NATIONAL RADIO ASTRONOMY OBSERVATORY
POST OFFICE BOX 2
GREEN BANK, WEST VIRGINIA 24944
TELEPHONE ARBOVALE 456-2011

REPORT NO. 11
CONTRACT NO. ____
PAGE 1 OF __
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PROJECT: LFST
SUBJECT: FTT

Tower for A Flat Transit Telescope

S. von Hoerner

1. Azimuth Drive

The support structure (for the secondary mirror, on top of the tower), suggested by O. Heine, will become more stiff and will have much less weight if the tower provides not only a ring for the azimuth drive but also a stiff pintle bearing high above this ring; the pintle bearing (point 3 in Fig. 1) shall take lateral and horizontal forces. The azimuth ring (points 4, 6, 7, 8), then, is mainly for driving, there is no strong force on it, and it needs an accuracy of 0.1 inch for 5 cm wavelength, and of 0.2 inch for 10 cm. With this arrangement, one really can take wheels for the azimuth drive, just as was done for the elevation drive, anyway.

The tower provides, without addition, the pintle bearing (point 3), and a basic triangle (points 4, 6, 8) for the azimuth ring. Additional points for the ring must be introduced, like point 7 which rests on point 5, where the lower parts of the legs meet.

2. Wind Area of Top Structure

O. Heine's structure has 408 m^2 wind area. From my Report 10 follows that this cannot be improved much; maybe some improvement is possible by using split-up members instead of filling the whole volumn with a regular lattice; I will adopt for the present purpose 370 m^2. The secondary mirror has about 100 m^2 itself, and I adopt the same area for any direction, including its structure. The ring of the azimuth drive on the tower was estimated with the help of Report 10 and gave 80 m^2 (in addition to the members of the tower itself). Altogether, we have

$$\text{wind area of top structure} = 550 \text{ m}^2 = 5900 \text{ ft}^2 . \qquad (1)$$

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The top structure is at an average height of 590 ft, the tower itself of about 400 ft; I have adopted for everything a height of 500-ft. During observation, I have adopted 20 mph wind velocity at the ground, which, according to E. Faelten's table, is 30.4 mph at 500 ft, including gust factors, giving a pressure of

$$3.22\ \mathrm{lb/ft^2} = 1.56\ \mathrm{g/cm^2}\ \text{during observation.} \tag{2}$$

Just for curiosity, we calculate the amount of steel needed for holding area (1) with an accuracy of 0.5 cm against pressure (2) at a height of 590 ft, with three legs at 67° above ground, if we completely neglect the wind area of these legs, as well as any steel needed for lacing. The result is:

$$W_o = 335\ \text{tons.} \tag{3}$$

For survival, I have adopted 100 mph on the ground, which is 152 mph at 500 ft including gust factors, giving a pressure of

$$80.5\ \mathrm{lb/ft^2} = 39.0\ \mathrm{g/cm^2}\ \text{for survival.} \tag{4}$$

Under the same neglections, we calculate the amount of steel needed to hold area (1) against pressure (4) not exceeding 17000 psi, and we find

$$W_s = 126\ \text{tons.} \tag{5}$$

Since (5) is so much smaller than (3), we can go to fairly large ℓ/r ratios, up to about 150, which is very convenient.

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3. Two Types of Towers

It follows from Report 10 that the tower should have three legs. In order to yield a stable triangle for the azimuth ring, each leg must consist of at least two chords, going to two different points of the triangle.

There are two ways in which this can be accomplished. First, we make these chords of ropes and have them in tension; this needs a central guyed compression tower, which holds everything up and provides the tension for the ropes. Second, without any central tower, the legs are in compression; in order to prevent buckling, we then need a third chord for each leg, and the best way is to let this chord go to the third point of the triangle. The chords are connected to struts in compression and diagonals in tension. This second approach seems to be somewhat more economical.

4. Tower with Three Compression Legs

The tower with three compression legs, three chords each, is sketched in Fig. 1. It must fulfill two conditions: a) keep the wind deflections during observation, Δx, below a specified value; usually, one takes $\lambda/16$, but in order to allow for some deformation of the top structure too, I have taken

$$\Delta x = \lambda/20 \text{ during observation,} \qquad (6)$$

and, b) the tower must be stable against survival winds (4). The chords should be made of pipes, which yields three free parameters: the outer diameter D of a pipe, its wall thickness τ, and the unsupported length ℓ. Many trials were calculated in order to minimize the total weight. The following table gives the best solution for two wavelengths, 10 cm and 5 cm. Main chords and struts are of normal steel, the diagonals are ropes, with Yield = 150 000 psi (S = 90 000 psi). W is the total weight of the tower, including struts and diagonals up to the pintle bearing, but excluding the azimuth ring and the support structure rotating

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in azimuth. N is the number of segments, from the point where the legs meet down to the ground (N = 8 in Fig. 1).

