THE ANKARA INDOOR STADIUM

THESIS BY:

İNCİ ÜSKÜDARLI

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Symbols :

g = dead load

p = live load

q = total load

W = section modulus (S)

J = moment of inertia (I)

F = area of the section

G = unit weight of the section

i = radius of gyration (r)

S_k = buckling length

$\lambda = \frac{S_k}{i} = \left(\frac{l}{r}\right)$ ratio

P.S. – It is necessary to state that I am under obligations of many kinds to Prof. M. Skarlatos for all his sincere help during the scholastic year and in bringing about this small thesis. I also thank Prof. F. Kocataşkın and Prof. V. Yerlici, for their help to me in finding references.

I must especially thank Prof. Flodin for his great help in encouraging me to choose my thesis.

INTRODUCTION

Sports, the most natural activity of any human being, is something that we perform all through our lives. But, now time has come to tame this instinctive activity of ours. Sports is considered a health improving activity when it is performed at the right time, in the right manner and in the right place. So the PLACE for sports is an important factor. Therefore design of a STADIUM is also very important.

Since many years there was the problem of how to provide for an adequate place, for the spectators as well as the athletes. There was also the problem of designing the field, since the activities are held during both summer and winter seasons, or both under sun or intense rain.

Although it was possible to have a roof over the place where the spectators were sitting and have a well-drained grassy field, still it was not too adequate. It was difficult for the athletes to play under intense rain.

For that reason many architects and engineers decided to have indoor stadiums that were adequate both for the spectators and the athletes under all climatic conditions. In Turkey the first indoor stadium was

was built in Ankara in 1956.

Since the subject of my thesis is the investigation of the causes of failure and the re-planning of the Ankara Indoor Stadium, I feel it necessary to begin with the history of that stadium.

In my thesis I am required to investigate the causes of failure of the Ankara Indoor Stadium and propose a new superstructure. The design of the superstructure is not asked in detail; giving a general appearance of the superstructure is sufficient. The important thing is that the superstructure must be light enough to be carried by the previous substructure. So, I must check for the substructure and strengthen it if necessary.

PART I

HISTORY OF THE ANKARA INDOOR STADIUM

The idea of building an indoor stadium in Ankara first came in 1947 and a competition among the architects was done in which the architectural plans designed by M. Evren and N. Hasekioğlu came first. In those plans the stadium was thought to cover an area of $60 \times 80\ m^2$. The roof of the building was planned to be a three-hinged steel frame with the tribunes and the other parts made of concrete. The steel frames were placed at 3.00 m. and 6.40 m. successively. The frame had an opening of 57.0 m. and a height of 24.0 m.

Later, by Prof. İhsan İnan, a new stadium was suggested proposing a more suitable construction area. This stadium was smaller than the previous one; it could take 3500 people under normal conditions and about 5500 people when box-races were being held.

Being 2.50 m. below the road level was giving a characteristic to the construction area. In that way the spectators could get into the gallery directly from the road level and then go down to the tribunes to find their places.

The construction was planned to have

steel frames with light concrete plates covering the distances between the frames. But later, the steel construction was changed to a concrete one.

In that way the construction was changed to a shell construction which was the first one to be built in Turkey.

CHARACTERISTICS OF THE STADIUM

The Ankara Indoor Stadium was the first big shell construction in Turkey. It was a cylindrical shell covering an area of 45.32 m. x 60.00 m. and having a circular cross section with a radius of 20.67 m. and a central angle of 110° as seen in Fig. I.

The thickness of the shell was 15 cm. at the points where the shell met the springs and that thickness decreased to 10 cm. in a distance of one meter.

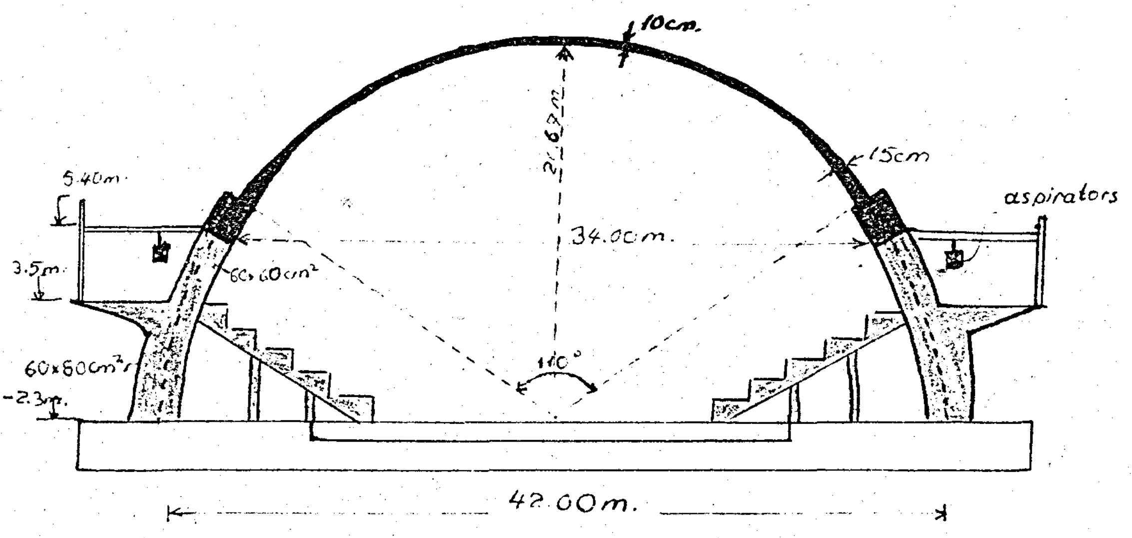
The side beams having an area of 60x110 cm^2 contained the part that was tangent to the springs of the shell and the longitudinal plate that was fixed to that beam and that formed the ceiling of the top gallery. In every 11.85 m. those side beams were sitting on columns 60x60 cm^2 that kept the circular shape of the shell. Those columns were 60x80 cm^2 in cross section below the tribunes.

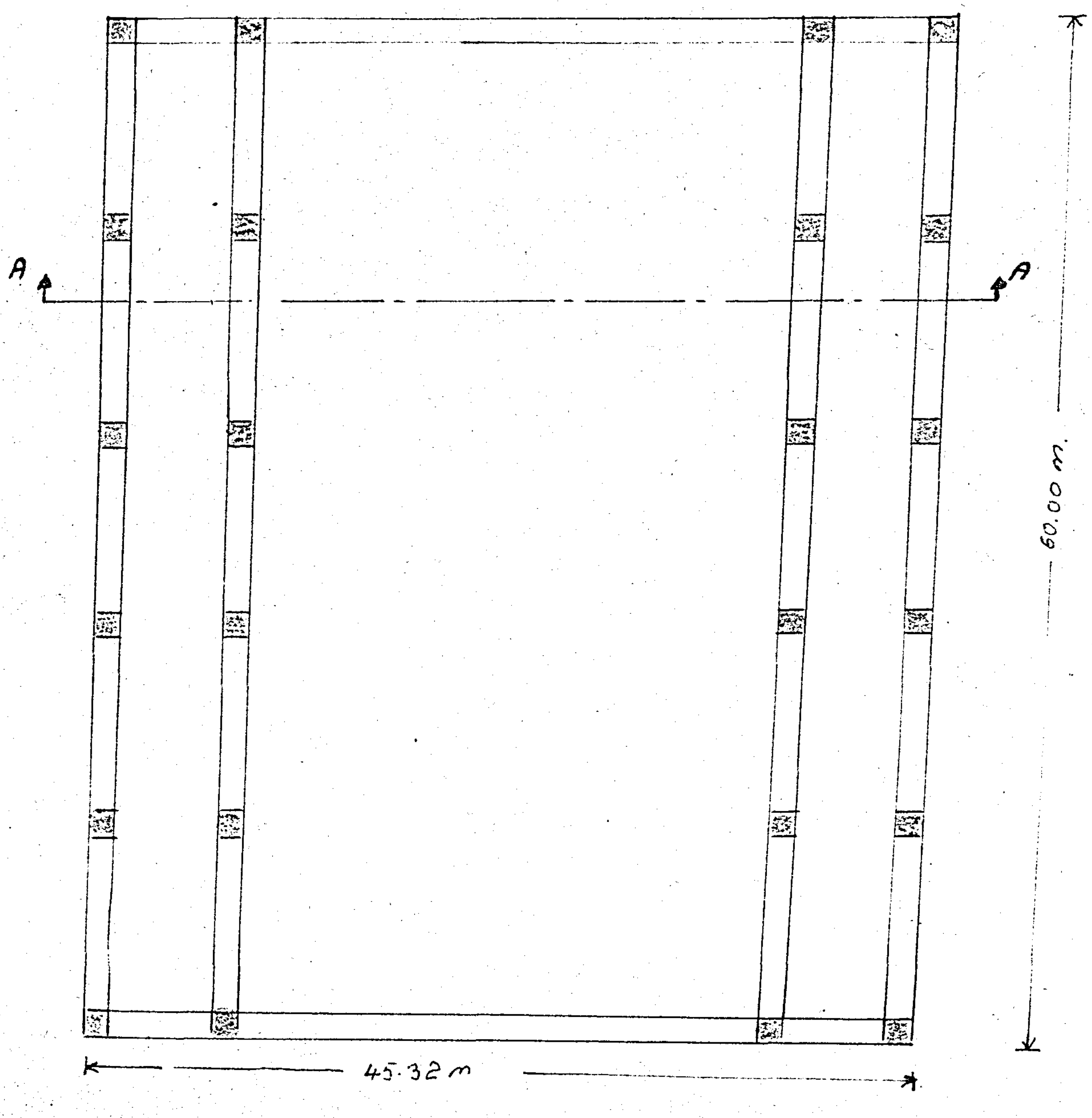
The construction of that stadium was completed in 1956 and the forms were removed in July 1956.

Then in 1958, ten aspirators, each having a weight of 550 kg. and a frequency of 24 cycles/sec. were placed on the side beams as shown in Fig: I. Later the frequency was reduced to 12 cycles/sec.

Fig: 1

A - A


10cm.
21.67m
15cm
5.40m
aspirators
34.00m.
3.5m.
60x60cm²
60x80cm²
110°
-2.3m.
42.00m.


A
A
60.00 m.
45.32 m

THE COLLAPSE OF THE STADIUM

On the night of 2-6-1958, after a match, the Ankara Indoor Stadium has collapsed suddenly without any warning. Although there were some cracking noises heard before the collapse, the cracks were hidden by the aluminum cover on the shell.

Fortunately there was no death, since the collapse had taken place after the match. But that collapse of the stadium caused great loss of money and a bad psychological effect on the people.

The part of the structure that has collapsed was a cylindrical shell of 10 cm. thickness covering an area of 34.00 x 58.00 m², having a circular cross section with a radius of 20.67 m. and a central angle of 110°, together with the side beams at the springs.

CAUSES OF FAILURE

A) According to Prof. İhsan İnan :

According to Prof. İhsan İnan, the designer of the stadium, the collapse is the result of resonance, since the aspirators weren't considered in the design and were put later. The resonance frequency of the building was 8 - 9 cycles/sec. , so reducing the frequency of the aspirators from 24 to 12 cycles/sec. made it even worse, since that frequency was closer to the resonance frequency.

He says that the collapse is not due to instability and wrong design calculations. He supports his defence by saying that the structure would fail immediately after the forms were removed if it were unstable.

In removing the forms, inorder not to cause any differential settlement, all the forms were decided to be removed at the same instant. For that reason a man with a wooden wedge in hand was placed at every support. All the men were told to hit the wedge in under the support when they hear the gun fired. In that way all the supports of the formwork would be removed at the same time.

This was done so, but they saw that the forms had stuck to the shell, and it took them some time to have the forms completely removed.

This is a further support to Prof. İhsan İnan's defence that the structure was stable; the structure could even carry the weight of the forms as well as its own weight without any failure.

B) Technical Reports on the Investigations of the Collapse of the Indoor Ankara Stadium.

The collapse has been studied entirely by two different commissions and the results of those investigations have been given by two technical reports which are kept as secrets.

One of those reports dated 4-8-1958 carries the signatures of Prof. Müfit İnan, Muhittin Toköz, Ali Terzipaşaoğlu, Nurettin Evin, Ali Terim and Fehman Tokluoğlu.

The second one dated 2-12-1958 is signed by Prof. Feridun Arısan, Vakkas Aykurt, Neş'et Akvandur and Hilmi Bayındır.

Since those reports were kept secret, unfortunately I couldn't have the opportunity of seeing those reports. Having many interviews with professors both in Ankara and Istanbul, the following informations were taken about the stadium:

Materials:

In the design calculations, the list of conditions that have been come across are that:

1) The concrete will be B 160.
2) The forms will be kept damp for three weeks, and it will be wetted every day and will be covered by mats.
3) The forms will be taken away after 45 days.
4) The joints will be done by electric welding.
5) Allowable stress for steel is taken as 1400 kg/cm^2.

But the investigators have not come across any report showing that all of these are done.

After the collapse, lab experiments on the concrete have shown that the concrete is B 160 which is also the one used in the calculations.

But examinations on the samples of concrete have shown that the concrete is very porous and there are air voids which show that the concrete has been poured dry and has not been squeezed enough by vibrators.

Also it is found that the stress in the steel surpasses 1400 kg/cm^2 which is the allowable.

Calculations:

The shell has been designed according to the membrane theory and therefore the moment between the shell and the side beam has not been taken into considerations.

Also, a steel tension bar is used at the bottom which is not shown in the calculations.

c) Causes OF Failure As a Conclusion:

The collapse has taken place on 2-6-1958, that is, about 4 years have passed by, therefore all the ruins have been cleared off and I don't have any evidence but the design calculations. For that reason, it is not possible to find out the reason of the collapse by investigations on the field. Therefore I must depend on the previous investigations on the field done by different commissions.

General considerations about the Collapse:

Shell design theories have been developed over many years by various analystes. The first analitical approach to the design of shells was presented by G. Lamé and E. Clapeyron in 1828 who produced the "membrane analogy" in which a shell was considered capable of resisting external loads by direct stresses unaccompanied by any bending. The next important contribution in this field was made in 1892 by A. E. Love who included in his theory radial shearing forces and moments, and thus provided the basis for subsequent theoretical developments.

Chief credit for the first application of Mr. Love's theory is due to Carl Zeiss who in 1924 used these formulas in designing a small concrete shell roof in Jena, Germany. Since then numerous writers, mostly German, have contributed to shell theory, aiming, in the main, at simplifying and systematizing the procedures of shell analysis.

In 1930, Mr. Finsterwalder presented a new approximate aggreement with experimental results. A few years later, Mr. Dischinger improved Mr. Finsterwalder's solution, and other writers among them Aas Jakobsen, have expanded the theory to include shell other than cylindrical.

During the 1940's, shell design was studied extensively although few results were published.

As we see, theory of shells is not a very old theory. The calculations contain lots of approximations and assumptions and those assumptions are supported by experienced engineers by long calculations and special lab experiments on models.

Failure of one of those assumptions may cause stresses that are much greater than those shown on calculations and that may cause the structure to collapse.

As it is told above, shell construction has not taken a definite form as we have in normal constructions and the formulas are empirical. Every author has his own assumptions, approximations and formulas about this system. Therefore to choose the right formulas and assumptions related to our conditions and materials need great care. So, shell construction is not a very safe construction yet.

It is not possible to find out the main factor causing failure since we don't have any definite or complete calculations in our hands.

Engineers doing investigations on the structure after the collapse, have not done the calculations because it takes a lot of time and needs lab work which costs a lot.

Therefore, those investigators were obliged to be satisfied with the previous calculations and were able to check only few of the calculations. So, they couldn't give a definite suggestion about the correctness of the calculations.

In my opinion, the calculations that have been done are the ones that are absolutely necessary but are not sufficient for full understanding. The drawings are not sufficient for full understanding either, especially for such a new type of construction in which the laborors have no experience at all.

Also, there are many approximations and assumptions which we can't guess whether they are correct or not. The moment between the shell and the side beam is taken as zero according to the membrane theory. But we can consider it as right since $\frac{t}{R} = \frac{10}{2067} = \frac{1}{206.7} < \frac{1}{50}$

Materials:

Although it was found out that the concrete is B160 as was used in the calculations, still we cannot say that the structure was safe on the materials side. Because a concrete of B160 is not a strong enough concrete to be used in such a big and important building. So a question rises in our minds as to whether concrete B 160 is strong enough for shell construction or not?

Also steel stress is found to surpass the allowable 1400 kg/cm^2.

Laboring:

Since we don't have any experienced laborors, the control engineer should always check the work. But unfortunately one sees that it wasn't so.

The steel network has been found in the lower sections of the shell, that is, in the zone of compression, which shows that the steel work was not done so carefully.

In shell construction, the assumed shape of the construction in the design must fit exactly the final shape that has been constructed. That is, after the forms have been taken away the structure will settle a little under its own weight and will take a new shape and this shape must fit the one that is assumed in the design. Therefore one must be very careful with the formwork.

Aspirators:

In the concrete design, aspirators were not taken into consideration, but in the application aspirators were put on the side beams.

Those 10 aspirators on the side beams caused the structure to vibrate and destroy the stability.

Other Factors:

On the concrete samples taken after the collapse, one can see that the steel is absolutely clean; there is no concrete sticking to the steel, which shows that there is no bond between the steel and the concrete.

Having so many factors reducing the safety of the construction, we can't say definitely which is the main factor causing failure. Although it is mainly due to aspirators, still we can't say that it is only aspirators that caused failure. Because shells are like eggs and it is practically impossible for a shell structure to collapse. During World War II. many shell structures in the war-torn lands were battered and even hit at vital parts, such as at supporting columns which were completely demolished, and yet the roof remained standing. In some important plants the damaged parts were removed and rebuilt repeatedly in spite of successive incidents while the shells bridged the gap of the damaged part.

So, if the structure were carefully built we wouldn't have a complete failure of the shell, but part of it.

EFFECT OF FAILURE ON SUBSTRUCTURE AND FOUNDATION

Investigations on the field after the collapse have shown that the shell has failed completely together with the side beams.

All the columns have failed at the joints of the steel and at the level of the top gallery at a height of +5.40 m.

As a result of the breaking of the columns, the springs, the horizontal side beams and the ceiling of the gallery carried by those columns have also failed.

But no failure or any crack have been investigated on the parts below the level of the top gallery.

We can be sure that the failure has begun from the central parts because the cover plates at the sides have fallen on top of the plates of the central part.

Having no cracks or any disconnections on the parts below the top gallery shows that the collapse has nothing to do with the lower parts. So, as a result, we can say that the footings and the foundation have not been so much disturbed as to be taken into consideration.

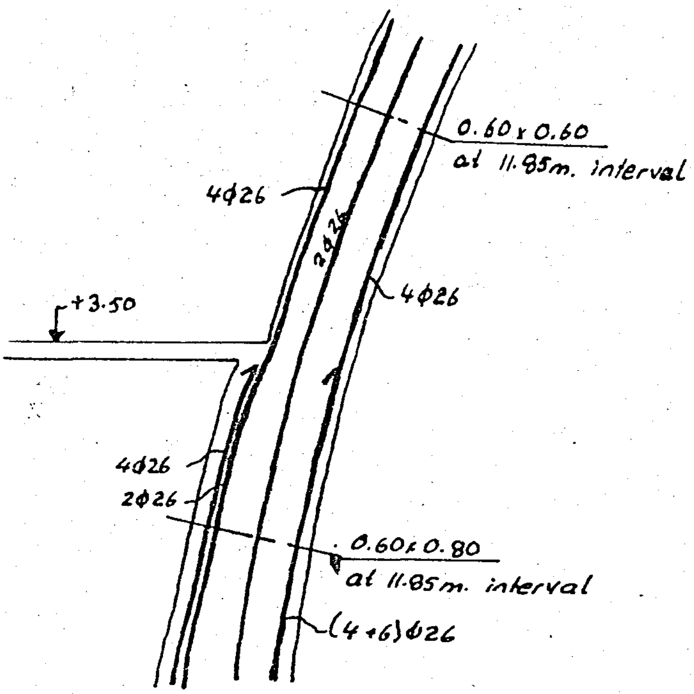
PART - II

PROJECTED NEW SUPERSTRUCTURE

Choosing the Type of Superstructure:

The requirement for the new superstructure to be built is that it will be supported by columns on two sides which are 38.00 m. apart and at an interval of 11.85 m.

Investigations made on the calculations have shown that the loading on the superstructure shall not exceed 240 kg/m² and that the lower columns were designed for an $H = 48.6t$ and $V = 87.0t$. Reinforcement for the column is shown in fig. below:



Scale 1/50

In choosing the new superstructure, both economical and psychological effects are considered:

First of all, it is not advisable to have another shell construction because of the bad psychological effects of the shell on the people after the collapse. So the most clever thing is to build a superstructure that is far from shells in appearance.

Although building a concrete superstructure seems to be more economical at first sight, it is impossible to build any type of superstructure but the shell again, since the substructure will not be able to carry a heavier loading.

Perhaps we could build a concrete gabled frame and increase the strength of the substructure, but still it wouldn't be economical. Having an opening of 38.00 m., the concrete gabled frame would be very thick in cross section and would look ugly.

So, the best solution is to have a light steel construction.

I first tried a steel truss roof on concrete columns, but my substructure was not strong enough to carry it. So, at the end I decided to have a steel frame sitting on the columns below the tribunes.

THE PROPOSED SUPERSTRUCTURE FROM THE ARCHITECTURAL POINT OF VIEW

I have chosen a three-hinged frame because I was not sure of the foundation conditions. A small settlement in the foundation may cause large moments in the middle.

In deciding on the architectural plans of my superstructure, I first decided to have a symmetrical three-hinged trussed frame with an opening of 38.00 m. The shape and dimensions of the frame is given in Fig: II.

As seen in the figure, this new superstructure is far from the appearance of a shell.

The frames are spaced at a distance of 11.85 m. and are sitting on the columns shown on page 19, as is recommended.

Then thinking of air conditioning and light I wanted to have some windows somewhere on the superstructure, and at last I decided to have a broken and wavy roof. In that way windows could be provided at the sides as seen in Fig. III.

Having such a roof is making the outside appearance of the roof completely different from that of a shell and gives the structure a special characteristic without forcing engineers to do complicated calculations.

Also in that way, we decrease the inside volume and hence the heating of the stadium is easier.

Broken roof also helps in the accustics, although it isn't a very important problem in stadiums.

PART - III

DESIGN

As seen in figures II and III, the new superstructure is a three-hinged truss frame with truss girders running between the frames. Since the superstructure is rather weak, in order to have a light superstructure, pipes are used in the girders. Since pipes are very light and very good as compression members, it is advantageous to use pipes.

In order to be consistent and simplify construction work, members of the same dimension are used wherever possible. For example, the same pipes are used at the bottom and top chords of the girder in order to facilitate labor and to have a better appearance.

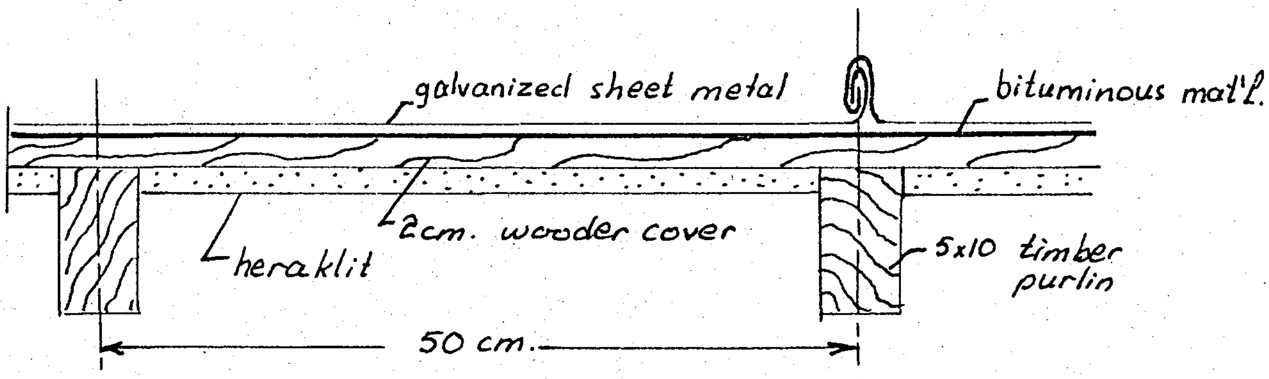
The pipes that are used in the girders are gas pipes available in Turkey, the dimensions of which are taken from a technical handbook written in 1959 by Reşat Kınıkaslan.

