NATIONAL RADIO ASTRONOMY OBSERVATORY
SOCORRO, NEW MEXICO
VERY LARGE ARRAY PROGRAM

VLA ELECTRONICS MEMORANDUM NO. 153

CONSIDERATION OF MECHANICAL STRESS IN THE 60-mm WAVEGUIDE

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(Revised by J. W. Archer December 1979)

To avoid deterioration of waveguide straightness it is important that it always remain under tension.

The following factors affecting waveguide stress should be considered.

1. Allowable tensile force on the waveguide

The tensile stress must be kept positive but, to avoid elongation, should not exceed the maximum allowable limits determined by the dimensions of the thread and by the properties of the materials. According to the report of Furukawa (memo to Dr. Weinreb December 1973), the tensile strength at the elastic limit is 15,000 kg. Allowing a safety factor, and variations of material properties and thread dimensions, the maximum allowable tensile force should be set around 5,000 kg (11,000 lbs).

2. Thermal stress

When waveguide is held fixed, there is a thermal stress due to temperature change. The thermal stress σ_t and thermal force F_t can be written as:

$$\sigma_t = E \alpha \Delta t$$

$$F_t = \sigma_t A$$

E; modulus of longitudinal elasticity, Young's modulus

α; modulus of heat expansion

Δt; temperature change

A; cross-sectional area of waveguide

In case of 60-mm diameter helix waveguide the following figures are applicable:

$$E = 2.1 \times 10^4 \ \mathrm{kg/mm^2}$$

$$\alpha = 1.2 \times 10^{-5} \ /°C$$

$$A = \pi(\gamma_0{}^2 - \gamma_i{}^2) = 731 \ (\mathrm{mm^2}) \quad (\gamma_0 = 35.0 \ \mathrm{mm}, \ \gamma_i = 31.5 \ \mathrm{mm})$$

In this case F_t has the following relationship with temperature change Δt

$$F_t = 184 \cdot \Delta t$$

3. Stress in pretensioned waveguide

When the waveguide is pretensioned by force F_p and held without moving, the tensile force F varies with temperature change.

$$F = F_p - F_t$$

$$= F_p - E \cdot \alpha \Delta t$$

From the requirements for keeping stress positive and with maximum allowable force to thread, the tensile force must fulfill the following conditions:

$0 < F < 5{,}000$ kg

The relationship between temperature change Δt and satisfactory F_p are shown in Figure 1.

4. Some consideration on pretensioning

When the waveguide is tensioned on the bottom of the trench or underground, the stress that is applied in the waveguide varies along the waveguide axis because of friction between waveguide and soil. It limits the maximum length that can be tensioned at one time.

If the friction can be considered uniform along the waveguide, the tensile force can be expressed as follows (refer to Figure 2):

$$F_p(x) = F_{p0} - \varepsilon \cdot W \cdot X$$

ε; coefficient of friction (0.2-0.3? on ground)

W; weight per unit length ($\fallingdotseq$ 6~7 kg/m; 60-mm helix waveguide)

X; the distance from the pulling point

Coefficient of friction is unknown, so should be measured in the first test.

