A DESIGN OF A ROOF I20 Ft. IN DIAMETER COVERED BY STEEL TRUSSES FORMING A GRID AND ITS COMPARISON WITH ASHELL IN TERMS OF COST

by

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The author wishes to express his great sense of gratitude to Prof. İsmet Seymen for his friendly interest, suggestions and encouragement.

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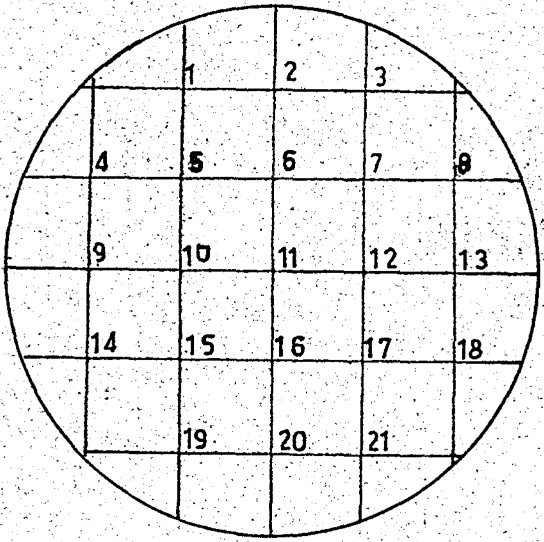
INTRODUCTION

The subject of the thesis is the study of a grid system of trusses and to design a grid system over a 12o feet diameter roof. The second part of the thesis is the comparison of this to a shell in terms of cost.

In the grid system we have five trusses in each direction and thus we get 21 unknowns as shown in the figure. If we try to solve it by the help of equations of deflections at the joints, taken by equating the deflection of the two trusses meeting at each joint we get 21 equations with 21 unknowns, and it is hard to solve these. In the thesis we solve the trusses by another method. We solve them by matrices and all the operations with matrices will be done by a computer. (Details of the matrices and operations are shown in the thesis.)

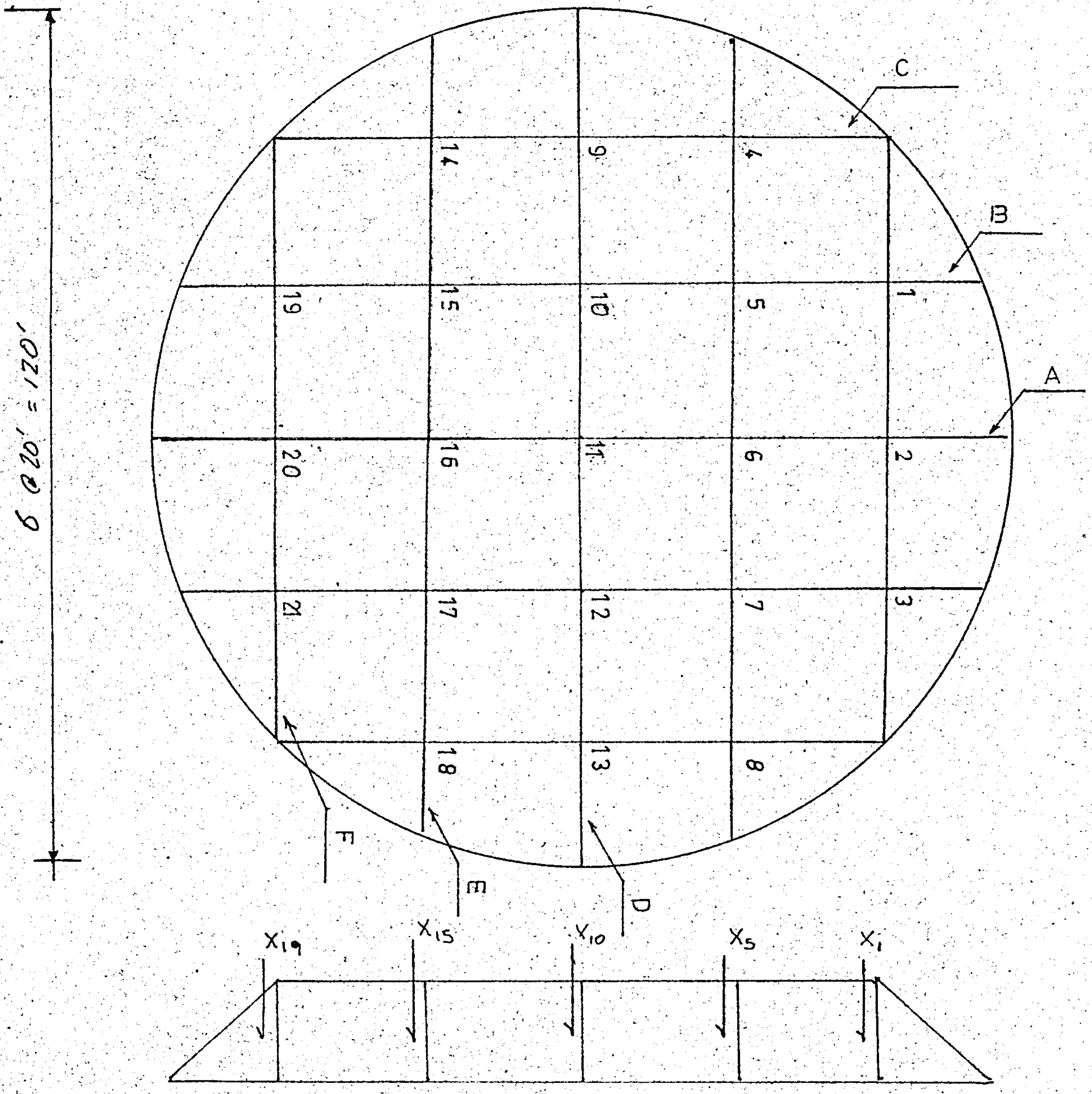


As a comparison in terms of cost, we choose a shell (symmetrically loaded) ,The comparison is made in the discussion of the thesis.

GRID SYSTEM OF TRUSSES

Assume: Loads acting on A, B, C

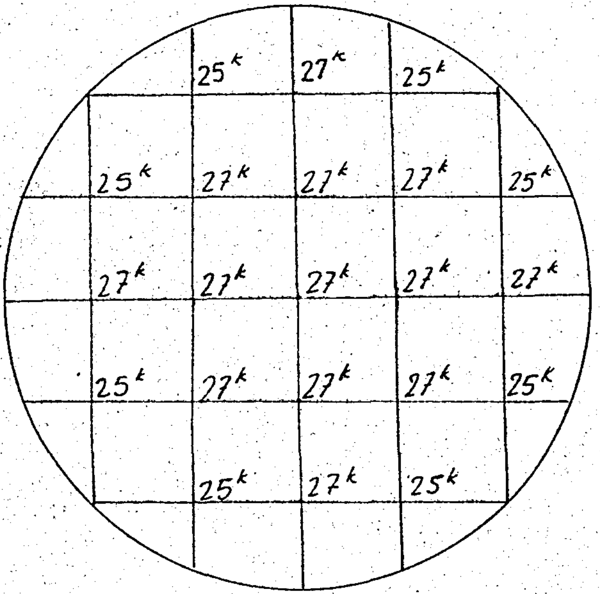
Redundants acting on D, E, F



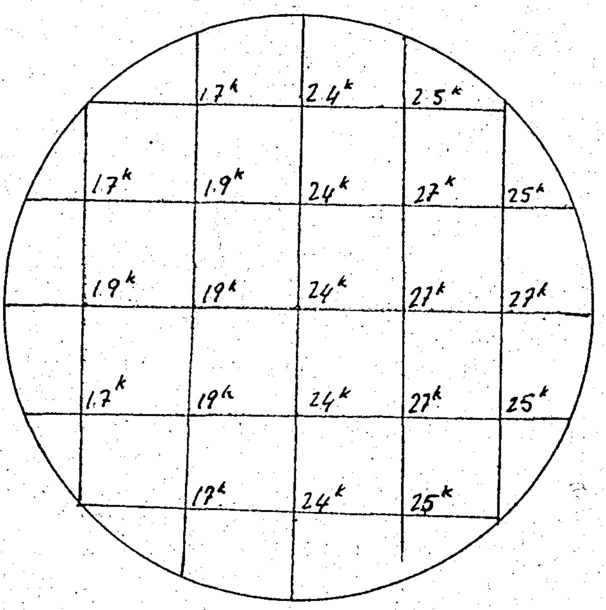
LOAD CASES

1. Sheets and girders : 7 lb/sq.ft.
2. Wind load : 20 lb/sq.ft.
3. Extra Load : 20 lb/sq.ft.
4. Wind load : 20 lb./sq.ft.

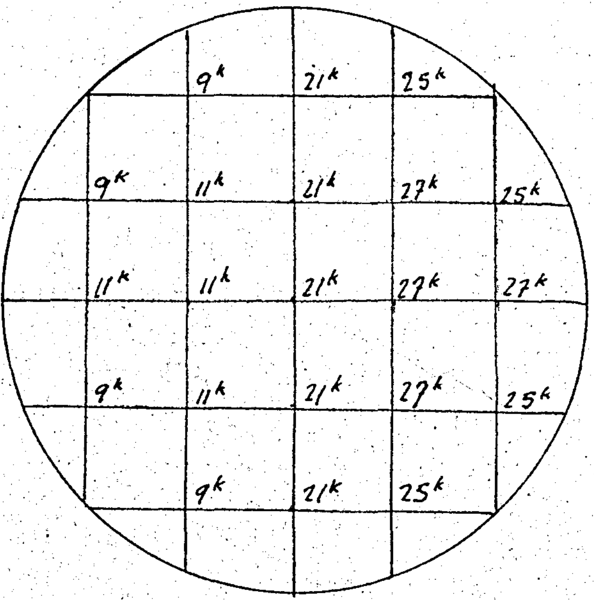
Total : 67 lb./sq.ft.



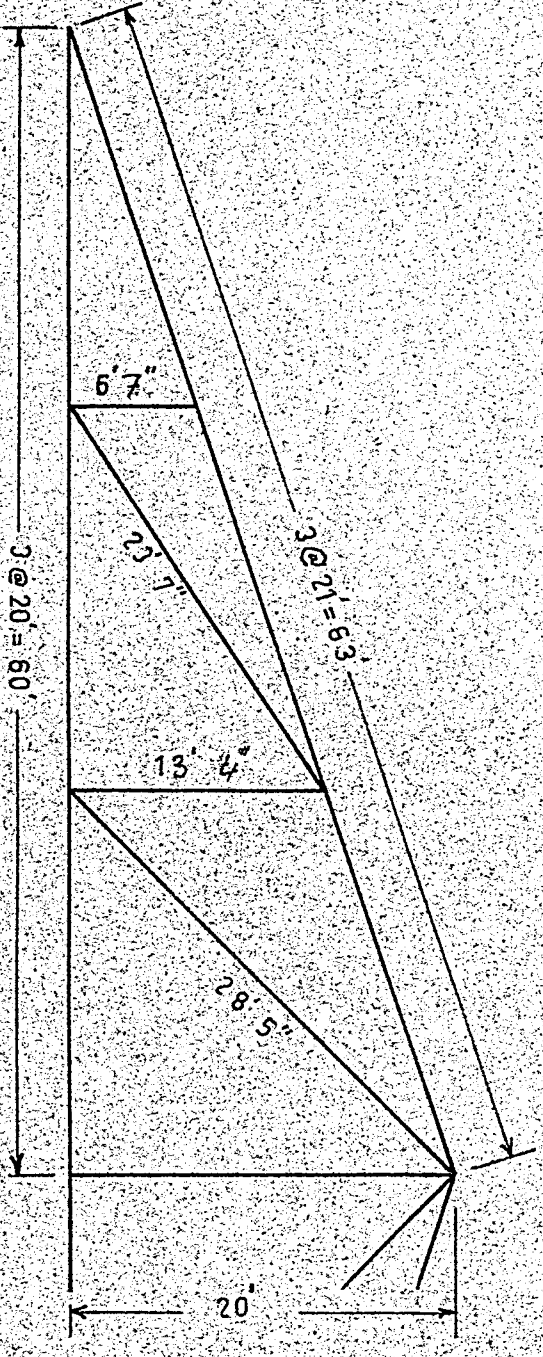
CASE 1



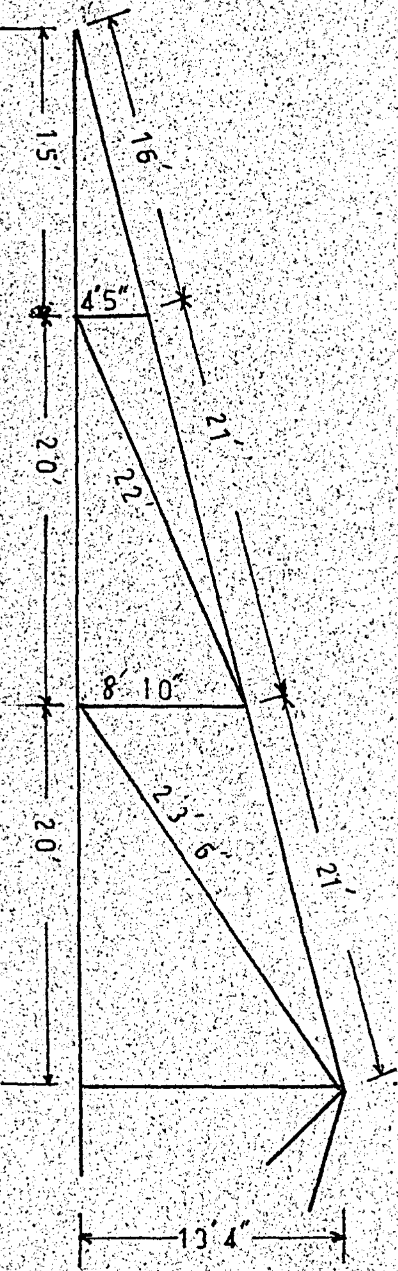
CASE 2



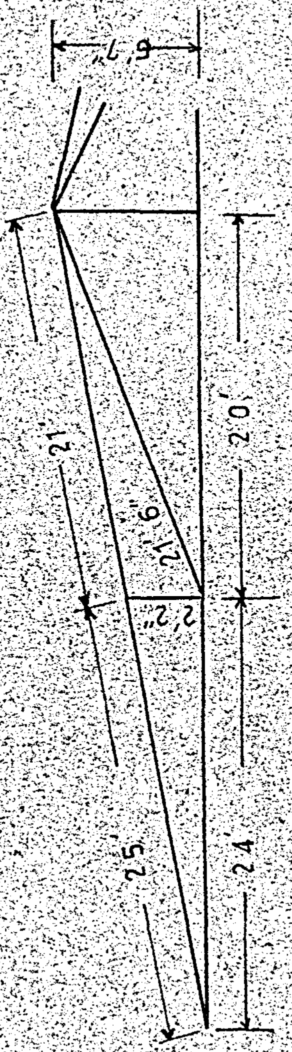
CASE 3



TRUSS A & D



TRUSS B & E



TRUSS C & F

DESIGN OF PURLINS

Length of purlins : 20 ft.

Space between purlins: 4 ft.

Use steel sheets 4' 5" (5" for overlap)

Thickness of sheets : 0.0568".

$$Wt/sq.\ ft. = \frac{1}{12}\ 0.0568'' \times 1\ sq.\ ft.\ 501.81\ lbs/W.\ ft.$$

$$= 2.4\ lb/sq.\ ft.$$

Weight on Purlins :

1. Sheets : 2.4 lb/sq ft x 4 ft = 9.6 lb/ft
2. Wind Load: 20lb/sq ft ⊥to surface x 4 = 80 lb/ft
3. Extra Load (Snow etc): 20lb/sq ft x 4ft=80 lb/ft

Sum =189.6 lb/ft

$$M = \frac{Wl^2}{8} = \frac{189.6 \times 400}{8} = 9450\ ft\ lb.$$

First Choice :

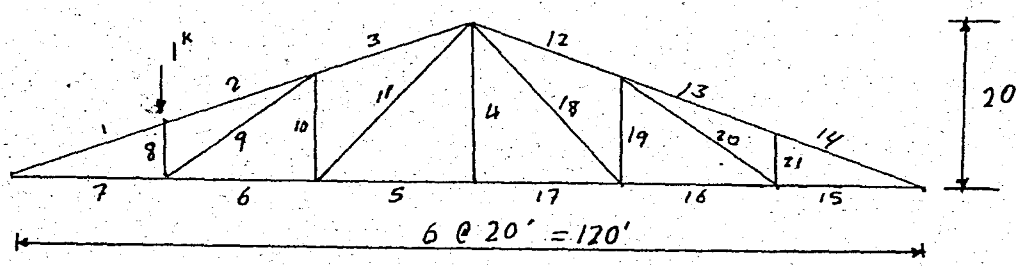
10 x 2 5/8" channel $\frac{1\ d}{bt} = 1700$

$$f = \frac{12,000,000}{1700} = 7,100$$

$$\frac{9450 \times 5 \times 12}{78.5} = 7080 \quad O.K.$$

(Ref. No. 5)

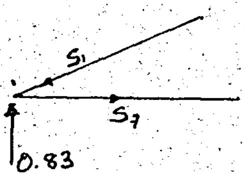
TRUSS A and D :



First Case : 1^k load at the first joint.