In the main frame double angles are used the dimensions of which are taken from "Beton Kalender 1958".

All throughout the design the allowable stress for steel is taken as 1400 kg/cm^2.

I- Loading of the Roof

As the roof cover, we have the materials as shown in the figure below:



Load on the roof:

a) Galvanized sheet metal 0.75 mm. $6\ kg/m^2 \times 1.10\ m. = 6.6\ kg/m^2$

b) Isolation and bonding material (bitumen + heraklit) ≈ 3.4 "

c) Wooden cover and timber purlins ≈ 15.0 "

D.L. $g = 25.0\ kg/m^2$

L.L. Snow load $p = 75.0$ "

Total load $q = 100.0\ kg/m^2$

II. PURLINS AND WOODEN COVER

Purlin dimension $5 \times 10 \ cm^2$

Distance between purlins 0.50 m.

σ for timber $= 80 \ kg/cm^2$

a) 2 cm. thick wooden cover:

The worst condition is assumed to be a concentrated 100 kg. load in the middle of a 20 cm. wooden plank. The wooden planks are assumed to be neither fixed or hinged. Therefore in calculating the maximum moment a value in between is chosen.

$$M_{max.} = 0.2 \times 25 \ \frac{\overline{0.5}^2}{10} + 100 \ \frac{0.5}{6} = 8.5 \ kg.m.$$

Check: Section modulus $W = \frac{bh^2}{6} = \frac{20 \times 2^2}{6} = 13.3 \ cm^3$

$$\sigma_{max} = \frac{M_{max}}{W} = \frac{850}{13.3} = 64 \ kg/cm^2 < 80 \ kg/cm^2 \ \text{o.k.}$$

b) Purlins:

Distance between girders $= 2.75$ m.

$$M_{max.} = 100 \times 0.5 \ \frac{\overline{2.75}^2}{8} = 48 \ kg.m.$$

$$W = \frac{5 \times 10^2}{6} = 83 \ cm^2$$

Moment of inertia $J = \frac{bh^3}{12} = \frac{5 \times 10^3}{12} = 415 \ cm^4$

$$\sigma_{max} = \frac{M_{max}}{W} = \frac{48.00}{83} = 58 \ kg/cm^2 < 80 \ kg/cm^2 \quad \text{o.k.}$$

Reaction at the end of the purlins $= 0.5 \times 100 \ \frac{2.75}{2} = 70$ kg.

III. GIRDERS

Girder Loadings at the joints:

2 x reaction = 2 x 70 kg. = 140 kg.

Wt. of girder 40 kg/m x 0.5 = 20 kg.

g = 160 kg.

Wind load = 150 sin α kg/m²

slope of the roof, tan α = 0.246

$\alpha = 13° \ 48'$

∴ wind load = 150 sin α = 53 kg/m²

At the joint wind load = 53 x 0.5 x 2.75 = 73 kg.

Total load at the joint = 160 + 73 = **233 kg.**

a) GIRDER NO. 8

Load at the joint is half of 233 kg = 116.5 kg.

Reaction = 116.5 x 12 = 1398 kg. ≈ 1.4 t.

$$M_{max.} = \left(1398 - \frac{233}{4}\right)\frac{11.85}{2} - \frac{233}{2} \times 12 \times 11 \times \frac{11.85}{24}$$

$$= 7940 - 3798 = 4142 \text{ kg m.}$$

At the chords $= \pm \dfrac{4142}{0.5} = \pm 8.3$ ton.

Diagonals $= \left(1398 - \dfrac{233}{4}\right)\sqrt{2} = +1.9$ ton.

Verticals $= -\left(1398 - \dfrac{233}{4}\right) = -1.34$ ton.

The sizes of the members are chosen from the tabulated table on the next page.

Name of Pipe	Outside diam. (mm.) D	Inside diam. (mm.) d	Unit wt. kg/m G	$\frac{\pi D^2}{4}$ cm² F_D	$\frac{\pi D^4}{64}$ cm⁴ J_D	$\frac{\pi d^2}{4}$ cm² F_d	$\frac{\pi d^4}{64}$ cm⁴ J_d	$F_D - F_d$ cm² F	$J_D - J_d$ cm⁴ J	$\sqrt{J/F}$ cm i
1/2"	21.75	14.75	1.44	3.7	1.1	1.7	0.2	2	0.9	0.67
3/4"	26.75	19.75	2.01	5.6	2.5	3.1	0.7	2.5	1.8	0.85
1"	33.50	25.50	2.91	8.8	6.2	5.1	2.1	3.7	4.1	1.05
1 1/4"	42.25	34.25	3.77	14.2	16.0	9.2	6.8	5.0	9.2	1.35
1 1/2"	48.25	39.75	4.61	18.2	26.0	12.4	12.2	6.0	13.8	1.51
2"	60.00	51.00	6.16	28.3	63.6	20.4	33.2	8.0	30.4	1.94
2 1/2"	75.00	65.75	7.61	44.1	155.0	34.0	92.0	10.1	63.0	2.50
3"	86.50	76.50	9.16	59.0	275.0	46.0	168.0	13.0	107.0	2.88

	S_k	50	60	70	80	90	100	125	150	175	200	225	250	σF for tension
1/2"	λ [1]	75	90	104	109	134	149	187	224	261				2.8
	ω [2]	1.48	1.71	1.98	2.38	3.03	3.75	5.91	8.47					
	P *	1.89	1.64	1.41	1.17	0.92	0.75	0.47	0.33					
3/4"	λ	59	71	82	94	106	118	147	176	205				3.50
	ω	1.29	1.42	1.58	1.78	2.02	2.35	3.65	4.65	7.10				
	P	2.72	2.47	2.22	1.97	1.73	1.49	0.96	0.75	0.49				
1"	λ	47	57	67	76	86	95	119	143	167	190			5.20
	ω	1.19	1.27	1.37	1.49	1.64	1.80	2.09	3.45	4.71	6.10			
	P	4.37	4.10	3.78	3.48	3.17	2.88	2.48	1.50	1.10	0.85			
1 1/4"	λ	37	44	52	59	67	74	92	111	130	148	167	185	7.00
	ω	1.12	1.16	1.23	1.29	1.37	1.48	1.74	2.14	2.85	3.70	4.71	5.78	
	P	6.25	6.0	5.70	5.40	5.10	4.70	4.0	3.77	2.45	1.88	1.47	1.21	

* $P = \frac{\sigma F}{\omega}$ = capacity of the pipe

[1] $\lambda = \frac{S_k}{i} \rightarrow \frac{l}{r}$ ratio   [2] ω found from tables in "Beton Kalender"

	S_k	50	60	70	80	90	100	125	150	175	200	225	250	275	P for tension
1½"	λ	33	40	46	53	60	66	83	99	116	132	149	166		8.4
	ω	1.10	1.14	1.18	1.23	1.30	1.36	1.59	1.88	2.27	2.94	3.75	4.65		
	P	7.63	7.36	7.10	6.80	6.45	6.20	5.30	4.45	3.70	2.85	2.24	1.82		
2"	λ	26	31	36	41	46	52	64	77	90	103	116	129	142	11.2
	ω	1.06	1.09	1.11	1.14	1.18	1.23	1.34	1.50	1.71	1.96	2.27	2.81	3.41	
	P	10.5	10.2	10.0	9.8	9.5	9.1	8.35	7.4	6.6	5.7	4.9	4.0	3.3	
2½"	λ	20	24	28	32	36	40	50							14.2
	ω	1.04	1.05	1.07	1.09	1.11	1.14	1.21							
	P	13.6	13.5	13.3	13.0	12.8	12.4	11.7							
3"	λ	17.5	21	24.5	28.0	31.0	35.0	43.5							18.2
	ω	1.02	1.04	1.05	1.07	1.09	1.11	1.16							
	P	17.9	17.5	17.3	17.0	16.7	16.4	15.7							

Girder No. 8:

Upper chord: $P_{max} = -8.3\ t.$

$Fe_{req.} = \frac{8.3}{1.4} = 5.94\ cm^2$

Use 2" pipe → $F = 8\ cm^2 > 5.94$ $G = 6.16\ kg/m.$

For $S_k = 49.4\ cm.$ Capacity $P = 10\ t. > 8.3\ t.$

Lower chord: For uniformity the lower chord is chosen to be the same as the upper chord → 2" pipe.

Verticals: $P_{max} = -1.4\ t.$

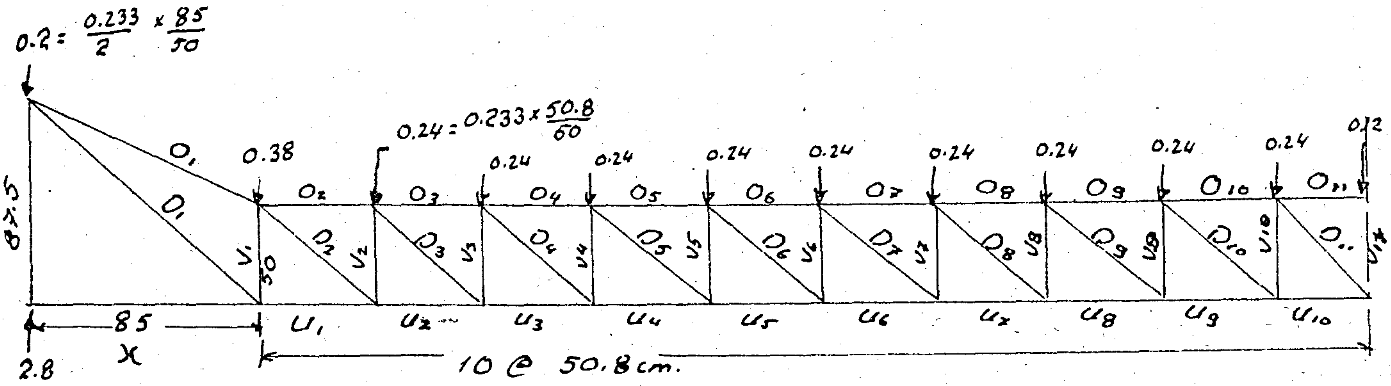
$F_{req.} = \frac{1.4}{1.4} = 1.0\ cm^2$ Use $\frac{1}{2}$" pipe → $F = 2\ cm^2 > 1.0$ $G = 1.44\ kg/m$

For $S_k = 50\ cm.$ $P = 1.89\ t. > 1.4\ t.$

Diagonals: $P_{max.} = +1.9\ t.$ $F_{req.} = \frac{1.9}{1.4} = 1.36\ cm^2$

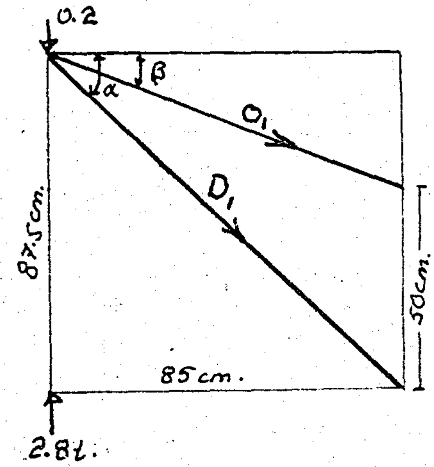
Use $\frac{1}{2}$" pipe → $F = 2\ cm^2 > 1.36\ cm^2$ $G = 1.44\ kg/m$

b) GIRDER NO. 7



$$\frac{x}{2.75} = \frac{11.85}{2 \times 19} \quad ; \quad x = 85 \text{ cm.} \qquad \frac{11.85 - 2 \times 0.85}{20} = 50.8 \text{ cm.}$$

Reaction $= 1.398 \times 2 \cong 2.8$ ton.



$\tan\alpha = \frac{87.5}{85} = 1.0294 \qquad \alpha = 45°\ 48'$

$\tan\beta = \frac{37.5}{85} = 0.441 \qquad \beta = 23°\ 48'$

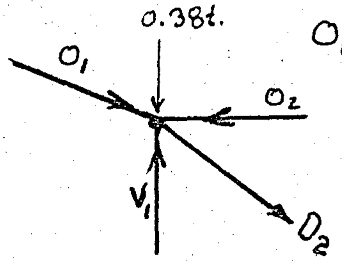
$\sin\alpha = 0.7169 \qquad \sin\beta = 0.4035$

$\cos\alpha = 0.6972 \qquad \cos\beta = 0.915$

$\Sigma H = 0; \quad O_1 \cos\beta + D_1 \cos\alpha = 0 \qquad D_1 = -O_1 \frac{\cos\beta}{\cos\alpha}$

$\Sigma V = 0; \quad O_1 \sin\beta + D_1 \sin\alpha = 2.6$

$2.6 = O_1 \sin\beta - O_1 \cos\beta \tan\alpha$



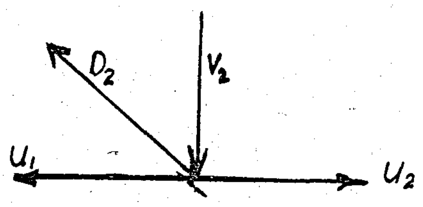
$O_1 = -4.8$ ton $\qquad D_1 = +6.3$ ton.

$V_1 = -\sin\alpha\, D_1 = -4.5$ ton

$U_1 = D_1 \cos\alpha = 4.4$ ton

$$V_1 - 0.38 - O_1 \sin\beta - D_2 \frac{\sqrt{2}}{2} = 0$$

$$D_2 = \left(\frac{4.5}{\sqrt{2}} - \frac{0.38}{\sqrt{2}} - \frac{4.8}{\sqrt{2}}\, 0.4035\right) 2 = 3.2 \text{ ton.}$$



$$O_1 \cos\beta + D_2 \frac{\sqrt{2}}{2} = O_2 = -6.7 \text{ ton.}$$

$$D_2\, 0.707 = V_2 = 3.2 \times 0.707 = -2.3 \text{ ton.} \quad \text{etc...}$$

Forces in the members in tons.

$O_1 = -4.8$	$D_1 = +6.3$	$V_1 = -4.5$	$U_1 = +4.4$
$O_2 = -6.7$	$D_2 = +3.2$	$V_2 = -2.3$	$U_2 = +6.7$
$O_3 = -8.75$	$D_3 = +3.0$	$V_3 = -2.07$	$U_3 = +8.75$
$O_4 = -10.6$	$D_4 = +2.6$	$V_4 = -1.84$	$U_4 = +10.6$
$O_5 = -12.2$	$D_5 = +2.3$	$V_5 = -1.61$	$U_5 = +12.2$
$O_6 = -13.6$	$D_6 = +2.0$	$V_6 = -1.38$	$U_6 = +13.6$
$O_7 = -14.7$	$D_7 = +1.65$	$V_7 = -1.15$	$U_7 = +14.7$
$O_8 = -15.6$	$D_8 = +1.32$	$V_8 = -0.92$	$U_8 = +15.6$
$O_9 = -16.3$	$D_9 = +0.98$	$V_9 = -0.69$	$U_9 = +16.3$
$O_{10} = -16.8$	$D_{10} = +0.66$	$V_{10} = -0.46$	$U_{10} = +16.8$
$O_{11} = -17.0$	$D_{11} = 0.33$	$V_{11} = -0.24$	

Upper Chord :

First , second and third panel $\quad P_{max} = -8.75\,t.$

$$F_{req.} = \frac{8.75}{1.4} = 6.25\ cm^2$$

Use 2" pipe

$F = 8\,cm^2 > 6.25 \qquad G = 6.16\ kg/m.$

For $S_K = \frac{85}{\cos\beta} = 93\,cm. \qquad P = 9.3\,t > 6.7\,t.$

For $S_K = 50.8\ cm. \qquad P = 10.4\,t > 8.75\,t.$

For the rest , $\quad P_{max} = -17.0\ t.$

$$F_{req.} = \frac{17}{1.4} = 12.1\ cm^2$$

Use 3" pipe

$F = 13.0\,cm^2 > 12.1\,cm^2 \qquad G = 9.16\ kg/m.$

For $S_K = 50.8 \qquad P = 17.9 > 17.0\ t.$

Lower Chord : the same as upper chord

Verticals :

First vertical , $\quad P_{max} = -4.5\ t.$

$$F_{req.} = \frac{4.5}{1.4} = 3.22\ cm^2$$

Use 1¼" pipe

$F = 5\,cm^2 > 3.22 \qquad G = 3.77\ kg/m$

For $S_K = 50\,cm. \qquad P = 6.25 > 4.5\,t.$

Next 2 verticals; $\quad P_{max} = -2.3\,t.$

$$F_{req.} = \frac{2.3}{1.4} = 1.64\ cm^2$$

Use ¾" pipe

$F = 2.5\ cm^2 > 1.64 \qquad G = 2.01\ kg/m.$

For $S_K = 50\ cm. \qquad P = 2.72\,t. > 2.3\,t.$

For the rest ; $\quad P_{max} = -1.84\,t.$

$$F_{req.} = \frac{1.84}{1.4} = 1.31\ cm^2$$

Use ½" pipe

$F = 2\,cm^2 > 1.31 \qquad G = 1.44\ kg/m.$

For $S_K = 50\,cm \qquad P = 1.89\,t > 1.84\,t.$

Diagonals:

First diagonal; $P_{max} = +6.3\ t$

$F_{req.} = \frac{6.3}{1.4} = 4.5\ cm^2$ — Use $1\frac{1}{4}$" pipe

$F = 5.0\ cm^2 > 4.5\ cm^2$ — $G = 3.77\ kg/m$

$P = 7.0\ ton > 6.3\ ton$

Next two diagonals; $P_{max} = +3.2\ t$

$F_{req.} = \frac{3.2}{1.4} = 2.29\ cm^2$ — Use $\frac{3}{4}$" pipe

$F = 2.5\ cm^2 > 2.29\ cm^2$ — $G = 2.01\ kg/m$

$P = 3.5\ t > 3.2\ t$

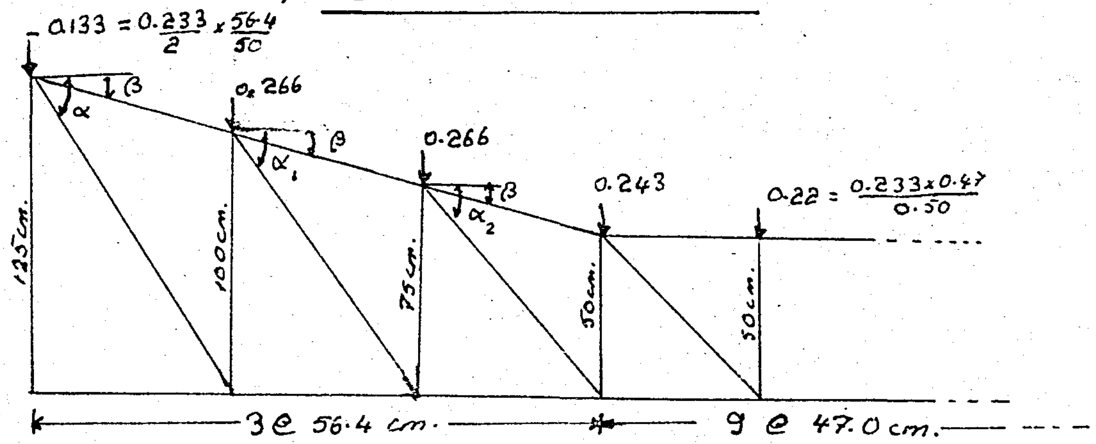
For the rest $P_{max} = 2.6\ t$

$F_{req.} = \frac{2.6}{1.4} = 1.86\ cm^2$ — Use $\frac{1}{2}$" pipe

$F = 2\ cm^2 > 1.86\ cm^2$ — $G = 1.44\ kg/m$

$P = 2.8\ t > 2.6\ t$

c) GIRDER NO. 6

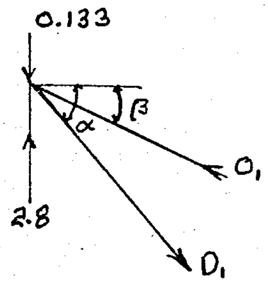


$\tan\beta = \frac{0.75}{1.692} = 0.4433$ — $\beta = 23°\ 54'$ — $\sin\beta = 0.4051$ — $\cos\beta = 0.9143$

$\tan\alpha = \frac{1.25}{0.564} = 2.2163$ — $\alpha = 65°\ 42'$ — $\sin\alpha = 0.9114$ — $\cos\alpha = 0.4115$

$\tan\alpha_1 = \frac{1.0}{0.564} = 1.756$ — $\alpha_1 = 60°\ 18'$ — $\sin\alpha_1 = 0.8686$ — $\cos\alpha_1 = 0.4955$

$\tan\alpha_2 = \frac{0.75}{0.564} = 1.3298$ — $\alpha_2 = 53°$ — $\sin\alpha_2 = 0.7986$ — $\cos\alpha_2 = 0.6018$



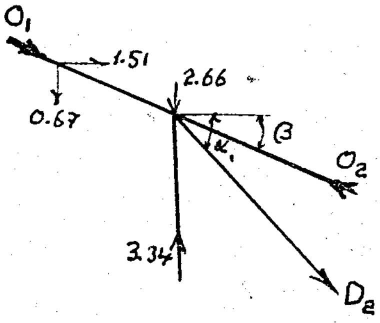
$\Sigma V = 0; \quad 2.8 - 0.133 - D_1 \sin\alpha + O_1 \sin\beta = 0$

$\Sigma H = 0; \quad O_1 \cos\beta = D_1 \cos\alpha \;; \quad D_1 = O_1 \dfrac{\cos\beta}{\cos\alpha}$

$2.667 - \tan\alpha \cos\beta\, O_1 + O_1 \sin\beta = 0$

$O_1 = \dfrac{2.667}{1.616} = 1.65 \text{ ton.}$

$D_1 = 3.66 \text{ ton.}$

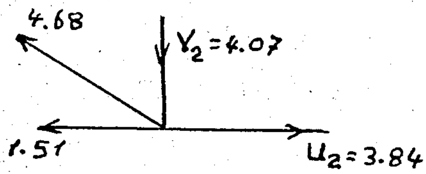


$\Sigma V = 0; \quad 0.67 - 3.34 + 0.266 - O_2 \sin\beta + D_2 \sin\alpha_1 = 0$

$\Sigma H = 0; \quad 1.51 + D_2 \cos\alpha_1 - O_2 \cos\beta = 0$

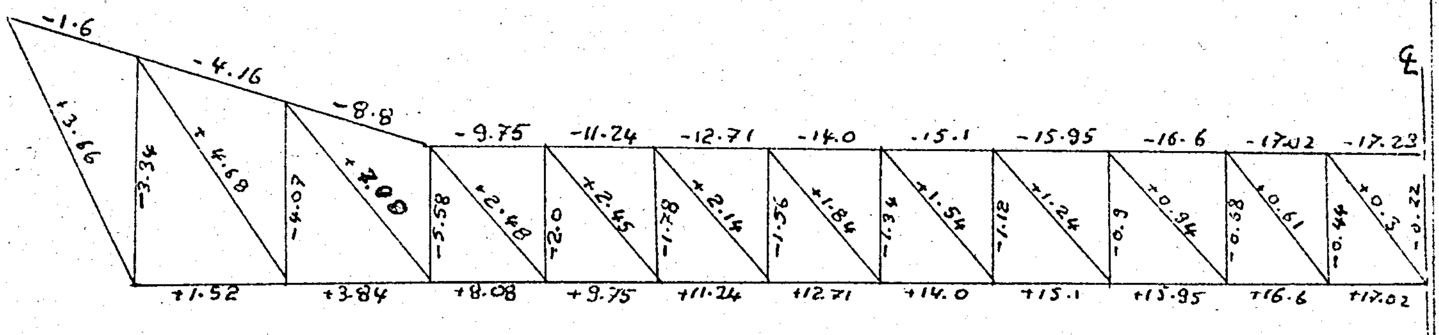
$D_2 = O_2 \dfrac{\cos\beta_1}{\cos\alpha_1} - \dfrac{1.51}{\cos\alpha_1}$

$O_2 = 4.16 \text{ ton} \qquad D_2 = 4.68 \text{ t.}$



$\Sigma V = 0$ and $\Sigma H = 0$ etc...

