Assumed wt.of rafters = $\underline{5.0}$

27.5 lb/ft.

$M = 1/8 \times 27.5 \times 17.64^2 \times 12$ = 12,800 in.lb.

$I/c = \frac{12800}{1000}$ = 12.8 in.^{3}

Rafters 3 in.x 8 in. at 5.47 I/c = 24.6 in.^{3} are used

$$2.53 \times 8.9 \times 17.64 = 397 \text{ lb.}$$

$$5.47 \times 17.64 = \underline{97 \text{ lb.}}$$

Ceiling Load = 494 lb. = 0.5 kips.

The stresses due to the ceiling load will be found below, referring to fig. 4.

Joint L_o

$L_oU_1 = 3.0 \times 2.24 = 6.72$ kips comp.

$L_oL_1 = 3.0 \times 2.00 = 6.00$ kips tension.

Joint U_1

$U_1L_1 = 0$ kips.

$U_1U_2 = 6.72$ kips comp.

Joint L_1

$L_1U_2 = \frac{0.50}{0.80} = 0.63$ kips tension.

$L_1L_2 = 6.0 - 0.6 \times 0.63 = 5.62$ kips tension.

Joint U_3

$U_3L_3 = 0$

Joint L_3

$U_2L_3 = 0$

Joint U_2

$U_2L_2 = 0.63 \times \frac{1}{2.24} = 0.28$ kips comp.

$U_2U_3 = 6.72 - \frac{0.63 \times 2}{2.24} = 6.12$ kips comp.

Joint L_2

$L_2L_3 = (0.75 + 0.895 \times 0.28) \times \frac{1}{0.8} = 1.25$ kips tension.

$L_2L_4 = 5.62 - 0.28 \times 0.447 - 1.25 \times 0.6 = 4.74$ kips tension.

Joint L_3

$L_3U_4 = 1.25$ kips tension

Joint U_3

$U_3U_4 = 6.12$ kips comp.

Joint U_7

$U_7L_7 = 0$ kips

Joint L_7

$U_6L_7 = 0$ kips.

Joint U_5

$U_5L_5 = 0$ kips.

Joint L_5

$L_5U_6 = 0$ kips.

Joint U_6

$U_6L_6 = 0$ kips.

Joint L_6

$L_5L_6 = 0 = L_5U_4$

Joint U_4

$U_4L_4 = 1.25 \times 0.447 = 0.56$ kips comp.

$U_4U_5 = 6.12 - 1.25 \times 0.895 = 5.0$ kips comp.

$U_5U_6 = 5.0 = U_6U_7 = U_7U_8$

Joint L_4

$$L_4L_6 = \left[\left(0.50 + 0.25 + \frac{8.6}{21.4} \times 1.0 \right) + 0.895 \times 0.56 \right] \times \frac{1}{0.8} = 2.06 \text{ kips tension.}$$

$L_6L_7 = 2.06 = L_7U_8$

$L_4L_8 = 4.74 - 0.56 \times 0.447 - 2.06 \times 0.6 = 3.25$ kips tension

$U_8L_8 = \frac{1.5}{2.5} \times 1.0 \times 2 = 1.2$ kips comp.

Members L_8L_6 and L_8L_{10} are added to the truss in order to make member L_4L_{12} regid, and at the same time take share in absorbing some of the ceiling load. The stresses in these two members are :

$$L_8L_6 = L_8L_{10} = \left(2 \times \tfrac{1}{2} \times \frac{12.8}{21.4} \right) \times \frac{1}{0.8} = 0.75 \text{ kips ten.}$$

A table containing coefficients of stresses, stresses, and maximum stresses for the various members is given on the next few pages.

TABLE I (A)