$\frac{20}{120} \times 1\text{ k} = 0.17$ k. R at right.

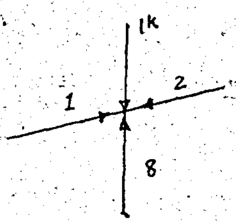
0.83 k. R at left.



$S_1(15/62) = 0.83 \qquad S_1 = -3.40$

$S_{14} = -0.63 \qquad S_7 = 60/62(3.40) = +3.32$

$S_{15} = 0.60$



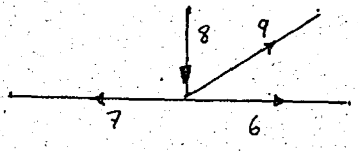
$S_2 = -3.40$ k. $\qquad S_{13} = S_{12} = -0.63$

$S_8 = -1$ k. $\qquad 0 = S_{21} = S_{20} = S_{19} = S_{18}$

$S_9(10/22.5) = 1$ k. $\qquad S_9 = 2.25$ k.

$S_{15} = S_{16} = S_{17} = 0.60$

$S_6 = 3.32 - 2.25(20/23) = +1.36$

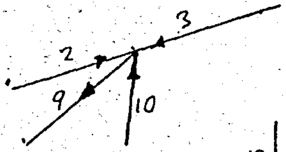


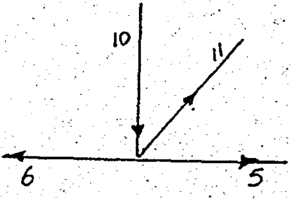
$S_3(60/62) = 1.76 - 3.40(60/62) \qquad S_3 = -1.4$

$S_{10} = 2.25(10/23) + 1.48(15/62) - 3.4(15/62)$

$S_{10} = -0.52 \qquad S_{11}(15/25) = 0.87$

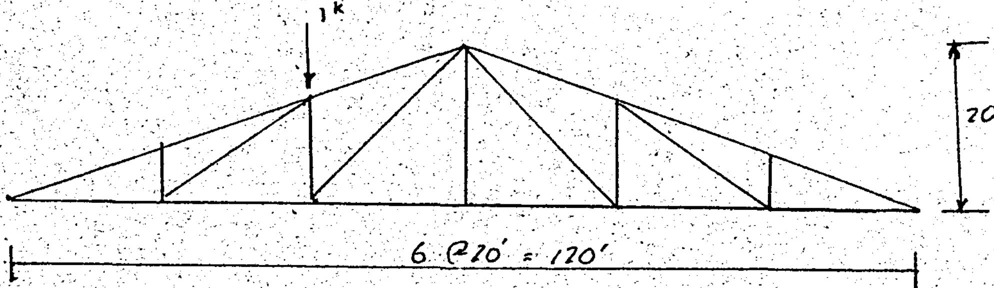
$S_5 = 1.36 - 0.87(20/25) \qquad S_5 = 0.66 \quad S_4 = 0$





Truss A and D :

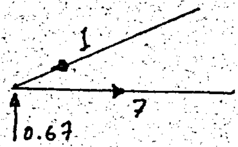
Second Case : One unit load at the second joint.



$R_{left} = 1 \times 80/120 = o.67$ $\qquad R_{right} = o.37$

$S_1(15/62) = 0.67 \qquad S_1 = -2.75$

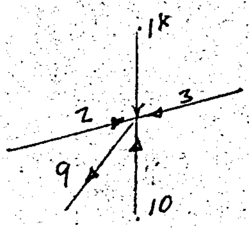
$S_7 = 2.75(60/62) = 2.65$



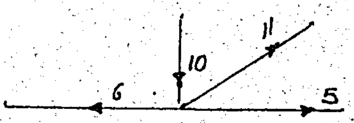
$S_2 = S_1 = -2.75 \qquad S_{14}=S_{13}=S_{12}= -1.52$

$S_8 = 0 \qquad S_{15}=S_{16}=S_{17}= +1.50$

$S_8 = 0 \quad S_9 = 0 \quad S_7 = 2.65 \quad S_6 = 2.65$



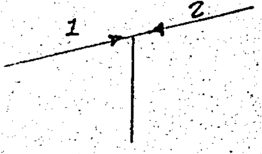
$S_3 = S_2 = -2.75 \qquad S_{1o} = -1$ k.



$S_{11} = 1 \frac{15}{25} = 1.4$

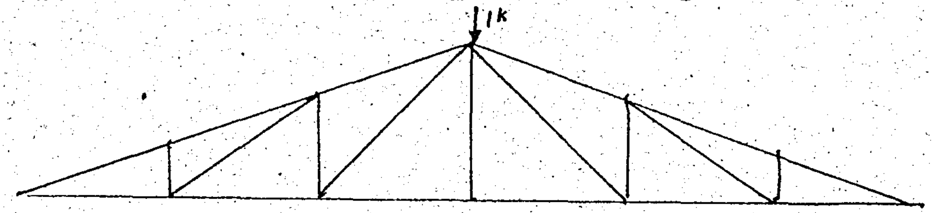
$S_5 = 2.65 - 1.4(20/25)$

$S_4 = 0$



Truss A and D

Third Case : One unit Load at the center.



$R_{left} = 0.5$ k.

$S_1 = 0.5(60/15) = -2$ k. $= S_{14}$

$S_7 = 2(60/62) = 1.94$ k. $= S_{15}$

$S_1 = S_2 = -2$ k. $= S_{13}$

$S_8 = S_{21} = 0$

$S_9 = 0$

$S_6 = S_7 = S_{16} = S_{15} = 1.94$ k.

$S_2 = S_3 = S_{13} = S_{12} = 2.0$ k.

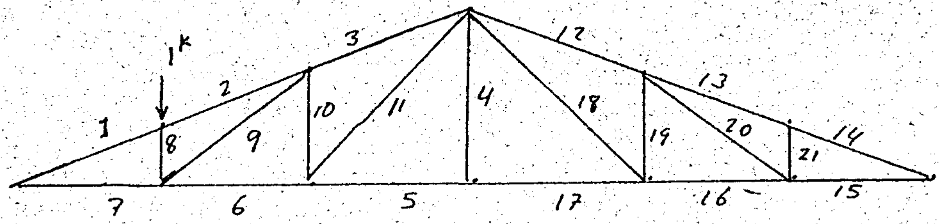
$S_9 = 0$ $S_{10} = S_{19} = S_{20} = S_{21} = 0$

$S_{11} = 0$ $S_{11} = S_{18} = 0$

$S_5 = S_{17} = 1.94$ k.

Truss B and E :

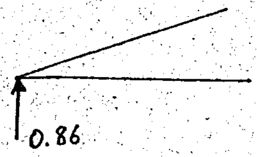
Load Case 1 : One unit load at first joint .



$R_{left} = (95/11o)\ 1 = 0.86 \qquad R_{right} = 0.14$

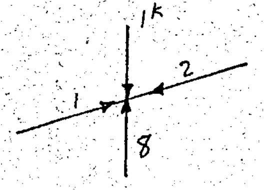
$S_1 = 0.86(56/10) = -4.8 \qquad S_8 = -1\ k.$

$S_7 = 4.8(55/56) = 4.75 \qquad S_2 = S_1 = -4.8$



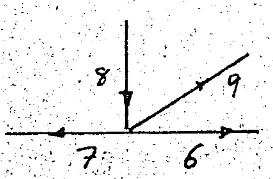
$S_9 = 1(21/6.35) = 3.30$

$S_6 = 4.75 - 3.30(20/21) = 1.60$



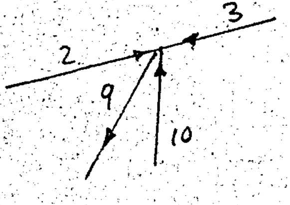
$S_3(55/56) = 3.15 - 4.75 \qquad S_3 = -1.57$

$S_{10} = 3.20(10/56) - 3.3(6.35/21) = -0.43$



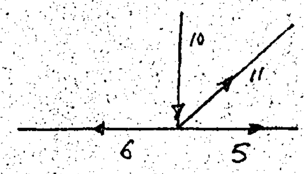
$S_{11} = 0.43(22.3/10) = 0.96$

$S_5 = 1.60 - 0.96(20/22.3) = 0.73$



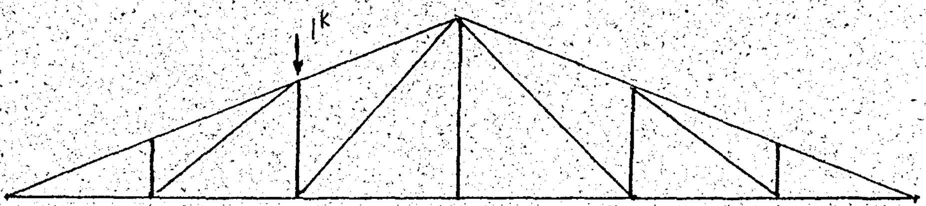
$S_{14} = S_{13} = S_{12} = -0.14(56/10) = -0.78$

$S_{15} = S_{16} = S_{17} = +0.78(55/56) = 0.75$



Truss B and E :

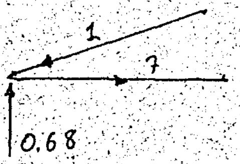
Load Case 11 :



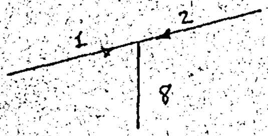
$$R_{left} = (75/110)\ 1 = 0.68 \qquad R_{right} = 0.32$$

$$S_1 = 0.68(56/10) = -3.80$$

$$S_7 = 3.80(55/56) = 3.75$$

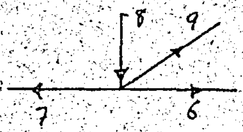


$$S_2 = S_1 = -3.80 \qquad S_8 = 0$$

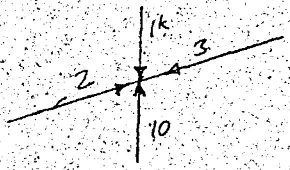


$$S_7 = S_6 = 3.75$$

$$S_8 = S_9 = 0$$



$$S_{10} = -1\ k. \quad S_3 = S_2 = -3.80$$

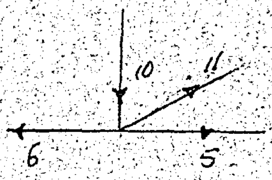


$$S_{11} = 1(22.3/10) = 2.23$$

$$S_5 = 3.75 - 2.23(20/22.3) = 1.75$$

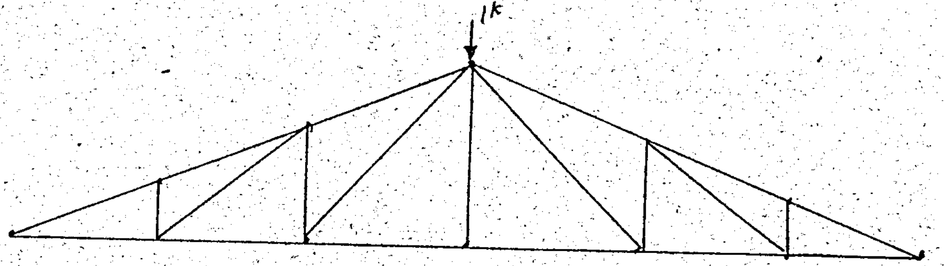
$$S_{14} = S_{13} = S_{12} = -0.32(56/10) = -1.8$$

$$S_{15} = S_{16} = S_{17} = 1.80(55/56) = 1.77$$



Truss B and E :

Load Case 111 :



$R_{left} = o.5$

$S_1 = 0.5(56/10) = -2.80$

$S_7 = 2.8(55/56) = 2.75$

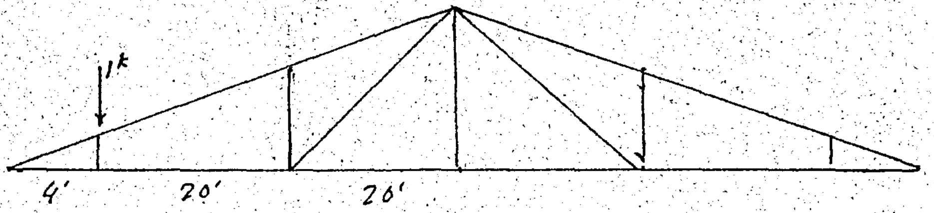
$S_1 = S_2 = S_3 = -2.80$

$S_5 = S_6 = S_7 = 2.75$

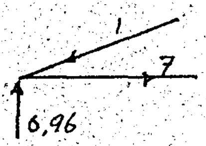
$S_4 = S_8 = S_9 = S_{10} = S_{11} = 0$

Truss C and F :

Load Case 1 :

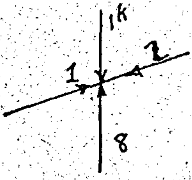


$R_{left} = (84/88)\ 1 = 0.96$ $R_{right} = 0.04$



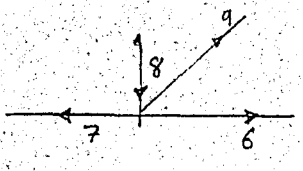
$S_1 = 0.96(45/5) = -8.6$

$S_7 = 8.60(44/45) = 8.4$



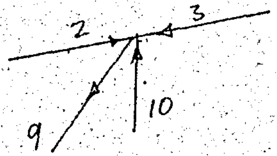
$S_1 = S_2 = -8.6$

$S_8 = 1\ k.$



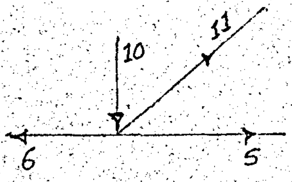
$S_9 = 1(20/2.75) = 7.30$

$S_6 = 8.4 - 7.2 = 1.20$



$S_3(44/45) = 7.2 - 8.4$ $S_3 = 1.23$

$S_{10} = 7.37(5/45) - 7.3(2.25/21) = -0.22$



$S_{11} = 0.22(20/5) = 0.88$

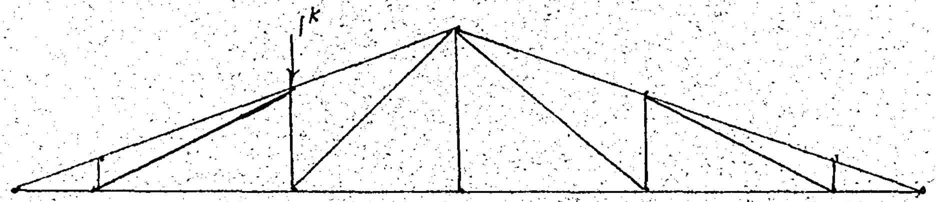
$S_5 = 1.20 - 0.88(20/21) = 0.32$

$S_{14} = S_{13} = S_{12} = -0.04 \times 0.9 = -0.36$

$S_{15} = S_{16} = S_{17} = +0.32$

Truss C and F :

Load Case 11 :