Forces in the members in tons :



Upper Chords:

First 5 panels ; $P_{max} = -11.24\ t$

$F_{req.} = \frac{11.24}{1.4} = 8.05\ cm^2$ Use $2\frac{1}{2}''$ pipe

$F = 10.1\ cm^2 > 8.05\ cm^2$ $G = 7.61\ kg/m$

For $S_k = \frac{56.4}{\cos\beta} = 61.8\ cm$ $P = 13.5\ t > 8.8\ t.$

For $S_k = 47\ cm$ $P = 13.6\ t > 11.24\ t.$

For the rest $P_{max} = -17.23\ t.$

$F_{req.} = \frac{17.23}{1.4} = 12.3\ cm^2$ Use $3''$ pipe

$F = 13.0\ cm^2 > 12.3\ cm^2$ $G = 9.16\ kg/m$

For $S_k = 47\ cm$ $P = 17.9\ t > 17.23\ t.$

Lower chord : same as upper chord

Verticals:

First 3 verticals; $P_{max} = -5.58\ t.$

$F_{req.} = \frac{5.58}{1.4} = 3.9\ cm^2$ Use $1\frac{1}{4}''$ pipe

$F = 5\ cm^2 > 3.9\ cm^2$ $G = 3.77\ kg/m$

For $S_k = 50\ cm$ $P = 6.25\ t > 5.58\ t.$

Fourth and fifth verticals; $P_{max} = -2\ t$

$F_{req.} = \frac{2}{1.4} = 1.43\ cm^2$ Use $3/4''$ pipe

$F = 2\ cm^2 > 1.43$ $G = 2.01\ kg/m$

For $S_k = 50$ $P = 2.72\ t > 2$

For the rest $P_{max} = -1.56\ t.$

$F_{req.} = \frac{1.56}{1.4} = 1.12\ cm^2$ Use $1/2''$ pipe

$F = 2\ cm^2 > 1.12\ cm^2$ $G = 1.44\ kg/m$

For $S_k = 50\ cm$ $P = 1.89\ t > 1.56\ t$

Diagonals :

First 3 diagonals ; $P_{max} = 7.0\ t$

$F_{req.} = \frac{7.0}{1.4} = 4.9\ cm^2$ Use $1\frac{1}{4}$" pipe

$F = 5.0\ cm^2 > 4.9\ cm^2$ $G = 3.77\ kg/m$

$P = 7.0\ t$ ✓

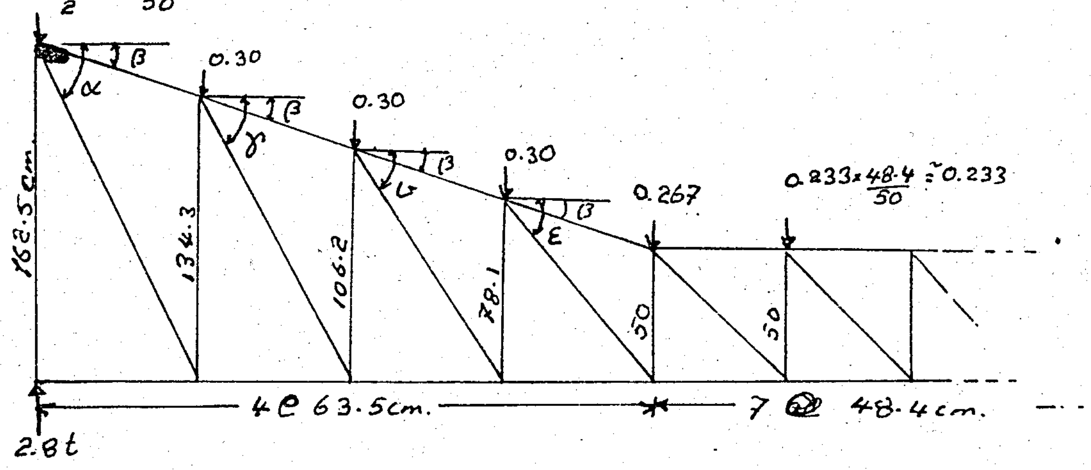
For the rest $P_{max} = 2.48\ t.$

$F_{req.} = \frac{2.48}{1.4} = 1.77\ cm^2$ Use ½" pipe

$F = 2\ cm^2 > 1.77\ cm^2$ $G = 1.44\ kg/m$

$P = 2.8\ t > 2.48\ t.$

d) GIRDER NO. 5



$\tan\beta = \frac{1.625 - 0.50}{4 \times 0.635} = 0.44$ $\beta = 23°\ 48'$ $\sin\beta = 0.40$ $\cos\beta = 0.92$

$\tan\alpha = \frac{1.625}{0.635} = 2.559$ $\alpha = 68°\ 36'$ $\sin\alpha = 0.93$ $\cos\alpha = 0.365$

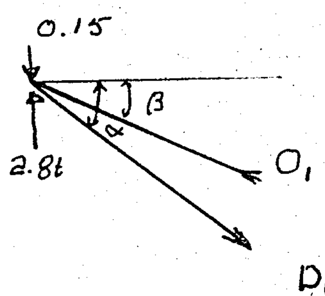
$\tan\gamma = \frac{1.625 - 0.635\tan\beta}{0.635} = 1.67$ $\gamma = 59°\ 5'$ $\sin\gamma = 0.905$ $\cos\gamma = 0.425$

$\tan\upsilon = \frac{1.625 - 2 \times 0.635\tan\beta}{0.635} = 1.07$ $\upsilon = 58°\ 5'$ $\sin\upsilon = 0.86$ $\cos\upsilon = 0.51$

$\tan\varepsilon = \frac{78.1}{63.5} = 1.24$ $\varepsilon = 51°\ 10'$ $\sin\varepsilon = 0.78$ $\cos\varepsilon = 0.63$

$\Sigma H = 0;$ $\quad O_1 \cos\beta = D_1 \cos\alpha$

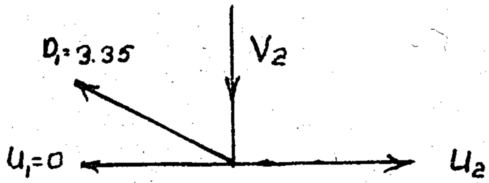
$$O_1 = D_1 \frac{\cos\alpha}{\cos\beta}$$



$\Sigma V = 0;$ $\quad (2.8 - 0.15) + O_1 \sin\beta = D_1 \sin\alpha$

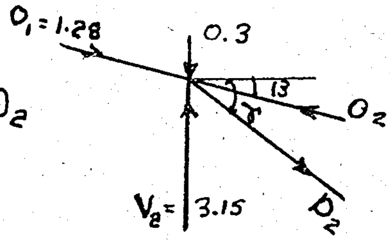
$$2.65 + D_1 \cos\alpha \tan\beta = D_1 \sin\alpha$$

$D_1 = 3.35\,t \qquad O_1 = 1.28\,t$



$\Sigma V = 0;$ $\quad V_2 = 3.35 \sin\alpha = 3.15\,t$

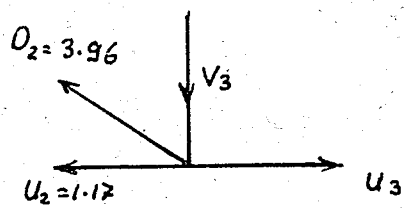
$\Sigma H = 0;$ $\quad U_2 = 3.35 \cos\alpha = 1.17\,t$



$\Sigma H = 0;$ $\quad 1.18 + 0.44\,D_2 = 0.92\,O_2$

$\Sigma V = 0;$ $\quad 3.15 - 0.3 + 0.4\,O_2 = 0.51 + 0.91\,D_2$

$D_2 = 3.96\,t \qquad O_2 = 3.18\,t$

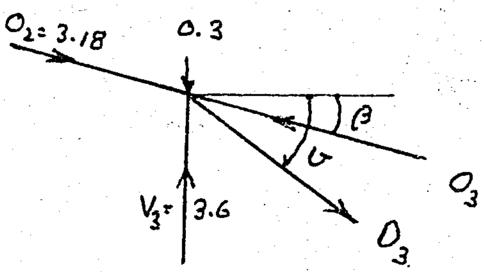


$\Sigma V = 0;$ $\quad V_3 = O_2 \sin\gamma = 3.6\,t$

$\Sigma H = 0;$ $\quad U_3 = 1.74 + 1.17 = 2.91\,t$

$3.18 \cos\beta + 0.51\,D_3 = O_3 \cos\beta$

$O_3 = 3.18 + 0.55\,D_3$

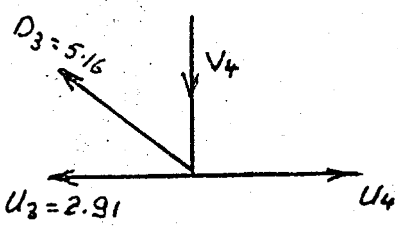


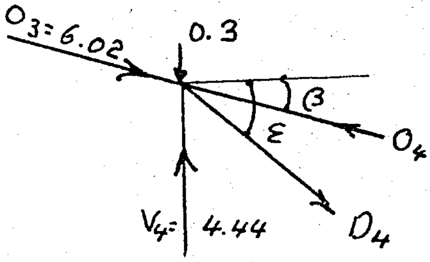
$3.60 - 0.30 + 0.4\,O_3 = 1.27 + 0.86\,D_3$

$D_3 = 5.16\,t \qquad O_3 = 6.02\,t$

$V_4 = 4.44\,t$

$U_4 = 2.91 + 2.63 = 5.54\,t$



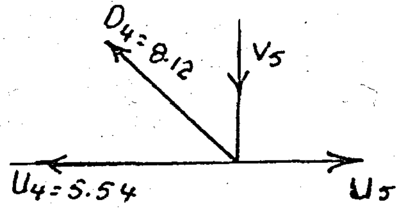


$$6.02 \cos\beta + 0.63\, D_4 = O_4 \cos\beta$$

$$O_4 = 6.02 + 0.68\, D_4$$

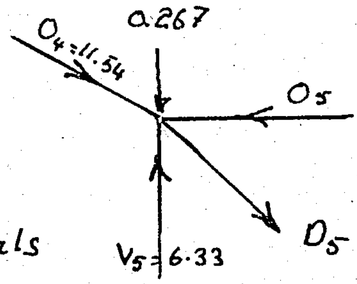
$$4.44 - 0.3 + 0.4\, O_4 = 2.41 + 0.78\, O_4$$

$$D_4 = 8.12\, t \qquad O_4 = 11.54\, t$$



$$V_5 = 8.12 \times 0.78 = 6.33\, t$$

$$U_5 = 5.54 + 5.12 = 10.66$$



$$O_5 = 10.62 + 0.707\, D_5$$

$$6.33 - 0.267 = 4.62 + 0.707\, D_5$$

$$D_5 = \frac{1.46}{0.707} = 2.07\, t. \qquad O_5 = 12.08\, t$$

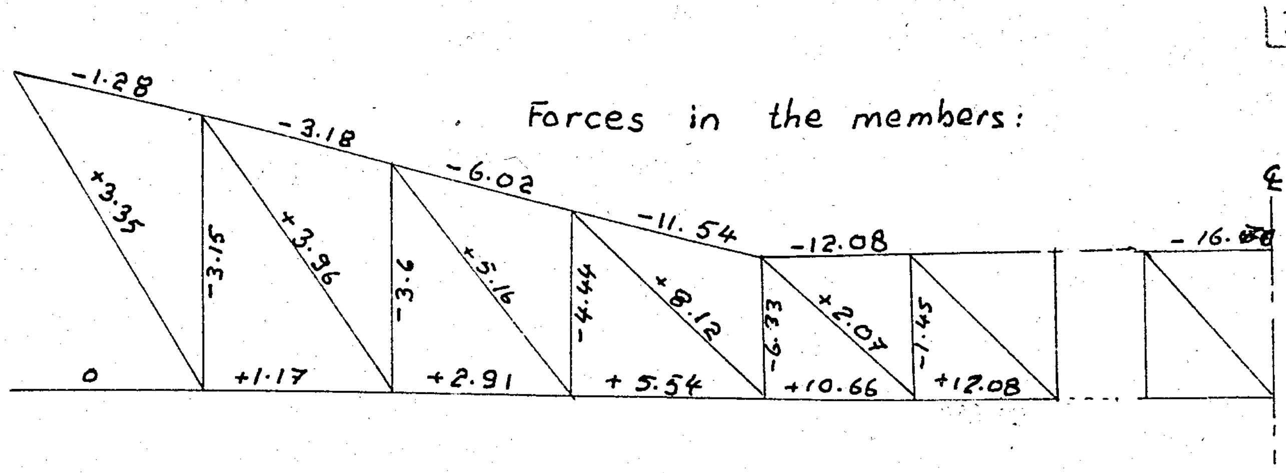
As we can see forces in the diagonals get smaller as we proceed after 2.07t, therefore diagonals after 2.07t are designed as 2.07t which is the maximum. The same thing is true with the verticals. But the chords get bigger, therefore we must calculate the maximum force in the chords which is at the mid span of the girder.

$$M_{max.} = (2.8 - 0.15)\frac{11.85}{2} - 0.233 \times 0.484 \times \frac{7 \times 8}{2} - 0.3\left(7 \times 0.484 \times 3 + \frac{3 \times 4}{2} \times 63.5\right)$$

$$= 8350 \text{ kg m.}$$

At the chords $P_{max} = \pm \dfrac{8350}{0.5} = \pm 16.70\, t.$

Forces in the members:



Upper Chords :

First 5 panels ; $P_{max} = -12.08\ t$

$F_{req.} = \frac{12.08}{1.4} = 9.15\ cm^2$ Use 2½" pipe

$F = 10.1\ cm^2 > 9.15\ cm^2$ $G = 7.61\ kg/m$

For $S_k = 48.4\ cm$ $P = 13.7\ t > 12.08\ t$

For the rest $P_{max} = -16.7\ t$

$F_{req.} = \frac{16.7}{1.4} = 11.9\ cm^2$ Use 3" pipe

$F = 13.0\ cm^2 > 11.9\ cm^2$ $G = 9.16\ kg/m$

For $S_k = 48.4\ cm.$ $P = 17.9\ t > 16.7\ t$

Bottom Chords : the same as upper chords

Verticals :

First 4 verticals ; $P_{max} = -6.33\ t$

$F_{req.} = \frac{6.33}{1.4} = 4.55\ cm^2$ Use 1¼" pipe

$F = 5.0\ cm^2 > 4.55\ cm^2$ $G = 3.77\ kg/m$

For $S_k = 50\ cm$ $P = 6.35\ t > 6.33\ t$

For $S_k = 134.3\ cm$ $P = 3.9\ t > 3.5\ t$

For the rest $P_{max} = -1.45\ t$

$F_{req.} = \frac{1.45}{1.4} = 1.02\ cm^2$ Use ½" pipe

$F = 2\,cm^2 > 1.02\,cm^2$ $G = 1.44\,kg/m$

For $S_k = 50\,cm$ $P = 1.89\,t > 1.45\,t$

Diagonals:

First 4 diagonals ; $P_{max} = 8.12\,t$

$F_{req.} = \frac{8.12}{1.4} = 5.8\,cm^2$ Use $1\frac{1}{2}$" pipe

$F = 6.0\,cm^2 > 5.8\,cm^2$ $G = 4.61\,kg/m$

$P = 8.4\,t > 8.12\,t$

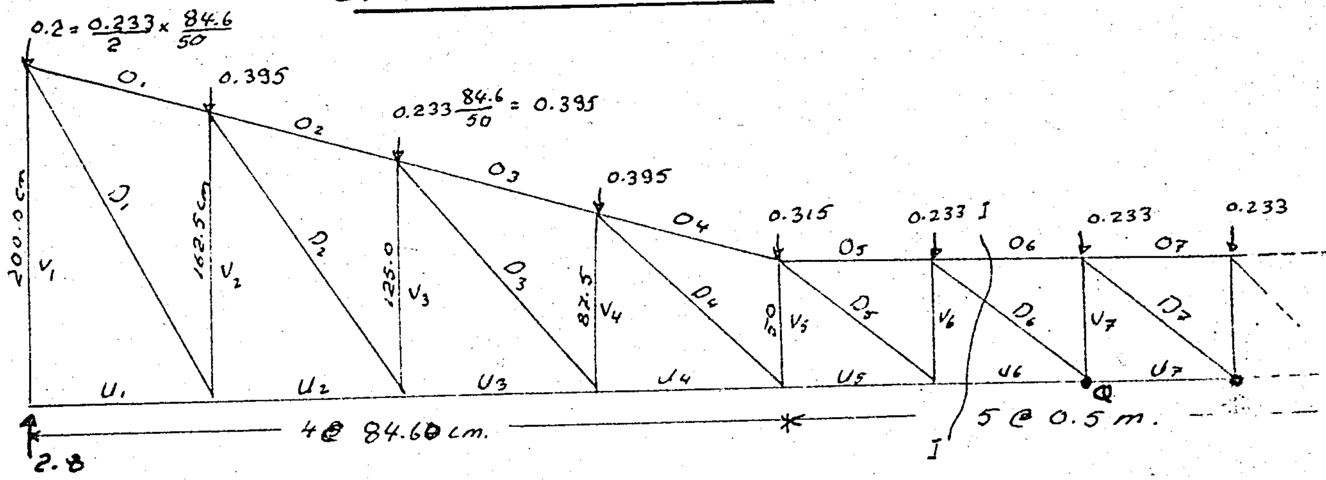
For the rest $P_{max} = 2.07\,t$

$F_{req.} = \frac{2.07}{1.4} = 1.48\,cm^2$ Use $\frac{1}{2}$" pipe

$F = 2\,cm^2 > 1.48\,cm^2$ $G = 1.44\,kg/m$

$P = 2.8\,t > 2.07\,t$

e) GIRDER NO. 4



Cut at I-I and take moments at Q ;

$0.5\,O_6 = 0.233 \times 0.5 + 0.315 \times 1.0 + 0.395\,(1.846 + 2.692 + 3.538)$

$- 2.6 \times 4.384$

$O_6 = 15.56\,t.$

$\Sigma V_6 = 0$; $\frac{\sqrt{2}}{2} D_6 = 2.6 - 3 \times 0.395 - 0.315 - 0.233 = 0.867$ t

$D_6 = 1.225$ t.

$U_6 = -O_6 - \frac{\sqrt{2}}{2} D_6 = 14.688$ t

$O_5 = -U_6 = -14.688$ t

$V_6 = -\frac{\sqrt{2}}{2} D_6 - 0.233 = -1.1$ ton

$\sqrt{2}\, D_5 = 1.1$ ton $\qquad D_5 = 1.55$ ton

$U_5 = 14.688 - 1.1 = 13.588$ ton

$O_{4H} = -U_5 = -13.588$ t

$O_4 = 14.86$ t.

$V_5 = -1.1 - 0.315 - 13.588 \frac{92.5}{84.6} = 7.435$ t.

$D_4 = 7.435 \frac{1220}{875} = 10.35$ t.

$U_4 = 13.588 - 7.435 \frac{846}{875} = 6.4$ t

$O_3 = -6.4 \frac{925}{846} = -7.0$ t.

$V_4 = 7.435 - 0.395 - 2.84 - 6.02 = -4.65$ t

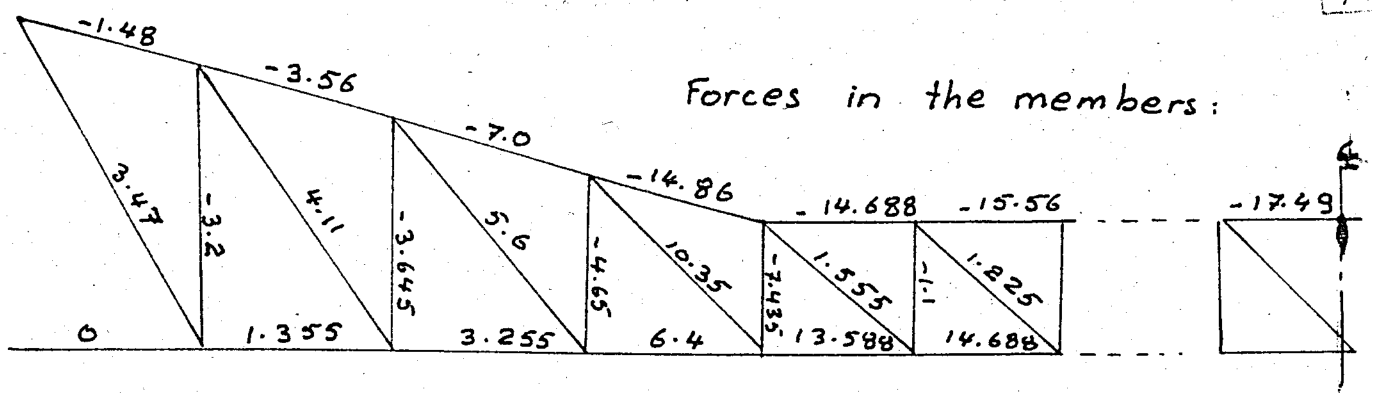
$D_3 = 4.65 \frac{1505}{1250} = 5.6$ t

$U_3 = 6.4 - 4.65 \frac{846}{1250} = 3.255$ t

$O_2 = -3.255 \frac{925}{846} = -3.56$ t

$V_3 = -4.65 - 0.395 - 3.255 \frac{375}{846} + 2.84 = 3.645$ t.

$D_2 = +3.645 \frac{1830}{1625} = 4.11$ t. $\qquad$ etc...



Forces in the members:

$$M_{max} = 2.6 \frac{11.85}{2} - 0.395 \left[\frac{3 \times 4}{2} (0.8464) + \frac{5.05 \times 3}{2} \right]$$

$$- 0.315 \times \frac{5.05}{2} - 0.233 \frac{4 \times 5}{2} \times 0.5$$

$$M_{max.} = 8745 \text{ kg m}$$

At the chords $P_{max} = \pm \frac{8.745}{0.5} = 17.49 \ t$

We don't need to calculate the rest of the verticals and the diagonals since the forces decrease.

Upper Chords:

First 3 panels ; $P_{max} = -7.0 \ t$

$F_{req.} = \frac{7.0}{1.4} = 5 \text{ cm}^2$ Use 2" pipe

$F = 8 \text{ cm}^2 > 5 \text{ cm}^2$ $G = 6.16$ kg/m

For $S_k = \frac{84.6}{\cos\beta} = 90$ cm. $P = 9.5 \ t > 7.0 \ t$

For the rest $P_{max} = -17.49 \ t$

$F_{req.} = \frac{17.49}{1.4} = 12.5 \text{ cm}^2$ Use 3" pipe

$F = 13.0 \text{ cm}^2 > 12.5 \text{ cm}^2$ $G = 9.16$ kg/m

For $S_k = 50$ cm. $P = 17.9 \ t > 17.49 \ t$.