Member	Coefficients of stresses			Individual stresses					
	D.L. or S.L.	Wind		D.L.	S.L.	S.L./2	Wind		Misc.
		W_L	W_R				W_L	W_R	
$L_o U_1$	-16.80	-10.00	- 5.00	-45.30	-47.20	-23.60	-31.50	-15.75	-6.72
$U_1 U_2$	-16.35	-10.00	- 5.00	-44.10	-45.95	-22.98	-31.50	-15.75	-6.72
$U_2 U_3$	-15.88	-10.00	- 5.00	-42.85	-44.60	-22.30	-31.50	-15.75	-6.12
$U_3 U_4$	-15.43	-10.00	- 5.00	-41.65	-43.35	-21.68	-31.50	-15.75	-6.12
$U_4 U_5$	-15.00	-10.00	- 5.00	-40.50	-42.12	-21.06	-31.50	-15.75	-5.00
$U_5 U_6$	-14.55	-10.00	- 5.00	-39.28	-40.85	-20.43	-31.50	-15.75	-5.00
$U_6 U_7$	-14.13	-10.00	- 5.00	-38.15	-39.70	-19.85	-31.50	-15.75	-5.00
$U_7 U_8$	-13.68	-10.00	- 5.00	-36.90	-38.40	-19.20	-31.50	-15.75	-5.00
$U_8 U_9$	-13.68	- 5.00	-10.00	-36.90	-38.40	-19.20	-15.75	-31.50	-5.00
$U_9 U_{10}$	-14.13	- 5.00	-10.00	-38.15	-39.70	-19.85	-15.75	-31.50	-5.00
$U_{10} U_{11}$	-14.55	- 5.00	-10.00	-39.28	-40.85	-20.43	-15.75	-31.50	-5.00
$U_{11} U_{12}$	-15.00	- 5.00	-10.00	-40.50	-42.12	-21.06	-15.75	-31.50	-5.00
$U_{12} U_{13}$	-15.43	- 5.00	-10.00	-41.65	-43.35	-21.68	-15.75	-31.50	-6.12
$U_{13} U_{14}$	-15.88	- 5.00	-10.00	-42.85	-44.60	-22.30	-15.75	-31.50	-6.12
$U_{14} U_{15}$	-16.35	- 5.00	-10.00	-44.10	-45.95	-22.98	-15.75	-31.50	-6.72
$U_{15} L_{16}$	-16.80	- 5.00	-10.00	-45.30	-47.20	-23.60	-15.75	-31.50	-6.72
$L_o L_1$	+15.00	+12.32	+ .90	+40.40	+42.20	+21.10	+38.80	+ 2.84	+6.00
$L_1 L_2$	+14.00	+11.20	+ .90	+37.80	+39.40	+19.70	+35.30	+ 2.84	+5.62
$L_2 L_4$	+12.00	+ 8.95	+ .90	+32.40	+33.70	+16.85	+28.20	+ 2.84	+4.74
$L_4 L_8$	+ 8.00	+ 4.48	+ .90	+21.60	+22.50	+11.25	+14.10	+ 2.84	+3.25
$L_8 L_{12}$	+ 8.00	+ 4.48	+ .90	+21.60	+22.50	+11.25	+14.10	+ 2.84	+3.25
$L_{12} L_{14}$	+12.00	+ 4.48	+ 5.37	+32.40	+33.70	+16.85	+14.10	+16.90	+4.74
$L_{14} L_{15}$	+14.00	+ 4.48	+ 7.62	+37.80	+39.40	+19.70	+14.10	+24.00	+5.62
$L_{15} L_{16}$	+15.00	+ 4.48	+ 8.74	+40.40	+42.20	+21.10	+14.10	+27.60	+6.00

TABLE I (continued) (A)

Member	Coefficients of stresses			Individual stresses					
	D.L. or S.L.	Wind		D.L.	S.L.	S.L./2	Wind		Misc.
		W_L	W_R				W_L	W_R	
$U_1 L_1$	-0.90	- 1.00	0	- 2.43	- 2.53	- 1.27	- 3.15	0	0
$U_2 L_2$	-1.79	- 2.00	0	- 4.83	- 5.03	- 2.52	- 6.30	0	-0.28
$U_3 L_3$	-0.90	- 1.00	0	- 2.43	- 2.53	- 1.27	- 3.15	0	0
$U_4 L_4$	-3.58	- 4.00	0	- 9.66	-10.06	- 5.03	-12.60	0	-0.56
$U_5 L_5$	-0.90	- 1.00	0	- 2.43	- 2.53	- 1.27	- 3.15	0	0
$U_6 L_6$	-1.79	- 2.00	0	- 4.83	- 5.03	- 2.52	- 6.30	0	0
$U_7 L_7$	-0.90	- 1.00	0	- 2.43	- 2.53	- 1.27	- 3.15	0	0
$U_9 L_4$	-0.90	- 0	- 1.00	- 2.43	- 2.53	- 1.27	0	- 3.15	0
$U_{10} L_{10}$	-1.79	0	- 2.00	- 4.83	- 5.03	- 2.52	0	- 6.30	0
$U_{11} L_{11}$	-0.90	0	- 1.00	- 2.43	- 2.53	- 1.27	0	- 3.15	0
$U_{12} L_{12}$	-3.58	0	- 4.00	- 9.66	-10.06	- 5.03	0	-12.60	-0.56
$U_{13} L_{13}$	-0.90	0	- 1.00	- 2.43	- 2.53	- 1.27	0	- 3.15	0
$U_{14} L_{14}$	-1.79	0	-2.00	- 4.83	- 5.03	- 2.52	0	- 6.30	-0.28
$U_{15} L_{15}$	-0.90	0	- 1.00	- 2.43	- 2.53	- 1.27	0	- 3.15	0
$U_2 L_1$	+1.00	+ 1.12	0	+ 2.70	+ 2.81	+ 1.41	+ 3.53	0	+0.63
$U_2 L_3$	+1.00	+ 1.12	0	+ 2.70	+ 2.81	+ 1.41	+ 3.53	0	0
$L_3 L_2$	+2.00	+ 2.24	0	+ 5.40	+ 5.62	+ 2.81	+ 7.06	0	+1.25
$L_3 U_4$	+3.00	+ 3.36	0	+ 8.10	+ 8.43	+ 4.22	+10.59	0	+1.25
$L_5 U_4$	+3.00	+ 3.36	0	+ 8.10	+ 8.43	+ 4.22	+10.59	0	0
$L_5 L_6$	+2.00	+ 2.24	0	+ 5.40	+ 5.62	+ 2.81	+ 7.06	0	0
$L_5 U_6$	+1.00	+ 1.12	0	+ 2.70	+ 2.81	+ 1.41	+ 3.53	0	0
$L_6 L_4$	+4.00	+ 4.48	0	+10.80	+11.24	+ 5.62	+14.12	0	+2.06
$L_6 L_7$	+6.00	+ 6.71	0	+16.20	+16.86	+ 8.43	+21.16	0	+2.06
$L_7 U_8$	+7.00	+ 7.83	0	+18.90	+19.67	+ 9.84	+24.65	0	+2.06

