T_1, T_2 = Cumulative hours of fair weather and rainy weather in a year (h)

R = Annual gross rainfall

The corona losses of various conductors computed as above are given on Table 5-20.

5.5.2. Current Capacity of Conductor

(a) Continuous Current-Carrying Capacity

(i) Equation of continuous current carrying capacity

Continuous current-carrying capacity I in amperes is concretely expressed by the following equation:

$$I = \sqrt{\frac{\{h_w + (h_r - W_s/\pi\cdot\theta)\eta\}\pi\cdot d\cdot\theta}{R_{20}\;1+\alpha(\theta+T-20)}} \qquad (A)$$

where

d = conductor outside diameter (cm)

= allowable temperature rise of conductor (°C)

= resistance temperature coefficient at ACSR (°C)

T = ambient temperature (°C)

W_s = Quantity of insolation (W/cm^2)

η = thermal emissivity of conductor

R_{20} = electrical resistance value of conductor per unit length at 20°C (/cm)

hw = convected heat coefficient ($w/°C.cm^2$)

$$hw = \frac{0.0572}{(273+T+\theta/2)^{0.123}}\cdot\sqrt{\frac{v}{d}}$$

V = steady wind velocity (m/sec)

hr = radiated heat coefficient ($w/°C.cm^2$)

$$hr = 0.000576 \frac{\left(\frac{273+T+\theta}{100}\right)^4 - \left(\frac{273+T}{100}\right)^4}{\theta}$$

(ii) Computation conditions and results

The computation of current capacity was made under the following conditions and shown on Fig.5-26.

$\theta = 50°C$, $T = 40°C$, $\eta = 0.9$
$W_s = 0.1\ w/cm^2$, $V = 0.5\ m/sec$, $\alpha = 0.0040/°C$

(b) Short-time Current Carrying Capacity

(1) Short time current carrying capacity

When one circuit of double circuit line is tripped out, the total load on the line is imposed on the remaining sound circuit until a part of the load is switched to the other line by system operation procedure. In this case, the conductors of the sound circuit are loaded over their capacity and immediately after the over-loading the temperature of these conductors goes up acutely. For ACSR, allowable temperature rise in short time ranging several to ten several minutes is limited up to 120°C.

The magnitude of current permitted in this duration is termed as short-time current carrying capacity of the conductor. It is very useful for system operation side to be acquainted with such short-time current carrying capacity of the line conductors and allowable maximum duration of the overloading.

The detailed computation procedure of short-time current carrying capacity is complicated and is explained in Appendix 2 for explanation. Fig. 2 in said Appendix shows the computation result of temperature rise in ACSR 795 MCM (CONDOR). Based on this figure, the relation of charging current and charging duration under the temperature tolerance of 120°C was depicted on Fig.5-27, and allowable loading time for the remaining sound circuit can be obtained.

(c) Instantaneous Current Carrying Capacity

This is the current carrying capacity of a conductor at short circuit fault over several seconds, and expressed in the following equation:

$$I = K.\frac{S}{\sqrt{t}} \qquad (A)$$

where, I = instantaneous current carrying capacity of the conductor (A)

t = charging time (sec)
S = sectional area of the conductor (mm^2)
K = constant, which is determined depending upon kind, size and initial allowable temperature

$$\text{ACSR} : \left.\begin{array}{l} T = 40°\text{C} \\ T + \theta = 180°\text{C} \end{array}\right] \quad K = 93$$

Instantaneous current carrying capacities of various ACSR were computed for varied charging durations by using above formula and shown on Fig. 5-28. The set values of main relays and back-up relays should be selected within the range derived from the above.

5.5.3. Maximum Line Tension

Maximum tension to be applied for stringing line conductors is one of important factors which affect the economy of construction. Preliminary design gives approximate weights of each tower type. Based on these data, the tower weights for various tensions were examined.

The tower weights computed on these conditions are tabulated on Table 5-21. As seen in this table, the higher tension would bring somewhat advantageous result. It is, therefore, desirable to apply 5,100 kg as maximum tension which is being applied for the present 230 kV lines and is equivalent to 40% of the tensile strength of the conductor (CONDOR - 5,182 kg). On the other hand, maximum tension of higher degree is studied with respect to vibration problem due to breeze. Since quadruple conductor has appreciable damping effect for such vibration, provision of vibration dampers would not be required in general.

5.6. Insulators

5.6.1. Suspension Insulator String

Vertical load to suspension insulator string can be computed by the following formula :

$$G = \sqrt{\{W \cdot S_m + T \cdot (\frac{h_1}{S_1} + \frac{h_2}{S_2}) + I\}^2 + \{W_w \cdot S_m \cdot \cos^2\frac{\theta}{2} + 2T\sin\frac{\theta}{2} + I_w\}^2}$$

where, G = Total load onto suspension insulator string (kg)

W = Weight of conductor (kg/m)

S_m = Loaded span length (m)

h_1, h_2 = Height difference between the support points (m)

S_1, S_2 = Length of span (m)

I = Weight of insulator string (kg)

W_w = Wind load per unit length of conductor (kg/m)

θ = Horizontal angle (°)

T = Horizontal tension (kg)

I_w = Wind pressure on insulator string (kg)

This formula is transformed to :

$$\frac{h_1}{S_1} + \frac{h_2}{S_2} = \sqrt{\frac{G^2 - (W_w S_m \cos^2\frac{\theta}{2} + 2T\sin\frac{\theta}{2} + I_w)^2}{T}} - \frac{W \cdot S_m + I}{T}$$

Based on this and with the following allowable strength of insulators ;

250 mm Insulator	$G = 16{,}500$ kg/2.5 = 6,600 kg
280 mm Insulator	$G = 21{,}000$ kg/2.5 = 8,400 kg
320 mm Insulator	$G = 30{,}000$ kg/2.5 = 12,000 kg

strength diagram of each insulator string was shown on Table 5 - 29 .

As seen on the diagram, 250 mm insulator single string can be applied up to the span length of 500 m at $\Sigma h/s = 0$, while 280 mm insulator single string can be permitted to the span length of 650 mm. It indicates that single string of 250 mm insulators is for use in flat and rolling terrains and that of 280 mm insulators is for use in mountainous terrains. If 250 mm insulators are used at the mountainous area, two strings will be required. The economic comparison result is given on Fig. 5 - 30, which shows that 280 mm insulator is advantageous if the ratio of the mountaineous terrain to flat terrain is more than 30 per cent.

As a result, 280 mm insulator having larger safety margin in strength and also being more economical was adopted for suspension insulator. 320 mm insulator did not show the economic merit.

5.6.2. Tension Insulator String

Strength of a tension insulator string is determined by the tension of conductor at the support point.

The tension at the support point of conductor can be obtained by the following equation:

$$T_B = T + W_{qdH}$$

where, T_B = Tension at the support point (kg)
T = Horizontal tensions of conductor (kg)
W = Weight of conductor (kg/m)
q = Loading factor
dH = The sag viewed from the higher support point

$$d_H = d(1 + \frac{h}{4d})^2$$

d = Sag (m)
h = Height difference in the support points (m)

The computation result is given on Fig. 5-31, on which following loading limits are also depicted.

250 mm insulator	16,500 kg x 4 strings/4 conductors/2.5 = 6,600 kg
280 mm insulator	21,000 kg x 3 strings/4 conductors/2.5 = 6,300 kg
320 mm insulator	30,000 kg x 2 strings/4 conductors/2.5 = 6,000 kg

Fig. 5-31 indicates that any type of insulator strings can be applied for EHV transmission lines.