Lower Chords : same as upper chords.

Verticals:

First 3 verticals ; $P_{max} = -4.65\ t$

$F_{req.} = \frac{4.65}{1.4} = 3.4\ cm^2$ Use 1¼" pipe

$F = 5.0\ cm^2 > 3.4\ cm^2$ $G = 3.77\ kg/m$

For $S_k = 87.5\ cm$ $P = 5.15\ t > 4.65\ t.$

Fourth vertical ; $P_{max} = -7.43\ t$

$F_{req.} = \frac{7.43}{1.4} = 5.3\ cm^2$ Use 1½" pipe

$F = 6.0\ cm^2 > 5.3\ cm^2$ $G = 4.61\ kg/m$

For $S_K = 50 cm$ $P = 7.63\ t > 7.43\ t$

For the rest $P_{max} = -1.1\ t$

$F_{req.} = \frac{1.1}{1.4} = 0.79\ cm^2$ Use ½" pipe

$F = 2 cm^2 > 0.79\ cm^2$

Diagonals:

First 3 diagonals ; $P_{max} = +5.6\ t$

$F_{req.} = \frac{5.6}{1.4} = 4 cm^2$ Use 1¼" pipe

$F = 5 cm^2 > 4 cm^2$ $G = 3.77\ kg/m$

$P = 7.0\ t > 5.6\ t$

Fourth diagonal ; $P_{max} = 10.35\ t$

$F_{req.} = \frac{10.35}{1.4} = 7.4\ cm^2$ Use 2" pipe

$F = 8 cm^2 > 7.4\ cm^2$ $G = 6.16$

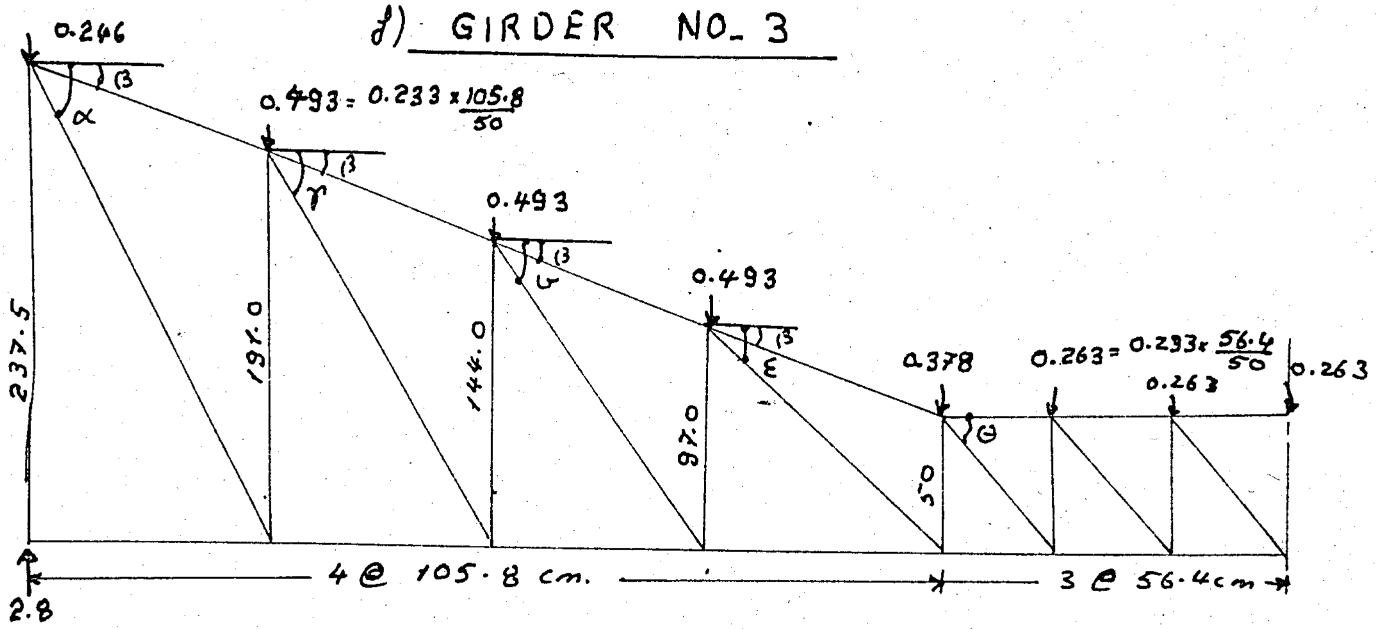
$P = 11.2\ t > 10.35\ t$

For the rest $P_{max} = +1.55\ t$

$F_{req.} = \frac{1.55}{1.4} = 1.11\ cm^2$ Use ½" pipe

$F = 2 cm^2 > 1.11\ cm^2$

d) GIRDER NO. 3



$\tan\beta = \frac{237.5 - 50}{4 \times 105.8} = 0.44$; $\beta =$ $\sin\beta = 0.4$ $\cos\beta = 0.92$

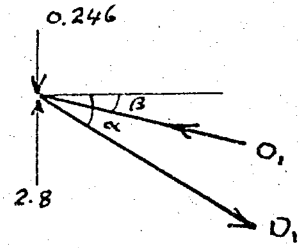
$\tan\alpha = \frac{237.5}{105.8} = 2.245$; $\alpha = 66°$ $\sin\alpha = 0.91$ $\cos\alpha = 0.41$

$\tan\gamma = \frac{191}{105.8} = 1.805$; $\gamma = 61°$ $\sin\gamma = 0.87$ $\cos\gamma = 0.48$

$\tan\sigma = \frac{144}{105.8} = 1.361$; $\sigma = 53°40'$ $\sin\sigma = 0.82$ $\cos\sigma = 0.59$

$\tan\varepsilon = \frac{97}{105.8} = 0.926$; $\varepsilon = 42°50'$ $\sin\varepsilon = 0.68$ $\cos\varepsilon = 0.73$

$\tan\theta = \frac{50}{56.4} = 0.887$; $\theta = 41°35'$ $\sin\theta = 0.66$ $\cos\theta = 0.75$



$\Sigma H = 0$; $O_1 \cos\beta = D_1 \cos\alpha$

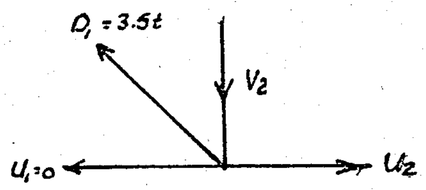
$O_1 = D_1 \frac{0.41}{0.92}$

$\Sigma V = 0$; $(2.8 - 0.246) + O_1 \sin\beta = D_1 \sin\alpha$

$2.554 + D_1 \frac{0.41}{0.92}\, 0.4 = D_1\, 0.91$

$D_1 = 3.5\ t$

$O_1 = 1.56\ t$



$\Sigma V = 0$; $V_2 = D_1 \sin\alpha = 3.18\ t$

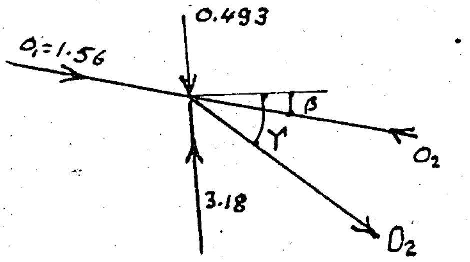
$\Sigma H = 0$; $U_2 = D_1 \cos\alpha = 1.43\ t$

$\Sigma V = 0; \quad \sin\gamma\, D_2 = (3.18 - 0.493) + (O_2 - 1.56)\sin\beta$

$D_2 = 2.98 + (O_2 - 1.56)\, 0.46$

$\Sigma H = 0; \quad D_2 \cos\gamma = (O_2 - 1.56)\cos\beta$

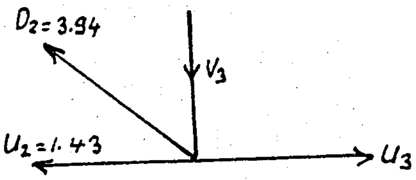
$D_2 = (O_2 - 1.56)\dfrac{0.92}{0.48}$



$D_2 = 3.94\,t \qquad O_2 = 3.62\,t$

$\Sigma V = 0; \quad V_3 = 3.94 \sin\gamma = 3.44\,t$

$\Sigma H = 0; \quad U_3 = 3.94 \cos\gamma + 1.43 = 3.32\,t$

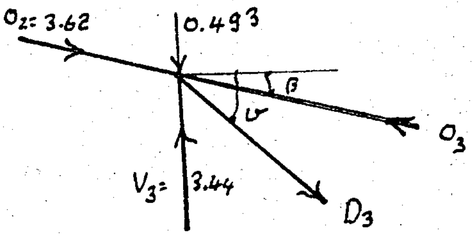


$\Sigma V = 0; \quad (3.44 - 0.493) + (O_3 - 3.62)\sin\beta = D_3 \sin\upsilon$

$\Sigma H = 0; \quad D_3 \cos\upsilon = (O_3 - 3.62)\cos\beta$

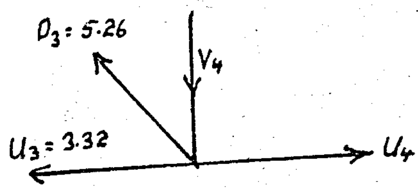
$D_3 = \dfrac{2.947}{0.563} = 5.26\,t$

$O_3 = 3.62 + 5.26\,\dfrac{0.59}{0.92} = 6.98\,t$



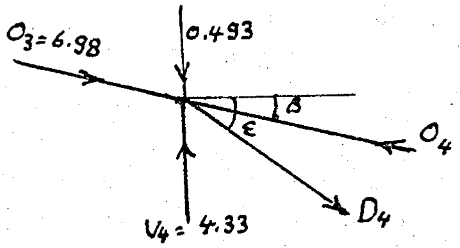
$\Sigma V = 0; \quad V_4 = 5.26 \sin\upsilon = 4.33\,t$

$\Sigma H = 0; \quad U_4 = 3.32 + 5.26(0.59) = 6.43\,t$



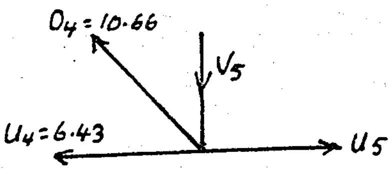
$D_4 = \dfrac{4.33 - 0.493}{0.68 - 0.44(0.73)} = 10.66\,t$

$O_4 = 6.98 + \dfrac{0.73}{0.92}\, 10.66 = 15.44\,t$



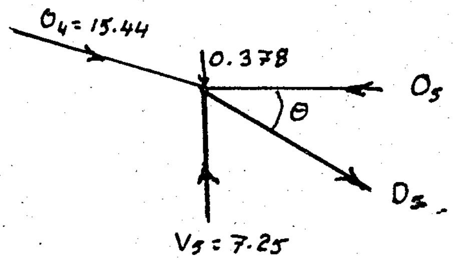
$\Sigma V = 0; \quad V_5 = 10.66 \sin\varepsilon = 7.25\,t$

$\Sigma H = 0; \quad U_5 = 6.43 + 10.66 \cos\xi = 14.21\,t$



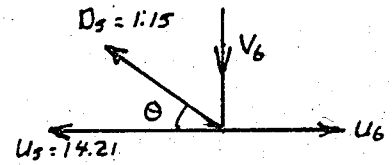
$\Sigma V = 0;$ $\quad D_5 = \dfrac{(7.25 - 0.378) - 15.44 \sin\beta}{\sin\theta}$

$= \dfrac{0.712}{0.66} = 1.15\,t$



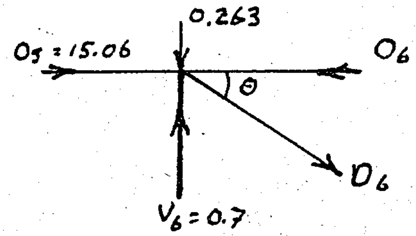
$\Sigma H = 0;$ $\quad 15.44 \cos\beta + 1.15 \cos\theta = O_5$

$O_5 = 15.06\ t$



$\Sigma V = 0;$ $\quad V_6 = D_5 \sin\theta = 0.7\ t$

$\Sigma H = 0;$ $\quad U_6 = U_5 + D_5 \cos\theta = 15.06\,t$



$\Sigma V = 0;$ $\quad D_6 = \dfrac{0.7 - 0.263}{\sin\theta} = 0.65\ t$

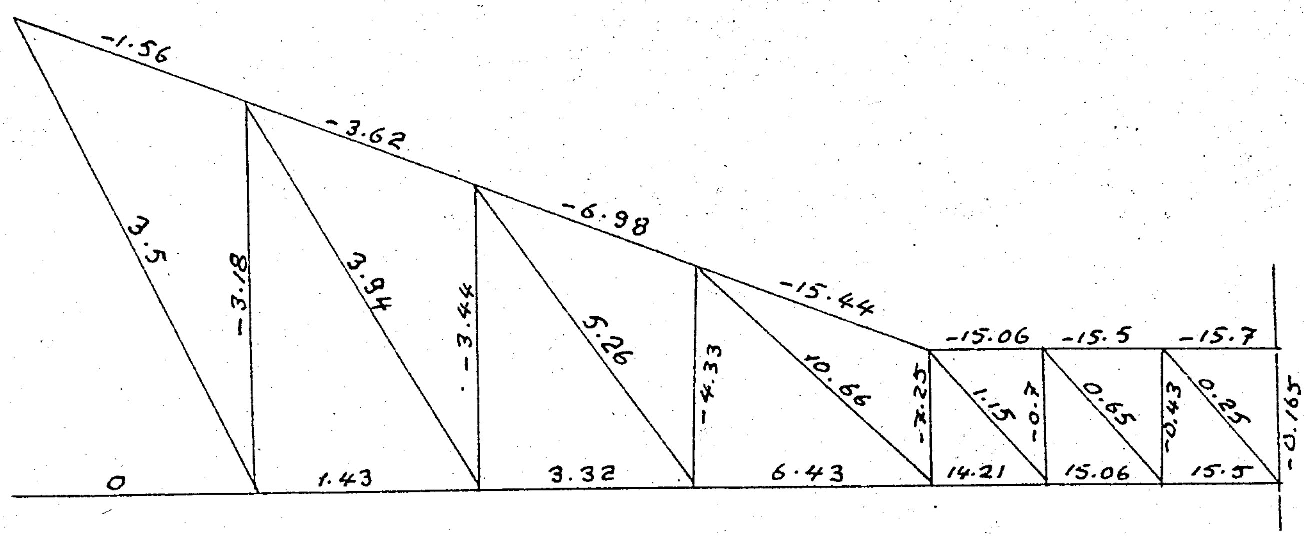
$\Sigma H = 0;$ $\quad O_6 = 15.06 + 0.65 \times 0.75 = 15.5\,t$

$V_7 = 0.65 \times 0.66 = 0.43\ t$

$V_8 = 0.25\ (0.66) = 0.165\ t$

Error : $0.165 - \dfrac{0.263}{2} = 34\ kg$ (acceptable)

Forces in the members :



Upper chords:

First 3 panels; $P_{max} = -6.98\,t$

$F_{req.} = \frac{6.98}{1.4} = 5\ cm^2$ — Use 2" pipe

$F = 8\ cm^2 > 5\ cm^2$ $G = 6.16\ kg/m$

For $S_k = \frac{105.8}{0.92} = 115\ cm$ $P = 8.65\,t > 6.98\,t$

For the rest $P_{max} = -15.7\,t$

$F_{req.} = \frac{15.7}{1.4} = 11.2\ cm^2$ — Use 3" pipe

$F = 13.0\ cm^2 > 11.2\ cm^2$ $G = 9.16\ kg/m$

For $S_k = 56.4\ cm$ $P = 17.7\,t > 15.7\,t$

Lower chords : same as upper chords.

Verticals:

First 3 verticals; $P_{max} = -4.33\,t$

$F_{req.} = \frac{4.33}{1.4} = 3.1\ cm^2$ — Use $1\frac{1}{4}$" pipe

$F = 5.0\ cm^2 > 3.1\ cm^2$ $G = 3.77\ kg/m$

For $S_k = 97\ cm$ $P = 4.5\,t > 4.33\,t$

For $S_k = 144\ cm$ $P = 3.75\,t > 3.44\,t$

For $S_k = 191\ cm$ $P = 3.45\,t > 3.18\,t$

Fourth vertical; $P_{max} = -7.25\,t$

$F_{req.} = \frac{7.25}{1.4} = 5.2\ cm^2$ — Use $1\frac{1}{2}$" pipe

$F = 6.0\ cm^2 > 5.2\ cm^2$ $G = 4.61\ kg/m$

For $S_k = 50\ cm$ $P = 7.63\,t > 7.25\,t$

For the rest $P_{max} = -0.7\ t$ Use ½" pipe .

Diagonals :

First 3 diagonals ; $P_{max} = 5.26\ t$

$F_{req.} = \frac{5.26}{1.4} = 3.78\ cm^2$ Use 1¼" pipe

$F = 5.0\ cm^2 > 3.78\ cm^2$

$P = 7.0\ t > 5.26\ t$

Fourth diagonal ; $P_{max} = 10.66\ t$

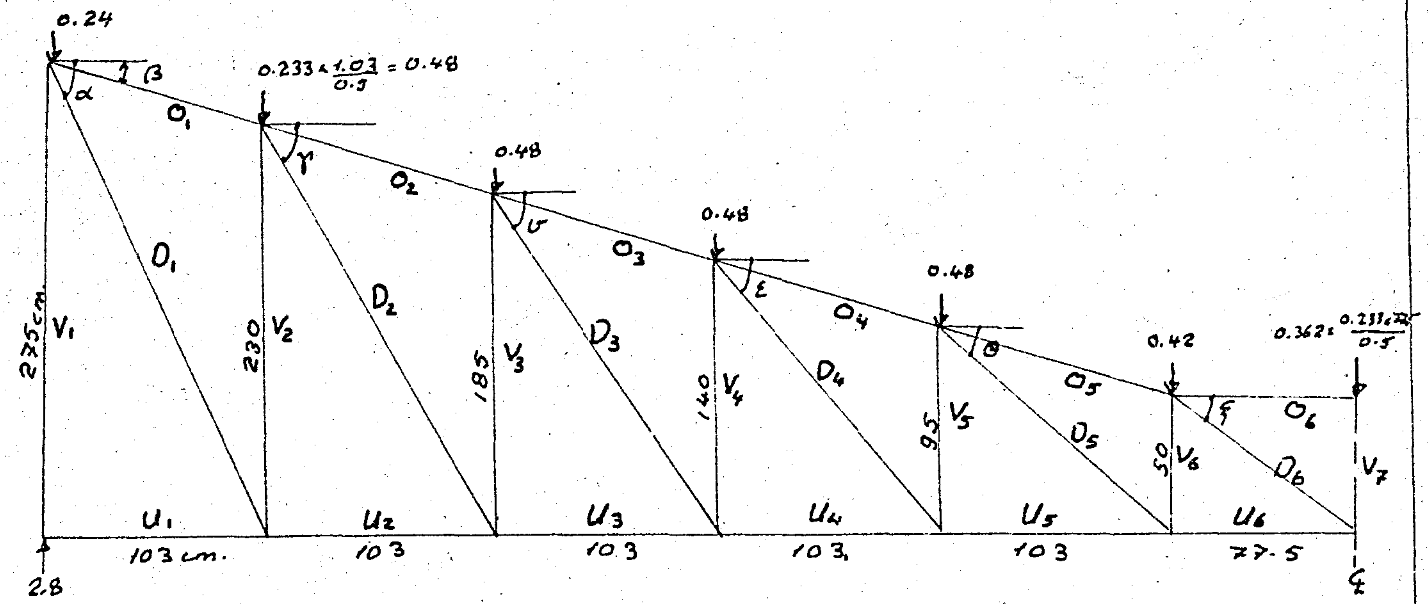
$F = \frac{10.66}{1.4} = 7.4\ cm^2$ Use 2" pipe

$F = 8.0\ cm^2 > 7.4\ cm^2$

$P = 11.2\ t > 10.66\ t$

For the rest use ½" pipe

g) GIRDER NO. 2



$\frac{11.85}{19 \times 2} = \frac{x}{6 \times 2.75}$ $x = 5.15\,m.$ $5.15 \overline{\smash{)}\,5\,}$ $1.03\,m.$

$\tan\beta = 0.44$ $\sin\beta = 0.40$ $\cos\beta = 0.92$

$\tan\alpha = \frac{2.75}{1.03} = 2.68$ $\alpha = 69° 32'$ $\sin\alpha = 0.94$ $\cos\alpha = 0.35$

$\tan\gamma = \frac{2.30}{1.03} = 2.23$ $\gamma = 65° 51'$ $\sin\gamma = 0.91$ $\cos\gamma = 0.41$

$\tan\upsilon = \frac{1.85}{1.03} = 1.8$ $\upsilon = 60° 57'$ $\sin\upsilon = 0.87$ $\cos\upsilon = 0.48$

$\tan\varepsilon = \frac{1.40}{1.03} = 1.36$ $\varepsilon = 53° 41'$ $\sin\varepsilon = 0.81$ $\cos\varepsilon = 0.59$

$\tan\theta = \frac{95}{103} = 0.92$ $\theta = 42° 37'$ $\sin\theta = 0.68$ $\cos\theta = 0.74$

$\tan\zeta = \frac{50}{103} = 0.645$ $\zeta = 32° 50'$ $\sin\zeta = 0.54$ $\cos\zeta = 0.84$

$$D_1 = \frac{2.8 - 0.24}{\sin\alpha - \cos\alpha\tan\beta} = \frac{2.56}{0.94 - 0.35(0.44)} = 3.25\ t.$$

$$O_1 = D_1 \frac{\cos\alpha}{\cos\beta} = 3.25 \frac{0.35}{0.92} = 1.23\ t$$

$$V_2 = 3.25 \sin\alpha = 3.06\ t$$

$$U_2 = 3.25 \cos\alpha = 1.13\ t$$

$$D_2 = \frac{3.06 - 0.48}{\sin\gamma - \cos\gamma\tan\beta} = \frac{2.58}{0.91 - 0.41(0.44)} = 3.54\ t.$$

$$O_2 = O_1 + D_2 \frac{\cos\gamma}{\cos\beta} = 1.23 + 3.54 \frac{0.41}{0.92} = 2.81\ t.$$

$$V_3 = D_2 \sin\gamma = 3.22\ t.$$

$$U_3 = D_2 \cos\gamma = 2.58\ t.$$

$$D_3 = \frac{3.22 - 0.48}{\sin\upsilon - \cos\upsilon\tan\beta} = \frac{2.74}{0.87 - 0.48(0.44)} = 4.10\ t$$

$$O_3 = 2.81 + 4.10 \frac{0.48}{0.92} = 4.92\ t$$

$V_4 = 4.10 \sin \upsilon = 3.56$ t

$U_4 = 2.58 + 4.10\,(0.48) = 4.50$ t.

$$D_4 = \frac{3.56 - 0.48}{\sin\varepsilon - \cos\varepsilon \tan\beta} = \frac{3.08}{0.81 - 0.59\,(0.44)} = 5.60 \text{ t.}$$

$$O_4 = 4.92 + 5.60\,\frac{\cos\varepsilon}{\cos\beta} = 8.52 \text{ t.}$$

$V_5 = 5.60 \sin\varepsilon = 4.54$ t.

$U_5 = 4.50 + 5.60\,(0.59) = 7.75$ t.

$$D_5 = \frac{4.54 - 0.48}{0.68 - 0.74\,(0.44)} = 11.6 \text{ t.}$$

$$O_5 = 8.52 + 11.6\,\frac{0.74}{0.92} = 17.87 \text{ t.}$$

$V_6 = 11.6\,(0.68) = 7.9$ t.