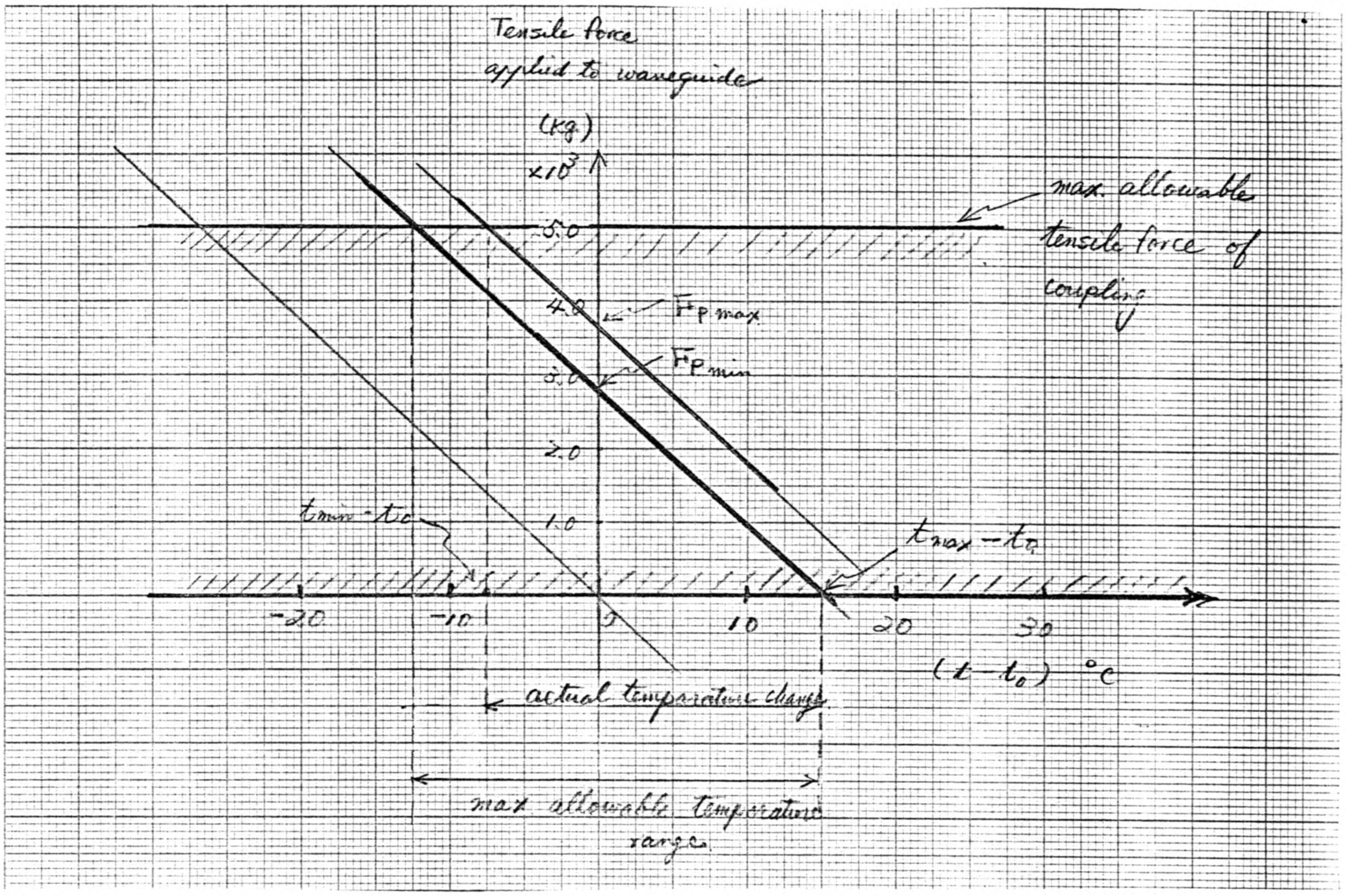
Even if the waveguide undergoes temperature changes,

$$0 < F = F_p(x) - F_t < 5{,}000 \text{ kg (maximum allowable stress)}$$

should be achieved.

Also important for keeping positive tensile force at any time is to fix both ends of the waveguide line without movement. If the ends are not fixed, elongation and expansion start* with temperature change at the ends and the tensile force does not

*Refer to Appendix B.