Table 1

λ cm	Δx cm	main chords N	main chords ℓ ft	main chords D inch	main chords τ inch	struts ℓ ft	struts D inch	struts τ inch	diagon. D inch	W 10^3 tons
10	.50	10	50	15.3	1.85	30	8.21	1.01	1.87	1.05
5	.25	9	56	17.1	4.20	30	8.97	2.00	2.61	2.21

There is a second system of secondary members shown in Fig. 1; it consists of a long central rope between any two chords, and a little triangle meeting the center points of the struts. I have not actually sized these members, but their estimated contribution to weight and wind area is already included in the above table. If we adopt about 1000$/ton, we find about 1 million dollars for 10 cm wavelength, and about 2 million dollars for 5 cm.

5. Temperature Deformation

Although the price is not inhibitive for going to still shorter wavelengths, the temperature deformations are. If one leg is ΔT degrees (centigrade) warmer than the other two legs, the top of the tower will shift by

$$\Delta x = 0.334 \text{ cm } \Delta T, \tag{7}$$

and the wavelength (16 Δx) thus will be limited to

$$\lambda = 5.3 \text{ cm } \Delta T. \tag{8}$$

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With a good protective paint, the difference between full sunshine and complete shadow amounts to about 5°, but this severe condition will not occur for the legs of our tower. Only the angle of the incident sun rays will be different from one leg to the other, and we will adopt $\Delta T = 2°C$ for this case. During nights and cloudy days we adopt $\Delta T = 1°C$. This gives the limiting wavelength as

$$\lambda = 10 \text{ cm in sunshine} \tag{9}$$

$$\lambda = 5 \text{ cm at night} \tag{10}$$

If still shorter wavelengths were desired, we would need a position-measuring device and a servo loop, adjusting the position of the secondary mirror, which is quite a complication.

Between summer and winter, the tower changes its height considerably:

$$\Delta h = 0.262 \text{ cm } \Delta T. \tag{11}$$

Taking 35°C for a hot summer day, and -15°C for a cold winter day, we have $\Delta T = 50°$ and obtain a change in height of

$$\Delta h = 13 \text{ cm between summer and winter.} \tag{12}$$

This means that we must give the secondary mirror a third degree of freedom, for example, moving up and down, or perpendicular to the elevation tracks. Each telescope needs a position calibration, which usually is a function of position; in our case, it will also be a function of temperature.