$R_{left} = 64/88 = 0.73$ $R_{right} = 0.27$

$S_1 = 0.73(45/3) = - 6,60$

$S_{12} = S_{13} = S_{14} = -2.40$

$S_{15} = S_{16} = S_{17} = 2.30$

$S_7 = 6.60(44/45) = 6.45$

$S_1 = S_2 = - 6.60$

$S_8 = S_9 = 0$

$S_6 = S_7 = 6.45$

$S_3 = - 6.60$

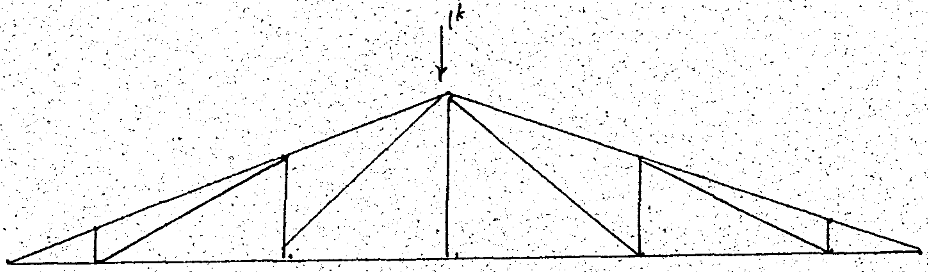
$S_{10} = - 1.0$

$S_{11} = 1(21/5) = 4.20$

$S_5 = 6.45 - 4.20(20/21) = 2.30$

Truss C and F :

Load Case 111 :



$S_1 = 0.5\ (45/5) = -4.5$

$S_2 = S_3 = -4.5$

$S_7 = 4.5\ (44/45) = 4.4$

$S_5 = S_6 = 4.4$

$S_8 = S_9 = S_{10} = S_{11} = 0$

DEFLECTIONS ACCORDING TO UNIT LOADS AT JOINTS

TRUSS A AND D

Estimated Areas: $A_1 = A_2 = A_3 = A_{12} = A_{13} = A_{14} = 10^{\square''}$

$A_7 = A_6 = A_5 = A_{17} = A_{16} = A_{15} = 7^{\square''}$

$A_8 = A_{21} = 1^{\square''}$ $A_9 = A_{20} = 1.5^{\square''}$

$A_{10} = A_{19} = 2^{\square''}$ $A_{11} = A_{18} = 1.5^{\square''}$

LOAD AT JONT I DEFLECTION AT I

Member	δ.E	u	δ.E.u
1	-86	-3,40	294
2	-86	-3,40	294
3	-37,5	-1,48	55
4	0	0	0
5	22	0,66	14,60
6	45,50	1,36	62
7	110	3,32	365
8	-60	-1	60
9	405	2,25	910
10	-31	-0,52	16
11	175	0,87	15,20
12	-16	-0,63	10
13	-16	-0,58	10
14	-16	-0,63	10
15	21	0,50	12,60
16	21	0,50	12,60
17	21	0,60	12,60
18		0	0
19		0	0
20		0	0
21		0	0

Σ = 2152,60

LOAD AT JOINT I DEFLECTION AT 2

Member	δ.E	u	δ.E.u
1	-86	-2,75	236
2	-86	-2,75	236
3	-37,5	-2,75	100,50
4	0	0	0
5	22	1,50	33
6	45,50	2,65	120
7	110	2,65	293
8	-60	0	0
9	405	0	0
10	-31	0	0
11	175	14	105
12	-16	-1,52	24,50
13	-16	-1,52	24,50
14	-16	-1,52	24,50
15	21	1,50	31,50
16	21	1,50	31,50
17	21	1,50	31,50
18		0	0
19		0	0
20		0	0
21		0	0

Σ = 1291,50

(Ref. No. 4)

LOAD AT JOINT L DEFLECTION AT 3

MEMBER	$\delta \cdot E$	μ	$\delta \cdot E\mu$
1	- 86	- 2	172
2	- 86	- 2	172
3	- 37.5	- 2	75
4	0	1	0
5	22	1.9	43
6	45.5	1.9	88
7	110	1.9	215
8	- 60	0	0
9	405	0	0
10	- 31	0	0
11	75	0	0
12	- 16	- 2	32
13	- 16	- 2	32
14	- 16	- 2	32
15	21	1.9	41
16	21	1.9	41
17	21	1.9	41

$\Sigma = 1284$

LOAD AT JOINT I DEFLECTION AT 4

MEMBER	$\delta \cdot E$	μ	$\delta \cdot E\mu$
1	- 86	- 1.52	130
2	- 86	- 1.52	130
3	- 37.5	- 1.52	57
4	0	0	0
5	22	1.5	33
6	45.5	1.5	68
7	110	1.5	167
8	- 60	0	0
9	405	0	0
10	- 31	0	0
11	75	0	0
12	- 16	- 2.75	44
13	- 16	- 2.75	44
14	- 16	- 2.75	44
15	21	2.65	56
16	21	2.65	56
17	21	1.5	33

$\Sigma = 852$

LOAD AT I DEFLECTION AT 5

MEMBER	$\delta \cdot E$	μ	$\delta \cdot E\mu$
1	- 86	- .63	54
2	- 86	- .63	54
3	- 37.5	- .63	23.5
4	0		
5	22	.60	13.2
6	45.5	.60	27.5
7	110	.60	66
8	- 60	0.0	0
9	405	0.0	0
10	- 31	0.0	0
11	75	0.0	0
12	- 16	- 1.48	24
13	- 16	- 3.40	55
14	- 16	- 3.40	55
15	21	3.32	70
16	21	1.36	28.5
17	21	.66	13.8

$\Sigma = 484.00$

LOAD AT JOINT 2 DEFLECTION 2

MEMBER	$\delta \cdot E$	μ	$\delta \cdot E\mu$
1	- 70	- 2.75	192
2	- 70	- 2 .75	192
3	- 70	- 2.75	192
4	0		
5	50	1.5	75
6	55	2.65	146
7	88	2.65	233
8	0		
9	0		
10	- 60	0	
11	120	1.4	168
12	- 38.5	-1.52	58.5
13	-38.5	-1.52	58.5
14	- 38.5	-1.52	58.4
15	52.5	1.5	77
16	52.5	1.5	77
17	52.5	1.5	77

$\Sigma = 1604.5$

(Ref. NO.4)

LOAD AT JOINT 2 DEFLECTION AT 3

Member	$\delta \cdot E$	u	$\delta \cdot E u$
I	-70	-2	I40
2	-70	-2	I40
3	-70	-2	I40
4	0		
5	50	I94	97
6	55	I.94	I07
7	88	I.94	I70
8	0		
9	0		
I0		0	
II		0	
I2	-3850	-2	77
I3	-38.50	-2	77
I4	-38.50	-2	77
I5	52.50	I.94	I02
I6	52.50	I.94	I02
I7	52.50	I.94	I02

$\Sigma =$ I33I

LOAD AT JOINT 2 DEFLECTION AT 4

Member	$\delta \cdot E$	u	$\delta \cdot E u$
I	-70	-I52	I06
2	-70	-I52	I06
3	-70	-I52	I06
4	0		
5	50	I.50	75
6	55	I.50	87
7	88	I.50	I37
8	0		
9	0		
I0		0	
II		0	
I2	-38.50	-2.75	I06
I3	-38.50	-2.75	I06
I4	-38.50	-3.75	I06
I5	52.50	2.65	I38
I6	52.50	2.65	I38
I7	52.50	2.65	I38

$\Sigma =$ I280

LOAD AT JOINT 2 DEFLECTION AT 5

Member	$\delta \cdot E$	u	$\delta \cdot E \cdot u$
I	-70	-0.63	44
2	-70	-063	44
3	-70	-0.63	44
4	0		
5	50	0.60	30
6	55	0.60	33
7	88	0.60	53
8	0		
9	0		
I0	0		
II	0		
I2	-38.50	-I.48	57
I3	-38.50	-340	I30
I4	-3850	-3.40	I30
I5	52.50	3.32	I75
I6	52.50	I.36	72
I7	52.50	0.66	35

$\Sigma = 847$

LOAD AT JOINT 3 DEFLECTION AT 3

Member	$\delta \cdot E$	u	$\delta \cdot E \cdot u$
I	-5I	-2	I02
2	-5I	-2	I02
3	-5I	-2	I02
4	0		
5	36.50	I.94	7I
6	36.50	I.94	7I
7	36.50	I.94	7I
8	0		
9	0		
I0	0		
II	0		
I2	-5I	-2	I02
I3	-5I	-2	I02
I4	-5I	-2	I02
I5	36.50	I.94	7I
I6	36.50	I.94	7I
I7	36.50	I.94	7I

$\Sigma = 1038$

(Ref. No.4)

TRUSS B AND E

Estimated Areas:

$A_1 = A_2 = A_3 = A_{12} = A_{13} = A_{14} = 13\ \square''$

$A_5 = A_6 = A_7 = A_{15} = A_{16} = A_{17} = 9\ \square''$

$A_8 = A_{21} = 1\ \square''$ $A_9 = A_{20} = 2\ \square''$

$A_{10} = A_{19} = 2\ \square''$ $A_{11} = A_{18} = 2\ \square''$

LOAD AT JOINT I DEFLECTION AT I

I	7I	4.80	340
2	94	4.80	450
3	3I	I.57	48
4	0	0	
5	I9.5	0.73	I4.20
6	43	I60	69
7	I27	4.75	600
8	32.50	I.00	32.50
9	4I.50	3.30	I36
I0	5.70	0.43	2.50
II	I3	0.96	I2.50
I2	I5	0.78	II.70
I3	I5	0.78	II.70
I4	I5	0.78	II.70
I5	I6	0.75	I2
I6	20	0.75	I5
I7	I7	0.75	I3

$\Sigma =$ I78I.80

LOAD AT JOINT I DEFLECTION AT 2

I	7I	3.80	270
2	94	3.80	360
3	3I	3.80	II8
4	0		
5	I9.50	I.75	34
6	43	3.75	I62
7	I27.50	3.75	485
8	32.50	0	
9	4I.50	0	
I0	5.70	I.00	5.70
II	I3	2.23	29
I2	I5	I.80	27
I3	I5	I.80	27
I4	I5	I.80	27
I5	I6	I.77	28.50
I6	20	I.77	35.50
I7	I6	I.77	35.50

$\Sigma =$ I644.20

(Ref. 4)

LOAD AT JOINT I DEFLECTION AT 3

Member	$\delta \cdot E$	u	$\delta \cdot E u$
I	71	2.80	200
2	94	2.80	265
3	31	2.80	87
4	0	0	0
5	19.5	2.75	53.50
6	43	2.75	118.0
7	127	2.75	350.0
8	32.5	0	0
9	41.5	0	0
10	5.7	0	0
11	13	0	0
12	15	2.80	42.0
13	15	2.80	42.0
14	15	2.80	42.0
15	16	2.75	44.0
16	20	2.75	55.0
17	20	2.75	55.0

Σ = 1173.50

LOAD AT JOINT I DEFLECTION AT 4

Member	$\delta \cdot E$	u	$\delta \cdot E u$
I	71	I.80	I28
2	94	I.80	I70
3	31	1.80	56
4	0	0	0
5	19.5	1.77	35
6	43.0	1.77	76
7	127.0	1.77	225
8	32.50	0	0
9	41.50	0	0
10	5.70	0	0
11	13	0	0
12	15	3.80	57
13	15	3.80	57
14	15	3.80	57
15	16	3.75	60
16	20	3.75	75
17	20	1.75	75

Σ = 1051.00

Load at JOINT I DEFLECTION at 5

Member	$\delta \cdot E$	u	$\delta \cdot E u$
1	71	.78	55
2	94	.78	73
3	31	.78	24
4	0	0	0
5	19.5	.75	14.6
6	43	.75	32.5
7	127	.75	95
8	32.5	0	0
9	41.5	0	0
10	5.7	0	0
11	13	0	0
12	15	1.57	23.5
13	15	4.8	72
14	15.0	4.8	72
15	16	4.75	76
16	20	1.6	32
17	20	.73	14.6

Σ = 584.2

LOAD AT JOINT 2 DEFLECTION AT 2

Member	$\delta \cdot E$	u	$\delta \cdot E u$
1	70	3.8	265
2	90	3.8	340
3	90	3.8	340
4	0	0	0
5	47	1.75	83
6	100	3.75	375
7	75	3.75	280
8	0	0	0
9	0	0	0
10	38	1	38
11	280	2.23	630
12	48	1.8	86
13	48	1.8	85
14	38	1.8	68
15	35	1.77	62
16	47	1.77	83
17	47	1.77	83

Σ = 2819

Ref. No. 4

LOAD AT JOINT 2 DEFLECTION AT 3

Member	$\delta \cdot E$	u	$\delta \cdot E \cdot u$
1	70	2.80	196
2	90	2.80	250
3	90	2.80	250
4	0	0	
5	47	2.75	130
6	100	2.75	275
7	75	2.75	206
8	0	0	
9	0	0	
10	38	0	
11	280	0	
12	48	2.8	134
13	48	2.8	134
14	38	2.8	106
15	35	2.75	96
16	47	2.75	129
17	47	2.75	129

$\Sigma =$ 2035

LOAD AT JOINT 2 DEFLECTION AT 4

Member	$\delta \cdot E$	u	$\delta \cdot E \cdot u$
1	70	1.8	126
2	90	1.8	162
3	90	1.8	162
4	0	0	
5	47	1.77	83
6	100	1.77	177
7	75	1.77	133
8	0	0	
9	0	0	
10	38	0	
11	280	0	
12	48	3.8	182
13	48	3.8	182
14	38	3.8	140
15	35	3.75	130
16	47	3.75	175
17	47	1.75	83

$\Sigma =$ 1735

LOAD AT JOINT 2 DEFLECTION AT 5

Member	$\delta \cdot E$	u	$\delta \cdot E \cdot u$
1	70	.78	55
2	90	.78	70
3	90	.78	70
4	0	0	
5	47	.75	35
6	100	.75	75
7	75	.75	56
8	0	0	
9	0	0	
10	38	0	
11	280	0	
12	48	1.57	75
13	48	4.80	230
14	38	4.80	182
15	35	4.75	167
16	47	1.60	75
17	47	.73	34

$\Sigma =$ 1124

LOAD AT JOINT 3 DEFLECTION 3

Member	$\delta \cdot E$	u	$\delta \cdot E \cdot u$
1	41.5	2.8	116
2	55	2.8	154
3	55	2.8	154
4	0	0	
5	73	2.75	200
6	73	2.75	200
7	55	2.75	151
8		0	
9		0	
10		0	
11		0	
12	55	2.8	154
13	55	2.8	154
14	41.5	2.8	116
15	55	2.75	151
16	73	2.75	200
17	73	2.75	200

$\Sigma =$ 1450

(Ref. No. 4)

TRUSS C AND F

Estimated Areas ;

$A_1 = A_2 = A_3 = A_4 = A_{13} = A_{12} = 16$ sq. inch.

$A_5 = A_6 = A_7 = A_{15} = A_{16} = A_{17} = 13$ sq. inch.

$A_8 = A_{21} = 1$ sq. inch. $A_9 = A_{20} = 6$ sq. inch.

$A_{10} = A_{19} = 1.5$ sq. inch. $A_{11} = A_{18} = 4$ sq. inch.

LOAD AT JOINT 2 DEFLECTION AT 2

Member	$\delta \cdot E$	u	$\delta \cdot E \cdot u$
1			
2	136	7.6	1030
3	114	7.6	880
4		0	
5	51	2.3	112
6	142	6.45	910
7			
8			
9			
10	33	1.	33
11	265	4.2	1110
12	36	2.4	86
13	43.5	2.4	105
14			
15			
16	53	2.30	122
17	44.5	2.30	102

$\Sigma =$ 4480

LOAD AT JOINT 2 DEFLECTION AT 3

Member	$\delta \cdot E$	u	$\delta \cdot E \cdot u$
1			
2	136	4.5	610
3	114	4.5	515
4			
5	51	4.4	225
6	142	4.4	630
7			
8			
9			
10			
11			
12	36	4.5	162
13	43.5	4.5	196
14			
15			
16	53	4.4	235
17	44.5	4.4	196

$\Sigma =$ 2769

(Ref. No. 4)

LOAD AT JOINT 2 DEFLECTION AT 4

Member	$\delta \cdot E$	u	$\delta \cdot E \cdot u$
1			
2	136	2.4	325
3	114	2.4	275
4			
5	51	2.3	118
6	142	2.3	327
7			
8			
9			
10			
11			
12	36	7.6	275
13	43.5	7.6	330
14			
15			
16	53	6.45	340
17	44.5	2.3	102

$\Sigma =$ 2192

LOAD AT JOINT 3 DEFLECTION AT 3

Member	$\delta \cdot E$	u	$\delta \cdot E \cdot u$
1			
2	81	4.5	365
3	68	4.5	305
4			
5	81	4.4	355
6	97	4.4	425
7			
8			
9			
10			
11			
12	68	4.5	305
13	81	4.5	365
14			
15			
16	97	4.4	425
17	81	4.4	355

$\Sigma =$ 2900

(Ref. No.4)

MATRICE OPERATIONS

21x21 R : Red. Mot. @ Red./Red.