The cost comparison is mentioned below:

250 mm	4 strings	1.04/string
280 mm	3 strings	1.10/string
320 mm	2 strings	2.00/string

250 mm 4 strings insulator assembly is inconvenient in handling because of the number of strings. Insulator assembly of 280 mm 3 strings in complicated in cross arm configuration and may cause unbalanced tension at the swing. It is, therefore, decided to adopt the insulator assembly of 320 mm 2 strings for tension insulator assembly of EHV lines.

5.6.3. Example Drawings of Insulator Assemblies

Drawings of insulator assemblies are shown on Fig. 5-32 which are recommendable for EHV design in the Philippines. Strings of both suspension and tension insulators are attached to tower arms through special tower fittings. These fittings have remarkable effects on the reinforcement against transversal load and abrasion in suspension insulator strings. Fittings for tension strings facilitate to support strong loads of 4 bundles effectively and are useful for the reinforcement against twisting force by jumper line swinging. Changes of catenary and deviation angles are also followed easily.

In the drawings, wedge type clamps are shown which save the time for stringing works and are useful for maintenance works because stringing is done without joint compressor.

5.7. Tower Design

5.7.1. Design Condition

(a) Tower Type and Design Conditions

EHV towers are desired to be designed for double circuit operation by taking the significance of the system into account. Also since two routes of one circuit line requires the construction cost of approx. 140 % as much as one route of double circuit line, double circuit tower is recommended.

The tower types and major design conditions for EHV transmission lines were determined with reference to those for the existing 230 kV lines. The tower structures are consisted of the following six (6) types:

Tower Type	Angle	Wind Span
EDQ Suspension	o° - (1°)	400 m
EDR$_1$ Suspension	0° - 5°	600 m
EDR$_2$ Suspension	0° - 5°	400 m
EDS Strain	5° - 15°	400 m
EDT Strain	15° - 30°	400 m
EDU Strain	30° - 90°, D.E.	400 m

The examples of tower design conditions for existing 230 kV lines are shown on Table 5-22.

The type of EDQ is based on the same design concept as for DQ type of 230 kV lines, which are most often used for average span in flat and mountain area. EDR, and EDR$_2$ were designed for suspension and strain respectively. These are based on DQ type which is common to both suspension and strain towers.

The reason for the division or non-common type adoption is that it become difficult to keep the clearance between overhead ground wire and conductor at a certain level if common-type is adopted.

EDR_1 type was designed for the wind span of 600 m in order to be applicable for long spans in the mountain area.

The type of EDS is made exclusive to the tension towers, although DS type for 230 kV was common to tension and strain towers. The reasons are that heavy angle suspension is not desirable in bulk transmission lines and also it is difficult to maintain the clearance between conductor and overhead ground wire.

Moreover, the former DT type, which is common to strain (30°) and heavy angle deadend towers, were divided into the type EDT for strain (30°) and the type EDU for heavy angle deadend. This is because application of EDT type is expected to be fairly frequent and also the design as a common type would largely increase the weight of tower, which is not economical.

In the area susceptive to salt contamination, the tower configuration should be augmented as the insulator assemblies increase. It is, therefore, necessary to have the tower type for such salt contamination area under the same design conditions.

(b) Increase of Wind Velocity

Since the tower design for EHV lines results in increase of the tower height, the increment of design wind velocity and pressure should be taken into account. A.S.C.E.'s guide for design of steel transmission towers also recommended that incremental wind pressure should be taken into consideration for the towers of 200 ft. or more.

In the said guide, application method of incremental wind velocity is shown in the "Standard wind pressure on the structures", which is explained as follows:

In the area along the seacoast, following equation is being applied:

$$V = V_{30}\left(\frac{Z}{30}\right)^{X}$$

where, V = Wind velocity (mph.)

V_{30} = Mean wind velocity at 30 ft.(mph.)

Z = Height of the tower (ft)

X = 0.3 ∿ 0.143

X = 0.3 at V_{30} = 60 mph.
X = 0.143 at V_{30} = 130 mph.

By this method, incremental factors of wind velocity and pressure are obtained. Applying 116 mph. of the design velocity for steel towers in the Philippines.

$$X = 0.3 - \frac{0.3 - 0.143}{130 - 60}(116 - 60) = 0.174$$

$$V_{30} = \frac{V_z}{(Z/30)^X} = \frac{116}{(200/30)^{0.174}} = 83.4 \text{ mph.}$$

From the above, the wind velocity to be applied below 300 ft. is obtained :

$$V_{300} = V_{30}\left(\frac{Z}{30}\right)^{X} = 83.4\left(\frac{300}{30}\right)^{0.174} = 124.5 \text{ mph.}$$

And the incremental factors in the velocity and the pressure are obtained as 124.5/116 = 1.073 and $(1.072)^2$ = 1.151, respectively.

In addition, the wind load curve in BPA design criteria is given on Fig. 5-33. According to this fugire, the wind pressure at 200 ft. of the tower height is 33 lb/ft^2 and 38 lb/ft^2 at 300 ft.

The incremental rate is 38/33 = 1.152, which is almost equivalent to the above-mentioned value.

As a result, the incremental rate of 1.15 shall be adopted for design wind pressure on tower.

The values are tabulated below :

Tower Height	Design Wind Velocity (kph)	Design Wind Pressure (kg/m^2)
< 60 m	185	264
> 60 m	198 ($185 \times \sqrt{1.15}$)	304 (264 x 1.15)

(c) Body Extension and Leg Extension

Body extension

As shown on Fig. 5-34, six (6) meters four (4) stages shall be applied.

Leg extension

Fig. 5-35 shows the relation between width of tower and necessary body extension. The existing 230 kV lines was 4.5 m leg extension at the maximum, however the EHV line should have increased value as the width of tower is larger.

Then, the leg extension of EHV towers was designed to be 7.5 m at the maximum width 1.5 m x 5 stages in order to be applicable for 30° slope and approx. 13 m width of the tower.

(d) Horizontal Separation between Conductors

Table 5-23 shows the results of computation of required horizontal separation by Thomas-Percy Formula. In the EHV tower design, the horizontal separation of conductors that is determined by the clearance to tower structure is about 20 meters, while the computation result in Table 5-23 indicates 9.06 m. It can be said that there is sufficient allowance.

(e) Cross Arm Design Load

The load on cross arms due to conductors is expressed by the following equation :

$$V = WSm + T(\frac{h_1}{S_1} + \frac{h_2}{S_2})$$

where, V = Vertical load at the supporting point of conductors (kg)

W = Weight of conductor (kg/m)

S_1, S_2 = Span length at both sides (m)

h_1, h_2 = Height differences of the supporting points at both sides (m)

$Sm = (S_1 + S_2)/2$ (m)

The conversion to the span per weight of conductor is expressed :

$$V/W = Sm + T/W(\Sigma h/S)$$

In EHV design, the maximum values of weight span and uplift span are determined to be 2,000 m and 1,600 m respectively so as to satisfy each condition of Sm = 300 m, $\Sigma h/s = \pm 0.5$; Sm = 400 m, $\Sigma h/s = \pm 0.45$ and Sm = 500 m, $\Sigma h/s = 0.4$.