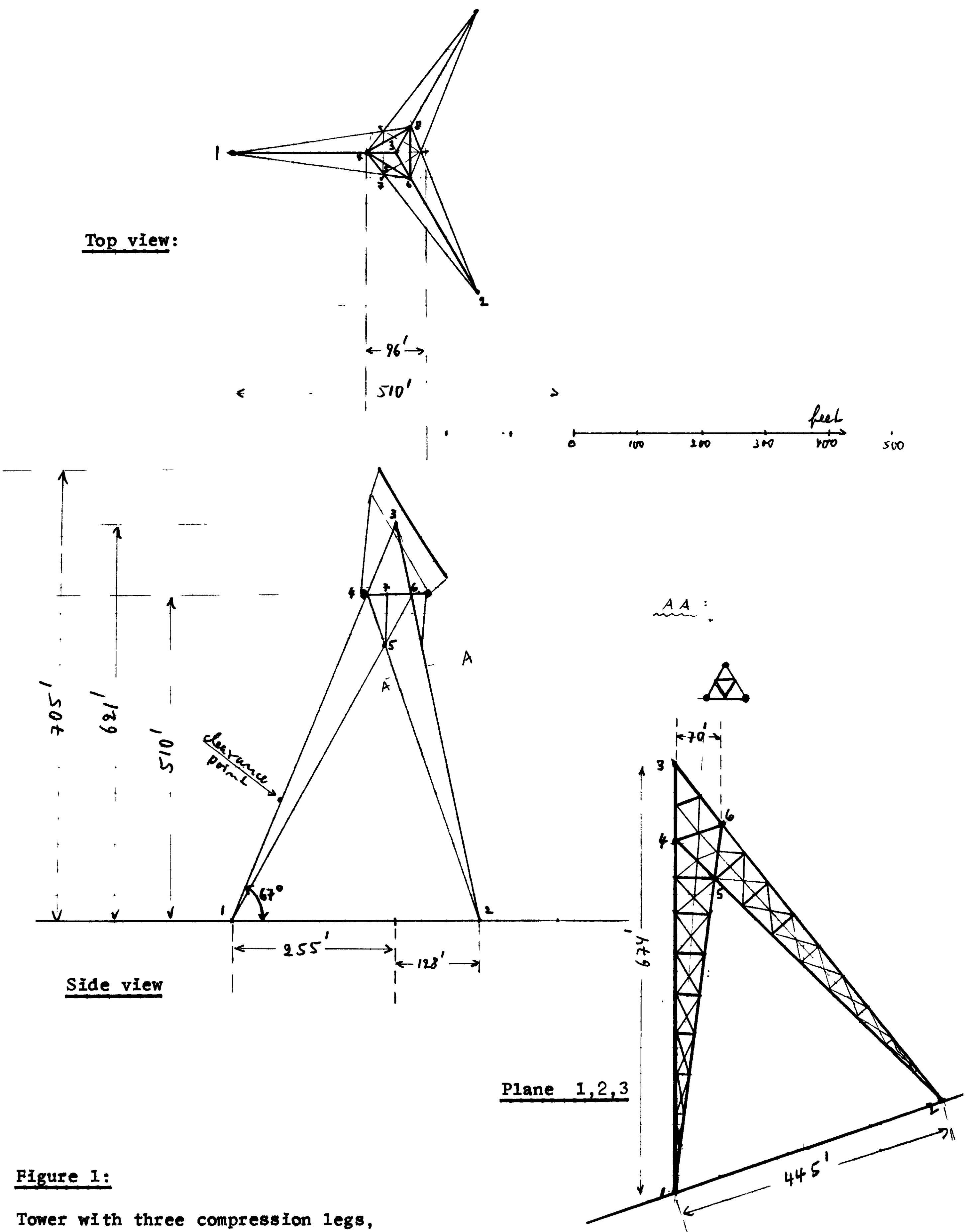

Figure 1:

Tower with three compression legs, three chords each.