$U_6 = 7.75 + 11.6\,(0.74) = 16.35$ t.

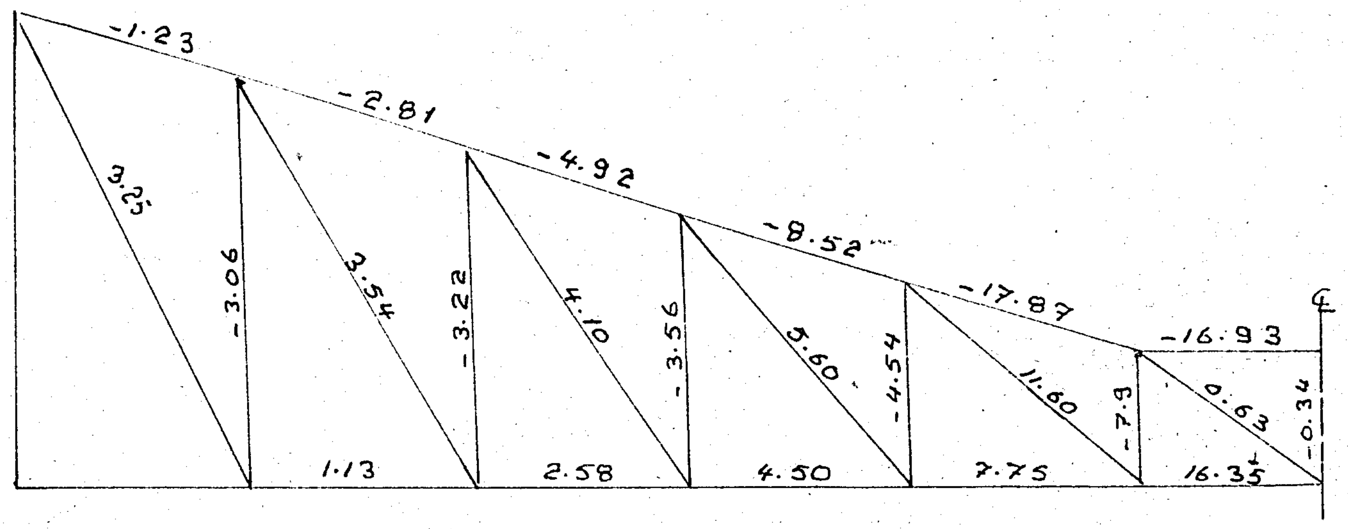
$$D_6 = \frac{7.9 - 0.42 - 17.87\,(0.40)}{0.54} = 0.63 \text{ t.}$$

$O_6 = 17.87\,(0.92) + 0.63\,(0.84) = 16.93$ t.

$V_7 = 0.63\,(0.54) = 0.34$ t.

Error: $0.34 - \frac{0.362}{2} = 0.159$ t (acceptable)

Forces in the members:



Upper Chords:

First 4 panels: $P_{max} = -8.52\ t$

$F_{req.} = \frac{8.52}{1.4} = 6.1\ cm^2$ Use 2" pipe

$F = 8\ cm^2 > 6.1\ cm^2$ $G = 6.16\ kg/m$

For $S_k = \frac{103}{0.92} = 112 cm.$ $P = 8.65\ t > 8.52\ t.$

For the rest; $P_{max} = -17.87\ t.$

$F_{req.} = \frac{17.87}{1.4} = 12.7 cm^2$ Use 3" pipe

$F = 13.0\ cm^2 > 12.7 cm^2$ $G = 13.0\ kg/m.$

For $S_k = 50$ $P = 17.9\ t > 17.87\ t.$

Lower chords: same as upper chords.

Verticals:

First 5 verticals; $P_{max} = -7.9\ t.$

$F_{req.} = \frac{7.9}{1.4} = 5.65\ cm^2$ Use 2" pipe

$F = 8.0\,cm^2 > 5.65\,cm^2$ $\quad G = 6.16\ kg/m.$

For $S_k = 230$ cm. $\quad P = 4.5\ t > 3.06\ t$

For $S_k = 185$ $\quad P = 6.0\ t > 3.22\ t$

For $S_k = 140$ $\quad P = 7.0\ t > 3.56\ t$

For $S_k = 95$ $\quad P = 9.3\ t > 4.54\ t$

For $S_k = 50$ $\quad P = 10.5\ t > 7.9\ t$

For the rest use $\frac{1}{2}$" pipe

Diagonals:

First 4 panels: $\quad P_{max} = 5.6\ t$

$F_{req.} = \frac{5.6}{1.4} = 4\ cm^2$ $\quad$ Use $1\frac{1}{4}$" pipe

$F = 5\ cm^2 > 4\ cm^2$ $\quad G = 3.77\ kg/m.$

$P = 7.0\ t > 5.6\ t$

Fifth panel: $\quad P_{max.} = 11.6\ t$

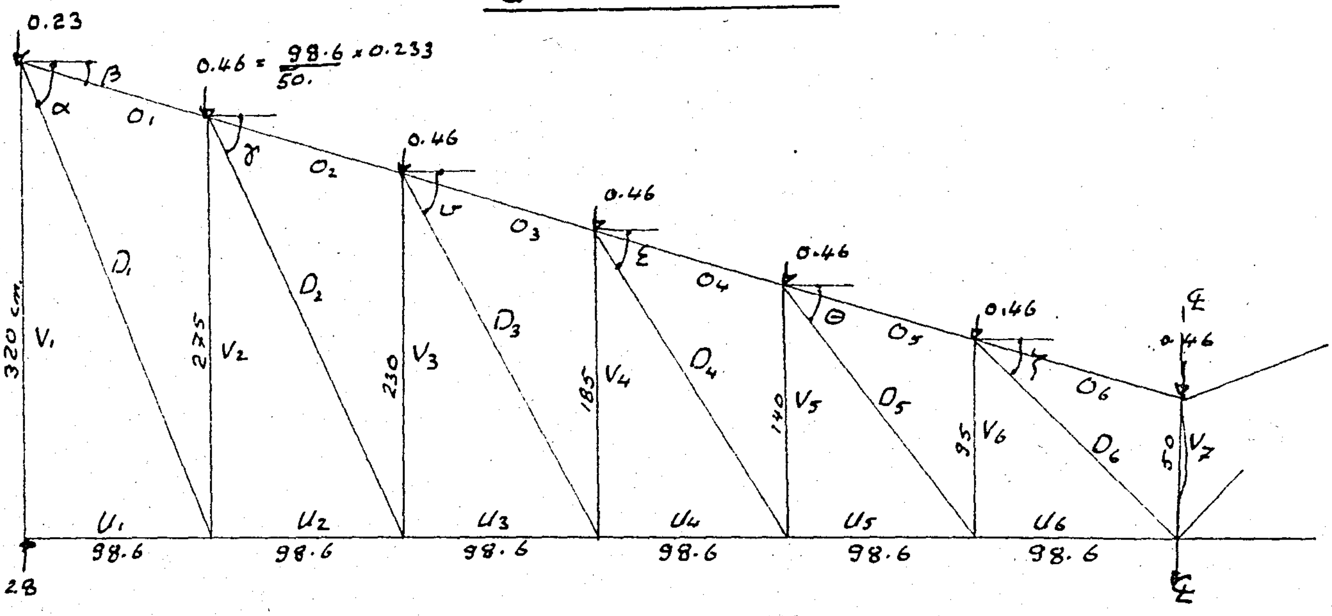
$F_{req.} = \frac{11.6}{1.4} = 8.3\ cm^2$ $\quad$ Use $2\frac{1}{2}$" pipe

$F = 10.1\ cm^2 > 8.3\ cm^2$ $\quad G = 7.61\ kg/m.$

$P = 14.2\ t > 11.6\ t.$

For the rest $\quad P_{max} = 0.63\ t$ $\quad$ Use $\frac{1}{2}$" pipe.

GIRDER NO. 1



$\tan\beta = 0.44$	$\beta = 23°45'$	$\sin\beta = 0.40$	$\cos\beta = 0.92$
$\tan\alpha = \frac{320}{98.6} = 3.24$	$\alpha = 72°51'$	$\sin\alpha = 0.96$	$\cos\alpha = 0.29$
$\tan\gamma = \frac{275}{98.6} = 2.78$	$\gamma = 70°13'$	$\sin\gamma = 0.94$	$\cos\gamma = 0.34$
$\tan\upsilon = \frac{230}{98.6} = 2.33$	$\upsilon = 66°47'$	$\sin\upsilon = 0.92$	$\cos\upsilon = 0.40$
$\tan\varepsilon = \frac{185}{98.6} = 1.88$	$\varepsilon = 62°$	$\sin\varepsilon = 0.88$	$\cos\varepsilon = 0.47$
$\tan\theta = \frac{140}{98.6} = 1.42$	$\theta = 54°51'$	$\sin\theta = 0.82$	$\cos\theta = 0.58$
$\tan\zeta = \frac{95}{98.6} = 0.964$	$\zeta = 43°58'$	$\sin\zeta = 0.69$	$\cos\zeta = 0.72$

$$D_1 = \frac{2.8 - 0.23}{0.96 - 0.29(0.44)} = 3.06\ t.$$

$$O_1 = 3.06\ \frac{0.29}{0.92} = 0.965\ t.$$

$$V_2 = 3.06 \times 0.96 = 2.94\ t.$$

$$U_2 = 3.06 \times 0.29 = 0.89\ t.$$

$$D_2 = \frac{2.94 - 0.46}{0.94 - 0.34(0.44)} = 3.14\ t$$

$$O_2 = 0.965 + 3.14 \frac{0.34}{0.92} = 2.13\ t.$$

$$V_3 = 3.14\ (0.94) = 2.96\ t.$$

$$U_3 = 0.89 + 3.14\ (0.34) = 2.06\ t.$$

$$D_3 = \frac{2.96 - 0.46}{0.92 - 0.44(0.40)} = 3.36\ t.$$

$$O_3 = 2.13 + 3.36 \frac{0.40}{0.92} = 3.59\ t.$$

$$V_4 = 3.36\ (0.92) = 3.09\ t.$$

$$U_4 = 2.06 + 3.36\ (0.4) = 3.4\ t.$$

$$D_4 = \frac{3.09 - 0.46}{0.88 - 0.44(0.47)} = 3.92\ t.$$

$$O_4 = 3.59 + 3.92 \frac{0.47}{0.92} = 5.59\ t.$$

$$V_5 = 3.92\ (0.88) = 3.44\ t.$$

$$U_5 = 3.4 + 3.92\ (0.47) = 5.24\ t.$$

$$D_5 = \frac{3.44 - 0.46}{0.82 - 0.44(0.58)} = 5.26\ t.$$

$$O_5 = 5.59 + 5.26 \frac{0.58}{0.92} = 8.91\ t.$$

$$V_6 = 5.26\ (0.82) = 4.32\ t.$$

$$U_6 = 5.24 + 5.26\ (0.58) = 8.29\ t.$$

$$D_6 = \frac{4.32 - 0.46}{0.69 - 0.44(0.72)} = 10.32 \ t.$$

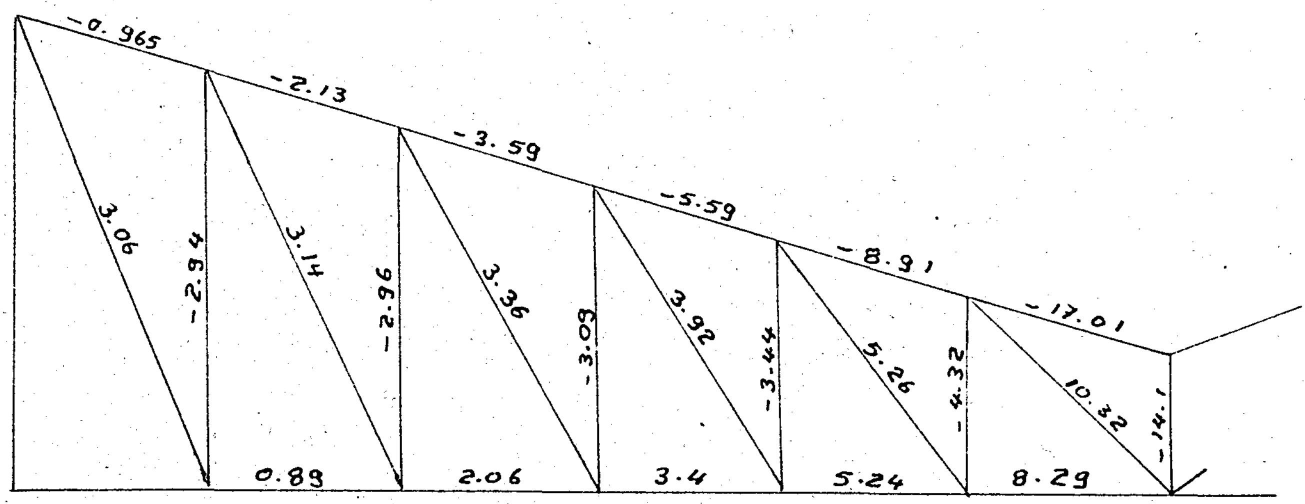
$$O_6 = 8.91 + 10.32 \frac{0.72}{0.92} = 17.01 \ t.$$

$$V_7 = 17.01 (0.4) 2 + 0.46 = 14.1 \ t.$$

From bottom : $V_7 = 2 \times 10.32 (0.69) = 14.3 \ t.$

Error = 0.2 t (acceptable).

Forces in the members:



<u>Upper chords:</u>

<u>First 4 panels;</u> $P_{max} = -5.59 \ t.$

$F_{req.} = \frac{5.59}{1.4} = 3.98 \ cm^2$ <u>Use 1½" pipe</u>

$F = 6 \ cm^2 > 3.98 \ cm^2$ $G = 4.61$ kg/m.

For $S_k = \frac{98.6}{0.92} = 107$ cm. $P = 5.8 \ t > 5.59 \ t.$

<u>For the rest;</u> $P_{max} = -17.01 \ t.$

$F_{req.} = \frac{17.01}{1.4} = 12.2 \ cm^2$ <u>Use 3" pipe</u>

$F = 13.0\ cm^2 > 12.2\ cm^2$ $G = 9.16\ kg/m$

For $S_k = \frac{98.6}{0.92} = 107\ cm.$ $P = 17.3\ t > 17.01\ t.$

Verticals:

First 3 verticals; $P_{max.} = -3.09\ t.$

$F_{req.} = \frac{3.09}{1.4} = 2.2\ cm^2$ Use 2" pipe.

$F = 8\ cm^2 > 2.2\ cm^2$ $G = 6.16\ kg/m.$

For $S_k = 275\ cm$ $P = 3.3\ t > 2.94\ t$

$S_k = 230$ $P = 4.75\ t > 2.96\ t$

$S_k = 185$ $P = 6.3\ t > 3.09\ t.$

4th. and 5th. Verticals; $P_{max} = -4.32\ t.$

$F_{req.} = \frac{4.32}{1.4} = 3.08\ cm^2$ Use 1¼" pipe

$F = 5\ cm^2 > 3.08\ cm^2$ $G = 3.77\ kg/m.$

For $S_k = 140\ cm.$ $P = 3.88\ t > 3.44\ t.$

$S_k = 95\ cm$ $P = 4.90\ t > 4.32\ t.$

Last vertical; $P_{max} = -14.1\ t.$

$F_{req.} = \frac{14.1}{1.4} = 10\ cm^2$ Use 3" pipe

$F = 13.0\ cm^2 > 10\ cm^2$ $G = 9.16\ kg/m.$

For $S_k = 50\ cm.$ $P = 17.9\ t > 14.1\ t.$

Diagonals:

First 3 diagonals; $P_{max} = 3.36\ t.$

$F_{req.} = \frac{3.36}{1.4} = 2.4\ cm^2$ Use ¾" pipe

$F = 2.5\ cm^2 > 2.4\ cm^2$ $G = 2.01\ kg/m.$ $P = 3.5\ t > 3.36\ t.$

4th. and 5th. diagonal; $P_{max} = 5.26\ t$ $F_{req.} = \frac{5.26}{1.4} = 3.76\ cm^2$

Use 1¼" pipe

$F = 5\ cm^2 > 3.76\ cm^2$

Last diagonal; $P_{max} = 10.32\ t.$ $F_{req.} = \frac{10.32}{1.4} = 7.4\ cm^2$

Use 2" pipe

$F = 8\ cm^2 > 7.4\ cm^2$

The dimensions of the pipes of the girders are shown in Fig: IV.

The joints of the pipes will be done by electric welding, so that the weight will be decreased and the structure will have a better appearance because of smoother surfaces and outlines. No gusset plate is used which is very advantageous, because by not using gusset plates, the joints are less rigid and in that way we eliminate secondary stresses. If we use gusset plates, then parts of the pipes that are between the gusset plates will not be painted well and they will rust by time. So, by not using gusset plates we eliminate corrosion and reduce the cost of cleaning.

We may be afraid that the joints will not be very strong without gusset plates, but we have several constructions built in that way, which prove that they are strong provided that the weld length is sufficient. One example of this type of construction, that is, pipes joined to one another by welding only, is the "Devlet Demiryolları Atölyesi" at Yedikule.

FRAME ANALYSIS

Loading at the joints:

Weight of roof cover and purlins = 25 kg./m²

Weight of girders ≅ 35 kg/m²

Wt of frame = 15 kg/m² (from tables corresponding to frame opening and distance between frames.)

$g = 75$ kg/m²

Snow $p = 75$ kg/m²

total load $q = 150$ kg/m²

Assuming all loads acting at the top joints ;

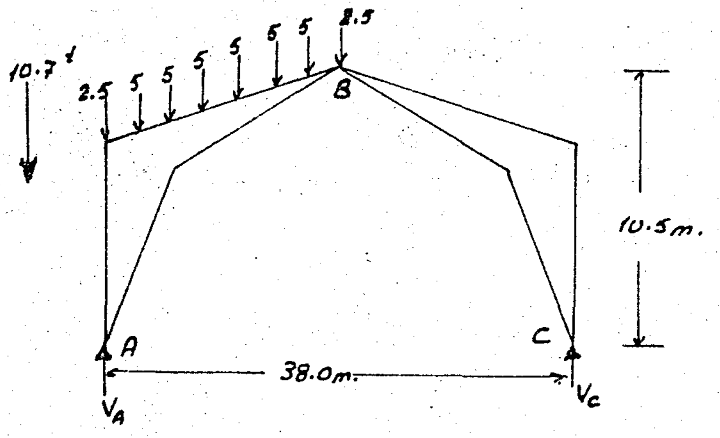
At a joint $P_g = 2.75 \times 11.85 \times 0.075 = 2.45\ t \approx 2.5\ t.$

$P_q = 2.75 \times 11.85 \times 0.150 = 4.90\ t \approx 5.0\ t.$

* Having a 6.00 m. cantilever roof over the galleries on both sides of the frame, additional weight on the frame coming from each cantilever is :

$P_g = 0.150 \times 11.85 \times 6.00 = 10.7\ t.$

Effect of Normal Loads:



$\Sigma M_A = 0;$

$-10.7 \times 3 + 5 \times 2.75 \times \frac{6 \times 7}{2} + 2.5 \times 19 - V_c\, 38 = 0$

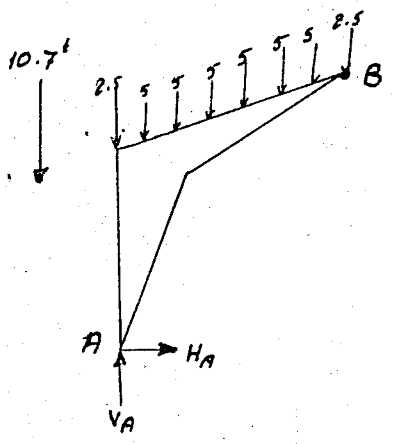
$V_c = 8.0\ t.$

$\Sigma V = 0;$

$V_A = 10.7 + 7 \times 5 - 8 = 37.7\ t.$

$V_{A\,max} = V_{c\,max.} = V_A + V_c = 37.7 + 8 = 45.7\ t.$

* Although the cantilever part of the roof is not designed, its effect on the frame is considered.



$\Sigma M_B = 0;$

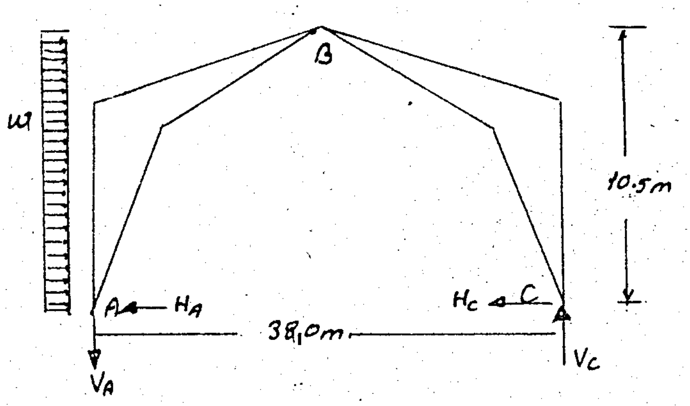
$5 \times \frac{6 \times 7}{2} \times 2.75 + 2.5 \times 19 + 10.7 \times 22 + H_A\, 10.5 - 19 \times 37.7 = 0$

$H_A = 14.5\ t$

$\Sigma H = 0; \qquad H_c = -14.5\ t.$

$H_{A_{max}} = H_{c_{max.}} = H_A + H_c = 29.0\ t.$

Effect of Wind Loads:



$w = 11.85 \times 0.15 = 1.78\ t/m.$

Considering that the wind load acts as a uniform load and not as concentrated loads at the joints;

$\Sigma M_A = 0; \qquad 1.78 \times \frac{\overline{10.5}^2}{2} = 38\, V_c \qquad V_c = 2.5\ t.$

$\Sigma V = 0; \qquad -V_A = +V_c = -2.5\ t.$

$\Sigma M_B = 0; \qquad H_A\, 10.5 = 1.78 \times \frac{\overline{10.5}^2}{2} + 19 \times 2.5$

$H_A = 14.0\ t.$

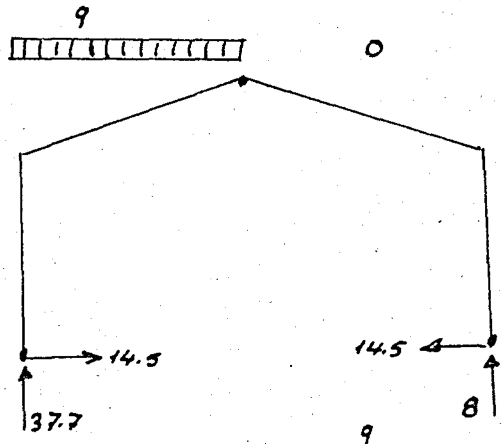
$\Sigma H = 0; \qquad H_A + H_c = 1.78 \times 10.5 = 18.7\ t.$

$H_c = 18.7 - 14.0$

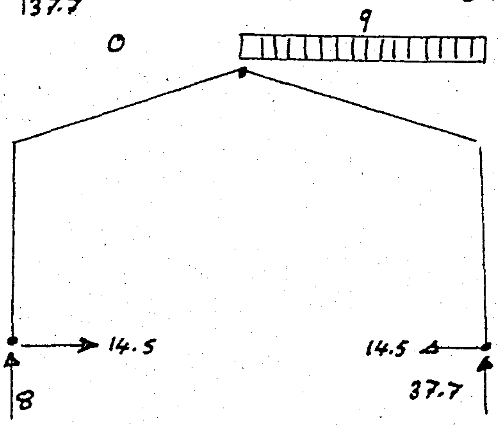
$H_c = 4.7\ t.$

Maximum Reactions:

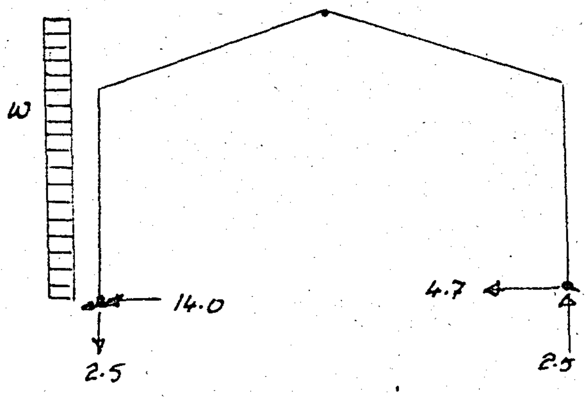
Case 1.