t_o; the temperature at installation

t_{max}; the maximum temperature after installation

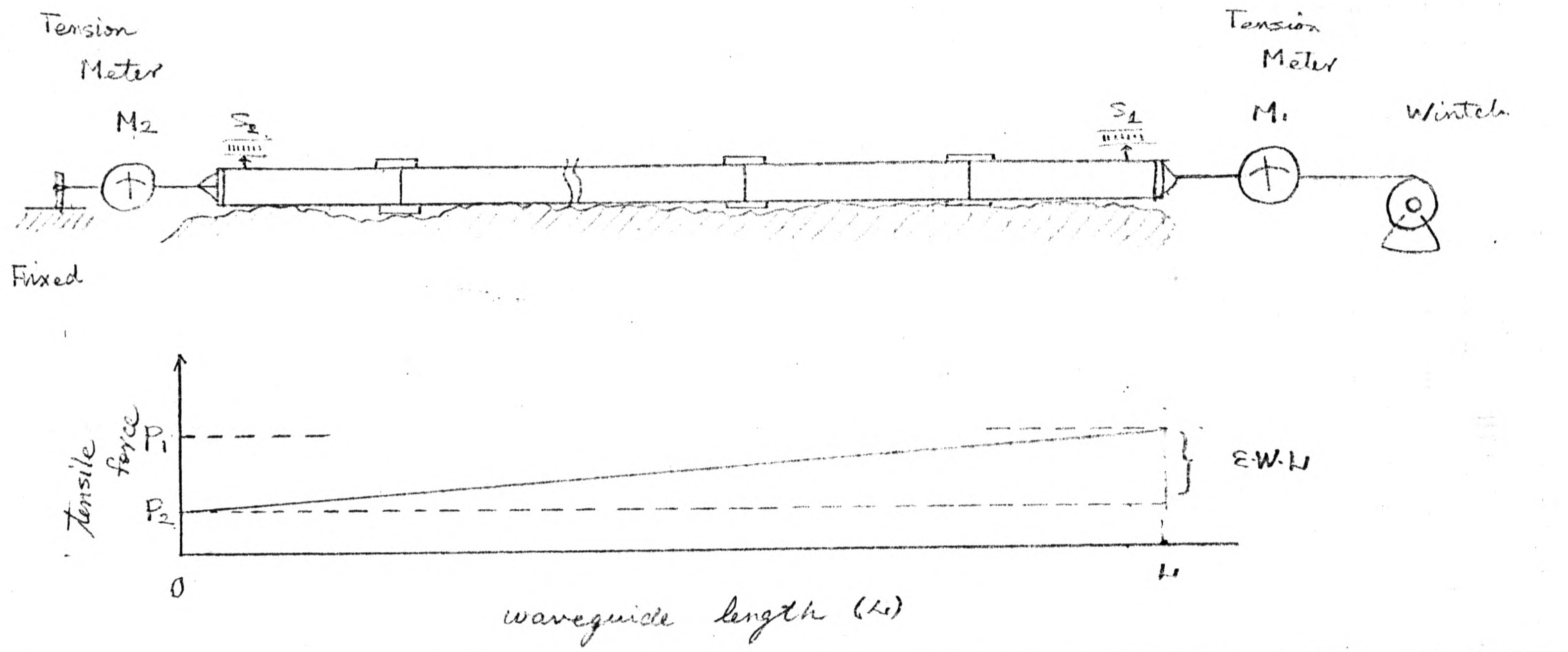
t_{min}; the minimum temperature after installation

F_{pmin}; minimum limit of required tensioning power

F_{pmax}; maximum limit of required tensioning power

NOTE: F_{pmin}, F_{min} and friction force from soil determine the maximum length that can be tensioned.

FIGURE 1: The relationship between temperature change and tensioning force that should be applied.



P_1, P_2; tensile force at both ends of waveguide under tensioning, can be shown by metres M_1 and M_2

E-W-L; frictional force from ground

S_1, S_2; scales to check the movement of waveguide.

FIGURE 2: Diagram for waveguide tensioning tests.

always remain positive along the full length of the waveguide.

According to Figure 1, the pretension in hot seasons seems to be unnecessary. But when we consider the random curvature after waveguide assembly, it might be worth doing even in the hot season.

5. Recommendation

The configuration for pretensioning shown in Figure 2 is recommended for the first trial. In this trial the following data should be taken.

1. Straightness before and after tensioning and also after backfilling.
2. Straightness deterioration with time.
3. Coefficient of friction between soil and waveguide.
4. Movement of ends with temperature change.

From this data the following points must be evaluated:

1. Contribution of tensioning to straightness and its deterioration.
2. Amount of tension that should be applied at different temperatures.

Also during this trial, the following should be determined:

1. How to tension the waveguide.
3. How to hold after tensioning.

APPENDIX A

TEST RESULTS OF STRENGTH OF THREAD ON WAVEGUIDE

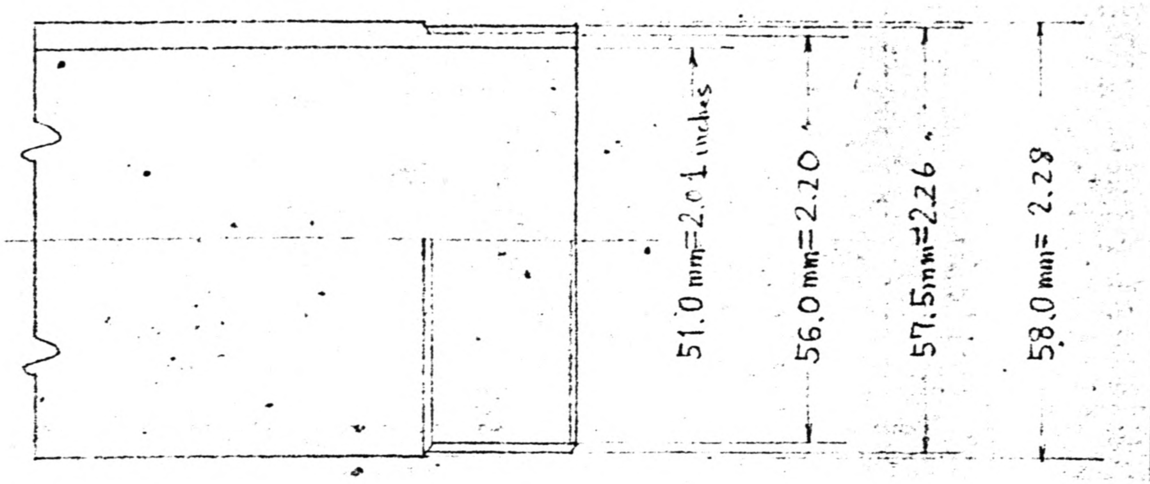


Figure 1: Dimension of Waveguide Supplied to Tension Test

Dimension of Steel Tube[1]: O.D. 58.3 mm 2.30 inches

I.D. 51.0 mm 2.01 inches

Yielding Stress (specified value) 21 kg/mm^2 30,000 psi

(test value) (32 kg/mm^2) 45,510 psi

Allowable Tensile Force $F = S \times A/K$

Where: F = Tensile force

S = Allowable stress

A = Area of cross section

K = Stress intensification factor

$$F = \frac{21 \times \pi/4\ (55.9^2-51.0^2)}{F} = \frac{8639}{F}\ (kg)^2 \quad \text{(specified value)}$$

$$\left[\frac{39,130}{F}\ \text{(pounds)}\right]$$

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[1]The dimension of our waveguide is different from this.

[2]This is calculated value. Tested value is shown on the following sheet. (11-2-76 M.O.)