TABLE I (continued) (A)

Member	Coefficients of stresses			Individual stresses					
	D.L. or S.L.	Wind		D.L.	S.L.	S.L./2	Wind		Misc.
		W_L	W_R				W_L	W_R	
$L_7 U_6$	+1.00	+1.12	0	+ 2.70	+ 2.81	+1.41	+3.53	0	0
$L_9 U_{10}$	+1.00	+ 0	+1.12	+ 2.70	+ 2.81	+1.41	0	+ 3.53	0
$L_9 U_8$	+7.00	0	+7.83	+18.90	+19.67	+9.84	0	+24.65	+2.06
$L_{10} L_9$	+6.00	0	+6.71	+16.20	+16.86	+8.43	0	+21.16	+2.06
$L_{10} L_{12}$	+4.00	0	+4.48	+10.80	+11.24	+5.62	0	+14.12	+2.06
$L_{11} U_{10}$	+1.00	0	+1.12	+ 2.70	+ 2.81	+1.41	0	+ 3.53	0
$L_{11} L_{10}$	+2.00	0	+2.24	+ 5.40	+ 5.62	+2.81	0	+ 7.06	0
$L_{11} U_{12}$	+3.00	0	+3.36	+ 8.10	+ 8.43	+4.22	0	+10.59	0
$L_{13} U_{12}$	+3.00	0	+3.36	+ 8.10	+ 8.43	+4.22	0	+10.59	+1.25
$L_{13} L_{14}$	+2.00	0	+2.24	+ 5.40	+ 5.62	+2.81	0	+ 7.06	+1.25
$U_{14} L_{13}$	+1.00	0	+1.12	+ 2.70	+ 2.81	+1.41	0	+ 3.53	0
$U_{14} L_{15}$	+1.00	0	+1.12	+ 2.70	+ 2.81	+1.41	0	+ 3.53	+0.63
$L_8 L_6$	0	0	0	0	0	0	0	0	+0.75
$L_8 L_{10}$	0	0	0	0	0	0	0	0	+0.75
V_L	8	4.92	2.24	21.60	22.48	11.24	15.50	7.05	3.00
V_R	8	2.24	4.92	21.60	22.48	11.24	7.05	15.50	3.00
H_L	0	3.58	3.58	0	0	0	11.30	11.30	0
H_R	0	0	0	0	0	0	0	0	0

TABLE I (continued) (B)

Member	Combined stresses in kips					Maximum stresses in kips			
	D.L. + S.L.	D.L. + $\frac{SL}{2}$ + W_L	DL + $\frac{SL}{2}$ + W_R	D.L. + W_L	D.L. + W_R	Without wind		With wind	
						Ten.	Comp.	Ten.	Comp.
$L_o U_1$	-92.50	-100.40	- 84.65	-76.80	-61.05		99.22		107.12
$U_1 U_2$	-90.05	- 98.58	- 82.85	-75.60	-59.85		96.77		105.30
$U_2 U_3$	-87.45	-996.65	- 80.90	-74.35	-58.60		93.57		102.77
$U_3 U_4$	-85.00	-94.83	- 79.08	-73.15	-57.40		91.12		100.95
$U_4 U_5$	-82.62	- 93.06	- 77.31	-72.00	-56.25		87.62		98.06
$U_5 U_6$	-80.13	- 91.21	- 75.46	-70.78	-55.03		85.13		96.21
$U_6 U_7$	-77.85	- 89.50	- 73.75	-69.65	-53.90		82.85		94.50
$U_7 U_8$	-75.30	- 87.60	- 71.85	-68.40	-52.65		80.30		92.60
$U_8 U_9$	- 75.30	-71.85	- 87.60	-52.65	-68.40		80.30		92.60
$U_9 U_{10}$	- 77.85	-73.75	- 89.50	-53.90	-69.65		82.85		94.50
$U_{10} U_{11}$	-80.13	- 75.46	- 91.21	-55.03	-70.78		85.13		96.21
$U_{11} U_{12}$	-82.62	- 77.31	- 93.06	-56.25	-72.00		87.62		98.06
$U_{12} U_{13}$	-85.00	- 79.08	- 94.83	-57.40	-73.15		91.12		100.95
$U_{13} U_{14}$	-87.45	- 80.90	- 96.65	-58.60	-74.35		93.57		102.77
$U_{14} U_{15}$	-90.05	- 82.85	- 98.58	-59.85	-75.60		96.77		105.30
$U_{15} L_{16}$	-92.50	- 84.65	-100.40	-61.05	-76.80		99.22		107.12
$L_o L_1$	+82.60	+100.30	+ 64.34	+79.20	+43.24	88.60		106.30	
$L_1 L_2$	+77.20	+ 92.80	+ 60.34	+73.10	+40.64	82.82		98.42	
$L_2 L_4$	+66.10	+ 77.45	+ 52.09	+60.60	+35.24	70.84		82.19	
$L_4 L_8$	+44.10	+ 46.95	+ 35.69	+35.70	+24.44	47.35		50.20	
$L_8 L_{12}$	+44.10	+ 46.95	+ 35.69	+35.70	+24.44	47.35		50.20	
$L_{12} L_{14}$	+66.10	+ 63.35	+ 66.15	+46.50	+49.30	70.84		70.89	
$L_{14} L_{15}$	+77.20	+ 71.60	+ 81.50	+51.90	+61.80	82.82		87.12	
$L_{15} L_{16}$	+82.60	+ 75.60	+ 89.10	+54.50	+68.00	88.60		95.10	