Design values of each tower type are shown below :

Tower Type	Ruling Span	Weight Span	Uplift Span
EDQ Suspension	400 m	1,000 m	-
EDR_1 Suspension	600 m	2,000 m	-
EDR_2 Strain	400 m	500 m	500 m
EDS Strain	400 m	1,500 m	1,000 m
EDT Strain	400 m	2,000 m	1,600 m
EDU Strain	400 m	1,000 m	500 m

5.7.2. Clearance Diagram

Clearance diagrams were drawn with the insulation clearance obtained in the insulation design and swing angle as shown Fig. 5-36.

The insulation clearance at normal swings corresponds to standard insulation clearance coordinated with lightning impulse strength of insulator strings and at maximum swings it does not go below minimum insulation clearance against commercial frequency voltages.

The swing angles (θ_1,θ_2) for suspension towers were considered as follows:

$$\theta_1 = \tan^{-1} \frac{2 \cdot T\sin\theta/2 + We}{W \cdot Smin + I/2}$$

where, θ_1 = Max. swing angle of suspension insulator string at normal condition

W = Weight of conductor (kg/m)

Smin = 0.6 x (weight span)

I = Weight of insulator string (kg)

T = Tension of conductor (kg)

θ = Horizontal angle

We = Wind pressure corresponding to 15° swing (kg)

$$\theta_2 = \tan^{-1} \frac{2 \cdot T \sin\theta/2 + Ww + Iw/2}{W \cdot Smin + I/2}$$

where,

θ_2 = Swing angle at the worst condition

Ww = Wind pressure on conductor at the worst condition (kg)

Iw = Wind pressure on insulator string at the worst condition (kg)

Standard dimensions, based on which clearance diagram is drawn, are given on Table 5-24.

5.7.3. Tower Structure Configuration

Tower structure configurations based on the results mentioned in the foregoing 5.7.1. and 5.7.2. are given on Fig.5-37. Besides tentative tower weight curve is shown on Fig. 5-38.

V-string type tower was also studied but was found uneconomical.

5.7.4. Tower Foundation Design

There are available tower foundation designs for 230 kV lines. These designs were reviewed and considered applicable to EHV lines. Accordingly the detailed descriptions are not made in this section. Only field application criteria are given on Table 5-25.

5.8. Electrostatic Induction and Radio Interference

In the foregoing sections, corona noise and electrostatic induction problems were discussed. Other similar problems to be caused by transmission line would include electro-magnetic induction and electrostatic induction interferences on telecommunication lines radio and TV interferences. These interferences would not develop so serious problems when the line voltage are relatively low, but they will be remarkable as the line voltage is raised to higher level such as 500 kV lines. Electromagnetic and electrostatic induction interferences would often cause socio-environmental problem accompanying serious complaints from communication companies and broadcasting stations as well as general community people. Therefore, where large influence is anticipated by the construction of transmission lines, preliminary studies on these aspects will be required. This section deals with general characters of these problems and their countermeasures.

5.8.1. Electromagnetic Induction

Where ground fault occurs at a transmission line, zero-phase earth-return current is caused and induces voltage along the communication lines in the vicinity to produce interference on communication.

Described below are the estimation of induced voltage, induced voltage limit and countermeasures against induced voltage beyond the limit.

(a) Computation of Expected Voltage Induction

The voltage induced to light current wires can be calculated in the following equation:

Vm = (1 Ƶm) I (v)

Ƶm = j 2 fM (/km)

where, Vm = Induced voltage (v)

Ƶm = Mutual impedance between transmission line and light current wires (/km)

M = Mutual inductance between transmission line and light current wires (H/km)

l = Length of the wires in parallel

= Overall shielding factor

f = Frequency of the current induced

Total mutual impedance (l Am) in the above formula is in the principle obtained by the following formula:

Ƶm = (lpƵmp) + (lcZmc) ( )

where, lp = The length of light current wire projected to the power conductor running in parallel or oblique.

lc = Projected length of the intersection (km)

Ƶmp = Mean mutual impedance in parallel or oblique running section (/Rm)

Ƶmc = Mean mutual impedance in intersection section Refer to Fig. 5-39.

(b) Allowable Induced Voltage Limit

When the voltage induced goes up beyond the following designated voltage level, necessary countermeasure should be provided.

General power circuits	430 V
Highly stable transmission lines	650 V

The values of above induced voltage limit have been determined in due consideration of bearing capacity of communication wire and hazard to the human bodies on the basis of CCITT's recommendation and currently being adopted in U.S.A., U.K., France, etc. The above values are considered to be applicable to 500 kV system in the Philippines, subject to conference with telecommunication utilities.

(c) Mitigative Measure for Electromagnetic Induction

Wherever the voltage induced is expected to be over the above-mentioned limit, it is necessary to provide the optimum countermeasure through conference with communication utilities.

Major mitigative measures are considered in the following:

a) Measure for transmission line

1) Change of the route
2) Increase of conductivity of ground wire

b) Measure for light current lines

1) Change of routes
2) Division of the induced voltage by junction circuit loop
3) Change of the wire to that with higher shielding factor
4) Installation of steel or cast iron pipe
5) Installation of arresters

Of the above, installation of arresters is considered as the most economical measure. Because of recent advancement of arrester manufacture with high reliability, the application of arresters is prevailing. At any event, this problem should be solved through close coordination with the communication company concerned.

5.8.2. Electrostatic Induction Interference

(a) Computation of Induced Current

$$L_T = V_k \cdot D_1 \text{ x } 10^{-3} \; (0.33_n + 26\Sigma \frac{\ell 12}{b_1 b_2}$$

where, L_T = Induced current (mA)
V_k = Nominal voltage of transmission line (kV)
D_1 = Separation of transmission line conductors
n = No. of intersecting points
b = Distance between powerline and communication line (m)
ℓ = Length of the communication wire

The above conditions were given on Fig. 5-40.

(b) Electrostatic Induction Current Limit

Unlike electromagnetic induction concerns, there is no common regulatory value for limiting the induced current being practised on world-wide basis. For instance, in U.K., such limit is set at 10 kV/m or below in field intersity; in France at 15 mA or below in current, but other countries such as West Germany, Switzerland and U.S.A. do not have any particular limitation. In Japan, it is regulated to be 3 μA or less at telephone receiver.

(c) Mitigative Measure for Electrostatic Induction

Whenever required, following measures can be considered.

(i) For transmission lines

1. Route change
2. Shielding wire provision

(ii) For telephone wires

1. Route change
2. Shielding wire provision
3. Replace with the wire having shielding layer

These are available mitigative measures against electrostatic induction, however, they are not always practised. It is, therefore, advisable to select the route with due consideration to the above-mentioned interference.

5.8.3. TV Interference

Large capacity transmission lines like EHV lines, if constructed in the proximity of TV stations or TV receiving antennas, would be a cause of TV interference due to reflection or shielding TV wave by the line. Presently, two kinds of interference are known. One interference is to degrade the receiving level of TV set by wave shielding and the other is so called ghost interference which is caused by the lagged arrival of TV wave reflected by the transmission line. For prevention of this ghost interference, D/U ratio should be taken more than 24 kb, where D = desired TV wave and U = TV wave reflected by the transmission line. The intensity of wave reflection would be increased as the transmission line is with larger capacity or located at nearer distance.

It is rather difficult to assess accurately the interference to be caused by transmission lines since many factors such as, the scale of transmission line, wave direction and angle to the line, and topographic conditions. Generally, the estimated range, within which some countermeasure is needed, is 2 km. It is to be noted however, that sometimes there would be interference beyond this limit.