Case 2.



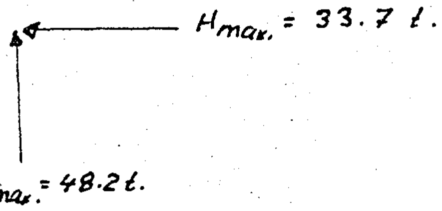
Case 3.

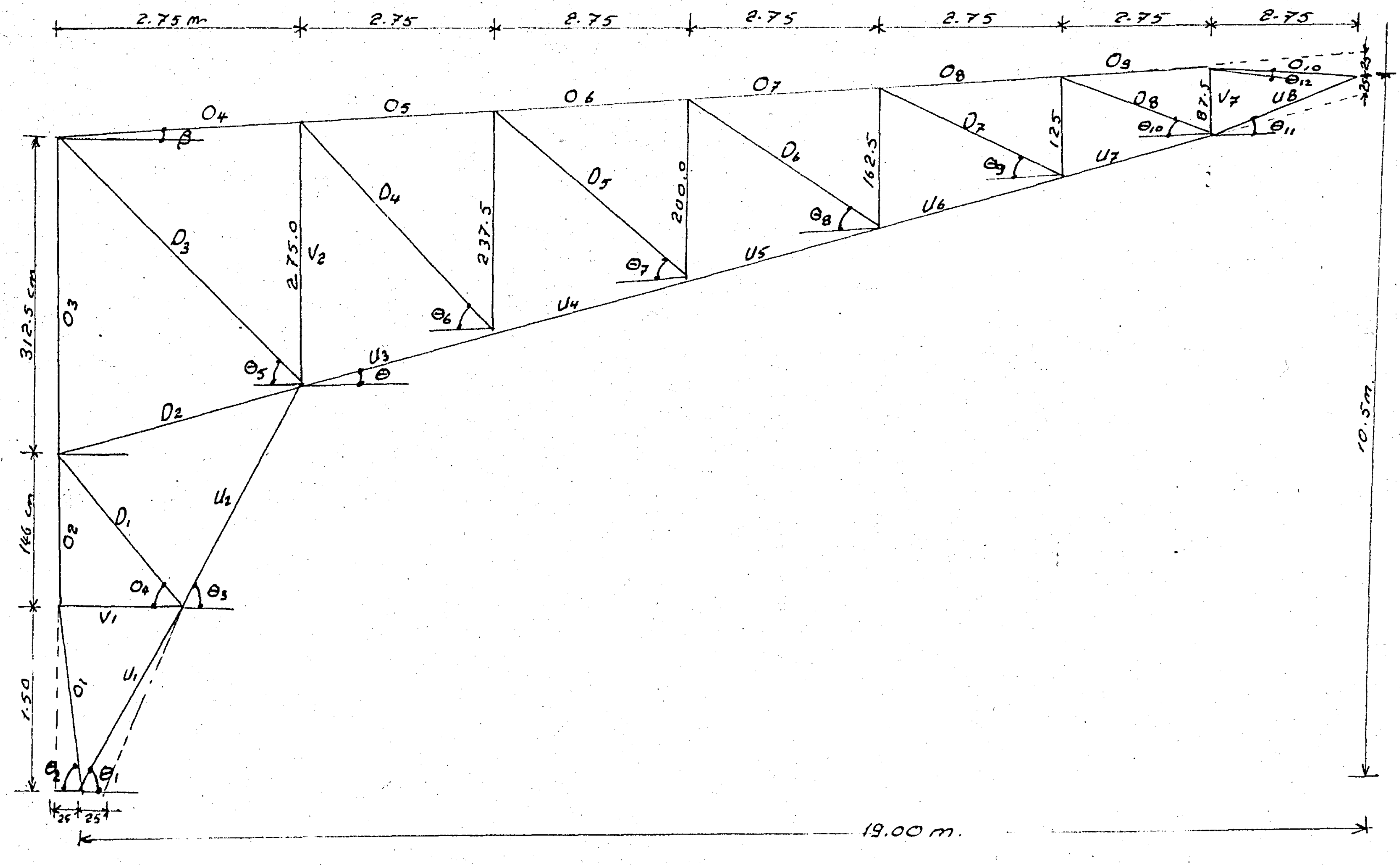


Case 4. (reverse of Case 3)

$V_{max.} = 37.7 + 8 + 2.5 = 48.2\ t.$

$H_{max.} = 14.5 + 14.5 + 4.7 = 33.7\ t.$





2.75 m
2.75
8.75
2.75
2.75
2.75
8.75
O4
O5
O 6
O7
O8
O9
O10
θ12
UB
V7
87.5
O8
θ10
θ11
125
O7
θ9
U7
162.5
O6
θ8
U6
200.0
O5
θ7
U5
237.5
O4
θ6
U4
275.0
V2
D3
θ5
U3
θ
β
312.5 cm
O3
D2
146 cm
O2
D1
U2
O4
θ3
V1
1.50
O1
U1
θ2
θ1
25
25
19.00 m.
10.5 m.

$\tan\beta = \frac{375}{6\times275} = 0.228 \quad \beta = 13° \quad \sin\beta = 0.22 \quad \cos\beta = 0.972$

$\tan\theta = \frac{521}{5\times275} = 0.38 \quad \theta = 20°48' \quad \sin\theta = 0.355 \quad \cos\theta = 0.935$

$\tan\theta_1 = \frac{150}{109} = 1.376 \quad \theta_1 = 54° \quad \sin\theta_1 = 0.809 \quad \cos\theta_1 = 0.588$

$\tan\theta_2 = \frac{150}{25} = 6.0 \quad \theta_2 = 80°33' \quad \sin\theta_2 = 0.987 \quad \cos\theta_2 = 0.164$

$\tan\theta_3 = \frac{146}{82.5} = 1.77 \quad \theta_3 = 60°33' \quad \sin\theta_3 = 0.87 \quad \cos\theta_3 = 0.491$

$\tan\theta_4 = \frac{146}{134} = 1.09 \quad \theta_4 = 47°30' \quad \sin\theta_4 = 0.737 \quad \cos\theta_4 = 0.676$

$\tan\theta_5 = \frac{212.5}{275} = 0.769 \quad \theta_5 = 37°35' \quad \sin\theta_5 = 0.61 \quad \cos\theta_5 = 0.792$

$\tan\theta_6 = \frac{175}{275} = 0.635 \quad \theta_6 = 32°25' \quad \sin\theta_6 = 0.536 \quad \cos\theta_6 = 0.844$

$\tan\theta_7 = \frac{137.5}{275} = 0.5 \quad \theta_7 = 26°34' \quad \sin\theta_7 = 0.447 \quad \cos\theta_7 = 0.894$

$\tan\theta_8 = \frac{100}{275} = 0.364 \quad \theta_8 = 20° \quad \sin\theta_8 = 0.34 \quad \cos\theta_8 = 0.94$

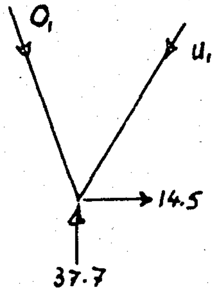
$\tan\theta_9 = \frac{62.5}{275} = 0.227 \quad \theta_9 = 12°48' \quad \sin\theta_9 = 0.221 \quad \cos\theta_9 = 0.975$

$\tan\theta_{10} = \frac{87.5}{275} = 0.318 \quad \theta_{10} = 4°20' \quad \sin\theta_{10} = 0.076 \quad \cos\theta_{10} = 0.997$

$\tan\theta_{11} = \frac{129.0}{275} = 0.47 \quad \theta_{11} = 25°11' \quad \sin\theta_{11} = 0.425 \quad \cos\theta_{11} = 0.905$

$\tan\theta_{12} = \frac{25}{275} = 0.091 \quad \theta_{12} = 5°11' \quad \sin\theta_{12} = 0.141 \quad \cos\theta_{12} = 0.99$

Calculation of Forces in the Members For Case 1.



$\Sigma H = 0; \quad O_1\, 0.164 + 14.5 = U_1\, 0.588$

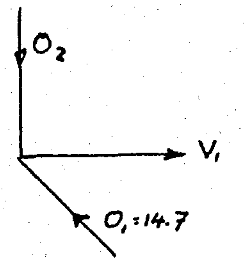
$U_1 = 0.279\, O_1 + 24.6$

$\Sigma V = 0; \quad O_1\, 0.987 + U_1\, 0.809 = 37.7$

$U_1 = 46.6 - 1.22\, O_1$

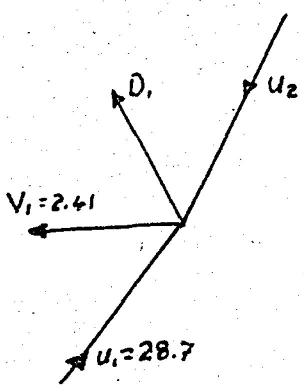
$46.6 - 1.22\, O_1 = 0.279\, O_1 + 24.6$

$O_1 = 14.7\ t \qquad U_1 = 28.7\ t.$



$\Sigma V = 0; \quad O_2 = 14.7 \times 0.987 = 14.5\ t.$

$\Sigma H = 0; \quad V_1 = 14.7 \times 0.164 = 2.41\ t$



$\Sigma H = 0; \quad 28.7\,(0.588) = U_2\,(0.491) + D_1\, 0.676 + 2.41$

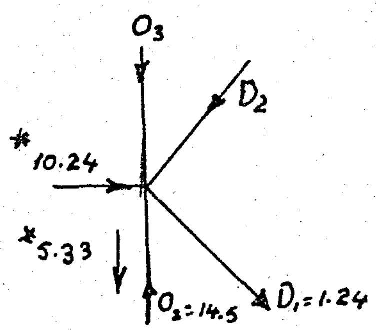
$U_2 = 29.5 - 1.38\, D_1$

$\Sigma V = 0; \quad 28.7\,(0.809) + D_1\,(0.737) = U_2\, 0.87$

$U_2 = 26.7 + 0.846\, D_1$

$26.7 + 0.846\, D_1 = 29.5 - 1.38\, D_1$

$D_1 = 1.24\ t. \qquad U_2 = 27.79\ t.$



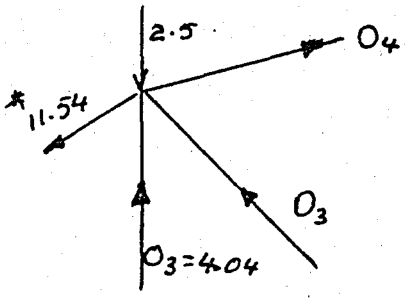
$\Sigma V = 0; \quad 14.5 - 5.33 - O_3 - D_2\,(0.355) - 1.24\,(0.737) = 0$

$O_3 = 8.255 - 0.355\, D_2$

$\Sigma H = 0; \quad 10.24 + 1.24\,(0.676) = D_2\, 0.935$

$D_2 = 11.89\ t \qquad O_3 = 4.04\ t.$

* 10.24 t and 5.33 t are the forces coming from the cantilever part.



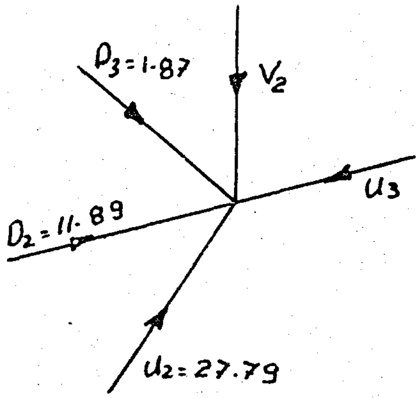
$\Sigma H = 0; \quad 0.94\, O_4 = D_3\, 0.792 + 11.54\,(0.887)$

$O_4 = 0.816\, D_3 + 10.58$

$\Sigma V = 0; \quad 4.04 - 2.5 + 0.61\, D_3 + 0.22\, O_4 = 11.54\,(0.462)$

$O_4 = 17.3 - 2.78\, D_3$

$D_3 = 1.87\, t \qquad O_4 = 12.1\, t.$



$\Sigma H = 0; \quad (11.89 - U_3)\,0.935 + 1.87\,(0.792) +$

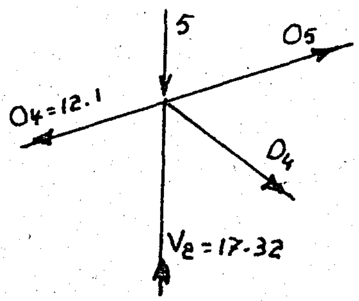
$+ 27.79\,(0.491) = 0$

$U_3 = 28.05\, t.$

$\Sigma V = 0; \quad V_2 + 1.87(0.61) + (28.05 - 11.89)\,0.355 =$

$= 27.79\,(0.87)$

$V_2 = 17.32\, t.$



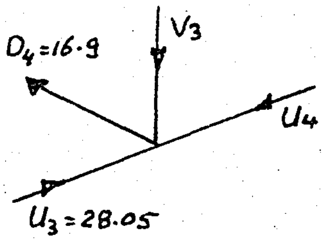
$\Sigma H = 0; \quad (O_5 - 12.1)\,0.972 + D_4\, 0.844 = 0$

$O_5 = 12.1 - 0.866\, D_4$

$\Sigma V = 0; \quad 12.32 + (O_5 - 12.1)\,0.22 = D_4\, 0.536$

$O_5 = 2.44\, D_4 - 43.9$

$D_4 = 16.9\, t \qquad O_5 = -2.5\, t.$

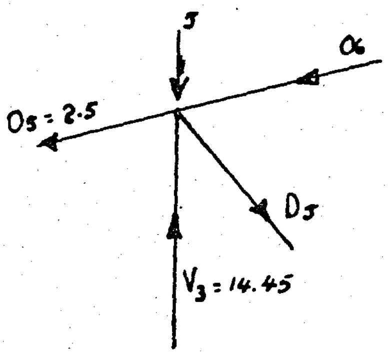


$\Sigma H = 0; \quad (28.05 - U_4)\,0.935 = 16.9\,(0.844)$

$U_4 = 15.2\, t.$

$\Sigma V = 0; \quad V_3 + (12.85 - 28.05)\,0.355 = 16.9\,(0.536)$

$V_3 = 14.45\, t.$



$\Sigma V = 0; \quad 9.45 - (O_6 + 2.5)\,0.22 - 0.447\,D_5 = 0$

$D_5 = 19.92 - 0.493\,O_6$

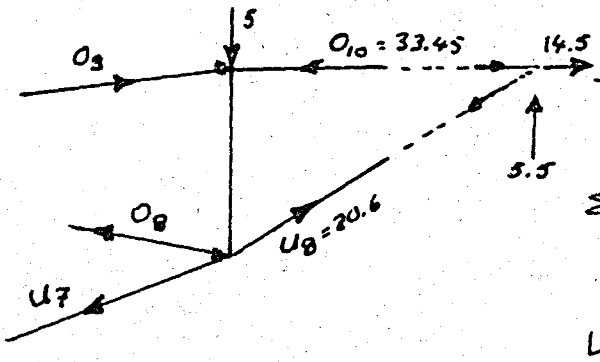
$\Sigma H = 0; \quad (2.5 + O_6)\,0.425 = 0.894\,D_5$

$D_5 = 1.19 + 0.475\,O_6$

$O_6 = 19.4\ t. \qquad D_5 = 10.39\ t.$

Then, beginning from hinge B;

$V_8 = 10.7 + 5 \times 6 + 2.5 - 37.7 = 5.5\,t.$



$\Sigma H = 0;$

$-O_{10}\,0.99 + 14.5 + U_8\,0.905 = 0$

$O_{10} = 14.65 + 0.914\,U_8$

$\Sigma V = 0; \quad -O_{10}\,0.14 + U_8\,0.425 - 5.5 = 0$

$O_{10} = 3.01\,U_8 - 36.9$

$U_8 = 24.5\,t \qquad O_{10} = 37.0\ t.$

$\Sigma H = 0; \quad 37.0 \times 0.99 = O_9\,0.97 \qquad O_9 = 37.7\,t$

$\Sigma V = 0; \quad -5 + V_7 + 37.7 \times 0.22 - 37.0 \times 0.141 = 0$

$V_7 = 1.9\ t.$

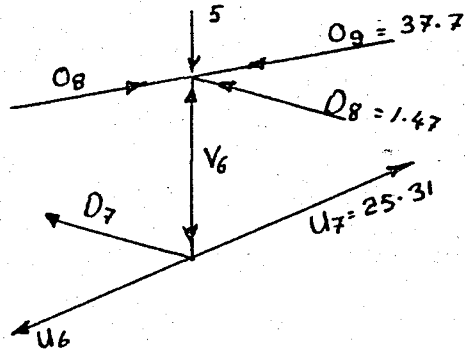
$\Sigma V = 0; \quad D_8 = \frac{1.9}{0.076} + \frac{0.355}{0.076}\,U_7 - \frac{0.425}{0.076} \times 24.5$

$D_8 = -119.7 + 4.67\,U_7$

$\Sigma H = 0; \quad D_8 = 24.5\,\frac{0.905}{0.997} - \frac{0.935}{0.997}\,U_7$

$D_8 = 22.27 - 0.938\,U_7$

$U_7 = 25.31\,t \qquad D_8 = -1.47\ t.$



$\Sigma H = 0;$

$O_8\, 0.972 = 37.7(0.972) + 1.47(0.997)$

$O_8 = 39.2\ t.$

$\Sigma V = 0;$

$O_8\, 0.22 + V_6 + 1.47(0.076) = 5 + 37.7(0.22)$

$V_6 = 4.59\ t.$

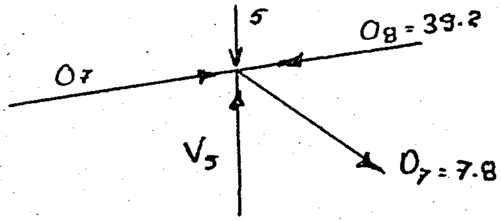
$\Sigma H = 0; \quad D_7\, 0.975 + U_6\, 0.935 = 25.31\,(0.935)$

$U_6 = 25.31 - 1.04\ D_7$

$\Sigma V = 0; \quad D_7\, 0.221 + 25.31\,(0.355) = 4.59 + 0.355\ U_6$

$U_6 = 0.62\ D_7 + 25.31 - 12.9$

$D_7 = 7.8\ t \qquad U_6 = 17.12\ t.$

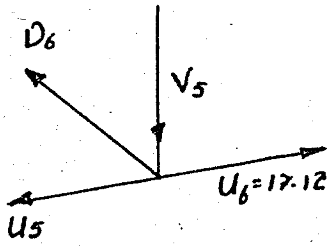


$\Sigma H = 0; \quad O_7\, 0.972 + 7.8(0.975) = 39.2\,(0.972)$

$O_7 = 31.35\ t.$

$\Sigma V = 0; \quad V_5 + 31.35\,(0.22) = 5 + 39.2\,(0.22) + 7.8(0.221)$

$V_5 = 8.44\ t.$



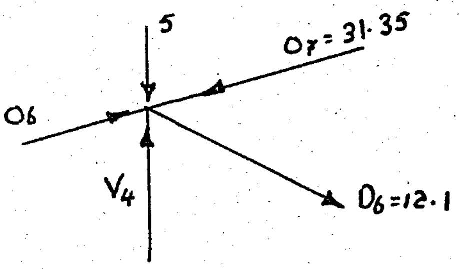
$\Sigma H = 0; \quad U_5\,(0.935) + D_6\,(0.94) = 17.12\,(0.935)$

$U_5 = 17.12 - 1.01\ D_6$

$\Sigma V = 0; \quad D_6\,(0.34) + 17.12(0.355) = 8.44 + U_5\,(0.355)$

$U_5 = 0.955\ D_6 - 6.68$

$D_6 = 12.1\ t \qquad U_5 = 2.8\,t.$



$\Sigma H = 0; \quad O_6\, 0.972 + 12.1(0.94) = 31.35\ (0.972)$

$O_6 = 19.65$

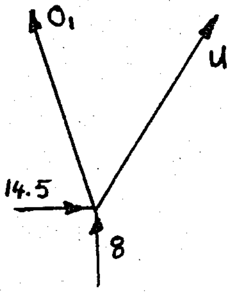
$\Sigma V = 0;$

$V_4 + 19.65\,(0.22) = 5 + 31.35\,(0.22) + 12.1\ (0.34)$

$V_4 = 11.61\ t.$

$O_6 = 19.65\,t \neq 19.4\,t$ Error = 0.25 t (acceptable)

Calculation of forces in the members for Case 2.