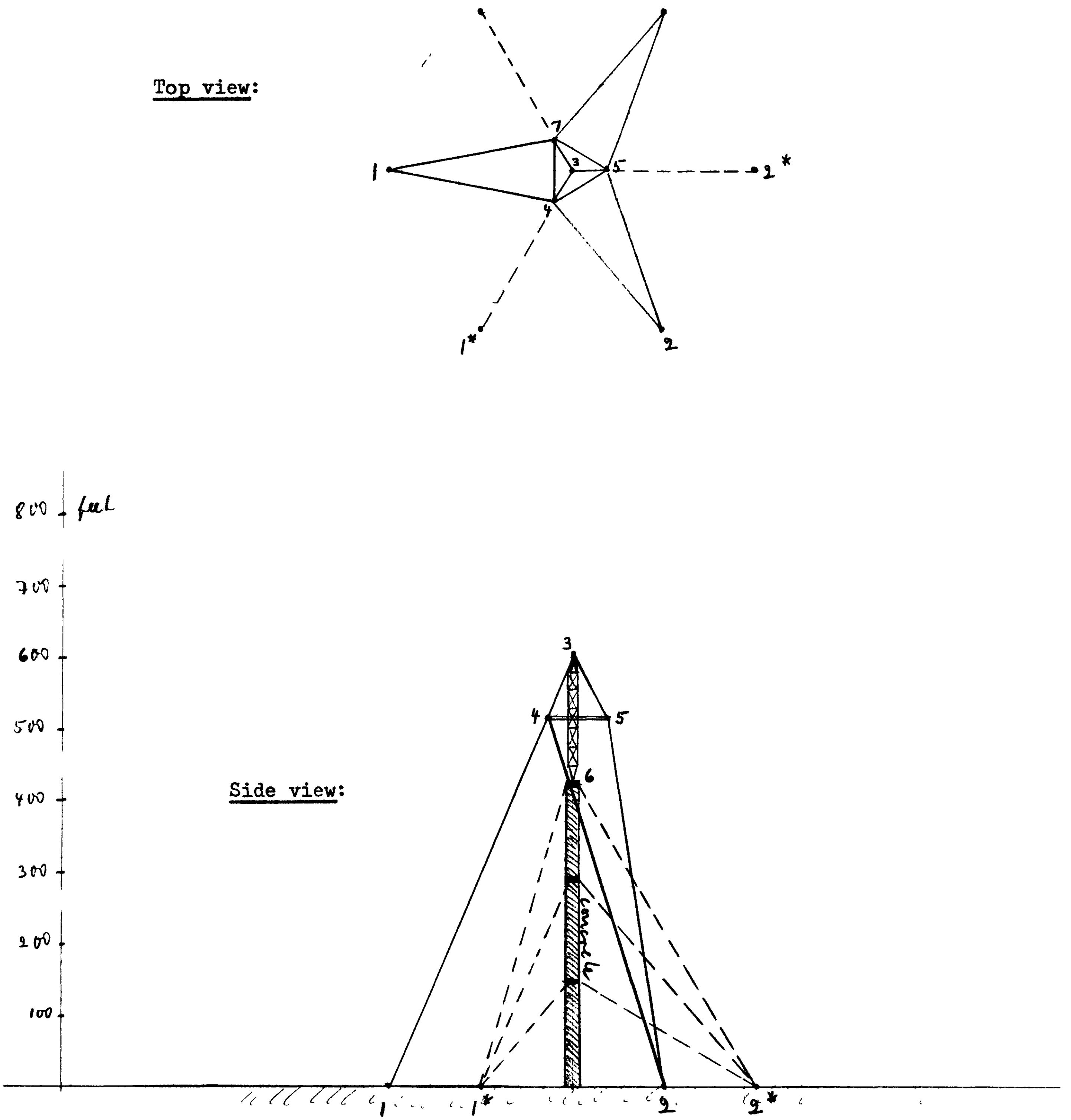

Figure 2:

Tower with central compression pillar, three tension legs, two ropes each.

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6. Central Compression Pillar

The other type of structure, with tensioned ropes as legs, and with a central compression pillar, is shown in Figure 2. The three legs have two ropes each, which is the minimum number necessary for providing a stable triangle for the azimuth ring.

For the other points of the azimuth ring we need now more additional structure, since we do not have stable points like point 5 of Figure 1. An estimate gave about 50 m^2 of additional wind area, and instead of (1), we now have

$$\text{wind area of top structure} = 600 \text{ m}^2 = 6450 \text{ ft}^2. \qquad (13)$$

The central pillar will pick up a large wind force. In order to isolate its wind deflections as much as possible from the azimuth ring, we split the pillar into two parts; an upper part from steel, resting in a pin joint on top of the lower part. The lower part is a thick, concrete pipe, guyed at three equal intervals; the foundations for these guy ropes (points 1*, 2*...) are different from those for the legs (ponts 1, 2 ..). In this way, the wind force acting on the concrete pillar is completely isolated from the main structure. This has the advantage that we can use concrete, in spite of its having much more wind area than a steel structure.

The upper part can be either a built-up member as shown in Figure 2, or just a single pipe. Calculations showed that the pipe is a little more economical. From many trials it turned out that we should use

singel pipe for upper pillar:
steel, 100 000 psi Yield; (14)
$\ell/r = 60.$

For calculating these trials, and also those of the previous structure, I have drawn the maximum stress, $S(\ell/r)$, for various steel types. I have used formulae (1) and (2) on page 5-16 of the Manual of Steel Construction, 7^{th} edition, where I adopted an elasticity of $E = 30\times10^6$ psi for all steels. The results are shown in Figure 3.

The leg ropes have 150 ksi Yield and are stressed to $S = 45.7$ ksi; according to my Report 8, this means $q = 1.77$ and $E = 2.18 \times 10^3$ ksi.