Followings are the countermeasure for TV interference:

- Adjustment of direction or relocation of antenna
- Replacement with high performance antenna
- Establishment of common receiving antenna

In selecting final transmission line route, this problem should also be taken into account.

5.8.4. Grounding of Metallic Articles

Ground clearance for unspecific articles such as umbrella, automobiles and human beings were examined previously.

In this section, the grounding method for specific permanent structures, namely metallic roof, signs/marks and the likes, is examined.

(a) Earth Capacity of Metallic Articles

The earth capacity of metallic articles can be expressed as follows:

$$C = 4\pi\varepsilon_0\gamma(1 + m + m^2 + m^3)$$

where, C = Earth capacity (F)

ε_0 = Induction factor (F.m)

γ = Surface area of the metallic article (m^2)

$$m = \frac{\gamma}{2(h+\gamma)}$$

h = Clearance between the article and the ground

The computation results are tabulated below:

	Large articles	Relatively small articles		
h (m)	100 m^2	1 m^2	2 m^2	3 m^2
2	–	50 PF	70 PF	90 PF
3	700 PF	–	–	–

(b) Stored Energy of Metallic Article

When the human body comes into contact with the metallic article perceived with electro static induction, the total of both transient and steady currents, which is determined by resistances of the human body and contact, flows to the human body.

The degree of sensibility at the contact depends mainly on the transient current. The result of this experiment is shown on Fig. 5-41.

The stored energy of a metallic article can be expressed by the following formula:

$$E = \frac{1}{2} CV^2$$

where, E = Stored energy (joule)
C = Earth capacity of the article
V = induced voltage of the article

Fig. 5-41 shows the allowable energy curve (the curve of $E = 2.5 \times 10^{-4}$ joule) set by the degree of shock.

(c) Induction Voltage and Grounding Coverage

The induction voltage limit can be obtained from the above-mentioned figure. Generally, the metallic articles posses leakage resistance between itself and the ground, so that the induced voltage is diminished. It is estimated that the induced voltage of large articles is reduced to 20% and that of small articles to 60%.

Taking into account this element, allowable intensity of electric field was computed.

Also, on the basis of the computed values, the separation distances of metallic articles from the line were also obtained and summarized in the following table.

	Large articles	Small articles			Remarks
	100 m^2	1 m^2	2 m^2	3 m^2	
Clearance from the ground (m)	3	2	2	2	(A)
Electrostatic capacity (PF)	700	50	70	90	
Induced voltage (V)	4225	5270	4455	3928	(B)
Allowable intensity (V/cm)	14.1	26.4	22.3	19.6	(B)/(A) x 100
Separation distance (m)	28	22	24	25	Re: Fig. 5-5

5.9. Tools and Devices for Erection and Stringing

The construction of a 423 km EHV transmission lines is of a large scale. Several tower structures having the weights of 30 to 80 tons per tower are to be constructed. Also the stringing work for a total 26 wires for the conductors and OGW should be carried out efficiently in order to meet the time schedule.

Moreover, introduction of large towers will accompany heavier materials and require higher capacities of various stringing tools. Since the EHV transmission route involves steep mountain areas in North Luzon which may hamper the effective progress of construction work, mechanical working forces should be introduced to excavation, assembling and erection of towers and stringing work in order to implement the work in a safe and efficient manner.

The detailed aspects of tools and devices should be studied in the stage of contract design. In this section, a sample of thrust-up type derrick for tower erection is shown on Fig. 5-42, and stringing tools and equipment are listed on Table 5-26.

Table 5-1. Sample of Ground Clearance in Japan[2]

Designation	Electric Field[1] Intensity (V/cm)	Clearance from Ground	Application
A	30	22 m	Flat terrain
B	40	18 m	Hilly terrain
C	50	15 m	Mountainous terrain

[1] The electric field intensity measured at the point one (1) meter above the ground.

[2] Standard of Kansai Electric Power Co., Inc.

Table 5-3. Proposed Clearance against Electrostatic Induction

Designation	Application	Electrical[1] Intensity (V/cm)	Minimum Clearance
A	Places having frequent traffic, public roads, agricultural fields.	50	16
B	Place of very sparse traffic, mountains, forests	80	12

[1] The intensity at the point 1 m above the ground.

Table 5-2 Influence on Human Body by Electric Current

	Influence	Current (mA)					
		DC		60 Hz		10,000 Hz	
		Male	Female	Male	Female	Male	Female
1.	No sensation on hand	1	0.6	0.4	0.3	7	5
2.	Slight tingling perception threshold	5.2	3.5	1.1	0.7	12	8
3.	Shock-not painful and muscular control not lost	9	6	1.8	1.2	17	11
4.	Painful shock-painful but muscular control not lost	62	41	9	6	55	37
5.	Painful shock-let-go threshold	76	51	16.0	10.5	75	50
6.	Painful and severe shock muscular contractions,breathing difficult	90	60	23	15	94	63
7.	Possible ventricular fibrillation from short shocks						
	a) Shock duration 0.03 sec	1,300	1,300	1,000	1,000	1,100	1,100
	b) Shock duration 3.0 sec	500	500	100	100	500	500
	c) Venticular fibrillation	1,375	1,375	275	275	1,375	1,375

Table 5-4 Vertical Clearance of Wires above Ground or Rails for 550 kV Line
(Philippine Electrical Code 232 A.B)

Nature of ground or rails	Vertical clearance 15,000-50,000 volts	Additional clearance for 550,000 volts	Total clearance
Track rails of railroads handling freight cars on top of which men are permitted	feet 30	feet inches 19 3	feet inches 49 3 (15.01 m)
Track rails of railroads not included above	22		feet inches 41 3 (12.57 m)
Public streets, alleys or roads in urban or rural districts	22		feet inches 41 3 (12.57 m)
Driveways to residence garages	22		feet inches 41 3 (12.57 m)
Spaces or ways accessible to pedestrians only	17		feet inches 36 3 (11.05 m)

Details on Additional clearance is shown in Table 5-4-1

Table 5-4-1 Additional Clearance (Philippine Electrical Code 232.B)

(1) For span length greater than 250 feet

span (m)	300	400	500	600	700	800
Final unloaded sag at 85°F no wind (m) (A)	6.30	11.59	18.44	26.82	36.73	48.17
Final loaded sag at 45°F 20 psf wind (m) (B)	6.87	12.21	19.08	27.47	37.39	48.83
Final unloaded sag at 120°F no wind (m) (C)	7.06	12.42	19.30	27.70	37.63	49.08
(C) - (A) (m) (D)	0.76	0.83	0.86	0.88	0.90	0.91
0.85 x (D) (m)	0.65	0.71	0.73	0.76	0.77	0.77

0.77m = 30.31" ∓ 31" = 21'7"

(2) For voltages exceeding 50,000 volts
(550 kV - 50 kV) x 0.4" = 200" = 16'8"

(3) Total sag increase
2'7" + 16'8" = 19'3"

Table 5-5 Required Vertical Clearance of Wires above Ground or Rails for 550 kV Line

Nature of ground or rails	Vertical clearance necessary by		Vertical clearance required
	Philippine Electrical Code	Electrostatic induction	
Track rails of railroads handling freight cars on top of which men are permitted	15.01 m	16 m	16 m
Track rails of railroads not included above	12.57 m	16 m	16 m
Public streets, alleys or roads in urban or rural districts	12.57 m	16 m	16 m
Driveways to residence garages	12.57 m	16 m	16 m
Spaces or ways accessible to pedestrians only	11.05 m	12 m	12 m

Table 5-6 Clearances at Crossing of Wires for 550 kV Line (Philippine Electrical Code 233.)