TABLE I (contin.) (B)

Member	Combined stresses in kips					Maximum stresses in kips			
	D.L. + S. L.	DL + $\frac{SL}{2}$ + W_L	DL + $\frac{SL}{2}$ + W_R	D.L. + W_L	D.L. + W_R	Without wind		With wind	
						Ten.	Comp.	Ten.	Comp.
U_1 L_1	- 4.96	- 6.85	- 3.70	- 5.58	- 2.43		-4.96		6.85
U_2 L_2	- 9.86	-13.65	- 7.35	-11.13	- 4.83		10.14		13.93
U_3 L_3	- 4.96	- 6.85	- 3.70	- 5.58	- 2.43		4.96		6.85
U_4 L_4	-19.72	-27.29	-14.69	-22.26	- 9.66		20.28		27.85
U_5 L_5	- 4.96	- 6.85	- 3.70	- 5.58	- 2.43		4.96		6.85
U_6 L_6	- 9.86	-13.65	- 7.35	-11.13	- 4.83		9.86		13.65
U_7 L_7	- 4.96	- 6.85	- 3.70	- 5.58	- 2.43		4.96		6.85
U_9 L_9	- 4.96	- 3.70	- 6.85	- 2.43	- 5.58		4.96		6.85
$U_{10}L_{10}$	- 9.86	- 7.35	-13.65	- 4.83	-11.13		9.86		13.65
$U_{11}L_{11}$	- 4.96	- 3.70	- 6.85	- 2.43	- 5.58		4.96		6.85
$U_{12}L_{12}$	-19.72	-14.69	-27.29	- 9.66	-22.26		20.28		27.85
$U_{13}L_{13}$	- 4.96	- 3.70	- 6.85	- 2.43	- 5.58		4.96		6.85
$U_{14}L_{14}$	- 9.86	- 7.35	-13.65	- 4.83	-11.13		10.14		13.93
$U_{15}L_{15}$	- 4.96	- 3.70	- 6.85	- 2.43	- 5.58		4.96		6.85
U_2 L_1	+5.51	+ 7.64	+ 4.11	+ 6.23	+2.70	6.14		8.27	
U_2 L_3	+ 5.51	+ 7.64	+ 4.11	+ 6.23	+ 2.70	5.51		7.64	
L_3 L_2	+11.02	+15.27	+ 8.21	+12.46	+ 5.40	12.27		16.52	
L_3 U_4	+16.53	+22.91	+12.32	+18.69	+ 8.10	17.78		24.16	
L_5 U_4	+16.53	+22.91	+12.32	+18.69	+ 8.10	16.53		22.91	
L_5 L_6	+11.02	+15.27	+ 8.21	+12.46	+ 5.40	11.02		15.27	
L_5 U_6	+ 5.51	+ 7.64	+ 4.11	+ 6.23	+ 2.70	5.51		7.64	
L_6 L_4	+22.04	+30.54	+16.42	+24.92	+10.80	24.10		32.60	
L_6 L_7	+33.06	+45.79	+24.63	+37.36	+16.20	35.12		47.85	
L_7 U_8	+38.57	+53.39	+28.74	+43.55	+18.90	40.63		55.45	

TABLE I (continued) (B)

Member	Combined stresses in kips					Maximum stresses in kips			
	D.L. + S.L.	DL + $\frac{SL}{2}$ + W_L	DL + $\frac{SL}{2}$ + W_R	D.L. + W_L	D.L. + W_R	Without wind		With wind	
						Ten.	Comp.	Ten.	Comp.
$L_7 U_6$	+ 5.51	+ 7.64	+ 4.11	+ 6.23	+ 2.70	5.51		7.64	
$L_9 U_{10}$	+ 5.51	+ 4.11	+ 7.64	+ 2.70	+ 6.23	5.51		7.64	
$L_9 U_8$	+38.57	+28.74	+53.39	+18.90	+43.55	40.63		55.45	
$L_{10} L_9$	+33.06	+24.63	+45.79	+16.20	+37.36	35.12		47.85	
$L_{10} L_{12}$	+22.04	+16.42	+30.54	+10.80	+24.82	24.10		32.60	
$L_{11} U_{10}$	+ 5.51	+ 4.11	+ 7.64	+ 2.70	+ 6.23	5.51		7. 64	
$L_{11} L_{10}$	+11.02	+ 8.21	+15.27	+ 5.40	+12.46	11.02		15.27	
$L_{11} U_{12}$	+16.53	+12.32	+22.91	+ 8.10	+18.69	16.53		22.91	
$L_{13} U_{12}$	+16.53	+12.32	+22.91	+ 8.10	+18.69	17.78		24.16	
$L_{13} L_{14}$	+11.02	+ 8.21	+15.27	+ 5.40	+12.46	12.27		16.52	
$U_{14} L_{13}$	+ 5.51	+ 4.11	+ 7.64	+ 2.70	+ 6.23	5.51		7.64	
$U_{14} L_{15}$	+ 5.51	+ 4.11	+ 7.64	+ 2.70	+ 6.23	6.14		8.27	
$L_8 L_6$	0	0	0	0	0	0.75		0.75	
$L_8 L_{10}$	0	0	0	0	0	0.75		0.75	
V_L	44.08	48.34	39.89	37.10	28.65	47.08		51.34	
V_R	44.08	39.89	48.34	28.65	37.10	47.08		51.34	
H_L	0	11.30	11.30	11.30	11.30	0		11.30	
H_R	0	0	0	0	0	0		0	