21x3 L : Red. Mot. @ Red./Loads

21x21 A : Thrusts @ El. of Truss A/Unit Red.

21x21 B : Thrusts @ El. of Truss B/Unit Red.

21x21 C : Thrusts @ El. of Truss C/Unit Red.

21x21 D : Thrusts @ El. of Truss D/Unit Red.

21x21 E : Thrusts @ El. of Truss E/Unit Red.

21x21 F : Thrusts @ El. of Truss F/Unit Red.

21x3 A2 : Thrusts @ El. of Truss A/Loads

21x3 B2 : Thrusts @ El. of Truss B/Loads

21x3 C2 : Thrusts @ El. of Truss C/Loads

21x3 D2 : Thrusts @ El. of Truss D/Loads

21x3 E2 : Thrusts @ El. of Truss E/Loads

21x3 F2 : Thrusts @ El. of Truss F/Loads

21x3 $X = - R^{-1} L$ = Redundants/Loads

Actual Thrusts

21x3		21x3		21x21	21x3	
AT	:	(A2)	+	(A)	(X)	: Thrusts @ A/Loads and Red.
BT	:	(B2)	+	(B)	(X)	: Thrusts @ B/Loads and Red.
CT	:	(C2)	+	(C)	(X)	: Thrusts @ C/Loads and Red.
DT	:	(D2)	+	(D)	(X)	: Thrusts @ D/Loads and Red.
ET	:	(E2)	+	(E)	(X)	: Thrusts @ E/Loads and Red.
FT	:	(F2)	+	(F)	(X)	: Thrusts @ F/Loads and Red.

(Ref. No. 8)

Note: In the formation of matrices one tenths of the loads were taken, therefore the results of the computer will be multiplied by ten.

R= RED. MOT. @ RED/ RED.

REDUNDANTS

RED. MOT.@RED.

6261																				
2769	5052																			
2192	2769	6261																		
0	0	0	6261																	
1644	0	0	1644	5638																
0	1392	0	1173	2035	2900															
0	0	1644	1051	1735	2035	5638														
0	0	0	594	1124	1173	1644	6261													
0	0	0	2769	0	0	0	0	5052												
1173	0	0	0	2035	0	0	0	1292	3055											
0	1284	0	0	0	1331	0	0	1284	1331	2076										
0	0	1173	0	0	0	2035	0	862	1280	1331	3055									
0	0	0	0	0	0	0	2769	484	847	1284	1292	5052								
0	0	0	2192	0	0	0	0	2769	0	0	0	0	6261							
1051	0	0	0	1735	0	0	0	0	2035	0	0	0	1644	5638						
0	862	0	0	0	1280	0	0	0	0	1331	0	0	1173	2035	2900					
0	0	1051	0	0	0	1735	0	0	0	0	2035	0	1051	1735	2035	5638				
0	0	0	0	0	0	0	2192	0	0	0	0	2769	584	1124	1173	1644	6261			
584	0	0	0	1124	0	0	0	0	1173	0	0	0	0	1644	0	0	0	6261		
0	484	0	0	0	847	0	0	0	0	1284	0	0	0	0	1292	0	0	2769	5052	
0	0	584	0	0	0	1124	0	0	0	0	1173	0	0	0	0	1644	0	2192	2769	6261

(Ref. No. 8)

L= RED MOTION @ RED/ LOADS

RED. MOT.@ RED.

	1	2	3
1	16110	11300	6400
2	16400	14600	12700
3	16110	16110	16110
4	24050	16550	9000
5	24700	17200	9960
6	17000	15200	13400
7	24700	24700	24700
8	24050	24050	24050
9	21200	14600	8000
10	20800	14500	8200
11	16900	15000	13100
12	20800	20800	20800
13	21200	21200	21200
14	24050	16550	9000
15	24700	17200	9900
16	17000	15200	13400
17	24700	24700	24700
18	24050	24050	24050
19	16110	11300	6400
20	16400	14600	12700
21	16110	16110	16110

A_I= THRUSTS ON EL $\overset{A}{\text{OF}}$/ LOADS

THRUSTS @ EL.

	LOADS		
	Load I	Load II	Load III
1	-34.50	-23.80	-11.10
2	-34.50	-23.80	-11.10
3	-34.50	-23.80	-11.10
4	0	0	0
5	23.50	16.20	9.15
6	33.70	22.10	12.85
7	33.70	22.10	12.85
8	0	0	0
9	0	0	0
10	-2.50	-1.90	-1.10
11	10.50	8.00	3.80
12	-34.50	-23.80	-11.10
13	-34.50	-23.80	-11.10
14	-34.50	-23.80	-11.10
15	33.70	22.10	12.85
16	33.70	22.10	12.85
17	23.50	16.20	9.15
18	10.50	8.00	3.80
19	-2.50	-1.90	-1.10
20	0	0	0
21	0	0	0

(Ref. No. 8)

B_2= THRUSTS ON EL. OF B/ LOADS

THRUSTS @ EL.

	Load I	Load II	Load III
1	-36.50	-25.50	-14.20
2	-36.50	-25.50	-14.20
3	-27.30	-19.20	-11.00
4	0	0	0
5	20.70	14.50	8.22
6	23.80	19.80	10.20
7	36.20	25.20	14.00
8	-2.50	-1.70	-0.90
9	8.30	5.60	2.90
10	-3.86	-2.37	-1.92
11	8.00	5.43	2.86
12	-27.30	-19.20	-11.00
13	-36.50	-25.50	-14.20
14	-36.50	-25.50	-14.20
15	36.20	25.20	14.00
16	28.30	19.80	10.20
17	20.70	14.50	8.22
18	8.00	5.43	2.86
19	-3.86	-2.37	-1.92
20	8.30	5.60	2.90
21	-2.50	-1.70	-0.90

C_1= THRUSTS ON EL. OF C/ LOADS

LOADS

	Load I	Load II	Load III
1	-28.50	-25.00	-22.00
2	-28.50	-25.00	-22.00
3	-22.50	-20.00	-17.50
4	0	0	0
5	16.60	14.80	13.00
6	21.60	19.30	17.00
7	29.60	26.50	23.00
8	-2.70	-2.40	-2.10
9	6.10	5.40	4.70
10	-4.10	-3.65	-3.20
11	16.12	15.42	14.72
12	-22.50	-20.00	-17.50
13	-28.50	-25.00	-22.00
14	-28.50	-25.00	-22.00
15	29.60	26.50	23.00
16	21.60	19.30	17.00
17	16.60	14.80	13.00
18	6.12	5.42	4.72
19	-4.10	-3.65	-3.20
20	6.10	5.40	4.70
21	-2.70	-2.40	-2.10

(Ref. No. 8)

A= THRUSTS ON EL. OF A / UNIT RED.

UNIT RED.

THRUSTS @ EL.

	1	4	.....	9	.....	14	 21
1		-6.60		-4.50		-2.40	
2		-6.60		-4.50		-2.40	
3		-6.60		-4.50		-2.40	
4		0		0		0	
5		2.30		4.40		2.30	
6		6.45		4.40		2.30	
7		6.45		4.40		2.30	
8		0		0		0	
9		0		0		0	
10		-1.00		0		0	
11		4.20		0		0	
12		-2.40		-4.50		-6.60	
13		-2.40		-4.50		-6.60	
14		-2.40		-4.50		-6.60	
15		2.30		4.40		6.45	
16		2.30		4.40		6.45	
17		2.30		4.40		2.30	
18		0		0		4.20	
19		0		0		-1.00	
20		0		0		0	
21		0		0		0	

(Ref. No. 8)

B = THRUSTS ON EL. OF B / UNIT RED.

UNIT REDUNDANT

THRUSTS @ EL.	1	..	5	..	10	..	15	..	19	 21
1	-4.80		-3.80		-2.80		-1.80		-0.78	
2	-4.80		-3.80		-2.80		-1.80		-0.78	
3	-1.57		-3.80		-2.80		-1.80		-0.78	
4	0		0		0		0		0	
5	0.73		1.75		2.75		1.77		0.75	
6	1.60		3.75		2.75		1.77		0.75	
7	4.75		3.75		2.75		1.77		0.75	
8	-1.00		0		0		0		0	
9	3.30		0		0		0		0	
10	-0.43		-1.00		0		0		0	
11	0.96		2.23		0		0		0	
12	-0.78		-1.80		-2.80		-3.80		-1.57	
13	-0.78		-1.80		-2.80		-3.80		-4.80	
14	-0.78		-1.80		-2.80		-3.80		-4.80	
15	0.75		1.77		2.75		3.75		4.75	
16	0.75		1.77		2.75		3.75		1.60	
17	0.75		1.77		2.75		1.75		0.73	
18	0		0		0		2.23		0.96	
19	0		0		0		-1.00		-0.43	
20	0		0		0		0		3.30	
21	0		0		0		0		-1.00	

(Ref. No. 8)

C = THRUSTS ON ELEMENTS OF C / UNIT RED.

UNIT REDUNDANT

THRUSTS @ EL.	1	2	...	6	...	11	...	16	...	20	21
1		-3.40		-2.75		-2.00		-1.52		-0.63	
2		-3.40		-2.75		-2.00		-1.52		-0.63	
3		-1.48		-2.75		-2.00		-1.52		-0.63	
4		0		0		0		0		0	
5		0.66		1.50		1.94		1.50		0.60	
6		1.36		2.65		1.94		1.50		0.60	
7		3.32		2.65		1.94		1.50		0.60	
8		-1.00		0		0		0		0	
9		2.25		0		0		0		0	
10		-0.52		-1.00		0		0		0	
11		0.87		1.40		0		0		0	
12		-0.63		-1.52		-2.00		-2.75		-1.48	
13		-0.63		-1.52		-2.00		-2.75		-3.40	
14		-0.63		-1.52		-2.00		-2.75		-3.40	
15		0.60		1.50		1.94		2.65		3.32	
16		0.60		1.50		1.94		2.65		1.36	
17		0.60		1.50		1.94		1.50		0.66	
18		0		0		0		1.40		0.87	
19		0		0		0		-1.00		-0.57	
20		0		0		0		0		2.25	
21		0		0		0		0		-1.00	

(Ref. No. 8)

D= THRUSTS ON EL. OF D/ UNIT RED.

THRUSTS @ EL.					UNIT RED.		
	1	9	10	11	12	13	 21
1		3.40	2.75	2.00	1.52	0.63	
2		3.40	2.75	2.00	1.52	0.63	
3		1.48	2.75	2.00	1.52	0.63	
4		0	0	0	0	0	
5		-0.66	-1.50	-1.94	-1.50	-0.60	
6		-1.36	-2.65	-1.94	-1.50	-0.60	
7		-3.32	-2.65	-1.94	-1.50	-0.60	
8		1.00	0	0	0	0	
9		-2.25	0	0	0	0	
10		0.52	1.00	0	0	0	
11		-0.87	-1.40	0	0	0	
12		0.63	1.52	2.00	2.75	1.48	
13		0.63	1.52	2.00	2.75	3.60	
14		0.63	1.52	2.00	2.75	3.40	
15		-0.60	-1.50	-1.94	-2.65	-3.32	
16		-0.60	-1.50	-1.94	-2.65	-1.36	
17		-0.60	-1.50	-1.94	-1.50	-0.66	
18		0	0	0	-1.40	-0.87	
19		0	0	0	1.00	0.52	
20		0	0	0	0	-2.25	
21		0	0	0	0	1.00	

(Ref. No. 8)

E = THRUSTS ON EL. OF E/ UNIT RED.

	UNIT RED.						
THRUSTS@EL.	1	4	5	6	7	8	......., 21
1		4.80	3.80	2.80	1.80	0.78	
2		4.80	3.80	2.80	1.80	0.78	
3		1.57	3.80	2.80	1.80	0.78	
4		0	0	0	0	0	
5		-0.73	-1.75	-2.75	-1.77	-0.75	
6		-1.60	-3.75	-2.75	-1.77	-0.75	
7		-4.75	-3.75	-2.75	-1.77	-0.75	
8		1.00	0	0	0	0	
9		-3.30	0	0	0	0	
10		0.43	1.00	0	0	0	
11		-0.96	-2.23	0	0	0	
12		0.78	1.80	2.80	3.80	1.57	
13		0.78	1.80	2.80	3.80	4.80	
14		0.78	1.80	2.80	3.80	4.80	
15		-0.75	-1.77	-2.75	-3.75	-4.75	
16		-0.75	-1.77	-2.75	-3.75	-1.60	
17		-0.75	-1.77	-2.75	-1.75	-0.73	
18		0	0	0	-2.73	-0.96	
19		0	0	0	1.00	0.43	
20		0	0	0	0	-3.30	
21		0	0	0	0	1.00	

(Ref. No. 8)

F = THRUSTS ON EL. OF F/ UNIT RED.

UNIT RED.

THRUSTS @ EL.	1	2	3	………………………………………… 21
1	6.60	4.50	2.40	
2	6.60	4.50	2.40	
3	6.60	4.50	2.40	
4	0	0	0	
5	-2.30	-4.40	-2.30	
6	-6.45	-4.40	-2.30	
7	-6.45	-4.40	-2.30	
8	0	0	0	
9	0	0	0	
10	1.00	0	0	
11	-4.20	0	0	
12	2.40	4.50	6.60	
13	2.40	4.50	6.60	
14	2.40	4.50	6.60	
15	-2.30	-4.40	-6.45	
16	-2.30	-4.40	-6.45	
17	-2.30	-4.40	-2.30	
18	0	0	-4.20	
19	0	0	1.00	
20	0	0	0	
21	0	0	0	

(Ref. No. 8)