Nature of wires crossed over	Clearance 8,700-50,000 Volts	Additional clearance for 550,000 Volts	Total clearance
Communication, including cables and messengers	feet 6	feet inches 19 3	feet inches 25 3 (7.70 m)
Supply cables having effectively grounded continuous metal sheath or insulated conductors supported on and cabled together with an effectively grounded messenger, all voltages; messengers associated with such cables	4		feet inches 23 3 (7.09 m)
Open supply wires : 0 to 50,000 volts	4		feet inches 23 3 (7.09 m)
Trolley contact conductors	6		feet inches 25 3 (7.70 m)
Guys, span wires, lightning protection wires, service drops 0 to 750 volts	4		feet inches 23 5 (7.09 m)

Details on Additional clearance is shown in Table 5-4-1

Table 5-7 Clearances from Buildings and Bridges (Philippine Electrical Code 234C, 234D)

Clearances from buildings	
Horizontal & vertical clearances for spans 0 to 150 feed	$26^{ft}\ 8^{i}$ *1
Increased clearance for spans exceeding 150 feet	$2^{ft}\ 7^{i}$ *2
Total clearance	$29^{ft}\ 3^{i}$ (8.92 m)
Where buildings exceed three stories (or 50 feet) in height, overhead lines should be arranged where practicable so that a clear space or zone at least 6 feet wide will be left, either adjacent to the building or beginning not over 8 feet from the building, to facilitate the raising of ladders where necessary for fire fighting.	
Clearances from bridges	
Clearances from bridges for conductors not attached to bridge	$28^{ft}\ 8^{i}$ *3 (8.74 m)

*1. 10' + 0.4" (550-50) = 26'8"

*2. refer to Table 5-4-1

*3. 12' + 0.4" (550-50) = 28'8"

Table 5-8

Required 250 mm Insulator Units for Switching Surges

Maximum allowable voltage	550 kV	
Voltage to ground	449 kV	550 x $\sqrt{2}/3$
Multiplier of switching surge	2.0	Note (1)
Switching surge voltage	898 kV	
Insulation deterioration factor	1,265	Note (2)
Necessary insulation strength	1,136 kV	898 x 1.265
Required no. of insulators [A]	22 units	Fig.5-6
Total no. of insulators [B]	23 units	[B] = [A] + 1, Note (3)

Note (1) - The initial practice in Japan was the multiplier of 2.2. However, owing to application of resistance circuit breakers and proper selection of resistance value, the multipliers of switching surge for EHV system is adequate to be 2.0 to ground and 1.8 between phases.

(2) - Estimated insulation deterioration below the elevation of 1,000 m - 1.10 plus margin for other 1.15 = 1.265

(3) - Include one spare insulator for maintenance purposes.

Table 5-9

Required Insulator Units of 280 mm and 320 mm for Switching Surges

Necessary length of insulator string for switching surge	3,212 mm	146 x 22
Required no. of 280 mm insulators [A]	19 units	3.212/170
Total no. of 280 mm insulators [B]	20 units	[B] = [A] + 1
Required no. of 320 mm insulators [A]	17 units	3.212/195
Total no. of 320 mm insulators [B]	18 units	[B] = [A] + 1

Table 5-10

Required 250 mm Insulator Units for Continuous Abnormal Voltage

Maximum allowable voltage	550 kV	
Effective voltage to ground	318 kV	$550/\sqrt{3}$
Multiplier of abnormal voltage	1.3	
Abnormal voltage	413 kV	318 x 1.3
Insulation deterioration factor	1.2	
Required insulation strength	496 kV	413 x 1.2
Required no. of insulators	16 units	Fig.5-7

Table 5-11

Necessary Arc Horn Gap Length for Switching Surges

Maximum allowable voltage	550 kV	
Voltage to ground	449 kV	550 x $\sqrt{2}/\sqrt{3}$
Multiplier of switching surge	2.0	
Switching surge voltage	898 kV	449 x 0.2
Insulation deterioration factor	1.2	
Required insulation strength	1,078	898 x 1.2
Required gap	2,600 mm	Fig. 5-8

Table 5-12

Necessary Clearance for Switching Surges

Switching surge voltage	898 kV	
Insulation deterioration factor	1.1	
Required insulation strength	988 kV	898 x 1.1
Required insulation strength for 50% F.O.V.	1,162 kV	988/0.85
Required clearance	2,700 mm	Fig. 5-9

Table 5-13

Necessary Clearance for Commercial Frequency Voltage

Effective voltage to ground	318 kV	$550/\sqrt{3}$
Insulation deterioration factor	1.1	
Required insulation strength	350 kV	318 x 1.1
Required clearance	1,300 mm	Fig. 5-10

Table 5-14

Necessary Gap between Conductors for Switching Surge

Multiplier of switching surges between conductors	1.8	
Switching surge voltage between phases	1,400 kV	$550 \times 1.8 \times \sqrt{2}$
Insulation deterioration factor	1.1	
Required 50% F.O.V.	1,812 kV	1,400 x 1.1/0.85
Necessary gap	4,300 mm	Fig. 5-11

Table 5-15 Required Number of Insulator Units in Contamination Area

Voltage (kV)	Contamination Severity (mg/cm^2)	Withstand voltage ** (kV/m)	String length (m)	Required number of insulator units *		
				250mm	280mm	320mm
349 ($550/\sqrt{3}$ x 1.1)	Very light 0.03 (<0.03)	86.9	4.02	28	24	21
	Light 0.06 (0.03 ~ 0.06)	67.5	5.17	35	30	27
	Moderate 0.1 (0.06 ~ 0.1)	59.3	5.89	40	35	30
	Heavy 0.3 (>0.1)	49.3	7.08	48	42	36

* Insulator units to be counted as one fractions of 0.5 and over, and to be cut away those of less.

** Refer to Fig. 5-12.

Table 5-16

Outage Rate Caused by Midspan Flashover

L	R_T = 10 Ω Z_T = 77 Ω		R_T = 20 Ω Z_T = 80 Ω		R_T = 30 Ω Z_T = 82 Ω	
	I	O	I	O	I	O
9 m	102 kA	0.8	98 kA	0.9	96 kA	1.0
10	114	0.55	109.5	0.65	107	0.7
11	126	0.4	121	0.45	118	0.5
12	137.5	0.3	132.5	0.3	129	0.35
13	149	0.3	144	0.3	140	0.3

L : Distance between conductor and ground wire

I : Lightning current

O : Outage rate/100 kM·year

Table 5-17

Outage Rate (for I.K.L. = 25 ∿ 30)

R_T (Ω)	I (kA)		Outage rate / 100 kM·Year		
	Tower top	Midspan	Tower top	Midspan	Total
0	182	142	-	0.15	-
10	143	138	0.15	0.15	0.30
20	105	133	0.35	0.15	0.50
30	88	130	0.65	0.18	0.83
40	80	128	0.9	0.18	1.08

R_T : Footing resistance

I : Lightning current

Table 5-18

Outage Rate in Luzon (I.K.L. = 60)

Footing Resistance	Outage rate / 100 kM·year		
	Tower top	Midspan	Total
Ω			
0	-	0.30	-
10	0.30	0.30	0.60
20	0.70	0.30	1.00
30	1.30	0.36	1.66
40	1.80	0.36	2.16