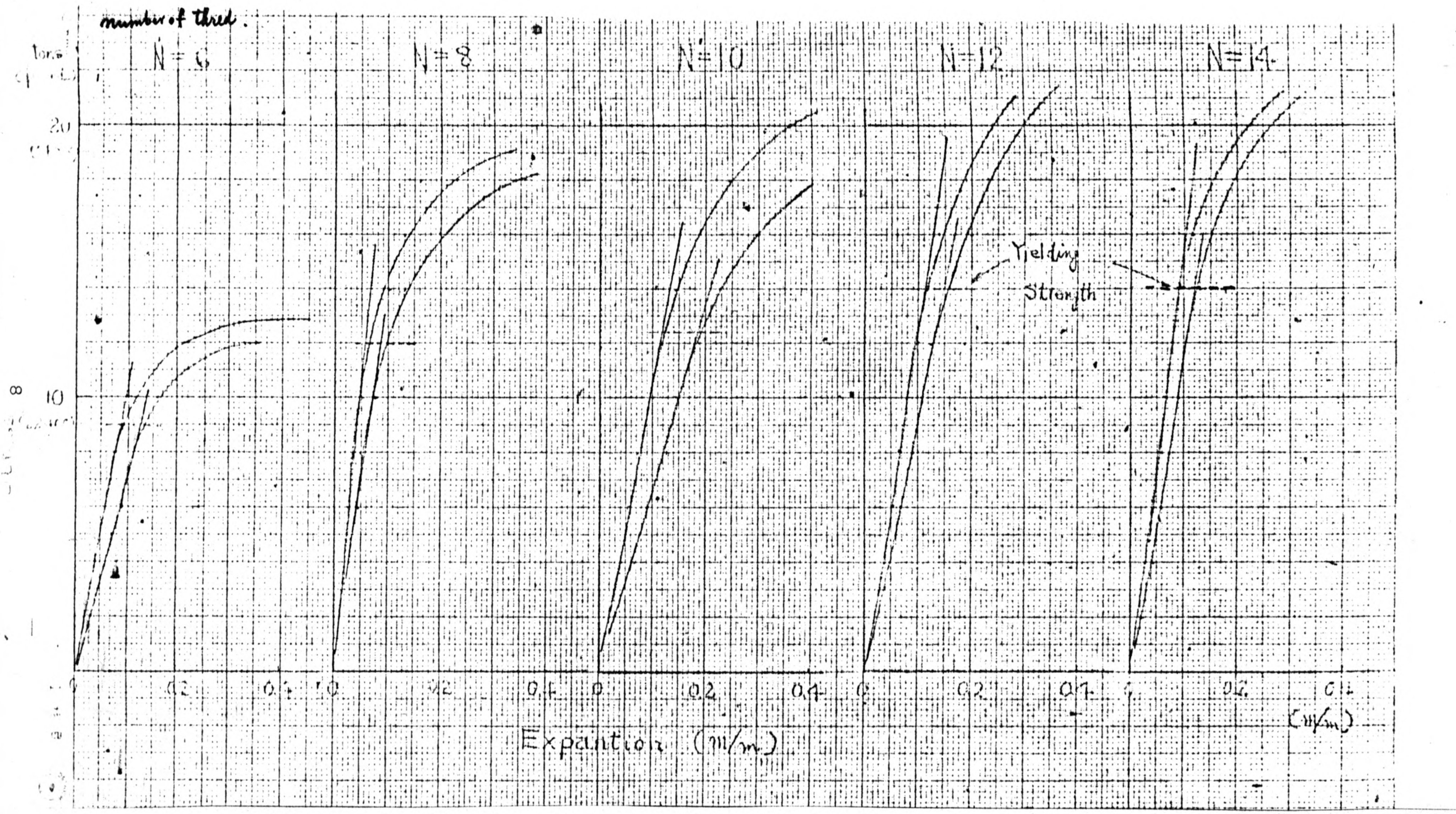
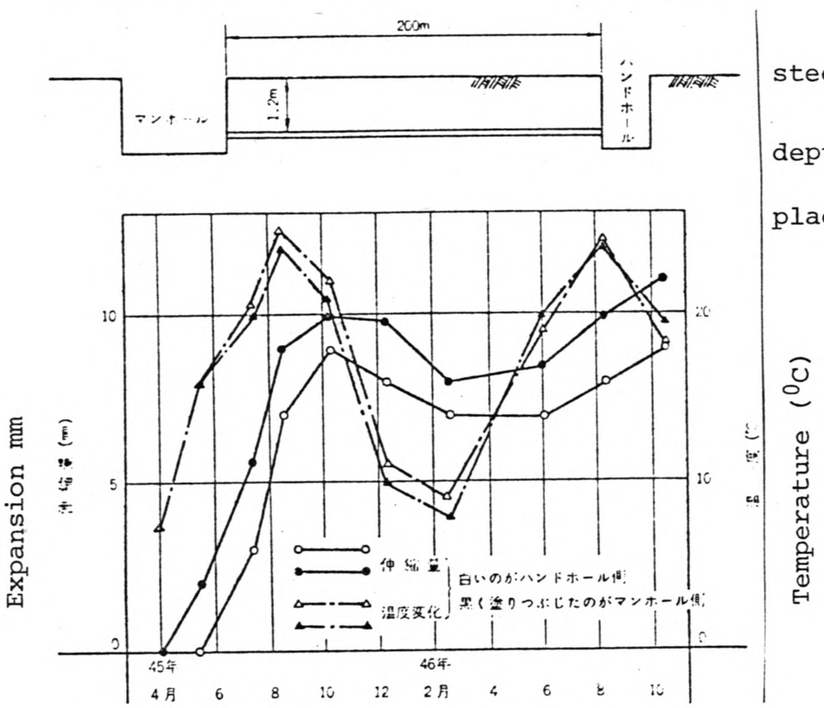


Figure 2: Stress-Expansion Diagram at the Screw Part of Waveguide Joint

APPENDIX B
EXPANSION OF STEEL CONDUIT UNDERGROUND
(from Japanese test results)

<Test line>

manhole — length — handholes



steel tube; about 6" standard pipe

depth; 1.2 m

place; 30 miles southeast of Tokyo

Apr. 1970 — Feb. 1971

o———o Expansion at manhole side

●———● Expansion at handhole side

Δ———Δ Temperature change at manhole side

▲———▲ temperature change at handhole side

APPENDIX C

HOW TO SET THE TENSIONING FORCE F_p

[Conditions]

Maximum temperature around waveguide - t_{max} (°C) t_{max}' (°F)
Minimum temperature - t_{min} (°C) t_{min}' (°F)
The temperature of soil at shading - t_o (°C) t_o' (°F)

[Pulling Force]

Maximum F_{pmax} $= 5000 - E \cdot \alpha (t_o - t_{min})$
$= 5000 - 184 (t_o - t_{min})$ kg
$= 11000 - 331 (t_o' - t_{min}')$ pounds

Minimum F_{pm} $= E \cdot \alpha (t_{max} - t_o)$
$= 184 (t_{max} - t_o)$ kg
$= 331 (t_{max}' - t_o')$ pounds

The tensioning force between maximum and minimum shown above should be applied*. Maximum limit is not critical because a safety factor of 3.0 is used. Also, in this formula, friction from the soil is not considered. For this reason, a figure close to maximum limit should be adopted.