CHAPTER

III

DESIGN OF TRUSS

1. Specifications: A.I.S.C. specifications are used, where the allowable unit stress for:

Tension..............................20000 lb/in^2

Compression..........................17000 $-0.485(\frac{L}{R})^2$ lb/in^2

Where $\frac{L}{R}$ is less than 120.

Bearing (double shear)..............40000 lb/in^2

Bearing (single shear)..............32000 lb/in^2

Shear................................15000 lb/in^2

Bearing of Portland Cement Concrete. 600 lb/in^2

Unit stresses are increased 33 1/3 % for members having wind stresses.

Slenderness ratio $\frac{L}{R}$ shall not exceed:

For main compression members..........120

For main tension members..............240

Size of rivets used...................3/4 in.

Minimum number of rivets in any member..2.

2. Design of Members:

<u>Members</u> L_oU_1 U_2U_3 $U_{12}U_{13}$ $U_{14}U_{15}$

U_1U_2 U_3U_4 $U_{13}U_{14}$ $U_{15}L_{16}$

Maximum stress = -99.22 kips (without wind)

Length = 7.96 ft. = 95.4 in.

Assumed 2Ls $5 \times 3\frac{1}{2} \times \frac{7}{16}$

$M = \frac{1}{8} \times 24 \times 7.96^2 \times 12 = 2280$ in.-lb.

$\frac{L}{R} = \frac{7.96 \times 12}{1.35} = 70.7$

$S = 17000 - 0.485 \left(\frac{L}{r}\right)^2 = 14580$ p. s. i.

Area $= \frac{99.22}{14.58} + \frac{2.28 \times 1.63}{20.0} = 6.81 + 0.19 = 7.00$ in^2 required.

2 Ls $5 \times 3\frac{1}{2} \times \frac{7}{16}$ at 12 lb/ft. $A = 7.06$ in^2 supplied.

<u>Members</u> U_4U_5 U_6U_7 U_8U_9 $U_{10}U_{11}$

U_5U_6 U_7U_8 U_9U_{10} $U_{11}U_{12}$

Maximum stress = -87.62 kips (without wind)

Length = 7.96 ft.

Assumed 2 Ls $5 \times 3 \times \frac{7}{16}$

$M = \frac{1}{8} \times 22.6 \times 7.96^2 \times 12 = 2140$ in.-lb.

$\frac{L}{r} = \frac{7.96 \times 12}{1.24} = 77.$ S = 14120 p.s.i.

$A = \frac{87.60}{14.12} + \frac{2.14 \times 1.73}{20.0} = 6.21 + 0.185 = 6.40$ in^2 required.

2 Ls $5 \times 3 \times \frac{7}{16}$ at 11.3 lb/ft. $A = 6.62$ in^2 supplied.

<u>Members</u> L_oL_1 $L_{14}L_{15}$

L_1L_2 $L_{15}L_{16}$

Minimum width[2] of lower chord $= \frac{L}{125} = \frac{114 x 12}{125} = 11$ in.

Maximum stress = + 88.60 kips (without wind)

Length = 8.9 ft.

Min. r $= \frac{8.9\ 12}{240} = 0.45$ in.

Area $= \frac{88.6}{20} = 4.43$ in^2. required.

2 L^s 6 x $3\frac{1}{2}$ x $\frac{5}{16}$ at 9.8 lb/ft.

A = 5.74 - 5/16 x 7/8 x 2 = 5.19 in^2. net supplied.

r = 1.00 in.

Members L_2L_4 $L_{12}L_{14}$

Maximum stress = + 70.84 kips (without wind)

Length = 17.8 ft.

$M = \frac{1}{8}\ w L^2 + \frac{PL}{4} = \frac{1}{8} \times 20 \times 17.8^2 \times 12 + \frac{0.5 \times 17.8}{4} \times 12$

= 9.5 + 26.7 = 36.2 in.- kip.

Area $= \frac{70.84}{20} + \frac{36.2 \times 0.76}{20 \times 1.0} = 3.54 + 1.38 = 4.92$ in^2. required.

2L^s 6 x $3\frac{1}{2}$ x $\frac{5}{16}$ at 9.8 lb/ft.

A = 5.74 - 0.55 = 5.19 in^2. net supplied.

r = 1.00

Members L_4L_8 L_8L_{12}

Maximum stress = + 47.35 kips (without wind)

Length = 21.4 ft.

Min. r $= \frac{21.4 \times 12}{240} = 1.07$ in.

$M = 1/8 \times 20 \times 21.4^2 \times 12 + \frac{8.6}{21.4} \times 1.0 \times 8.6 \times 12$

= 13.7 + 41.5 = 55.2 in.-kip.