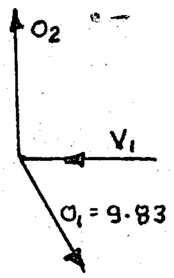
$\Sigma H = 0; \quad -O_1\, 0.164 + 14.5 + U_1\, 0.588 = 0$

$\Sigma V = 0; \quad O_1\, 0.987 + 8 + U_1\, 0.809 = 0$

$O_1 = 3.58\, U_1 + 88.41$

$3.53\, U_1 + 87.26 + 8 + 0.814 = 0$

$U_1 = 21.95\, t \qquad O_1 = 9.83\, t$



$\Sigma V = 0; \quad O_2 = 9.83\,(0.987) = 9.7\, t$

$\Sigma H = 0; \quad V_1 = 9.83\,(0.164) = 1.61\, t.$

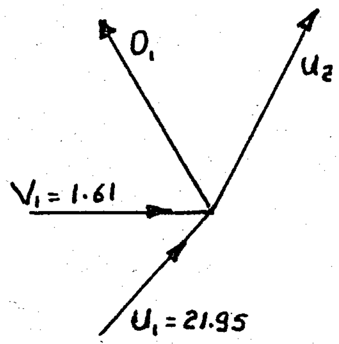
$\Sigma H = 0; \quad 21.95\,(0.588) + 1.61 - D_1\, 0.676 + U_2\, 0.491 = 0$

$\Sigma V = 0; \quad 21.95\,(0.809) + D_1\, 0.737 + U_2\, 0.87 = 0$

$-U_2 = 20.44 + 0.847\, D_1$

$12.907 + 1.61 - 0.676\, D_1 - 10.04 - 0.416\, D_1 = 0$

$D_1 = 4.10\, t \qquad U_2 = 23.91\, t$



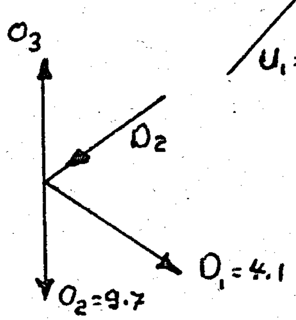
$\Sigma H = 0;$

$D_2 = 4.10\, \frac{0.676}{0.935} = 2.96\, t.$

$\Sigma V = 0;$

$-9.7 - 4.10\,(0.737) + O_3 - 2.96\,(0.355) = 0$

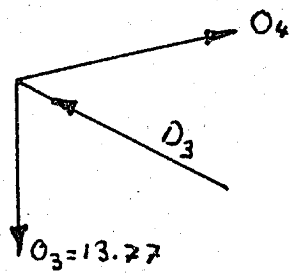
$O_3 = 13.77\, t$



$\Sigma H = 0; \quad 0.97\, O_4 = 0.792\, D_3 \qquad O_4 = 0.82\, D_3$

$\Sigma V = 0; \quad 0.82\, D_3\,(0.236) + 0.61\, D_3 = 13.77$

$D_3 = 17.23\, t \qquad O_4 = 14.13\, t$

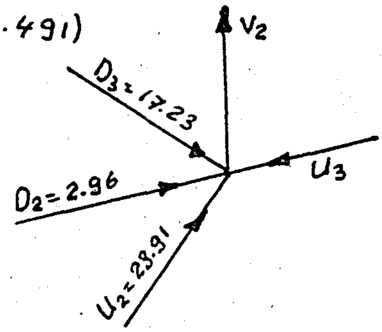


$\Sigma H = 0;\quad U_3\,0.935 = 17.23\,(0.792) + 2.96\,(0.935) + 23.91\,(0.491)$

$U_3 = 30.20\ t.$

$\Sigma V = 0;\quad V_2 - 30.2\,(0.355) - 17.23\,(0.61) + 2.96\,(0.355) + 23.91\,(0.871) = 0$

$V_2 = -0.71\ t.$



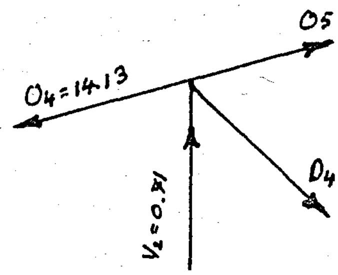
$\Sigma H = 0;\quad O_5\,0.972 + D_4\,0.844 - 14.13\,(0.972) = 0$

$O_5 = 14.13 - 0.866\,D_4$

$\Sigma V = 0;\quad (O_5 - 14.13)\,0.22 + 0.71 = 0.536\,D_4$

$O_5 = 2.44\,D_4 + 10.9$

$D_4 = 0.98\ t \qquad O_5 = 13.28\ t.$

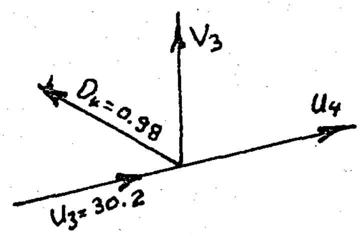


$\Sigma H = 0;\quad (30.2 + U_4)\,0.935 - 0.98\,(0.844) = 0$

$U_4 = -29.32\ t.$

$\Sigma V = 0;\quad -V_3 = (30.2 - 29.32)\,0.355 + 0.98\,(0.536)$

$V_3 = -0.84\ t.$

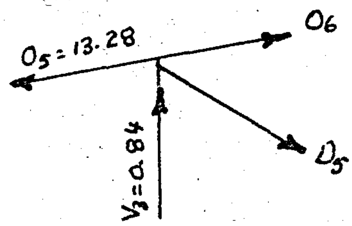


$\Sigma H = 0;\quad (O_6 - 13.28)\,0.972 + 0.894\,D_5 = 0$

$O_6 = +13.28 - 0.926\,D_5$

$\Sigma V = 0;\quad 0.84 - 0.447\,D_5 - 13.28\,(0.22) + O_6\,0.22 = 0$

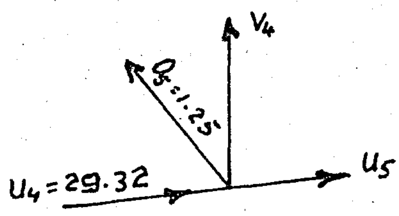
$D_5 = 1.25\ t \qquad O_6 = 12.12\ t$



$\Sigma H = 0;\quad 29.32 + U_5 = 1.25\,\dfrac{(0.894)}{0.935} \qquad U_5 = -28.12\ t$

$\Sigma V = 0;\quad V_4 + 1.2\,(0.355) + 1.25\,(0.447) = 0$

$V_4 = -0.98\ t.$

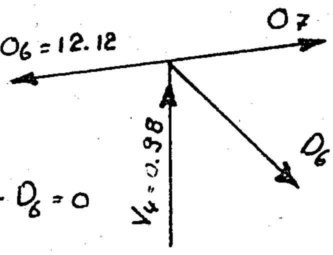


$\Sigma H = 0;$ $(O_7 - 12.12)0.972 + D_6\,0.94 = 0$

$O_7 = 12.12 - 0.97\,D_6$

$\Sigma V = 0;$ $0.98 - 12.12(0.22) - D_6\,0.34 + 12.12\,(0.22) - 0.214\,D_6 = 0$

$D_6 = 1.8\,t \qquad O_7 = 10.37\,t.$

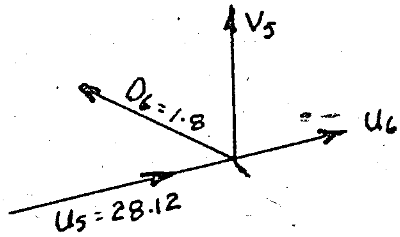


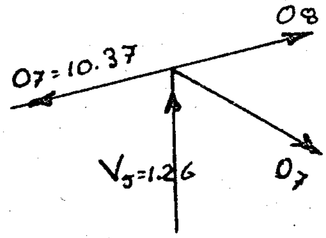
$\Sigma H = 0;$ $(28.12 + U_6)\,0.935 - 1.8\,(0.94) = 0$

$U_6 = -26.31\ \ t.$

$\Sigma V = 0;$ $V_5 + 1.8\,(0.34) + 1.81\,(0.355) = 0$

$V_5 = -1.26\,t.$



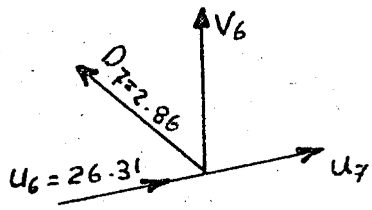


$\Sigma H = 0;$ $(O_8 - 10.37)\,0.972 + 0.975\,D_7 = 0$

$O_8 = 10.37 - D_7$

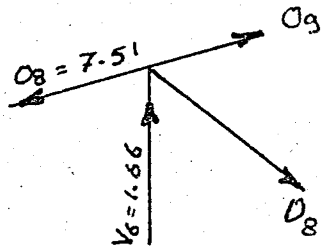
$\Sigma V = 0;$ $1.26 - D_7\,0.221 - 0.22\,D_7 = 0$

$D_7 = 2.86\,t. \qquad O_8 = 7.51\,t$



$\Sigma H = 0;$ $U_7 = -26.31 + 2.86\,\dfrac{0.975}{0.935} = -23.41\,t.$

$\Sigma V = 0;$ $V_6 = -2.86\,(0.221) - 2.9\,(0.355) = -1.66\,t.$



$\Sigma H = 0;$ $(O_9 - 7.51)\,0.972 + D_8\,0.997 = 0$

$O_9 = 7.51 - 1.026\,D_8$

$\Sigma V = 0;$ $1.66 - 0.076\,D_8 - 1.026\,(0.22)\,D_8 = 0$

$D_8 = 5.5\,t \qquad O_9 = 1.87\,t.$

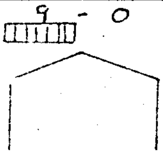
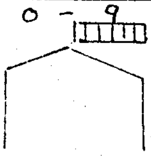
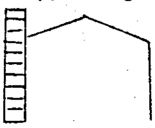
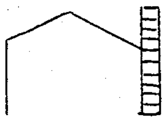
Check: $\Sigma H = 0;$ $1.87\,(0.972) + 5.5\,(0.997) - 23.41\,(0.935) = H$

$H = 14.48\,t. \neq 14.5\,t.$

Error $= 0.02\,t$ (acceptable)

Cases 3 and 4 are solved by graphical method, the results of which are given in the table.

Table for maximum forces in the members:

	q - 0 	0 - q 	$q_{max.}$	w - 0 	0 - w 	± $P_{max.}$ (tons)
U_1	-28.7	-21.95	-50.65	+18.2	-7.0	-57.65
U_2	-27.79	-23.91	-51.70	+18.3	-7.9	-59.60
U_3	-28.05	-30.20	-58.25	+18.5	-9.8	-68.05
U_4	-12.85	-29.32	-42.17	+18.7	-9.4	-51.57
U_5	+2.81	-28.12	-25.31	+16.6	-9.1	-34.40
U_6	+17.12	-26.31	-17.75 +3.97	+16.6	-8.8	-26.55
U_7	+25.31	-23.41	-10.76 +13.61	+16.6	-7.4	-18.16 +30.21
U_8	+24.50	-20.00	-7.50 +14.50	+11.4	-6.5	-14.00 +25.90
O_1	-14.7	+9.83	+2.48 -9.79	-13.4	+3.2	-23.9
O_2	-14.5	+9.70	+2.45 -9.65	-12.05	+3.1	-21.7
O_3	-4.04	+13.77	+11.75 +2.8	-13.1	+4.1	+15.85 -10.26
O_4	+12.1	+14.13	+26.23	-12.3	+4.4	+30.63
O_5	-2.5	+13.28	+12.03 +4.14	-16.0	+4.3	+16.33 -11.86
O_6	-19.4	+12.12	+2.42 -13.34	-17.25	+4.0	-30.59
O_7	-31.35	+10.37	-5.30 -26.17	-17.9	+3.4	-44.07

O_8	-39.2	+7.51	-12.09 -35.45	-17.2	+2.6	-52.65
O_9	-37.7	+1.87	-36.77	-15.9	+1.3	-52.67
O_{10}	-37.0	+3.68	-35.16	-15.1	+1.3	-50.16
V_1	+2.41	-1.61	-0.41	+0.7	-0.6	-1.1 +2.3
V_2	-17.32	-0.71	-18.03	-0.7	-0.2	-18.73
V_3	-14.45	-0.84	-15.29	-0.4	-0.3	-15.69
V_4	-11.61	-0.98	-12.59	-0.07	-0.3	-12.89
V_5	-8.44	-1.26	-9.70	+0.26	-0.4	-10.1
V_6	-4.59	-1.66	-6.25	+0.8	-0.5	-6.75
V_7	-1.9	-1.0	-2.9	+0.5	-0.1	-3.0
D_1	+1.24	+4.10	+5.34	-3.0	+1.4	+6.74
D_2	-11.89	-2.96	-14.85	-0.2	-1.0	-15.85
D_3	-1.87	-17.23	-19.10	+0.8	+0.2	-18.9
D_4	+16.9	+0.98	+17.88	+0.4	+0.3	+18.28
D_5	+10.4	+1.25	+11.65	+0.1	+0.4	+12.05
D_6	+12.5	+1.8	+14.3	-0.4	+0.5	+14.8
D_7	+7.8	+2.86	+10.66	-1.33	+0.8	+11.46
D_8	-1.47	+5.5	+1.23 +4.77	-3.16	+1.5	+6.27 -1.93

Members U_1 and U_2 ; $P_{max} = -59.6\ t$

$F_{req.} = \frac{59.6}{1.4} = 42.6\ cm^2$ **Use ⊥L 2×130×130×12**

$F = 2 \times 30 = 60 cm^2 > 42.6\ cm^2$

$G = 23.6\ kg/m$ $i_x = 3.97 \times 2$

$S_k = 285\ cm$ $\lambda = \frac{285}{2 \times 3.97} = 36 \rightarrow \omega = 1.11$ $\sigma_{max} = 1.11 \frac{59.6}{60} = 1100\ kg/cm^2 < 1400$

$S_k = 180\ cm$ $\lambda = \frac{180}{2 \times 3.97} = 22 \rightarrow \omega = 1.05$ $\sigma_{max} = 1.05 \frac{57.65}{60} = 1010\ kg/cm^2 < 1400$

Members $U_3 - U_4 - U_5$; $P_{max} = -68.05\ t.$

$F_{req.} = \frac{68.05}{1.4} = 48.6\ cm^2$ **Use ⊥L 2×130×130×12**

$F = 60 cm^2 > 48.6 cm^2$

$G = 23.6\ kg/m$ $i_x = 2 \times 3.97$

$S_k = 310$ $\lambda = \frac{310}{2 \times 3.97} = 39.0 \rightarrow \omega = 1.13$ $\sigma_{max} = 1.13 \frac{68.05}{60} = 1285\ kg/cm^2 < 1400$

Members $U_6 - U_7 - U_8$; $P_{max} = -26.55 t$ and $+30.21\ t$

$F_{req.} = \frac{30.21}{1.4} = 21.6\ cm^2$ **Use ⊥L 2×80×80×10**

$F = 2 \times 15.1 = 30.2 cm^2 > 21.6 cm^2$ $G = 11.9\ kg/m$ $i_x = 2 \times 2.41$

$S_k = 310$ $\lambda = \frac{310}{2 \times 2.41} = 65 \rightarrow \omega = 1.35$ $\sigma_{max} = 1.35 \frac{26.55}{30.2} = 1180\ kg/cm^2 < 1400$

Members $O_1 - O_2 - O_3$; $P_{max} = -23.9\ t$

$F_{req.} = \frac{23.9}{1.4} = 17.1\ cm^2$ **Use ╞ 2×80×80×8**

$F = 2 \times 12.3 = 24.6 cm^2 > 17.1 cm^2$

$G = 9.66\ kg/m$ $i_x = 2 \times 2.42$

$S_k = 150$ $\lambda = \frac{150}{2 \times 2.42} = 31 \rightarrow \omega = 1.09$ $\sigma_{max} = 1.09 \frac{23.9}{24.6} = 1060\ kg/cm^2 < 1400$

Members O_4 and O_5; $P_{max} = -11.86\ t$ and $+30.63\ t$

$F_{req.} = \frac{30.63}{1.4} = 21.8\ cm^2$ Use ㄒㄏ $2 \times 80 \times 80 \times 8$

$F = 24.6\ cm^2 > 21.8\ cm^2$

$G = 9.66\ kg/m$ $i_x = 2 \times 2.42$

$S_k = 300$ $\lambda = \frac{300}{2 \times 2.42} = 62 \rightarrow \omega = 1.32$ $\sigma_{max} = 1.32\ \frac{11.86}{24.6} = 705\ kg/cm^2 < 1400$

Members $O_6 - O_7 - O_8 - O_9 - O_{10}$; $P_{max} = -52.67\ t$

$F_{req.} = \frac{52.67}{1.4} = 37.6\ cm^2$ Use ㄒㄏ $2 \times 130 \times 130 \times 12$

$F = 60\ cm^2 > 37.6\ cm^2$

$G = 23.6\ kg/m$ $i_x = 2 \times 3.97$

$S_k = 300$ $\lambda = \frac{300}{2 \times 3.97} = 38 \rightarrow \omega = 1.13$ $\sigma_{max} = 1.13\ \frac{52.67}{60} = 1000\ kg/cm^2 < 1400$

Diagonals

Members $D_4 - D_5 - D_6$; $P_{max} = +18.28\ t$

$F_{req.} = \frac{18.28}{1.4} = 13.1\ cm^2$ Use ㄒㄏ $2 \times 60 \times 60 \times 6$

$F = 2 \times 6.91 = 13.82\ cm^2 > 13.1\ cm^2$

$G = 5.42\ kg/m$ $\sigma_{max} = \frac{18.28}{13.82} = 1320\ kg/cm^2 < 1400\ kg/cm^2$

Members D_7 and D_8; $P_{max} = +11.46\ t$

$F_{req.} = \frac{11.46}{1.4} = 8.2\ cm^2$ Use ㄒㄏ $2 \times 45 \times 45 \times 5$

$F = 2 \times 4.30 = 8.6\ cm^2 > 8.2\ cm^2$

$G = 3.38\ kg/m$ $\sigma_{max} = \frac{11.46}{8.6} = 1330\ kg/cm^2 < 1400\ kg/cm^2$

Members D_2 and D_3 ; $P_{max} = -18.9\ t$

$F_{req.} = \frac{18.9}{1.4} = 13.5\ cm^2$ — **Use ⌐⌐ 2x 80x 80x 8**

$F = 24.6\ cm^2 > 13.5\ cm^2$

$G = 9.66\ kg/m$ $\quad i_x = 2 \times 2.42$

$S_k = 405$ $\quad \lambda = \frac{405}{2 \times 2.42} = 89 \rightarrow \omega = 1.69$

$\sigma_{max} = 1.69\ \frac{18.9}{24.6} = 1300\ kg/cm^2 < 1400\ kg/cm^2$

Members D_1 and V_1 ; $P_{max} = +6.74\ t$ and $-1.1\ t$

$F_{req.} = \frac{6.74}{1.4} = 4.8\ cm^2$ — **Use ⌐⌐ 2x 35x 35x 4**

$F = 5.34\ cm^2 > 4.8\ cm^2$

$G = 2.10\ kg/m$ $\quad i = 2 \times 1.05$

$S_k = 134$ $\quad \lambda = \frac{134}{2 \times 1.05} = 64 \rightarrow \omega = 1.34$ $\quad \sigma_{max} = 1.34\ \frac{1.1}{5.34} = 250\ kg/cm^2 < 1400$

Verticals :

Members $V_2 - V_3 - V_4$; $P_{max} = -18.73\ t$

$F_{req.} = \frac{18.73}{1.4} = 13.4\ cm^2$ — **Use ⌐⌐ 2 x 80x 80 x 8**

$F = 24.6\ cm^2 > 13.4\ cm^2$

$G = 9.66\ kg/m$ $\quad i_x = 2 \times 2.42$

$S_k = 275$ $\quad \lambda = \frac{275}{2 \times 2.42} = 57 \rightarrow \omega = 1.27$ $\quad \sigma_{max} = 1.27\ \frac{18.73}{24.6} = 990\ kg/cm^2 < 1400$

Members $V_5 - V_6 - V_7$; $P_{max} = -10.1\ t$

$F_{req.} = \frac{10.1}{1.4} = 7.2\ cm^2$ — **Use ⌐⌐ 2x 45x 45x 5**

$F = 8.6\ cm^2 > 7.2\ cm^2$ $\quad G = 3.38\ kg/m$ $\quad i = 2 \times 1.35$

$S_k = 162.5$ $\quad \lambda = \frac{162.5}{2 \times 1.35} = 38 \rightarrow \omega = 1.13$ $\quad \sigma_{max} = 1.13\ \frac{10.1}{8.6} = 1320\ kg/cm^2 < 1400$

Actual Weight Of the Frame

$2 \times 130 \times 130 \times 12$; $23.6\,(2.85 + 1.8 + 9.3 + 15.0) = 682$ kg

$2 \times 80 \times 80 \times 10$; $11.9\,(9.3) = 111$ kg

$2 \times 80 \times 80 \times 8$; $9.66\,(1.5 + 1.46 + 3.125 + 6.0 + 3.1 + 4.05 + 2.75 + 2.375 + 2.0)$

$= 254$ kg

$2 \times 60 \times 60 \times 6$; $5.42\,(3.2 + 3.06 + 2.9) = 49.6$ kg

$2 \times 45 \times 45 \times 5$; $3.38\,(2.8 + 2.75 + 1.625 + 1.25 + 0.875)$

$= 31.4$ kg

$2 \times 35 \times 35 \times 4$; $2.10\,(2.0 + 1.34) = 7.0$ kg

Total $= 1135.0$ kg.

$$\frac{1135}{11.85 \times 19} = 5.05 \text{ kg/m}^2$$

This is raised to 8 kg/m² including the roof of the gallery. So it is less than the assumed value of 15 kg/m², which is safer.

PART - IV

CHECK FOR THE SUBSTRUCTURE

I- Weight on the Frame:

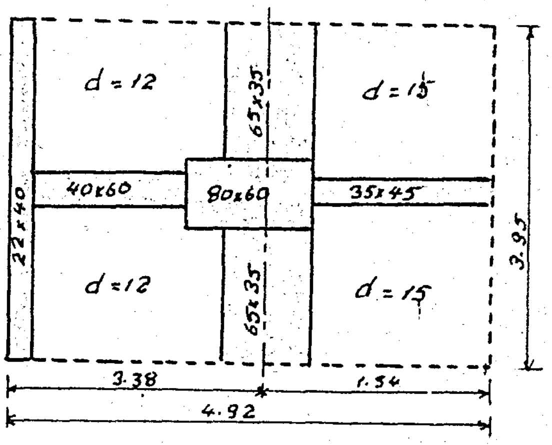
$$\frac{48.2}{11.85\,(19+6)} = 163 \text{ kg/m}^2 < 240 \text{ kg/m}^2$$

So, the weight on the frame is less than the recommended value 240 kg/m².

II- Weight on the footing:

A- Dead Load of tribunes:

Volume of concrete:



$0.22 \times 0.4 \times 3.95$ . . . . . . = 0.348 m³

$0.65 \times 0.35 \times 3.35$ . . . . = 0.762

$0.4 \times 0.6 \times 2.64$ . . . . = 0.624

$0.35 \times 0.45 \times 1.22$ . . . . = 0.019

$0.12\,[2.84 \times 3.95 - 0.4 \times 2.84 - 0.2 \times 0.15]$ = 1.200

$0.15\,[1.22 \times 3.95 - 0.35 \times 1.22]$ = 0.670

Total volume of concrete = 3.659 m³

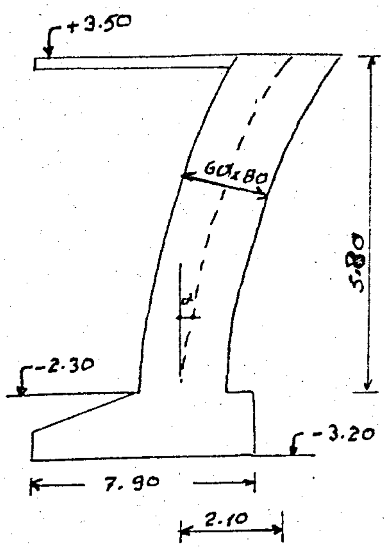
Weight of concrete = 3.659×2.4 = 8.7 t

B- Live Load on tribunes:

Assume L.L. to be 0.4 t/m²

Total live load = $0.4 \times 3.95 \times 4.92$ = 7.1 t

C- Weight of Column below the tribunes:



Assuming the column to be straight,

length of column = $\sqrt{5.8^2 + 2.1^2}$

= 6.15 m.

Weight of column = 0.6 x 0.8 x 6.15 x 2.4

= 7.0 t.