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  (21X 3)
1-.126208E+02 1 2-.975320E+01 1 3-.490760E+01 2 1-.126208E+02 2 2-.975320E+01
3-.490760E+01 3 1-.126208E+02 3 2-.975320E+01 3 3-.490760E+01 5 1 .126275E+02
2 .908456E+01 5 3 .544388E+01 6 1 .124097E+02 6 2 .842440E+01 6 3 .680646E+01
1 .124097E+02 7 2 .842440E+01 7 3 .680646E+0110 1 .103100E-0110 2-.319230E-0
3-.536768E-0011 1-.433000E-0111 2 .136077E+0111 3 .143443E+0112 1-.146815E+02
2-.115483E+0212 3-.642910E+0113 1-.146815E+0213 2-.115483E+0213 3-.642910E+01
1-.151455E+0214 2-.123940E+0214 3-.842184E+0115 1 .144458E+0215 2 .101982E+02
3 .830985E+0116 1 .144458E+0216 2 .101982E+0216 3 .830985E+0117 1 .126275E+02
2 .908456E+0117 3 .544388E+0118 1 .201739E+0118 2 .315589E+0118 3 .295592E+01
1-.480330E-0019 2-.746640E-0019 3-.899029E-0021 3 .000000E-99
  (21X 3)
1-.179613E+02 1 2-.153561E+02 1 3-.126800E+02 2 1-.179613E+02 2 2-.153561E+02
3-.126800E+02 3 1-.770000E+01 3 2-.791490E+01 3 3-.821344E+01 5 1 .680930E+01
2 .843049E+01 5 3 .105512E+02 6 1 .902960E+01 6 2-.111028E+02 6 3 .744164E+01
1 .179645E+02 7 2 .152101E+02 7 3 .124768E+02 8 1-.282857E+01 8 2-.205333E+01
3-.129214E+01 9 1 .938428E+01 9 2 .676598E+01 9 3 .419406E+0110 1-.116847E+01
2 .148420E-0010 3 .626740E-0011 1 .581830E-0011 2-.152088E+0111 3-.417650E+01
1-.134572E+0212 2-.129374E+0212 3-.124805E+0213 1-.206248E+0213 2-.176994E+02
3-.147094E+0214 1-.206248E+0214 2-.176994E+0214 3-.147094E+0215 1 .205820E+02
2 .175133E+0215 3 .144719E+0216 1 .146641E+0216 2 .136132E+0216 3 .116190E+02
1 .676340E+0117 2 .839030E+0117 3 .105169E+0218 1 .834160E+0118 2 .534890E+01
3 .188414E+0119 1-.401349E+0119 2-.233386E+0119 3-.148254E+0120 1 .622361E+01
2 .402863E+0120 3 .190783E+0121 1-.187078E+0121 2-.122382E+0121 3 .120065E+01
  (21X 3)
1-.195274E+02 1 2-.163614E+02 1 3-.137444E+02 2 1-.195274E+02 2 2-.163614E+02
3-.137444E+02 3 1-.206211E+02 3 2-.173853E+02 3 3-.142027E+02 5 1 .117840E+02
2 .977692E+01 5 3 .787673E+01 6 1 .198734E+02 6 2 .168389E+02 6 3 .138570E+02
1 .206320E+02 7 2 .178895E+02 7 3 .147954E+02 8 1 .994620E-00 8 2 .737450E-0
3 .482450E-00 9 1-.221289E+01 9 2-.165926E+01 9 3-.111051E+0110 1-.711412E+01
2-.615613E+0110 3-.515104E+0111 1 .981514E+0111 2 .848307E+0111 3 .708475E+01
1-.108156E+0212 2-.884060E+0112 3-.695840E+0113 1-.137408E+0213 2-.113171E+02
3-.946510E+0114 1-.137408E+0214 2-.113171E+0214 3-.946510E+0115 1 .154942E+02
2 .134106E+0215 3 .109954E+0216 1 .106330E+0216 2 .878670E+0116 3 .703018E+01
1 .119096E+0217 2 .988631E+0117 3 .796939E+0118 1-.154970E+0118 2-.142038E+01
3-.131144E+0119 1 .129600E+0119 2 .116839E+0119 3 .105478E+0120 1 .169599E+01
2 .178562E+0120 3 .184504E+0121 1-.109854E+0121 2-.108568E+0121 3-.106183E+01
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 (21X 3)
-.159543E+02 1 2-.113150E+02 1 3-.640422E+01 2 1-.159543E+02 2 2-.113150E+02
-.640422E+01 3 1-.157563E+02 3 2-.109542E+02 3 3-.555398E+01 5 1 .112503E+02
 .991479E+01 5 3 .843457E+01 6 1 .152750E+02 6 2 .107136E+02 6 3 .557983E+01
 .154771E+02 7 2 .110820E+02 7 3 .644778E+01 8 1-.103100E-00 8 2-.187943E-0
-.442832E-0010 1-.349063E+0110 2-.677968E-0010 3 .252165E+0111 1 .490152E+01
 .975843E-0011 3-.346743E+0112 1-.147958E+0212 2-.155568E+0212 3-.166738E+02
-.154957E+0213 2-.156626E+0213 3-.160757E+0214 1-.154957E+0214 2-.156626E+02
-.160757E+0215 1 .150823E+0215 2 .151295E+0215 3 .153920E+0216 1 .143679E+02
 .150214E+0216 3 .160026E+0217 1 .112660E+0217 2 .990682E+0117 3 .838931E+01
 .378276E+0118 2 .622753E+0118 3 .926281E+0119 1-.266500E+0119 2-.444264E+01
-.664789E+0120 1 .820143E-0020 2 .124002E-0020 3-.700866E-0021 1-.364508E-0
-.551124E-0121 3 .311496E-00
 (21X 3)
-.166324E+02 1 2-.125660E+02 1 3-.868702E+01 2 1-.166324E+02 2 2-.125660E+02
-.868702E+01 3 1-.852412E+01 3 2-.746017E+01 3 3-.686778E+01 5 1 .687863E-0
 .714615E-00 5 3 .863923E-00 6 1 .853747E+01 6 2 .743060E+01 6 3 .678467E+01
 .164449E+02 7 2 .124100E+02 7 3 .855885E+01 8 1-.251031E+01 8 2-.158077E+01
-.563232E-00 9 1 .828402E+01 9 2 .521654E+01 9 3 .185866E+0110 1-.391225E+01
-.335009E+0110 3-.295755E+0111 1 .872708E+0111 2 .747244E+0111 3 .659597E+01
-.918155E+0112 2-.780407E+0112 3-.620922E+0113 1-.167445E+0213 2-.160532E+02
-.152277E+0214 1-.167445E+0214 2-.160532E+0214 3-.152277E+0215 1 .165525E+02
 .158819E+0215 3 .150791E+0216 1 .917685E+0116 2 .783714E+0116 3 .628404E+01
 .683331E-0017 2 .699401E-0017 3 .843539E-0018 1 .944675E+0118 2 .793291E+01
 .603810E+0119 1-.423505E+0119 2-.355610E+0119 3-.270629E+0120 1 .772688E+01
 .842790E+0120 3 .921393E+0121 1-.234148E+0121 2-.255391E+0121 3-.279210E+01
 (21X 3)
-.137217E+02 1 2-.114084E+02 1 3-.900008E+01 2 1-.137217E+02 2 2-.114084E+02
-.900008E+01 3 1-.137217E+02 3 2-.114084E+02 3 3-.900008E+01 5 1 .147957E+02
 .126297E+02 5 3 .104294E+02 6 1 .134322E+02 6 2 .111634E+02 6 3 .880203E+01
 .134322E+02 7 2 .111634E+02 7 3 .880203E+0110 1 .328570E-0010 2 .353330E-0