$A = \frac{47.35}{20} + \frac{55.2 \times 0.76}{20 \times 1.0} = 2.37 + 2.10 = 4.47$ in^2. required.

2 L^s 6 x $3\frac{1}{2}$ x 5/16 at 9.8 lb/ft. A = 5.19 in^2. supplied.

r = 1.00 in.

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2. " Structural Design in Steel", by T.C. Shedd.

Members U_1L_1 U_5L_5 U_9L_9 $U_{13}L_{13}$
U_3L_3 U_7L_7 $U_{11}L_{11}$ $U_{15}L_{15}$

Maximum stress = - 6.85 kips (with wind)

Length = 3.98 ft.

Assumed 2L^s 2 x 2 x $\frac{1}{4}$

$\frac{L}{r} = \frac{3.98 \times 12}{0.61} = 78.3$ S = 14000 p.s.i.

$A = \frac{6.85}{4/3 \times 14.0} = 0.37$ in^2. required.

2 L^s 2 x 2 x $\frac{1}{4}$ at 3.19 lb/ft.

A = 1.88 in^2. supplied.

Members U_2L_2 $U_{10}L_{10}$
U_6L_6 $U_{14}L_{14}$

Maximum stress = - 13.93 kips (with wind)

Length = 7.96 ft.

Min. $r = \frac{7.96 \times 12}{120} = 0.796$

Assumed r = 0.95 S = 12150 p.s.i.

$\text{Area} = \frac{13.95}{\frac{4}{3} \times 12.5} = 0.86$ in^2. required.

2 L^s 3 x 2$\frac{1}{2}$ x $\frac{1}{4}$ at 4.5 lb/ft. are used

Area = 2.62 in^2. supplied

r = 0.95 in^2. supplied.

Members U_4L_4 $U_{12}L_{12}$

Maximum stress = - 27.85 kips (with wind)

Length = 7.96 x 2 = 15.82 ft.

Min. $r = \frac{15.82 \times 12}{120} = 1.58$ in.

2 L^s 6 x 6 x 3/8 at 14.9 lb/ft. are used.

r = 1.88 in. supplied

A = 8.72 in^2. supplied.

Members :	U_2L_1	L_5U_6	L_9U_{10}	$L_{13}U_{12}$
	U_2L_3	L_5U_4	$L_{11}U_{10}$	$L_{13}U_{14}$
	L_3L_2	L_5U_4	$L_{11}L_{10}$	$U_{14}L_{13}$
	L_3U_4	L_7U_6	$L_{11}U_{12}$	$U_{14}L_{15}$

Maximum stress = + 24.16 kips (with wind)

Length = 8.9 ft.

Min. $r = \frac{8.9 \times 12}{240} = 0.45$ in. required

$A = \frac{24.16}{20 \times 4/3} = 0.9$ in^2. required.

2 L^s 2 x 2 x $\frac{1}{4}$ at 3.19 lb/ft. are used.

$A = 1.88 - \frac{1}{4} \times 7/8 \times 2 = 1.88 - 0.44 = 1.44$ in^2. supplied.

r = 0.61 supplied.

Members	L_4L_6	L_9U_8
	L_7L_6	$L_{10}L_9$
	L_7U_8	$L_{10}L_{12}$

Maximum stress = + 55.45 kips (with wind)

Length = 8.9 x 2 = 17.8 ft.

Min. $r = \frac{8.9 \times 2 \times 12}{240} = 0.89$ in. required.

Area $= \frac{55.45}{20 \times 4/3} = 2.08$ in^2. required.

2 L^s 3 x 3 x $\frac{1}{4}$ at 4.9 lb/ft.

r = 0.93 in. supplied

$A = 2.88 - 0.44 = 2.44$ in^2. supplied.

3. Design Of Connections:

Stresses carried by:

Single shear 3/4 in. rivet = $(3/4)^2 \times 0.785 \times 15 = 6.62$ k.

Bearing on 7/16 in. gusset (double shear) $= 7/16 \times \frac{3}{4} \times 40 = 13.10$ k.

Bearing on 7/16 in. angle (single shear) $= 7/16 \times \frac{3}{4} \times 32 = 10.50$ k.

Bearing on 3/8 in. angle (single shear) = $3/8 \times \frac{3}{4} \times 32 = 9.50$ k.

Bearing on 5/16 in.angle (" ") = $5/16 \times \frac{3}{4} \times 32 = 7.50$ k.

Bearing on 1/4 in. angle (" ") = $1/4 \times \frac{3}{4} \times 32 = 6.00$ k.

Joint L_o

$L_oU_1 = \frac{99.22}{13.10} = 7.6$ .... 8 rivets

$L_oL_1 = \frac{88.6}{13.10} = 6.7$ .... 7 "

Joint U_2

$L_oU_2 = \frac{96.77 - 93.57}{13.10} = 0.25$.... 2 rivets

2 rivets are used for $L_o U_8$ at joints U_1, U_2, U_3, U_5, U_6, U_7 .

Joint U_4

$U_3U_4 = \frac{91.12}{13.10} = 6.9$ .... 7 rivets

$U_4U_5 = \frac{87.62}{13.10} = 6.7$ .... 7 rivets

Joint U_8

$U_7U_8 = \frac{80.3}{13.10} = 6.1$ .... 6 rivets

$L_7U_8 = \frac{55.45}{4/3 \times 6.0 \times 2} = 3.45$ .... 4 rivets

Joint L_1

$L_oL_2 = \frac{88.60 - 82.82}{13.10} = 0.44$ .....2 rivets

Joint L_2

$L_1L_4 = \frac{82.82 - 70.84}{13.10} = 0.91$ ....2 rivets

Joint L_4

$L_2L_8 = \frac{70.84 - 47.35}{13.10}$ = 1.7 .... 2 rivets.