Table 5-19 Corona Noise Level for Various Conductors and Bundles

Phase Voltage (kV)		230/ $\sqrt{3}$	550/ $\sqrt{3}$						
Conductor		CONDOR	CONDOR			Dipper		Bluebird	Thrasher
Number of Subconductor		1	2	3	4	3	4	2	2
G_{max} (kV/cm)		15.5	23.3	18.3	15.2	15.0	12.5	15.7	15.7
N_1 + 3 (dB)		49.8	78.6	60.1	48.7	52.0	42.8	58.8	58.1
N'_1 (dB)	R=1(mm/H)	65.9	88.4	76.4	62.9	67.9	53.2	70.3	69.3
	2 "	68.2	87.7	77.8	65.4	70.3	56.3	72.9	72.0
	4 "	70.2	87.4	78.8	67.5	72.5	59.3	75.0	74.1
	6 "	71.0	87.3	79.2	68.5	73.4	60.7	75.8	75.0
Radio of N'_1 for 230 kV CONDORx1	R=1 (mm/H)	1	1.34	1.16	0.95	1.03	0.81	1.07	1.05
	2 "	1	1.29	1.14	0.96	1.03	0.83	1.07	1.06
	4 "	1	1.25	1.12	0.96	1.03	0.84	1.07	1.06
	6 "	1	1.23	1.12	0.96	1.03	0.85	1.07	1.06

Table 5-20 Corona Loss for Various Conductors and Bundles

Conductor	G_{max} (kV/cm)	Corona loss (kW/KM.1 Φ)			Annual corona power less	
		Fair weather	High humidity	1mm/H Rain	MWH/kM.1 Φ	MWH/KM.2 cct
CONDOR x 2	23.3	6.11	12.22	61.13	211.7	1269.9
" x 3	18.3	0.68	1.36	6.81	23.6	141.5
" x 4	15.2	0.18	0.36	1.81	6.3	37.6
DIPPER x 3	15.0	0.20	0.39	1.97	6.8	41.0
DIPPER x 4	12.5	0.07	0.14	0.72	2.5	14.9
BLUEBIRD x 2	15.7	0.31	0.61	3.06	10.6	63.6
THRASHER x 2	15.4	0.27	0.54	2.74	9.5	56.9

Conditions : Fair weather 3,540 hour [(365-140)x 24 + 140x12)] x 0.5
High humidity 3,540 hour
Annual rainfall 2,400 mm

Table 5-21 Tentative Estimate for EHV Tower Weights

Maximum tension (kg)	5,100	4,900	4,700	4,500
Sag (120°C,no wind, 400m) (m)	12.42	12.97	13.56	14.20
Difference	0	+0.6	+1.2	+1.8
Type of tower (ton)				
E D Q	45.6	46.0	46.5	46.9
E D R_1	56.0	56.1	56.1	56.2
E D R_2	50.1	50.1	50.1	50.1
E D S	57.7	57.1	56.6	56.2
E D T	70.5	69.6	68.8	67.8
Average weight per Kilometer (ton)	129.5	129.7	130.0	130.1

percentage of each tower type	EDQ	60%
	EDR_1	10
	EDR_2	5
	EDS	10
	EDT	15
average span length	400m	
average body extension	18m	

tower weight : based on Fig. 5-38

Table 5-22 Examples of Tower Design Conditions on Existing 230 kV Lines in Philippines

bundles of "CONDOR"	Type	DQ Suspension	DR Suspension strain	DS Suspension strain	DR Strain D.E.
795MCM x 1	Angle	0°	0°~15°	0°~15°	0°~30°A 0°~30°D.E.
	Max.span				
	Wind span	400m	400m	400m	500^mA 250^mD.E.
	Weight span C	600m	900m	1200m	1200m
	G	800m	1300m	1800m	1800m
795MCM x 2	Angle	1°... 5°	5°... 0°	15°..7.5°..0°	0°~30°A ↗ 0°~45/2°D.E.
	Max.span	510^m.... 510^m	680^m.... 680^m	850^m..850^m..850^m	850^m 850^m
	Wind span	340^m.... 380^m	340^m.... 540^m	340^m..640^m..940^m	430^m 215^m
	Weight span C	510^m.... 510^m	765^m.... 765^m	1020^m.1020^m.1020^m	1020^m 1020^m
	G	680^m.... 680^m	1105^m... 1105^m	1530^m.1530^m.1530^m	1530^m 1530^m
795MCM x 4	Angle	1°... 0°	5° ... 0°	10°.. 5° .. 0°	0°~30°A ↗ 0°~45/2°D.E.
	Max.span	400^m .... 400^m	550^m .... 550^m	700^m..700^m..700^m	700^m 700^m
	wind span	270^m .... 310^m	270^m .... 470^m	270^m..470^m..670^m	340^m 270^m
	Weight span C	405^m .... 405^m	608^m .... 608^m	810^m..810^m..810^m	810^m 810^m
	G	540^m .... 540^m	878^m .... 878^m	1215^m.1215^m.1215^m	1215^m 1215^m

C : Conductor G : Ground wire

Table 5-23 Calculation of Required Horizontal Separation

Span length (m)	300	400	500	600	700	800
ditto (ft) A	984	1312	1640	1969	2297	2625
60°F final Sag (m)	5.75	10.98	17.80	26.17	36.08	47.52
ditto (ft) B	18.86	36.02	58.40	85.86	118.38	155.91
% Sag B/A x 100	1.92	2.75	3.56	4.36	5.15	5.94
A (ft)	0.025 (550) = 13.75					
L/2 (ft)	4.9m/0.304794/2 = 8.04					
Horizontal separation (ft)	23.02	25.45	26.54	27.61	28.66	29.72
ditto (m)	7.02	7.76	8.09	8.42	8.74	9.06

Horizontal separation = C.D/W.(% Sag)+A+L/2

where C : Experience factor larger than 1.25

D : Diameter of conductor (in) "CONDOR" = 1.093

W : Weight of bare conductor (lbs/ft) "CODOR" = 1.024

(% Sag) = (60°F final sag in ft)/(Span length in ft) x 100

A : 0.025 x (Voltage between phases in kV)

L : Length of insulator strings (ft)

Table 5-24 Dimensions for Tower Clearance Diagram

		Suspension EDQ (1°)	Suspension EDR_1 (5°)	Strain
Insulation distance (mm)	a	1300 (1300)		
	b	3600 (3600)		
Swinging angle of insulator strings (°)	θ_1	21 (21)	39 (39)	15 (15)
	θ_2	67 * (70)	74 (74)	60 (60)
Length of swinging Hanger		- (-)	800 (-)	- (-)
Length of insulator strings (mm)		4,900 (6,700)	4,900 (6,700)	4,900 (6,000)

( ) Contamination design

a : Minimum insulation clearance for commercial frequency voltage

b : Standard insulation clearance for lightning impulse

θ_1 : Swinging angle of insulator strings in ordinary condition

θ_2 : Swinging angle of insulator strings in worst condition

* : Calculation results is 70 degrees but is limited up to 67 degrees not to install swinging hanger

Table 5-25 Application Standard for EHV Tower Foundation

Type (bearing capacity)	Typical land	Soil condition	Remarks
I (>30 t/m^2)	Mountainous land Hill Forest Farm	Hard soil	
II (20~30 t/m^2)	Rice field Farm near the river or close to the rice field	Medium soil with low underground water level	
III (10~20 t/m^2) IV (<10 t/m^2)	Rice field near the river Marshy ground	Soft soil with high underground water level or submerged condition	This type can be applied for the standard penetration value not less than around 5. For angle towers piles should be applied.