D- Total Weight on the footing:

D.L.	from tribunes	= 8.7 t
L.L.	from tribunes	= 7.1 t
Weight of column below tribunes		= 7.0 t
Weight from frame		= 48.2 t
		71.0 t

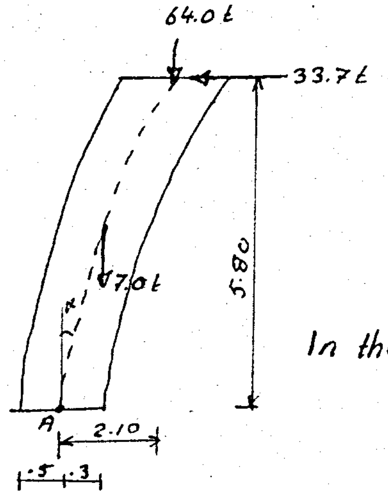
Area of footing = 2.80 x 7.90 m^2

$\sigma_{soil} = \frac{71000}{2.80 \times 7.90} = 2.52\ t/m^2$ or $0.252\ kg/cm^2$

III - Check For Concrete Column:

Weight on the column:

Weight from frame		= 48.2 t
D.L.	of tribunes	= 8.7 t
L.L.	of tribunes	= 7.1 t
	total	= 64.0 t



$\cos\alpha = \frac{5.8}{6.15} = 0.94$

$\sin\alpha = \frac{2.10}{6.15} = 0.34$

$M_A = 33.7 \times 5.8 - 64.0 \times 2.10 - 7.0 \times \frac{2.10}{2}$

$= 53.65\ tm.$

In the direction of the axis of the column;

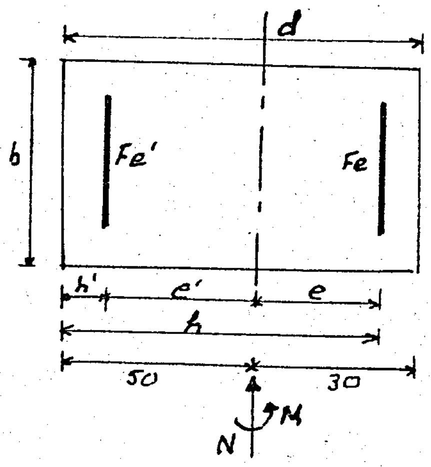
$N_A = 0.94\,(64.0 + 7.0) + 0.34\,(33.7)$

$= 78.0\ t$

$e = \frac{M}{N} = \frac{53.65}{78.0} = 0.69$

$\varepsilon = \frac{e}{d} = \frac{69}{80} = 0.86 > 0.407$

∴ big eccentricity



$M_e = M + Ne$

$= 5365 + 78\,(26)$

$= 7395\ tcm.$

$M_e' = M - Ne'$

$= 5365 - 78\,(46)$

$= 1785\ tcm.$

$h' = 4\ cm$ $\frac{\sigma_e}{\sigma_b} = \frac{1.4}{0.7} = 20$ $\frac{h'}{h} = \frac{4}{76} \cong 0.05$

$\sigma_b\, b h^2 = 70 \times 60 \times 76^2 = 24.2 \times 10^3\ tcm.$

Reading from graph for $h' = 0.05h$ values of μ and μ' corresponding to ρ and ρ' are obtained.

$$\rho = \frac{Me}{\sigma_b bh^2} = \frac{7395}{24.2 \times 10^3} = 0.305 \longrightarrow \mu = 1.1\ \%$$

$$\rho' = \frac{Me'}{\sigma_b bh^2} = \frac{1785}{24.2 \times 10^3} = 0.074 \longrightarrow \mu' = 0.52\ \%$$

$$\frac{\sigma_e}{\sigma_b} = 10.5 < 20 \checkmark$$

$$Fe = \mu bh = \frac{1.1}{100} \times 60 \times 76 = 50.0\ cm^2$$

In the column we have 10 ϕ 26 → 53.09 cm^2 > 50.0 cm^2 ✓

$$Fe' = \mu' bh = \frac{0.52}{100} \times 60 \times 76 = 23.8\ cm^2$$

In the column we have 6 ϕ 26 → 31.8 cm^2 > 23.8 cm^2 ✓

∴ reinforcement of the column is sufficient to carry such a superstructure. There is no need to add more steel to the columns.

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"Betonarme inşaat" by F. Dischinger

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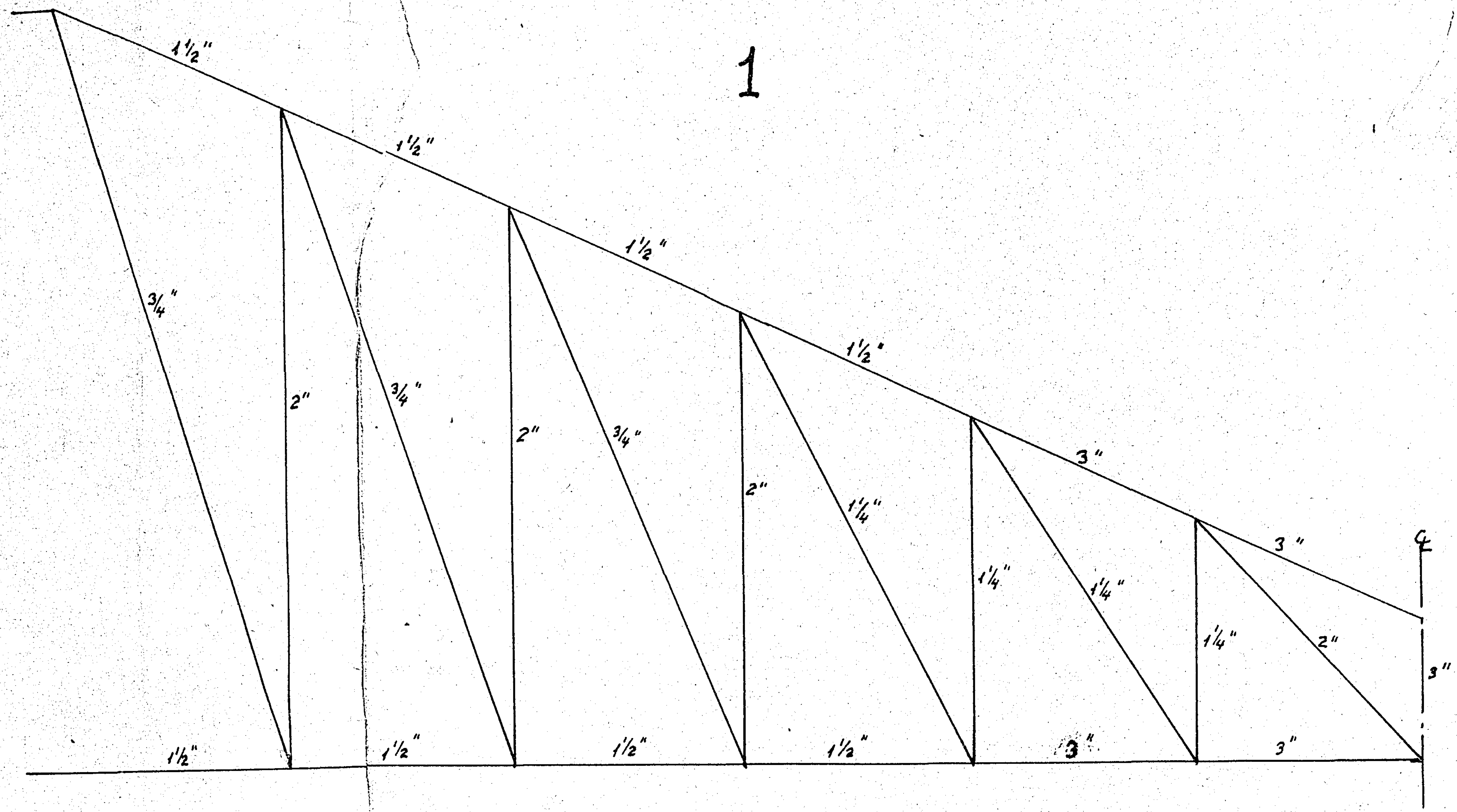
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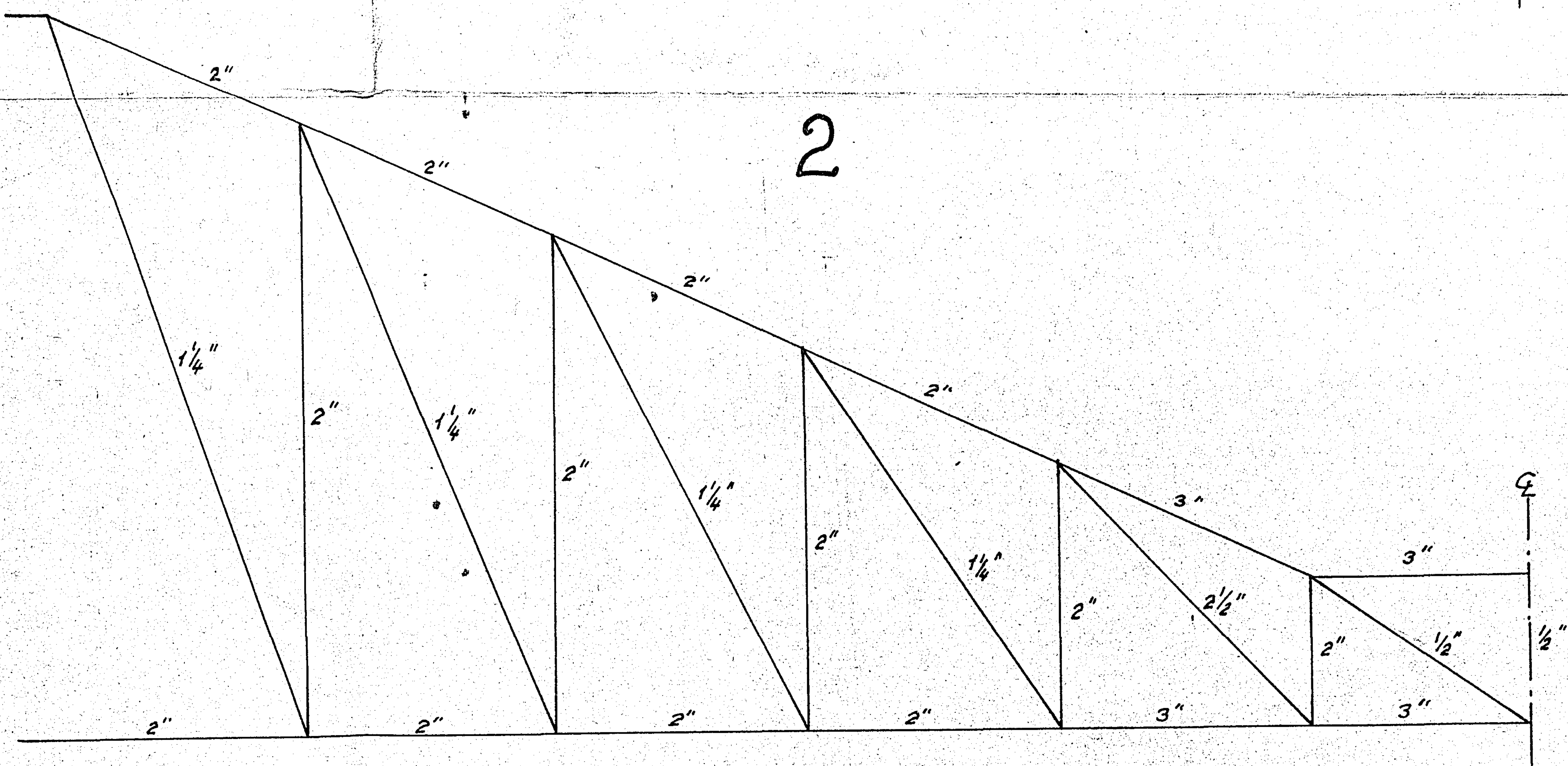
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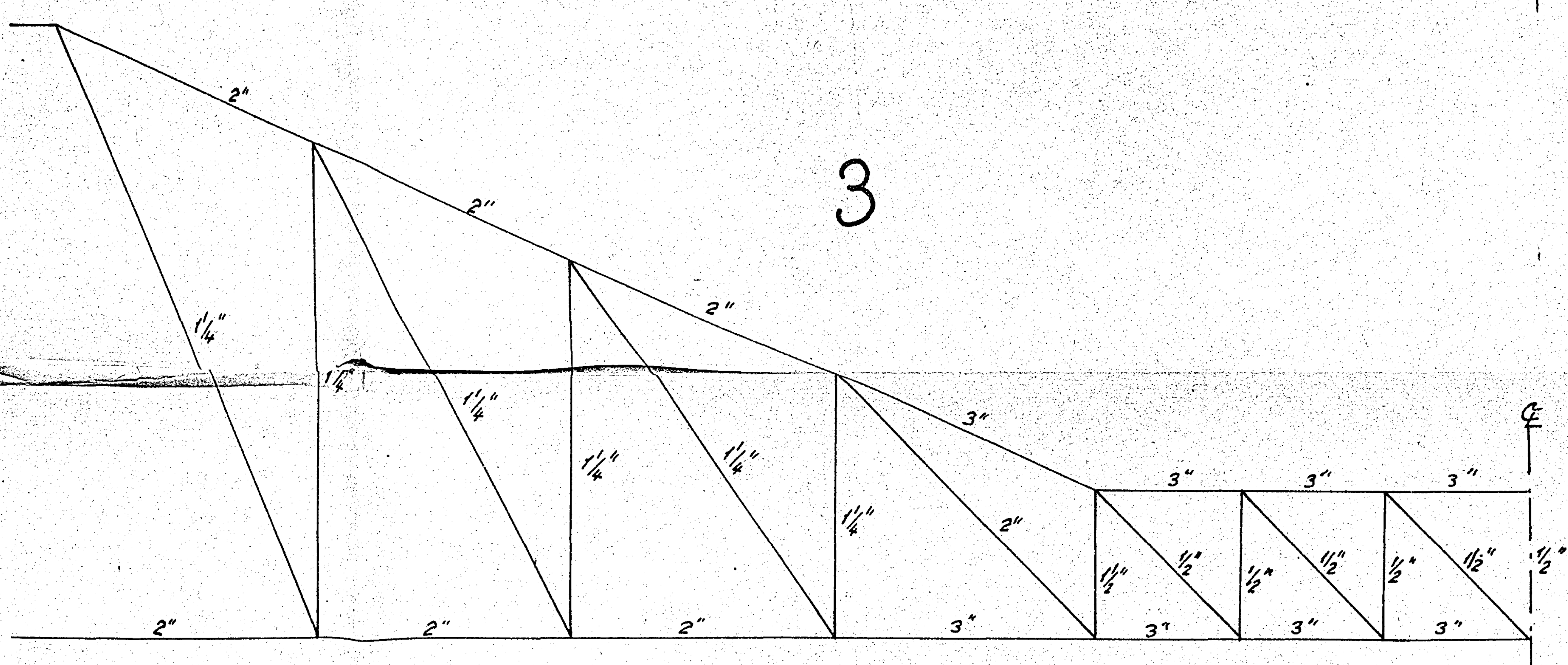
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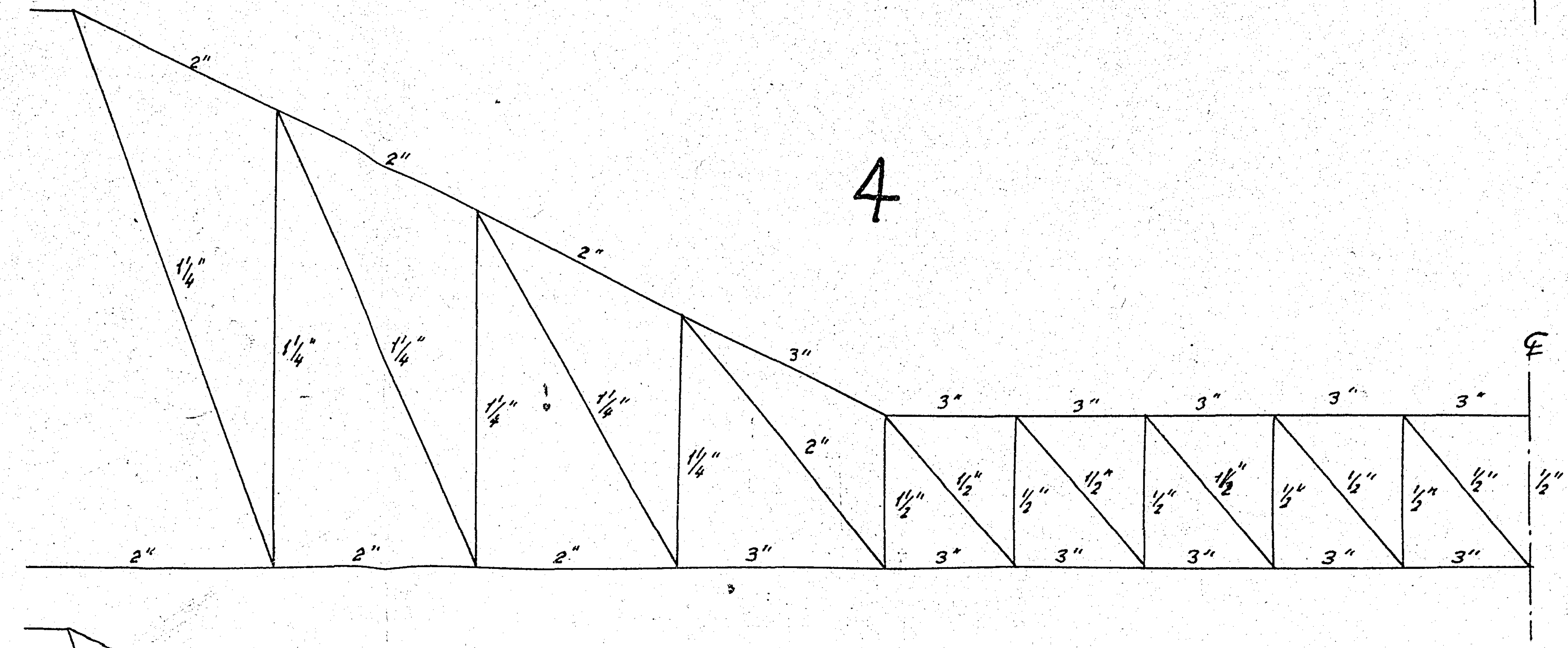
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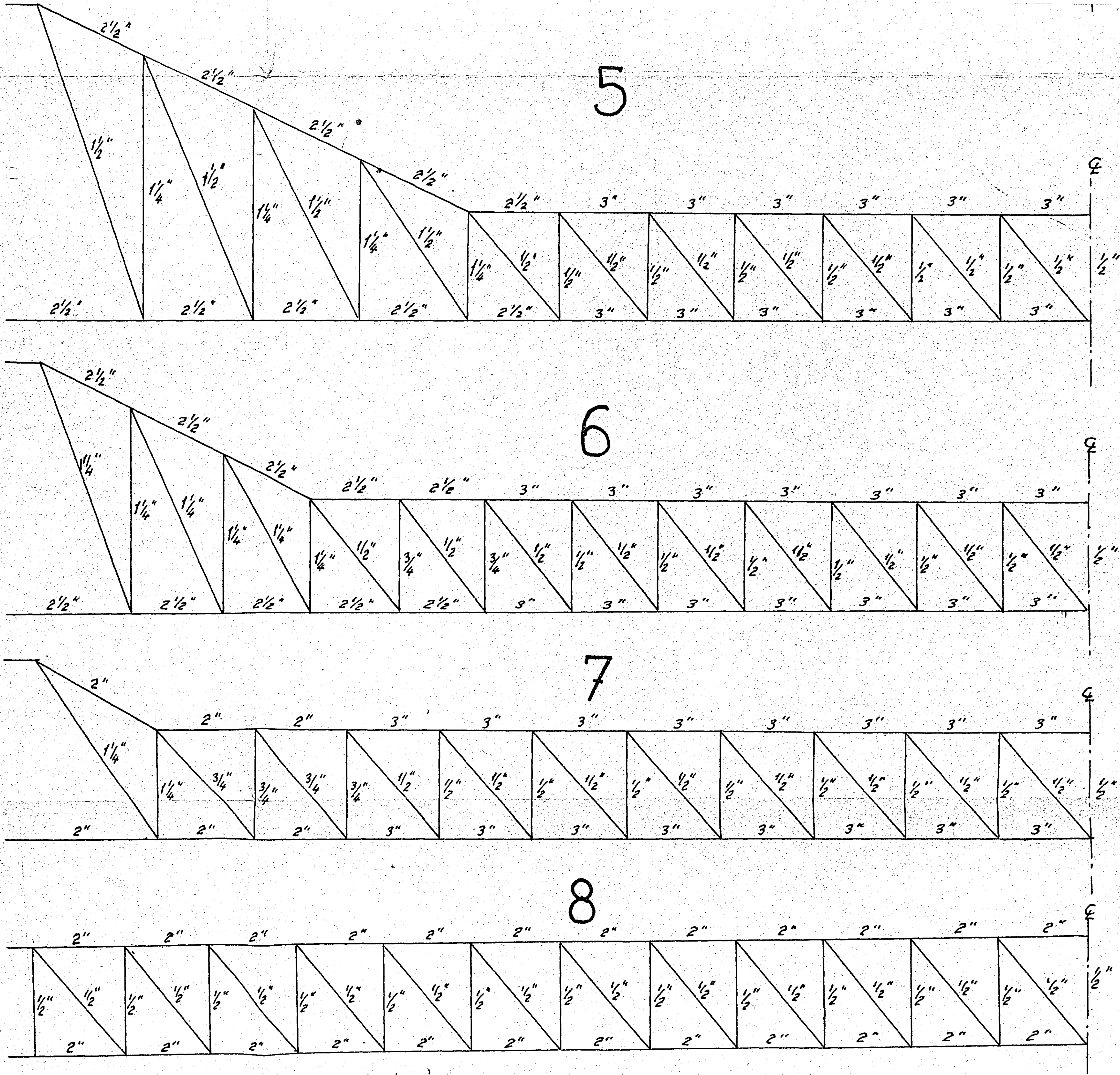

Fig: IV

THE GIRDERS:

SIZES OF THE PIPES

SCALE: 1/20

FIG: II

Cross-section Of the Ankara Indoor Stadium

Scale 1/100

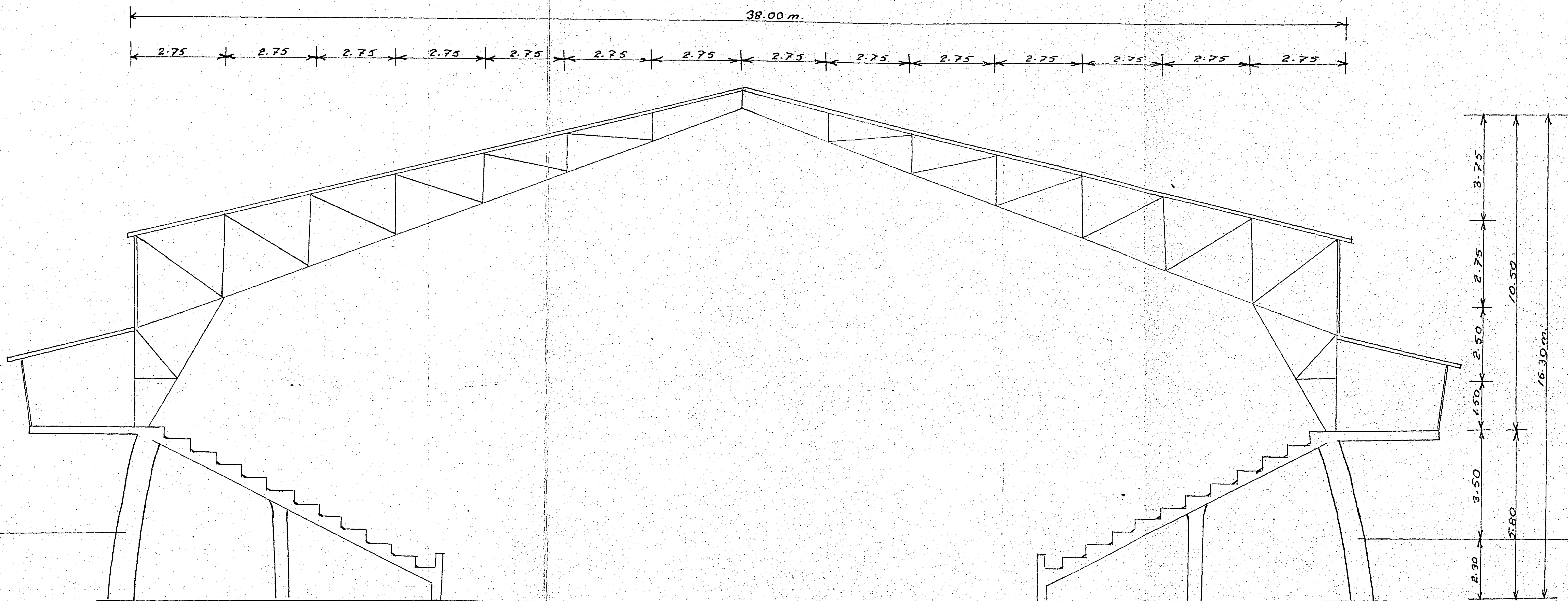

FIG: III

Roof of the Indoor Stadium

Scale: 1/200