$U_4L_4 = \frac{27.85}{4/3 \times 13.1}$ = 1.6 .... 2 rivets.

$L_4L_6 = \frac{32.60}{4/3 \times 13.1}$ = 1.9 .... 2 rivets.

The rest of the members for the left side of the truss are connected by two rivets each.

Splice plates at joint U_4

Stress in side plates = $\frac{5}{5 + 3} \times 87.62 = 54.80$ kips.

Area required $= \frac{54.8}{20} = 2.74$ in^2.

Area provided $= 5 \times \frac{5}{16} \times 2 = 3.12$ in^2.

Number of rivets $= \frac{54.8}{6.62 \times 2} = 4.15$ .... 5 rivets.

Stress in top plate $= 3/8 \times 87.62 = 32.82$ kips.

Area required $= \frac{32.82}{20} = 1.64$ in^2.

Area provided $= 6\frac{1}{4} \times 5/16 = 1.95$ in^2.

Number of rivets $= \frac{32.82}{6.62} = 4.9$ .... 5 rivets.

Splice plates at joint L_4

Stress in side plates $= \frac{3.5}{9.5} \times 47.35 = 17.45$ kips.

Area required $= \frac{17.45}{20} = 0.87$ in^2 net

Area provided $= (3 \times \frac{1}{4} - 7/8 \times \frac{1}{4}) \times 2 = 1.06$ in^2 net.

Number of rivets $= \frac{17.45}{6.0 \times 2} = 1.45$ .... 2 rivets.

Stress in bottom plates $= \frac{6}{9.5} \times 47.35 = 29.90$ kips.

Area required $= \frac{29.90}{20} = 1.49$ in^2 net.

Area provided $= 11 \times \frac{1}{4} - 7/8 \times \frac{1}{4} \times 2 = 2.31$ in^2 net.

Number of rivets $= \frac{29.90}{6.0} = 5$ rivets.

There is no need to design the connections of the right side of the truss as both are symetrical so that corresponding connections of both sides are similar.

3. Design Of Masonry Plate

V_R = 47.08 kips.

$A = \frac{47.08}{.60} = 78.4 \text{ in}^2.$

2 Ls $3\frac{1}{2}$ x $3\frac{1}{2}$ x 3/8 will furnish an area of 84 in^2.

having a width of 7 in. and a length of 12 in.

Number of rivets = $\frac{47.08}{13.10}$ = 3.6 .... 4 rivets.

The angles rest on a 12" x 12" wall plate.

That is each side of the plate projects 2.5 in. beyond the leg of each angle so as to be anchored to anchor bolts.

The upward pressure on the plate = $\frac{47.08}{144}$ = .327.

Moment at the center line of the plate =.327 x 6 x 6/2 = 5.88 in.-kip.

$d = \left(\frac{6M}{bf} \right)^{\frac{1}{2}} = \left(\frac{6 \times 5.88}{1 \times 20.0} \right)^{\frac{1}{2}} = 1.33 \text{ in.}$

Thickness of plate = 1.33 - .375 = 0.95 in.

A plate 1 x 12 x 12 will be used.

H_L = 11.30 kips.

$A = \frac{11.30}{2 \times 15} = .38 \text{ in}^2$ area of each bolt.

2 ϕ $\frac{3}{4}$" bolts are used.

TABLE II

Member	Stress Kips	Unit stress K.S.I.	Required area in²	Section	O.S.	Supplied area in²	Weight lb./ft.	Length ft.	Weight lb.
L_0U_1	-99.22	14.58	7.00	2∠s 5 x 3½ x 7/16	3 ½	7.06	24.0	7.96	191.0
U_1U_2	-96.77	do	6.84	do	do	do	do	do	191.0
U_2U_3	-93.57	do	6.62	do	do	do	do	do	191.0
U_3U_4	-91.12	do	6.45	do	do	do	do	do	191.0
U_4U_5	-87.62	14.12	6.40	2∠s 5 x 3 x 7/16	3	6.62	22.6	do	180.0
U_5U_6	-85.13	do	6.22	do	do	do	do	do	180.0
U_6U_7	-82.85	do	6.06	do	do	do	do	do	180.0
U_7U_8	-80.30	do	5.88	do	do	do	do	do	180.0
L_0L_1	+88.60	20.00	4.43	2∠s 6 x 3½ x 5/16	6	5.19	19.6	8.9	174.5
L_1L_2	+82.82	do	4.14	do	do	do	do	8.9	174.5
L_2L_4	+70.84	do	4.92	do	do	do	do	17.8	349.0
L_4L_8	+47.35	do	4.47	do	do	do	do	21.4	419.0
U_1L_1	- 6.85	18.65	0.37	2∠s 2 x 2 x 1/4	2	1.88	6.38	3.98	25.4
U_2L_2	-13.93	16.20	0.86	2∠s 3 x 2½ x 1/4	2½	2.62	9.00	7.96	71.6
U_3L_3	- 6.85	18.65	0.37	2∠s 2 x 2 x 1/4	2	1.88	6.38	3.98	25.4
U_4L_4	-27.85	16.06	2.00	2∠s 6 x 6 x 3/8	6	8.72	29.8	15.82	441.5
U_5L_5	- 6.85	18.65	0.37	2∠s 2 x 2 x 1/4	2	1.88	6.38	3.98	25.4