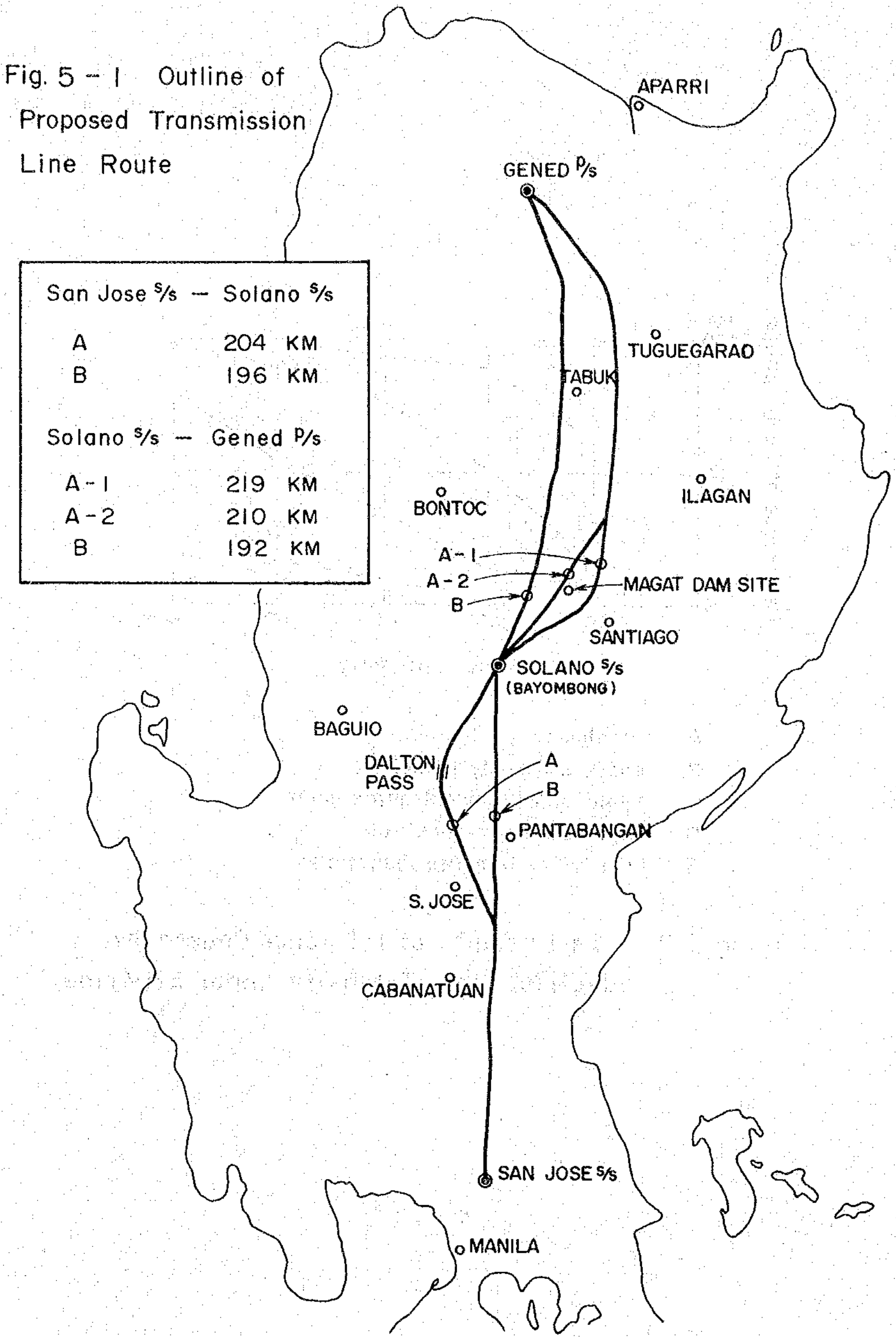
The details of such expressions are possible only after the precise survey of the tower position is finished and appropriate soil survey results are obtained.

Table 5-26

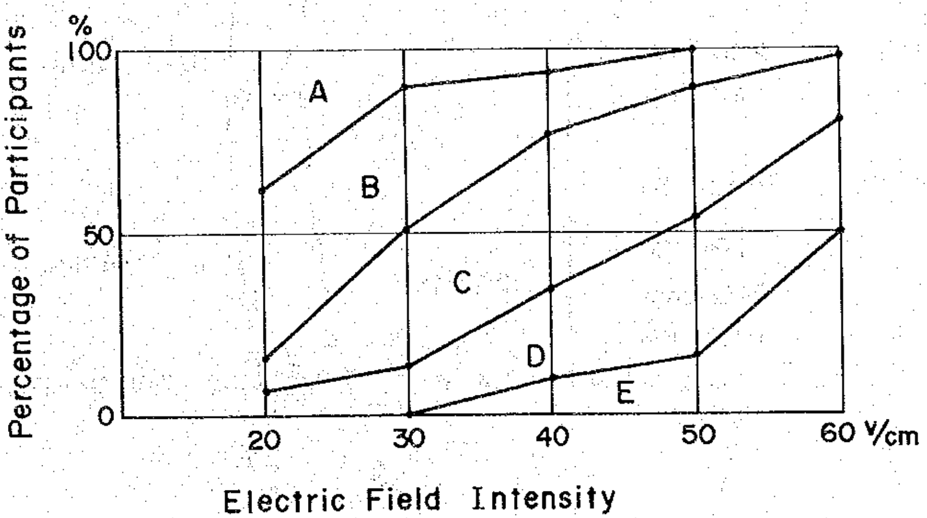
List of Stringing Tools and Equipment for EHV Line Construction

Description	Q'ty Unit
Engine puller 5t. double capstan	2
Tensioner for conductor	4
Tensioner for wire	4
Wire reel (empty)	20
Reel winder	4
Stringing block for bundle conductors	200
Stringing sheave for conductor	50
Stringing sheave for ground wire	50
Running board	4
Running board for wire	4
Gondola for bundle 4 conductors	8
Engine compressor for joint 100t.	4
Dise for joint compression work	12
Cutter for stranded aluminum conductor	5
Joint protector	40
Engine winch	4
Come along for conductor	45
Come along for ground wire	15
Wire rope 16mm dia.	60 KM
Wire rope 12mm dia.	3 KM
Wire rope 10mm dia.	25 KM
Cable clamp for pulling conductors	20
Wire net	10
Swivel	6
Shackle for wire joint	60
Wire pulling clamp	20
U-clevis	50
Turn backle	20
Ladder for stringing work	6
Complession type wire cutter	6
Exchanger for 320mm insulators	1
Exchanger for 280mm insulators	1
Others	1

Fig. 5 - 1 Outline of Proposed Transmission Line Route



San Jose S/s — Solano S/s	
A	204 KM
B	196 KM
Solano S/s — Gened P/s	
A - 1	219 KM
A - 2	210 KM
B	192 KM



A. no shock
B. shock scarecely perceived
C. slight shock but not unpleasant
D. unpleasant but torelable
E. hateful to tolerate manytimes

Fig. 5-2 Test Results of Influence Caused by Electric Field Intensity under EHV Line

Fig. 5-3 Relations between Conductor Height and Electric Field Intensity under EHV Transmission Line