 .392141E-0011 1-.137999E+0111 2-.148398E+0111 3-.164699E+0112 1-.138146E+02
-.122306E+0212 3-.105896E+0213 1-.138146E+0213 2-.122306E+0213 3-.105896E+02
-.138146E+0214 2-.122306E+0214 3-.105896E+0215 1 .135240E+0215 2 .119758E+02
 .103726E+0216 1 .135240E+0216 2 .119758E+0216 3 .103726E+0217 1 .147957E+02
 .126297E+0217 3 .104294E+0218 1-.128707E+0118 2-.661735E-0018 3-.574140E-01
 .306446E-0019 2 .157556E-0019 3 .136700E-0121 3 .000000E-99
```

Truss A and D (Taking max. stress) :

Members : 1, 2, 3	Max. Stress: 195.50 kips.
Members : 5, 6, 7	Max. Stress: 200.00 kips.
Members : 8, 10	Max. Stress: 72.00 kips.
Members : 9, 11	Max. Stress: 92.00 kips.

Truss B and E :

Members : 1, 2, 3	206 kips comp.
Members : 5, 6, 7	205.82 kips tension.
Members : 8,10	42.10 kips comp.
Members : 9,11	94.46 kips tens.

Truss C and F :

Members : 1, 2, 3	151.00 kips comp.
Members : 5, 6, 7	154.97 kips tens.
Members : 8,10	10.31 kips comp.
Members : 9,11	31.55 kips tens.

DESIGN OF TRUSSES

Truss A and D :

Members : 1, 2, 3 Stress : 195.5o kips comp.
$L = 21'$ Use 5/8'' gusset pl. and 1 1/8" rivets.
Choose two 8x6x5/8" $A = 16.72 \text{ in}^2$ $r = 2.55$ i

$$\frac{L}{r} = \frac{21 \times 12}{2.55} = 99. \qquad = 13.10 \text{ ksi.}$$

$$\frac{F}{A} = \frac{195}{16.72} = 11.65 \qquad 13.10 \qquad \text{O.K.}$$

Rivets : $\frac{195}{29.82} = 6.55$ ---- 7

Members : 5, 6, 7 Stress : 2oo.00 kip s tens.

$$A_{net} = \frac{200}{22} = 9.1 \text{ in}^2. \qquad A = 9.1 + 2 = 11.1 \text{ in}^2.$$

Choose two 6 x 4 x 5/8" $A = 11.72$

Rivets : $\frac{200}{29.82} = 6.75$ ---- 7

Members : 8, 1o Stress: 72.00 kips comp.

$L = 12.7o$ Choose two 4x3x5/8" $A = 7.95 \text{ in}^2$

$r = 1.46$ in. $\frac{L}{r} = \frac{12.70 \times 12}{1.46} = 104$

$\frac{F}{A} = \frac{72}{7.95} = 9.10$ 12.47 O.K.

Rivets : $\frac{72}{7.95} =$ Use 3 rivets.

Members : 9 , 11 Stress : 92.00 kips tens.

$\frac{92}{22} = 4.20$ Add 1 = 5.20

Use two 4X3x5/8" $A = 7.95$ O.K.

$\frac{92}{29.82} = 3.06$ Use 4 Rivets.

(Ref. No. 4, 5)

Splices at 5 :

F = 117 kips.   5/8" plate

$\frac{117}{14.91} = 8$ rivets

Truss B and E

Members: 1, 2, 3   F = 206 kips comp.   L = 21'

Use 5/8" gusset pl.   1 1/8" rivets

Choose two 8 x 6 x 5/8" $A = 16.72$ in^2. r= 2.55in^2.

$\frac{L}{r} = \frac{21 \times 12}{2.55} = 99$ ---- = 13.10 ksi

$\frac{F}{A} = \frac{206}{16.72} = 12.40 < 13.10$ O.K.

Rivets : $\frac{206}{29.82} = 6.90$ ---- 7

Members : 5, 6, 7   F = 2o5.82 kips tens.

$A_{net} = \frac{205.82}{22} = 9.35$ A = 9.35 + 2 = 11.35

Use two 6 x 4 x 5/8"   A = 11.74 in^2.

Rivets : $\frac{205.82}{29.82} =$ Use 7 rivets.

Members : 8, 1o

(For these the forces of the same members of truss C and F will be added and one member will be designed.)

42.10 + 1o.31 = 52.41 comp.

Use two 4x3x5/8"   A = 7.95 in^2.   r= 1.46 in.

$\frac{F}{A} = \frac{52.41}{7.95} =$ (O.K.)   Checked in trusss A.

Rivets : $\frac{52.41}{29.82} =$ Use Two rivets.

(Ref. No. 4, 5)

Members : 9, 11

94.46 kips tens.

$A_{net} = \frac{94.46}{22} = 4.3$ $\qquad A = 4.3 + 2 = 6.3$

Use two 4 x 3 x 5/8" A = 7.96

Truss C and F :

Members : 1, 2, 3 151 kips comp. L = 21'
Use 5/8" gusset pl. 1 1/8" rivets.
Choose two 8x6x1/2" A = 13.50 in^2. r = 2.55 in.

$\frac{L}{r} = \frac{21 \times 12}{2.55} = 99$ $\qquad = 13.10$

$\frac{151}{13.50} = 13.10$ O.K. Rivets : $\frac{151.o}{29.82} = 5.2$ --- 6

Members : 5, 6, 7 154.97 kips tens.

$A_{net} = \frac{154.97}{22} = 7.05$ $\qquad A = 7.05 + 2 = 9.05$

Use two 5x3 1/2x5/8" A = 9.84 in^2.

Members : 1o, 11 31.55 kips tens.

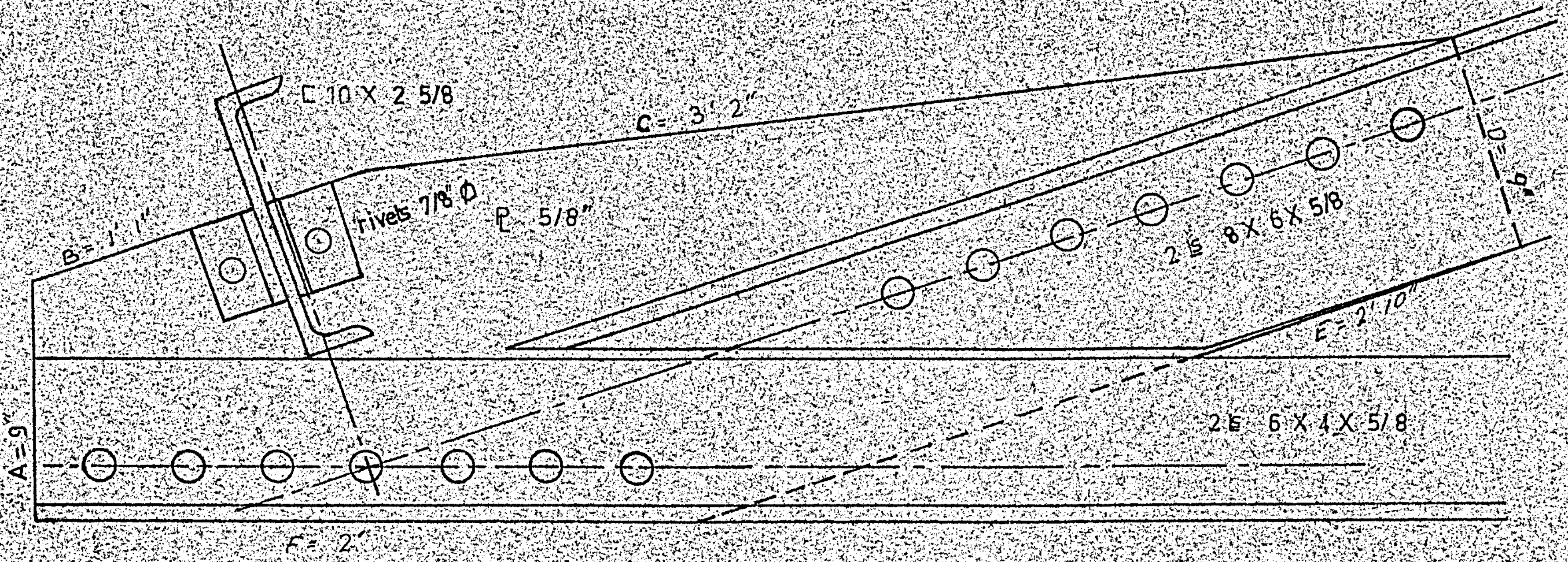
$A_{net} = \frac{31.55}{22} = 1.43$

Use two 4x3x5/8" A = 7.96 in^2.

Rivets : $\frac{31.55}{29.82} =$ Use 2 rivets.

(Ref. No. 4, 5)

JOINT 1 TRUSS A & D



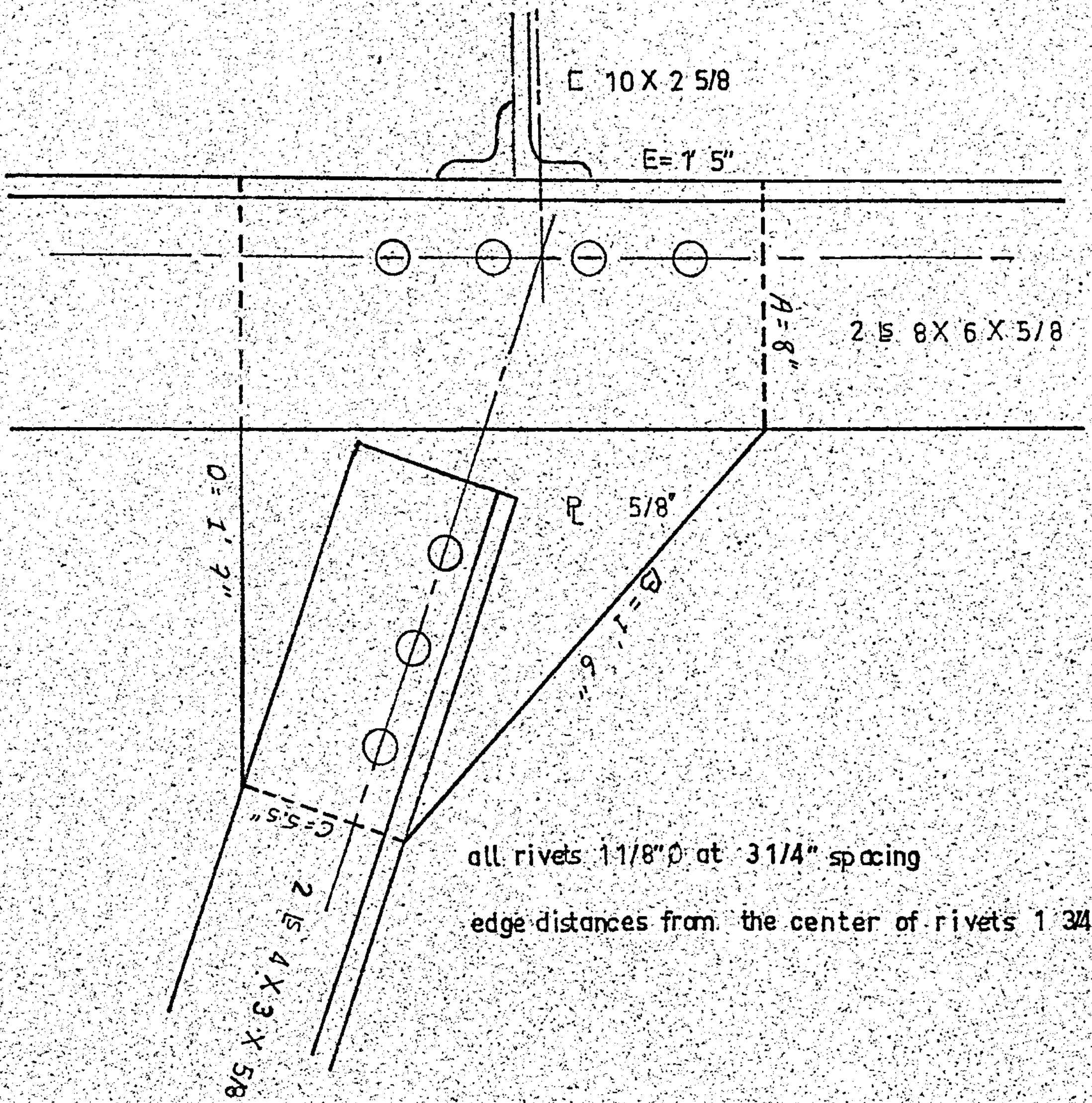
all rivets 1 1/8" Ø at 3 1/4" spacing unless specified

edge distances from the center of rivets 1 3/4"

SCALE 5cm = 1'

JOINT 1

TRUSS	MEMBER	No. of RIVETS	GUSSET PLATE
B & E	1 2 Ls 8 x 6 x 5/8	7	A = 9"
	7 2 Ls 6 x 4 x 5/8	7	B = 1'1"
			C = 3'2"
			D = 9"
			E = 2'10"
			F = 2'
C & F	1 2 Ls 8 x 6 x 1/2	6	A = 9"
	7 2 Ls 5 x 3 1/2 x 5/8	6	B = 1'1"
			C = 3'
			D = 9"
			E = 2'10"
			F = 1'10"



all rivets 1 1/8" ∅ at 3 1/4" spacing

edge distances from the center of rivets 1 3/4"

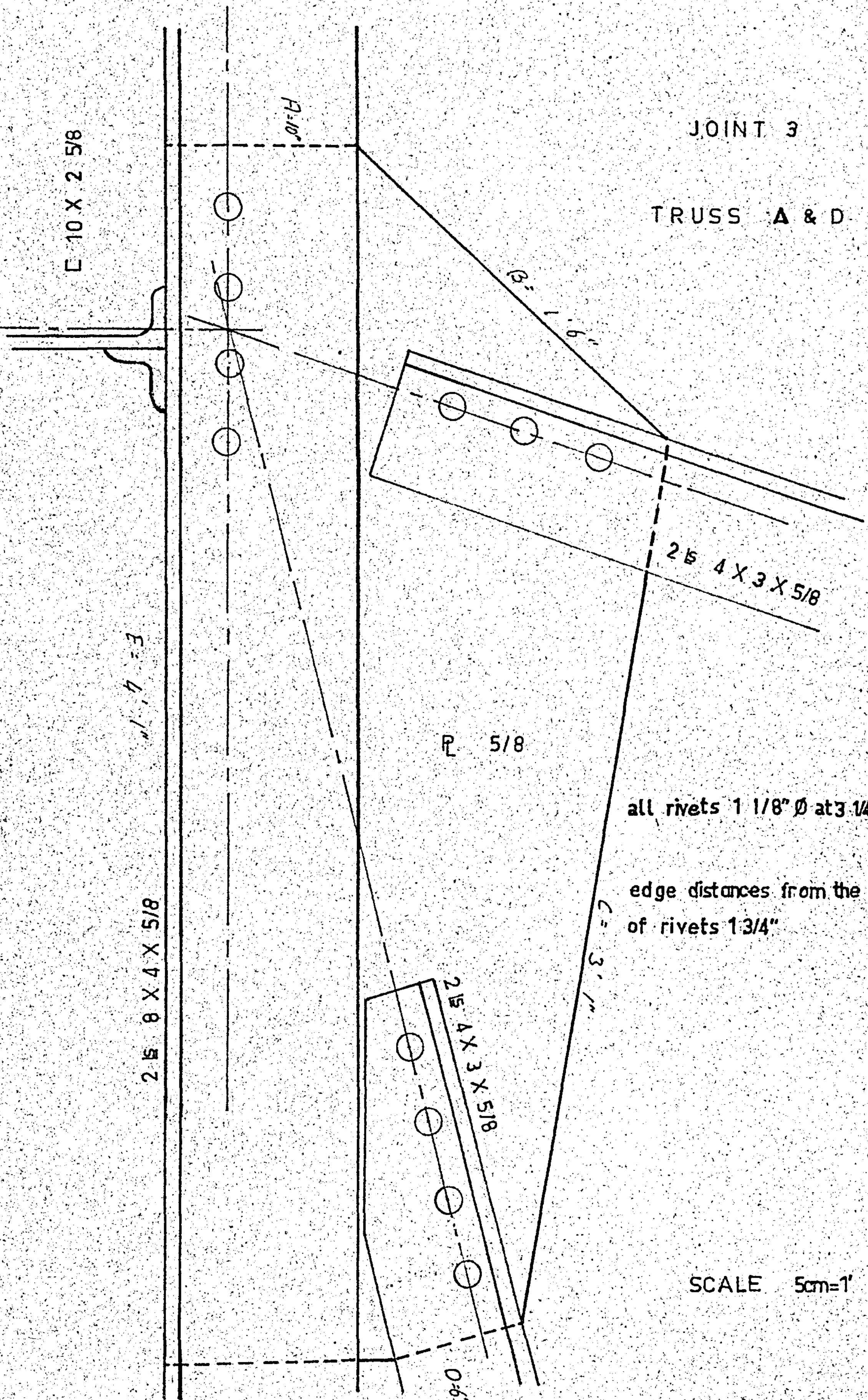
TRUSS A & D

JOINT 2

SCALE 5cm = 1'

JOINT 2

TRUSS	MEMBER	No of RIVETS	GUSSET PLATE
B & E	1 2L 8x 6 x 5/8	2	A = 8"
	2 2L 8x 6x 5/8	2	B = 1'4"
	8 2L 4x 3x 5/8	2	C = 5"
			D = 1'6"
			E = 1'5"
C & F			



JOINT 3

TRUSS A & D

all rivets 1 1/8" Ø at 3 1/4" spacing

edge distances from the center
of rivets 1 3/4"

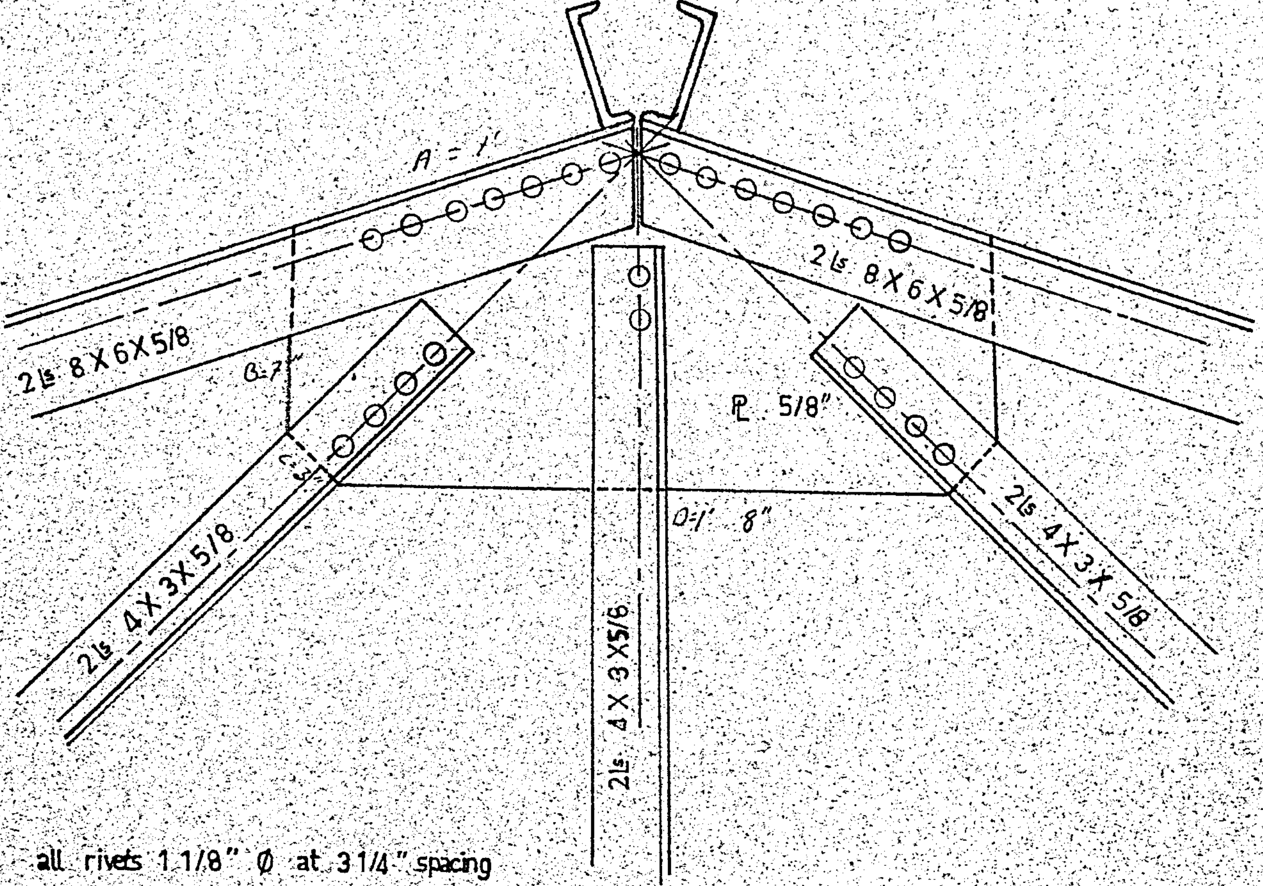
SCALE 5cm=1'

JOINT 3

TRUSS	MEMBER	No of RIVETS	GUSSET PLATE
B & E	2 2∟s 8x 6x 5/8	2	A = 10″
	3 2∟s 8x 6x 5/8	2	B = 1′4″
	9 2∟s 4x 3x 5/8	4	C = 3′1″
	10 2∟s 4x 3x 5/8	2	D = 6″
			E = 4′1″
C & F	2 2∟s 8x 6x 1/2	2	A = 10″
	3 2∟s 8x 6x 1/2	2	B = 1′4″
	10 2∟s 8x 6x 1/2	2	C = 6″
			D = 1′7″