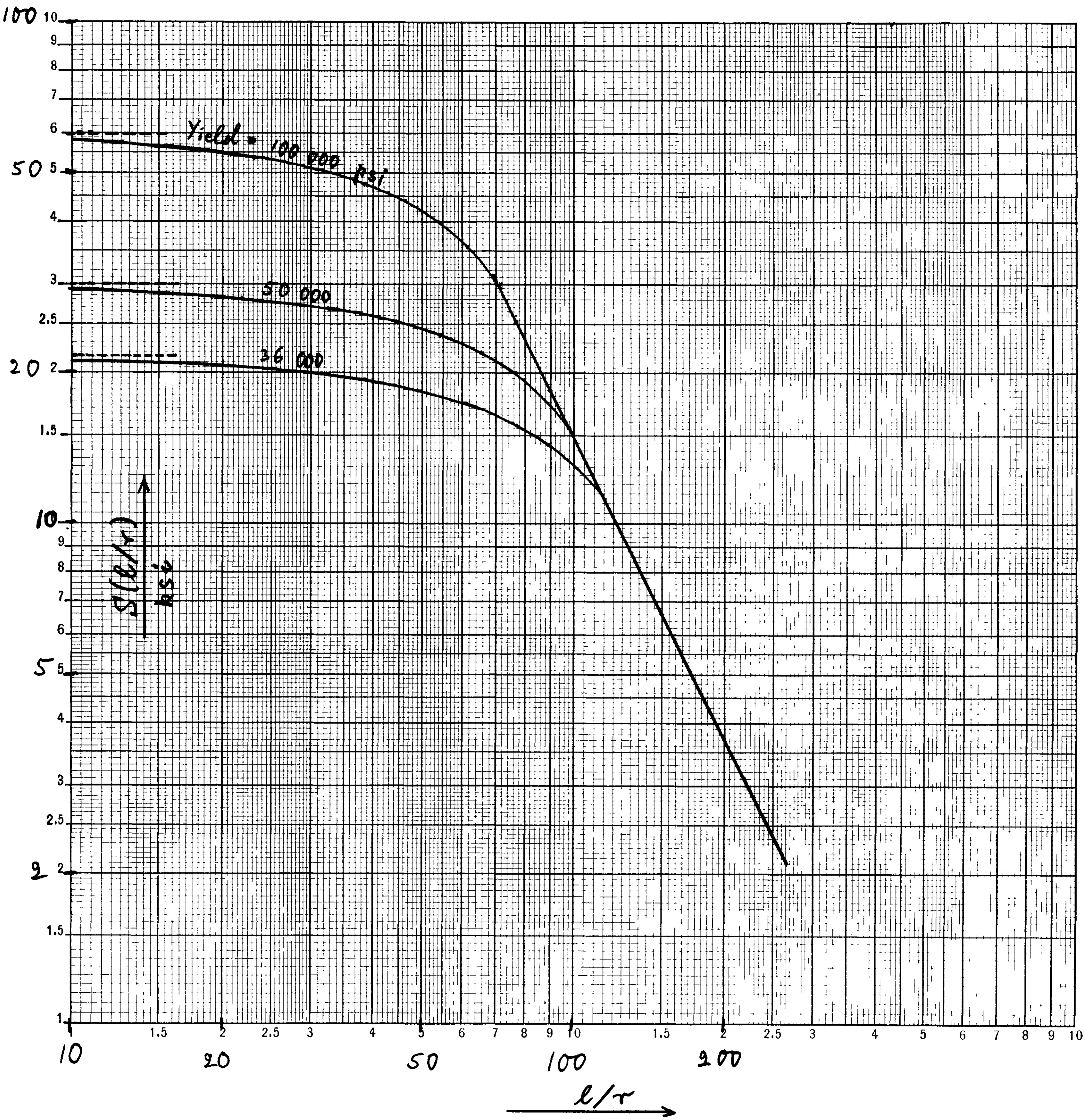

Figure 3.

Maximum stress and slenderness ratio.

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As to the concrete pillar, I have adopted an inner diameter of 10 feet, for elevator, cables and so on. I have taken a maximum compression stress of 2.0 ksi; the own weight subtracts 0.45 ksi, and the weight of the structure above gives a reduction of 3%. This leaves 1.5 ksi for the force from stressing the leg ropes, which defines the cross section of the concrete once the cross section of the leg ropes is given.

The guy ropes were sized such that they can hold in horizontal direction 2% of the vertical force compressing the pillar. (I found this rule for lacings in the Manual, page 5-42, but I am not sure that this applies to guying, too.)

As to the price of steel, E. Faelten suggested to adopt 1000 $/ton of normal steel, including erection. In our case, the total weight of steel consists to 78% of high stress ropes which are about 840 $/ton without erection, and to 22% of steel with 100 ksi yield. The material costs thus are much higher than for normal steel, but since we just have a small number of simple pieces, ropes and one pipe, the erection costs will be much less than for normal structures. In lieu of any well founded estimate, I have adopted 1100 $/ton including erection, in the average for pipe and ropes. For the concrete, I have adopted 140 $/m^3 including erection. The results, for two wavelenghts, are given in Table 2.