TABLE II (continued)

Member	Stress kips	Unit stress K.S.l.	Required area in²	Section	O.S.	Supplied area in²	Weight lb./ft.	Length ft.	Weight lb;
U_6L_6	-13.65	16.20	0.84	2∠s 3 x 2½ x 1/4	2½	2.62	9.00	7.96	71.6
U_7L_7	- 6.85	18.65	0.37	2∠s 2 x 2 x 1/4	2	1.88	6.38	3.98	25.4
U_2L_1	+ 8.27	26.70	0.31	2∠s 2 x 2 x 1/4	2	1.44	6.38	8.90	56.8
U_2L_3	+ 7.64	do	0.29	do	do	do	do	do	56.8
L_3L_2	+16.52	do	0.62	do	do	do	do	do	56.8
L_3U_4	+24.16	do	0.91	do	do	do	do	do	56.8
L_5U_4	+22.91	do	0.86	do	do	do	do	do	56.8
L_5L_6	+15.27	do	0.57	do	do	do	do	do	56.8
L_5U_6	+ 7.64	do	0.29	do	do	do	do	do	56.8
L_6L_4	+32.60	do	1.22	2∠s 3 x 3 x 1/4	3	2.44	9.8	17.8	174.5
L_6L_7	+47.85	do	1.79	do	do	do	do	8.9	87.2
L_7U_8	+55.45	do	2.08	do	do	do	do	do	87.2
L_7U_6	+ 7.64	do	0.38	2∠s 2 x 2 x 1/4	2	1.44	6.38	do	56.8
L_8L_6	+ .75	20	0.04	2∠s 3½x 2½x 1/4	2½	2.44	9.8	18	176.5
									4297.1

Total weight of truss = 2 x 4297.1 = 8594.2 lb.
+ details = 9000 lb.

CONCLUSION

The following cost estimate for the scheme, gives a more or less an idea about the amount of capital needed.

Cost Of Building

	Cost	Units	Amount
<u>Walls</u>			
Limestone with concrete backing	L.L.20/m^2	1970 m^2	L.L. 39400
Partions 15 cm.	L.L.6/m^2	390 m^2	L.L. 2340
<u>Doors</u>			
Interior doors	L.L.65/m^2	18 m^2	L.L. 1170
Exterior "	L.L.75/m^2	18 m^2	L.L. 1350
Revolving "	L.L.1000/door	2	L.L. 2000
<u>Windows</u>			
Windows without shutters	L.L.50/m^2	700 m^2	L.L. 33000
Windows with shutters	L.L.80/m^2	175 m^2	L.L. 14000
<u>Concrete</u>			
P. concrete	L.L.90/m^3	108 m^3	L.L. 9720
R. "	L.L.120/m^3	216 m^3	L.L. 25900
Celcrete	L.L.40/m^3	837 m^3	L.L. 33480
<u>W.C.</u>	L.L.125 each	5	L.L. 625

	Cost	Units	Amount
Roof			
Asbestos	L.L.5/m^2	2310 m^2	L.L. 11550
Sheathing, joists and rafters	L.L.200/m^3	108 m^3	L.L. 21600
Purlins	L.L. 0.27/lb	53460 lb.	L.L. 14600
Trusses and labor	L.L. 0.59 lb	90000 lb.	L.L. 53100

Cost Of Machinery

2 compressors	L.L. 40000
Evaporative condenser	L.L. 15000
Tank	L.L. 20000
Storage R. evaporator	L.L. 2000
Piping	L.L. 54000
Miscellanious	L.L. 10000
Installation	L.L. 10000
	L.L.416835

BIBLIOGRAPHY

1. " Statistical Abstract of Palestine "
   of 1944-45 compiled and published by the Department of Statistics of Palestine
2. " Competitive Design of Steel Structures "
   by Peter Russell and George Dowell
3. " Heating Ventilating Airconditioning Guide 1947 "
   by The American Society of Heating and Ventilating Engineer
4. " Refrigerating Data Book "
   by The American Society of Refrigerating Engineers of 1943
5. " Refrigerating Data Book "
   by The American Society of Refrigerating Engineers of 1946
6. " Refrigerating Engineering Application Data Section "
   by The American Society of Refrigerating Engineers
7. " Refrigeration and Refrigerating Machinery "
   by The International Library of Technology
8. " Steel Construction Manuel "
   by The American Society of Steel Construction
9. " Steel and Timber Structures "
   by Hool and Kinne

10. " Structural Engineers Handbook "

by Ketchum

11. " Architectural Record "

of January 1949

12. " Engineering "

An illustrated weekly journal vol. 166 - No. 4313,

September 24, 1948

13. " Specifications "

of 1943 with which is incorporated the British municipal

engineers specifications

14. " Trane Refrigeration Manual "

by Trane Co. La Cresse, Wisconsin

15. " Celcrete "

A pamphlet on celcrete produced by the Contracting and

Trading Co. Lebanon - Syria