JOINT 4

TRUSS A & D



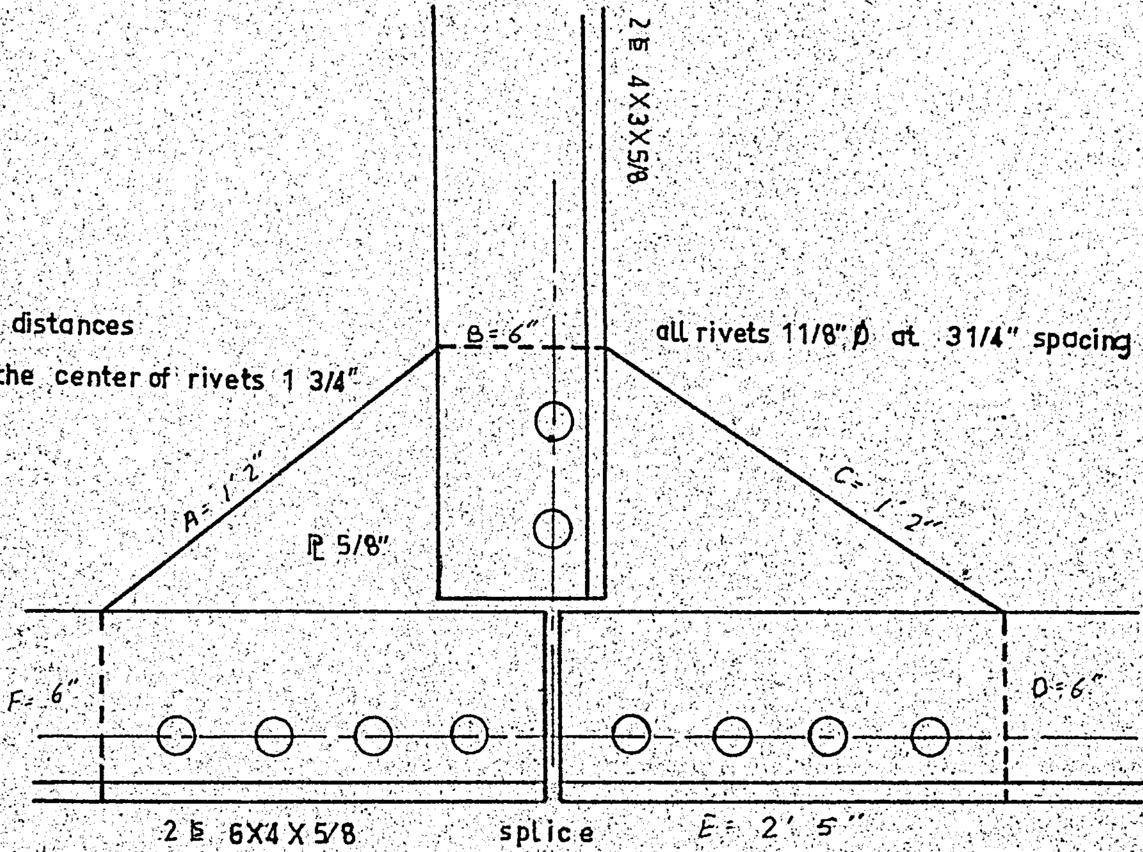
all rivets 1 1/8" Ø at 3 1/4" spacing

edge distances from the center of rivets 1 3/4"

SCALE 2cm = 1'

JOINT 4

TRUSS	MEMBER	No of PIVETS	GUSSET PLATE
B & E	3 2 Ls 8 x 6 x 5/8	7	A = 1′
	4 2 Ls 4 x 3 x 5/8	2	B = 7″
	11 2 Ls 4 x 3 x 5/8	4	C = 3
			D = 1′8″
C & F	3 2 Ls 8 x 6 x 1/2	6	A = 10
	4 2 Ls 4 x 3 x 5/8	2	B = 6
	11 2 Ls 4 x 3 x 5/8	2	C = 3″
			D = 1′6′



edge distances
from the center of rivets 1 3/4"

all rivets 11/8" ∅ at 31/4" spacing

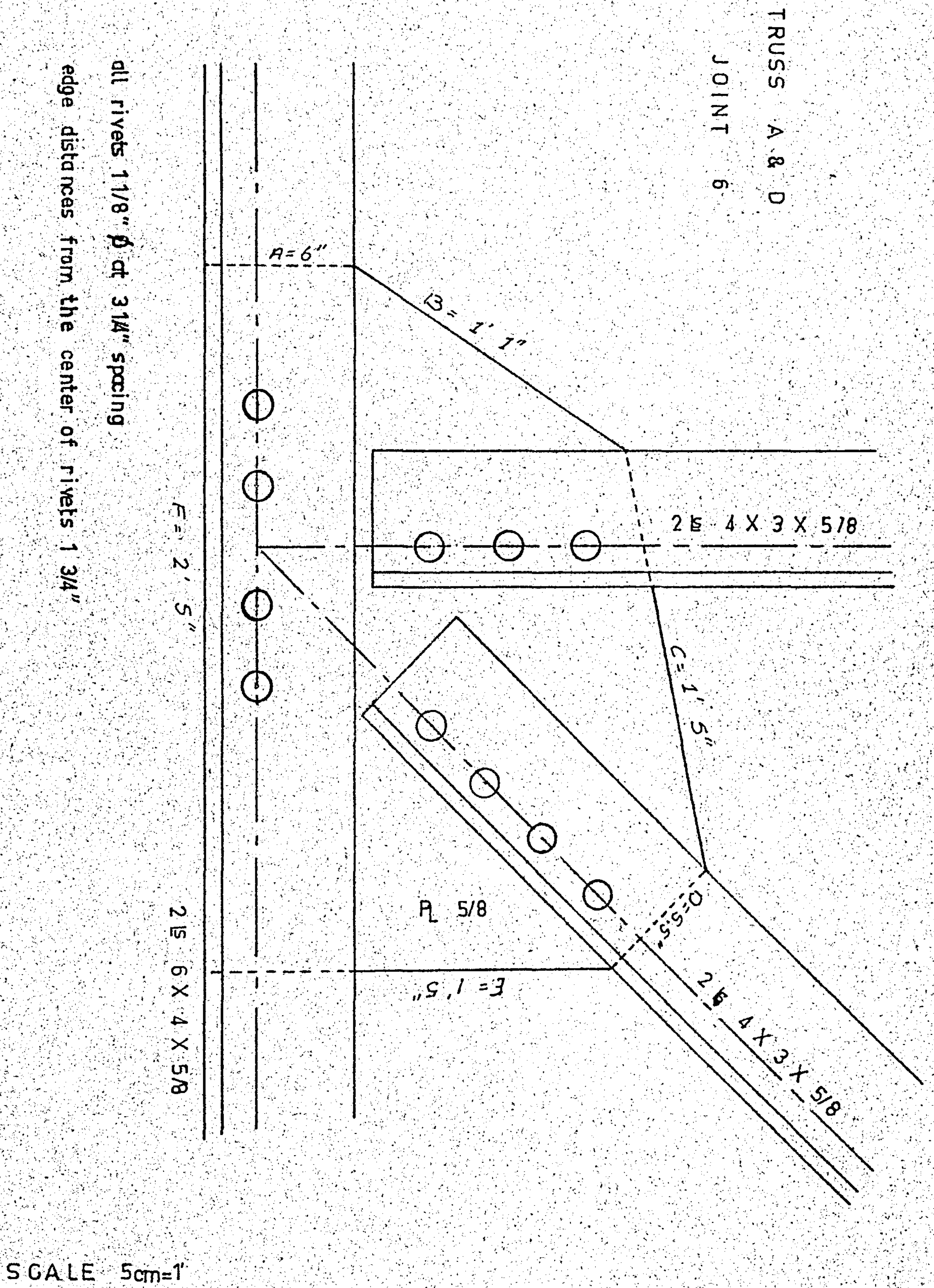
JOINT 5

TRUSS A & D

SCALE 5cm= 1'

JOINT 5

TRUSS	MEMBER	No of RIVETS	GUSSET PLATE
B & E	4 2Ls 4x 3x 5/8	2	A = 1' 2"
	5 2Ls 4x 6x 5/8	4	B = 6"
			C = 1 2
			D = 6"
			E = 2' 5"
C & F	4 2Ls 4x 3x 5/8	2	A = 1' 2"
	5 2Ls 4x 6x 1/2	4	B = 6
			C = 1' 2"
			D = 6"
			E = 2' 5"

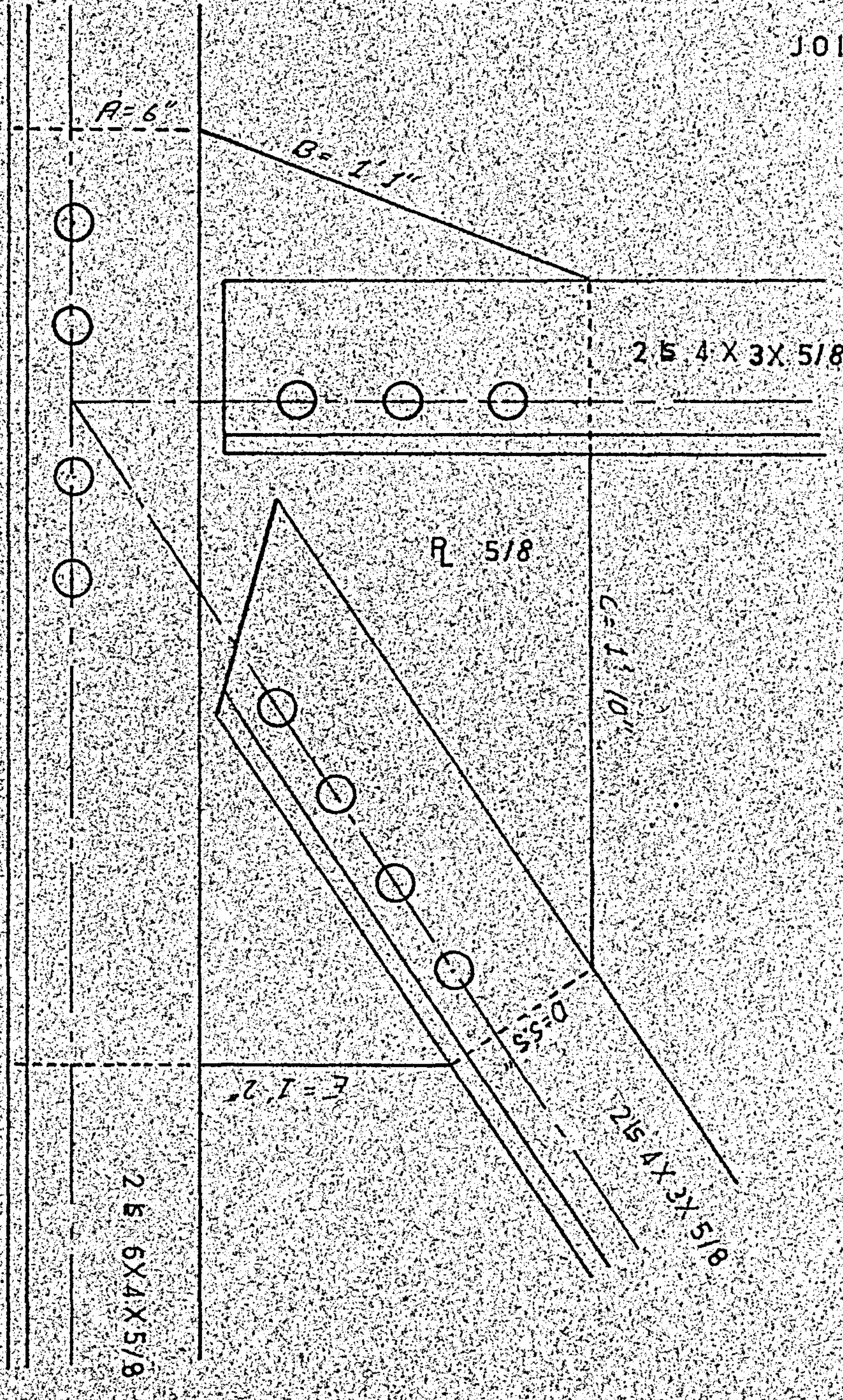

TRUSS A & D
JOINT 6
all rivets 11/8" Ø at 31/4" spacing
edge distances from the center of rivets 1 3/4"
A= 6"
B= 1' 1"
C= 1' 5"
D= 5.5"
E= 1' 5"
F= 2' 5"
2 L 4 X 3 X 5/8
2 L 4 X 3 X 5/8
2 L 6 X 4 X 5/8
PL 5/8
SCALE 5cm=1'

JOINT 6

TRUSS	MEMBER	No of RIVETS	GUSSET PLATE
B & E	6 2Ls 4x 6 x 5/8	2	A = 6"
	5 2Ls 4x 6 x 5/8	2	B = 1'
	10 2Ls 4x 3 x 5/8	2	C = 1'5"
	11 2Ls 4 x 3 x 5/8	4	D = 5"
			E = 1'5"
			F = 2'5"
C & F	6 2Ls 4 x 6 x 5/8	2	A = 6"
	5 2Ls 4 x 6 x 5/8	2	B = 1'
	10 2Ls 4 x 3 x 5/8	2	C = 1' 3"
	11 2Ls 4 x 3 x 5/8	2	D = 5"
			E = 1' 3"
			F = 2' 4"

TRUSS A & D

JOINT 7



all rivets 11/8" at 31/4" spacing
edge distances from the center of rivets 1 3/4"

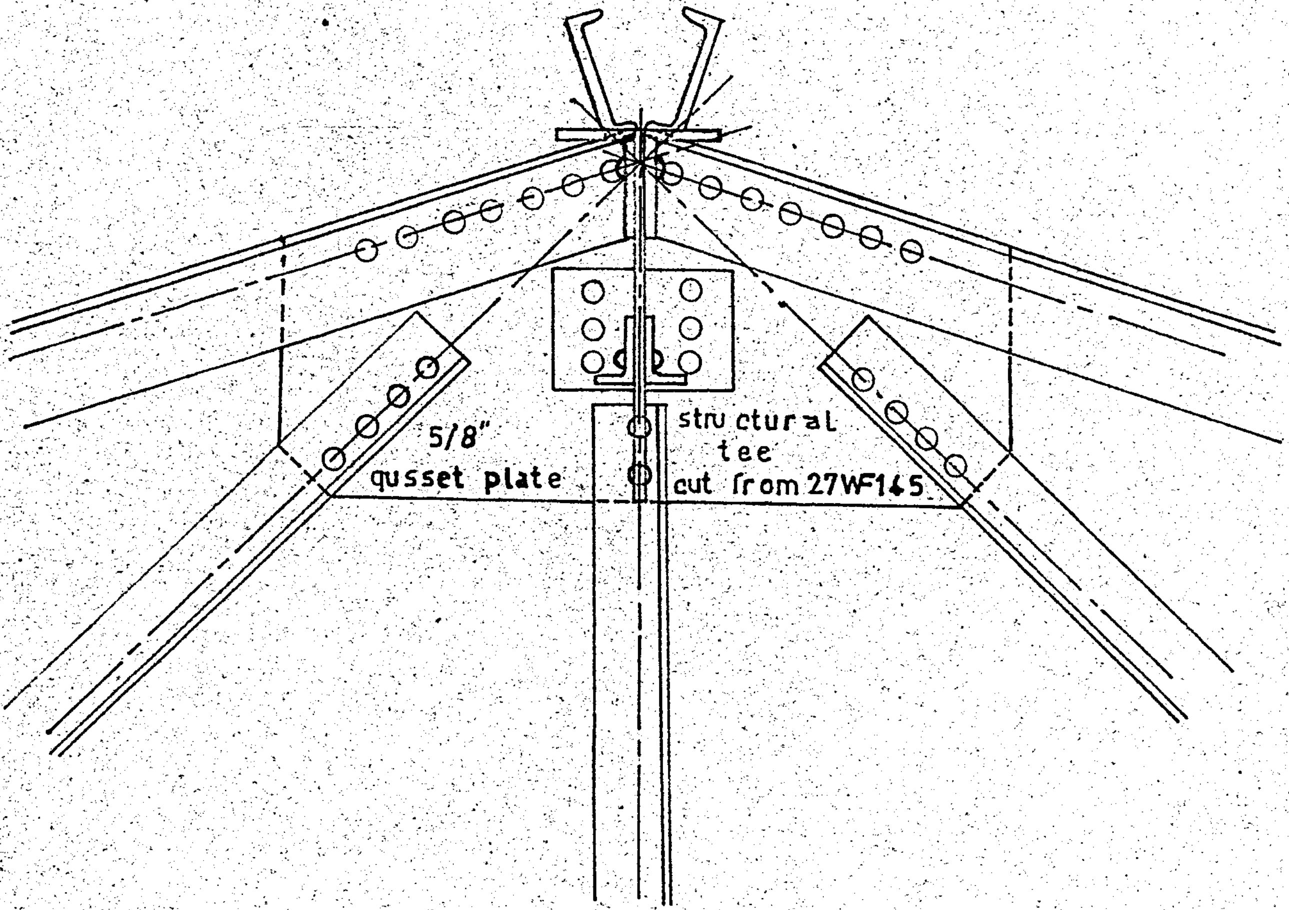
SCALE 5cm=1'

JOINT 7

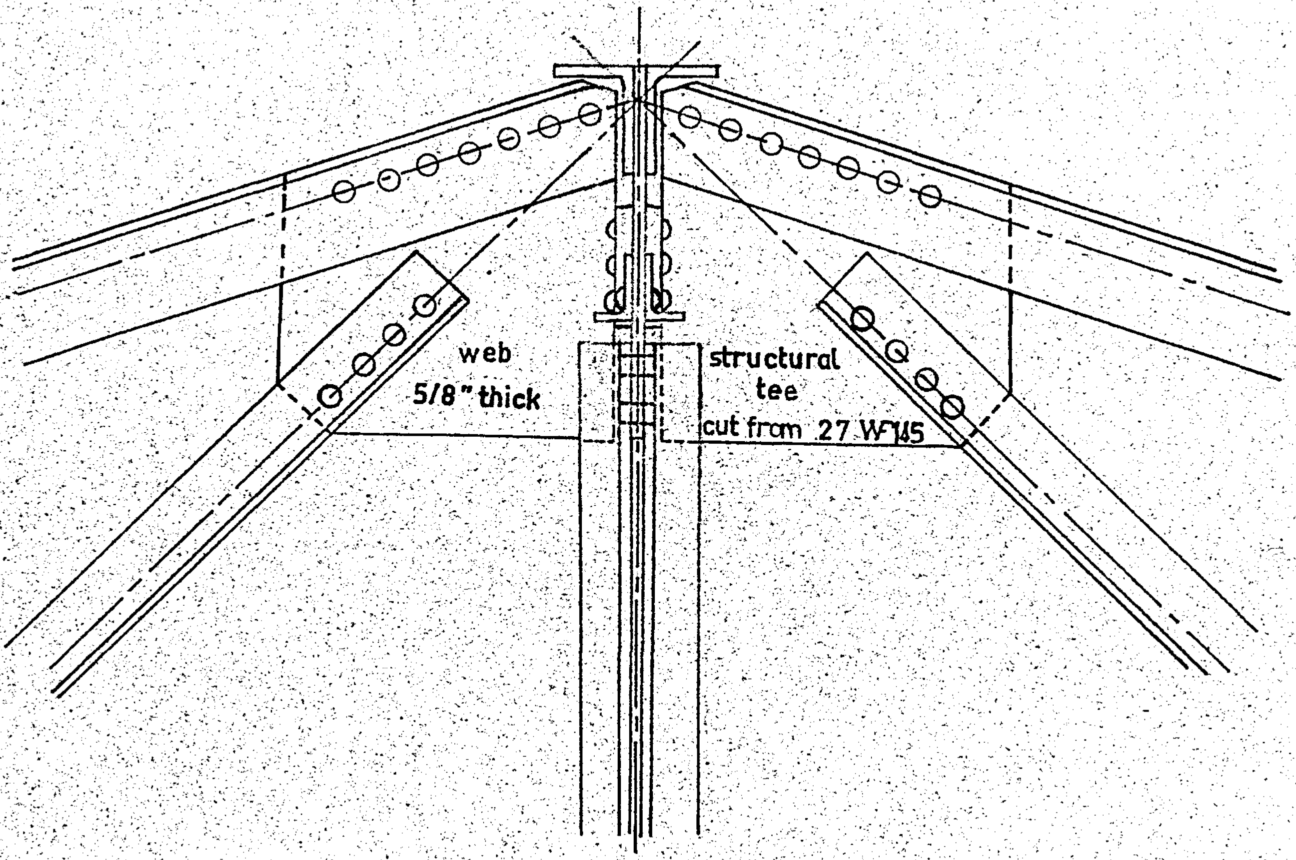
TRUSS	MEMBER	No of RIVETS	GUSSET PLATE
B & E	7 2∟s 4×6×5/8	2	A = 6"
	6 2∟s 4× 6 × 5/8	2	B = 1"
	8 2∟s 4 × 3 × 5/8	2	C = 1' 10"
	9 2∟s 4 3 5/8	4	D = 5"
			E = 1' 2"
			F = 2' 5"
C & F			

DETAIL A

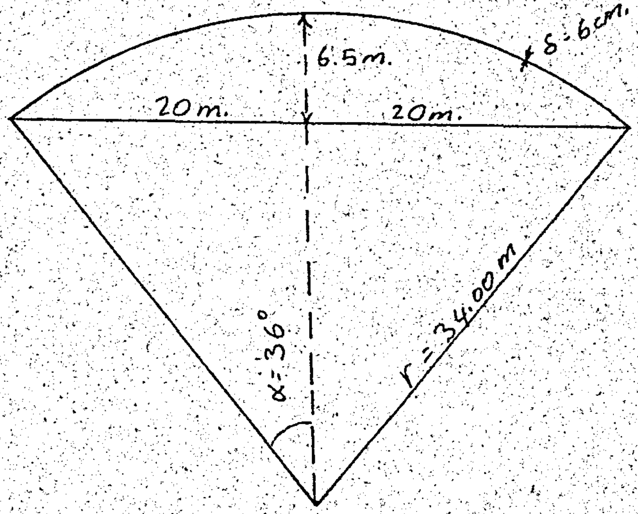
DETAIL OF JOINTS WHERE TRUSSES CROSS EACH OTHER



CROSS SECTION OF DETAIL A



SHELL DESIGN :



$$r^2 = (r - 6.5)^2 + 20^2$$

$$r^2 = r^2 - 13r + 42 + 400$$

$$13r = 442$$

$$r = 34 \text{ m.}$$

$\alpha = 36°$ $\sin\alpha = 0.59$ $\cos\alpha = 0.80$ $\cot\alpha = 1.38$

$\delta = 2h = 6 \text{ cm.}$

$g =$ load : dead load (including insulation) $= 350 \text{ kg/m}^2$

wind load + snow load $= 200 \text{ kg/m}^2$

$g = 550 \text{ kg/m}^2 \doteq 0.055 \text{ kg/cm}^2$

$E = 21\,000 \text{ kg/cm}^2$ $\mu \cong 0$

$g \cdot a = 0.055 \times 3400 \doteq 188 \text{ kg/cm}$

(Ref. 1, 2, 7)

$\frac{E}{K} = \frac{12}{8^3} = \frac{12}{215} = 0.056$

$X^2 = \frac{1}{6} \cdot 3400\sqrt{3} = 960.00$ $X = 31.00$

Solution of membrane :

$$n_{\varphi_0} = -\frac{g \cdot a}{1+\cos\alpha} = -\frac{188}{1.80} = -102 \text{ kg/cm.}$$

$$n_{\theta_0} = -(n_{\varphi_0}) - g a \cos\alpha = +102 - 150 = -48 \text{ kg/cm}$$

$$\frac{dn_{\theta_0}}{d\varphi} = g a \sin\varphi \left(1 + \frac{1}{(1+\cos\varphi)^2}\right) = 188 \times 0.59 \left(1 + \frac{1}{3.25}\right) = 146 \text{ kg/cm}$$

for $\mu = 0$

$$E \cdot \Delta r_0 = -\frac{1}{6}(31 \times 2000) = -11600 \text{ kg/cm}$$

$$H = -(n_{\varphi_0}) \cos\alpha = +102 \times 0.8 = 84 \text{ kg/cm}$$

assuming for the beam at the side $b = 40$ cm. $d = 50$ cm.

$$E \cdot \Delta r_0^* = \frac{2000^2 \times 84}{40 \times 50} = 170\,000 \text{ kg./cm}$$

Effect of the force R :

$$E \cdot \Delta r_R = \frac{R}{3} \times 2000 \times 0.59 \times 31 = 9100 \ R$$

$$E \cdot \Delta r_R^* = -4R \times \frac{2000^2}{2000} = -8000 \ R$$

and

$$\Delta r_0 + \Delta r_R = \Delta r_0^* + \Delta r_R^*$$

$$-11600 + 9100 R = 170\,000 - 8000 R$$

$$17100 R = 181\,600$$

$$R = 11.00 \text{ kg/cm}$$

$$m_{\varphi_R} = \frac{Ra}{X} \cdot e^{-xw} \sin\alpha \cdot \sin xw = \frac{11 \times 3400}{31} \cdot e^{-31w} \cdot 0.59 \sin 31w$$

$$m_{\varphi_R} = 720\, e^{-31w} \sin 31w$$

w	1°	2°	5°	10°
m_{φ_R}	194	215	28	2.1

kgcm/cm

$$m_{\theta_R} = \frac{Ra}{X^2\sqrt{2}}\, e^{-xw} \sin\alpha \cdot \cot g\varphi \cdot \sin\left(xw + \frac{\pi}{4}\right)$$

for $\cot g\varphi$ we will use $\frac{1}{\varphi}$ because in the zone of disappearance of moments $\cot g\varphi$ gets very large values.

$$m_{\theta_R} = \frac{11 \times 3400}{960\sqrt{2}} \cdot e^{-xw} \cdot 0.59 \cdot \cot g\varphi \cdot \sin\left(xw + \frac{\pi}{4}\right) = 16.3\, e^{-31w} \cot g\varphi \sin\left(31w + \frac{\pi}{4}\right)$$

w	0°	1°	5°	10°
m_{θ_R}	6	very small	very small	very small

kgcm/cm

$$n_{\varphi_R} = \sqrt{2}\, R \cdot e^{-xw} \cdot \sin\alpha \cdot \cot g\varphi \cdot \cos\left(xw + \frac{\pi}{4}\right)$$

w	0°	1°	5°	10°
n_{φ_R}	9	almost zero	almost zero	almost zero

kg/cm

$$n_{\theta_R} = 2 R X\, e^{-xw} \sin\alpha \cdot \cos xw$$

w	0°	2°	5°	10°
n_{θ_R}	400	200	26	about zero

kg/cm

from membrane solution

$$n_\varphi = -\frac{ga}{1+\cos\varphi} = -\frac{188}{1+\cos\varphi}$$

φ	0°	5°	10°	15°	20°	25°	30°	36°
n_φ	−94	−96	−96	−97	−97	−102	−102	−105

kg/cm