[Anchor]

Both ends of the pulled section have to be fixed well enough to withstand 5,000 kg tensioning force.

<reference>

$t\ (°F) = \frac{5}{9} \{t'(°C) - 32\}$

1 pound = .454 kg 1 kg = 2.2 pounds

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*Refer to the attached Figure 1.

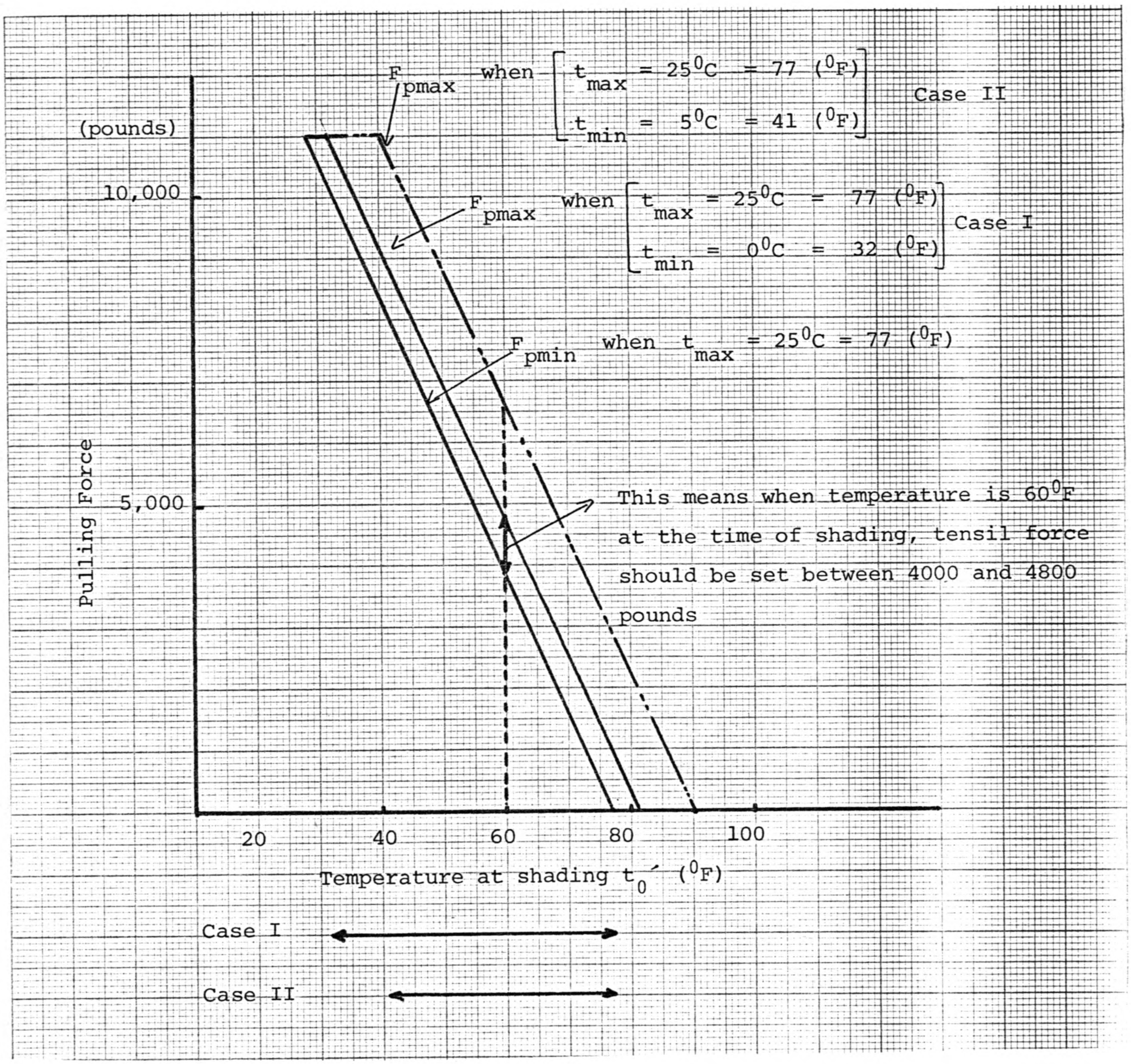

Figure 1: The Relationship Between Temperature (t_o') and Pulling Force (F_p)