Table 2

	leg rope	pipe		concrete		guy rope	total price
λ	D	D	τ	D	τ	D	P
cm	inch	inch	inch	feet	feet	inch	10^6 Dollar
10	12.4	104	2.6	16.5	3.3	5.1	1.37
5	18.3	107	5.7	22.2	6.1	7.5	3.03

7. Comparison

Both types of towers were calculated for six wavelengths each, and the results are plotted in Figure 4. We see that the tower with central compression pillar is always about 36% more expensive than the one with compression legs. But it is not really sure that this diefference is outside the error limits of my estimate.

The erection is certainly easier and quicker for the tower with the pillar.

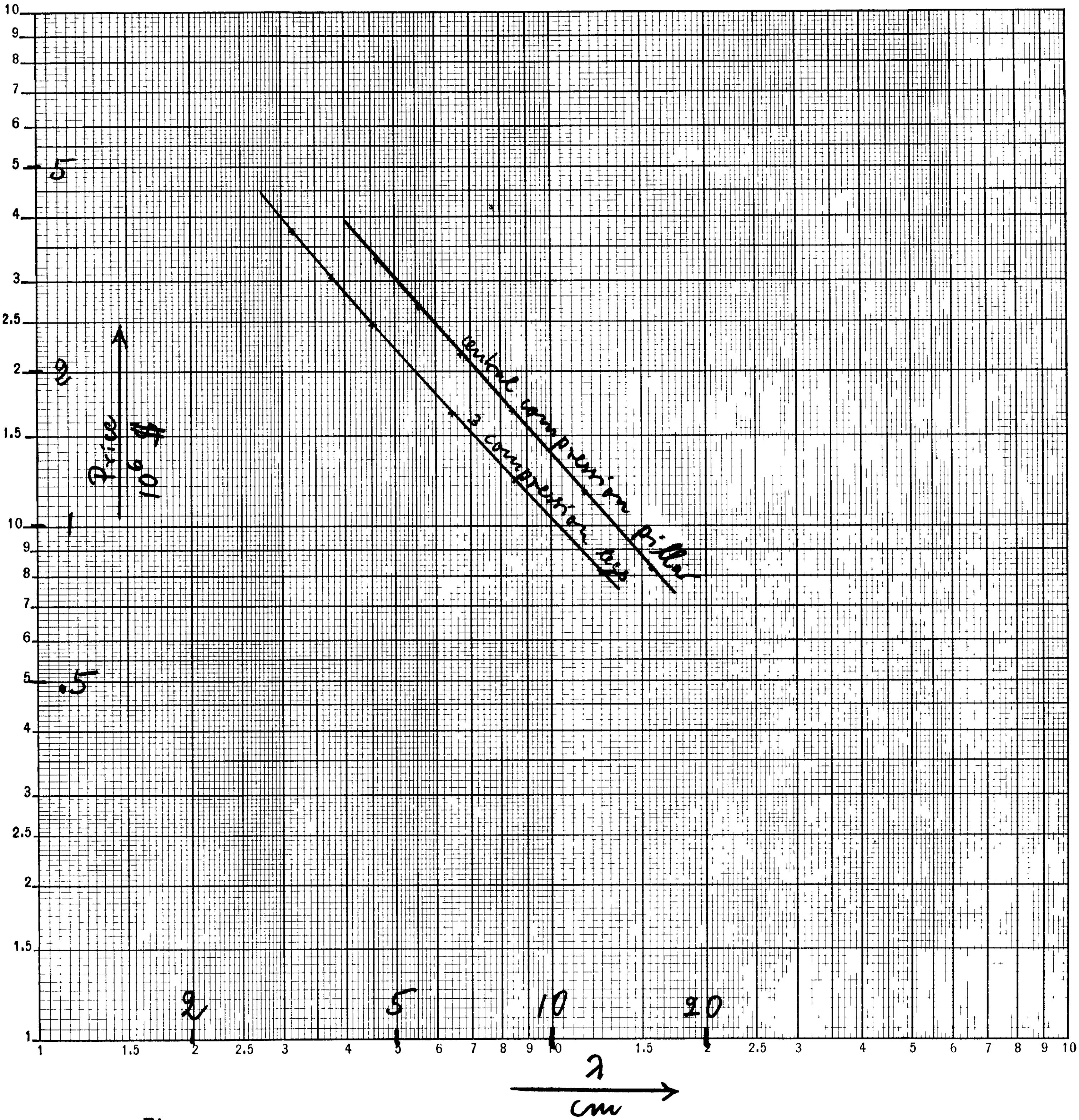

Figure 4.
Total price and shortest wavelength,
for both types of towers.