$$n_\theta = -ga\left(\cos\varphi - \frac{1}{1+\cos\varphi}\right) = -188\left(\cos\varphi - \frac{1}{1+\cos\varphi}\right)$$

φ	0°	5°	10°	15°	20°	25°	30°	36°
n_θ	−94	−89	−86	−84	−77	−70	−60	−47

Resultant stresses:

	0°	2°	5°	10°	15°	20°	25°	30°	36°
$\frac{n_\theta}{n}+\frac{6m_\theta}{n^2}$	53	18	−10	−14.4	−13.8	−12.8	−11.6	−10	−8
$\frac{n_\theta}{n}-\frac{6m_\theta}{n^2}$	51	18	−10	−14.4	−13.8	−12.8	−11.6	−10	−8
$\frac{n_\varphi}{n}+\frac{6m_\varphi}{n^2}$	18.2	21.7	−11	−16	−16	−16	−17	−17	−17.5
$\frac{n_\varphi}{n}-\frac{6m_\varphi}{n^2}$	−46.2	−53	−21	−16	−16	−16	−17	−17	−17.5

kg/cm²

	0°	2°	5°	10°	15°	20°	25°	30°	36°
$\frac{n_\theta}{n}+\frac{6m_\theta}{n^2}$	760	260	−144	−205	−200	−186	−170	−144	−115
$\frac{n_\theta}{n}-\frac{6m_\theta}{n^2}$	730	260	−144	−205	−200	−186	−170	−144	−115
$\frac{n_\varphi}{n}+\frac{6m_\varphi}{n^2}$	260	310	−158	−230	−230	−230	−245	−245	−250
$\frac{n_\varphi}{n}-\frac{6m_\varphi}{n^2}$	−660	−760	−300	−230	−230	−230	−245	−245	−250

lbs/in²

All the compressive stresses are less than the compressive strength of concrete, therefore we use minimum reinforcement. At the sides we have reinforcement for tension also.

In θ direction

Max. tension : 760 lbs/in^2

760 x 2.4 : 1820 lbs/in tension

1820/20000 : 0.09 in^2 of steel/in

: 1.08 in^2 of steel/ft

No. 10 bars at 1 ft spacing A : 1.27 O.K.

In $n\varphi$ direction

Max. tension : 310 lbs/in^2

310 x 2.4 : 740 lbs/in tension

740/20000 : 0.037 in^2 of steel/in

: 0.46 in^2 of steel/ft

No. 7 bars at 1 ft spacing A : 0.60 O.K.

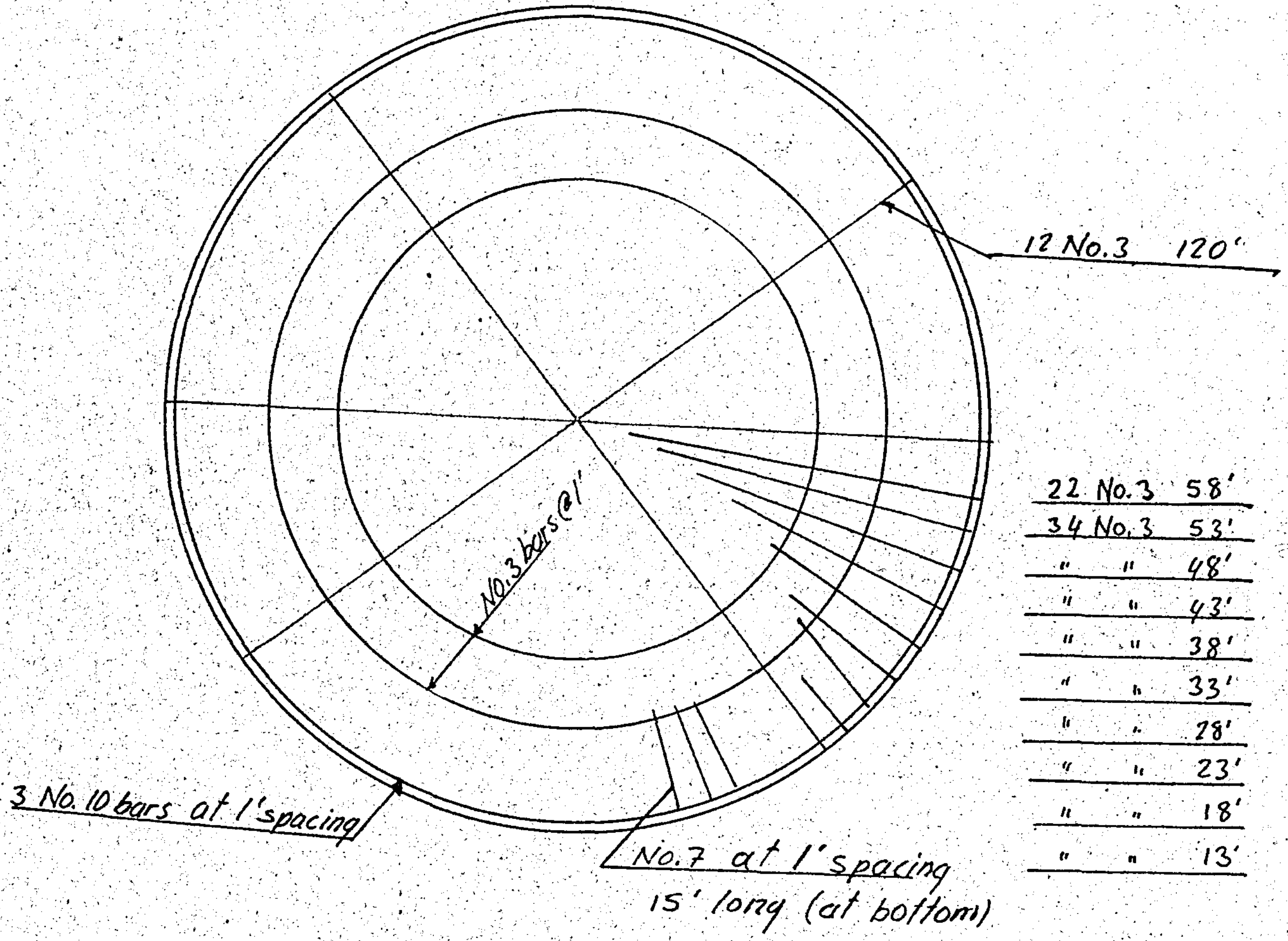
Min. Reinforcement

0.0025 x 12 x 2.4 : 0.072 in^2/ft

No. 3 bars at 1 ft spacing A : 0.11 O.K.

(Ref. No. 6)
(Ref. No. 3)

REINFORCEMENT OF SHELL



DISCUSSION

	Material	Weight or Area	Cost/wgt. or A	Total Cost	Poz. No.
1	Corrugated Sheet	1400 m^2	33.00 TL/m^2	46 000 TL	9716
2	2 ∠s 8×6×5/8	17 800 kg	3.56 TL/kg	63 500 TL	9904
3	2 ∠s 8×6×1/2	8 700 kg	3.56 TL/kg	31 000 TL	9904
4	2 ∠s 4×3×5/8	1 100 kg	3.56 TL/kg	3 900 TL	9904
5	2 ∠s 6×4×5/8	11 400 kg	3.56 TL/kg	40 500 TL	9904
6	2 ∠s 5×3½×5/8	5 600 kg	3.56 TL/kg	20 000 TL	9904
7	5/8" gusset pl. 240 ft^2	2 650 kg	3.56 TL/kg	9 400 TL	9904
8	5/8" rivets 2 500	400 kg	3.56 TL/kg	1 420 TL	9904
9	27 WF 145 240 ft	1340 kg	3.56 TL/kg	4 750 TL	9904
10	Channels 10×25/8 500 ft	5220 kg	3.56 TL/kg	18 800 TL	9904
	Total			239 270 TL	

COST ANALYSIS OF STELL TRUSSES (Ref. No. 9)

1	Concrete	84 m³	91.78 TL/m³	7 700	9453
2	Bituminous Covering	1400 m²	25.28 TL/m²	35 000	9492
3	Forms	1400 m²	17.00 TL/m²	24 000	9492
4	No. 7 bars 5700 ft	5000 kg	2.32 TL/kg	12 000	9481
5	No. 10 bars 1150 ft	2100 kg	2.32 TL/kg	4 900	9481
6	No. 3 bars 10200 ft				
7	No. 3 bars 11450 ft	3550 kg	2.32 TL/kg	8 200	9481
8	Int. whitewash	1400 m²	5.06 TL/m²	7 100	9642
	Total			98 900	

COST ANALYSIS OF SHELL

NOTE:
THESE COSTS ARE TAKEN FROM "NAFIA BIRIM FİAT LİSTESİ" (Ref. No.9)

In comparing the steel truss roofing and shell in terms of cost we see that shell is much cheaper than the steel truss grid system. However, if we had designed the shell with unsymmetrical loading we should get a higher percentage of steel in concrete and we shoudn't get this much difference in cost, even though the shell would again be cheaper.

On the other hand the truss roofing has advantages over the shell in its uses. For example, if we suppose this was the roof of a factory or a store house we can easily hang cranes from the trusses, and the trusses are so arranged that the cranes can move in both directions. This is impossible to be done in a shell roof.

So from this we can say that the truss roofing even though it is more expensive than a shell it is more preferable in factories, store houses, and such like places where we have heavy loads to be hanged from the roof.

Shells, however, are more preferable in long span roof where we do not need any hanging of loads from the roof, because it is much cheaper. It is also easy to make a shell over long spans since a shell takes direct stresses in the longitidunal and transverse directions.

REFERENCES

1. TIMOSHENKO, S.; "Theory of Plates and Shells"
McGraw-Hill Book Company, Inc. New York 1940

2. GIRKMANN, KARL (Çeviren: TAMEROĞLU, SACİT S.); "Yüzeysel Taşıyıcı Sistemler"
T.C. Istanbul Teknik Üniversitesi Kütüphanesi, sayı 607, Istanbul 1965

3. URQUHART, L.C., O'ROURKE, C.E., WINTER, G.; "Design of Concrete Structures"
McGraw-Hill Book Company, Inc. New York 1958

4. SHEDD, T.C., VAWTER, J.; "Theory of Simple Structures"
John Wiley and Sons, Inc. New York 1958

5. Manual of "Steel Construction"
American Institute of Steel Construction, New York, N.Y. 1963

6. ACI Building Code Requirements for Reinforced Concrete ACI 318-56
American Concrete Institute publication Mich. 1958

7. "Elementary Analysis of Hyperbolic Paraboloid Concrete Shells"
Portland Cement Association publication Illinois 1958

8. SEYMEN, Ismet; Lecture notes of Computer Course

9. 1964 Nafıa Birim Fiat Listesi