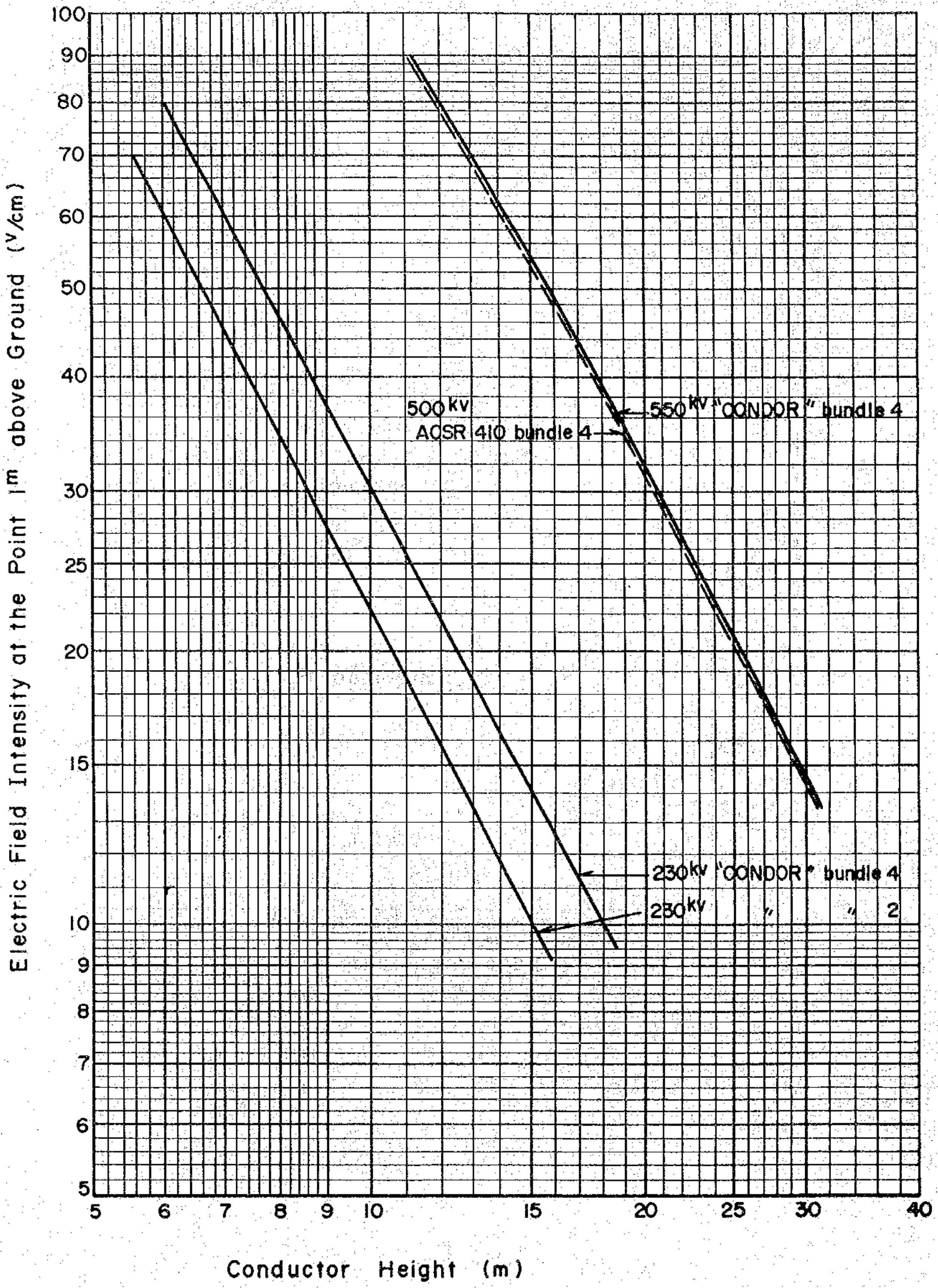


Fig. 5-4 Relations between Grounding Current and Conductor Height for EHV Lines

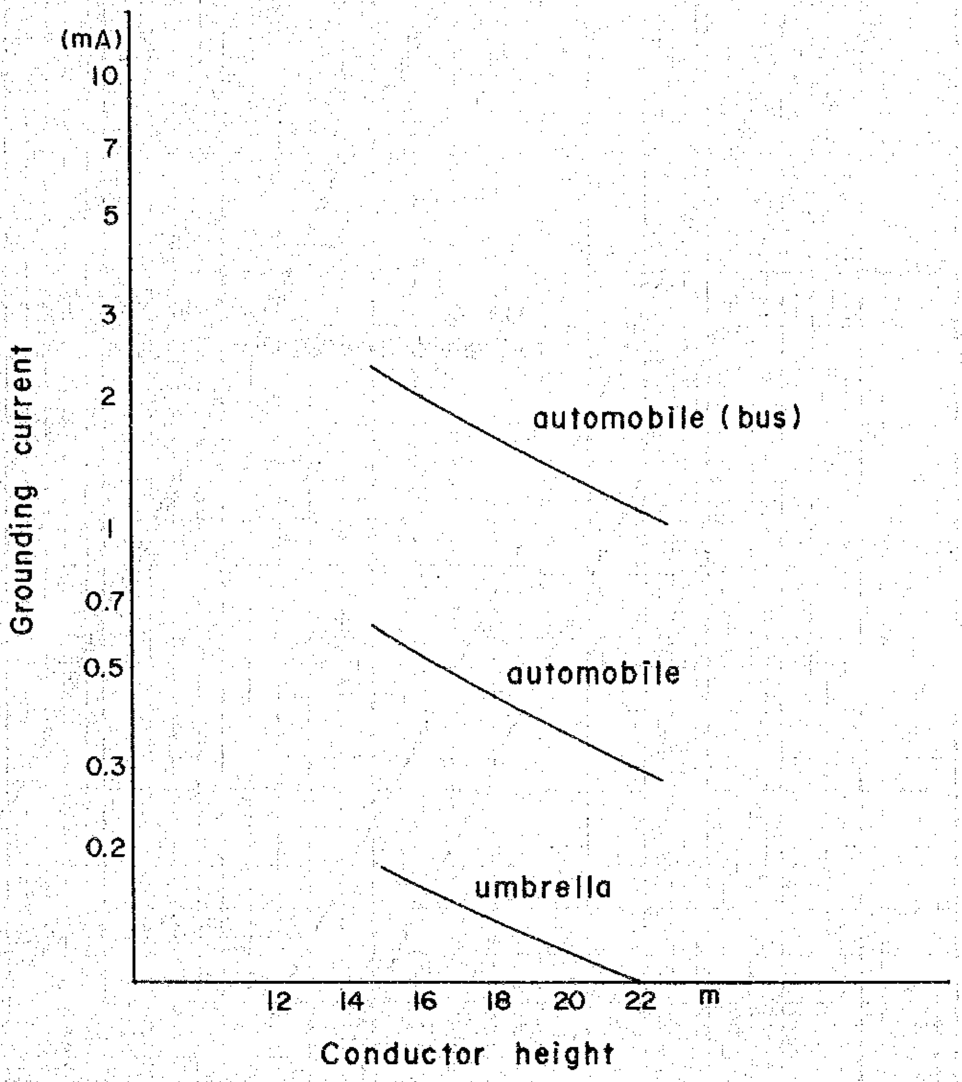
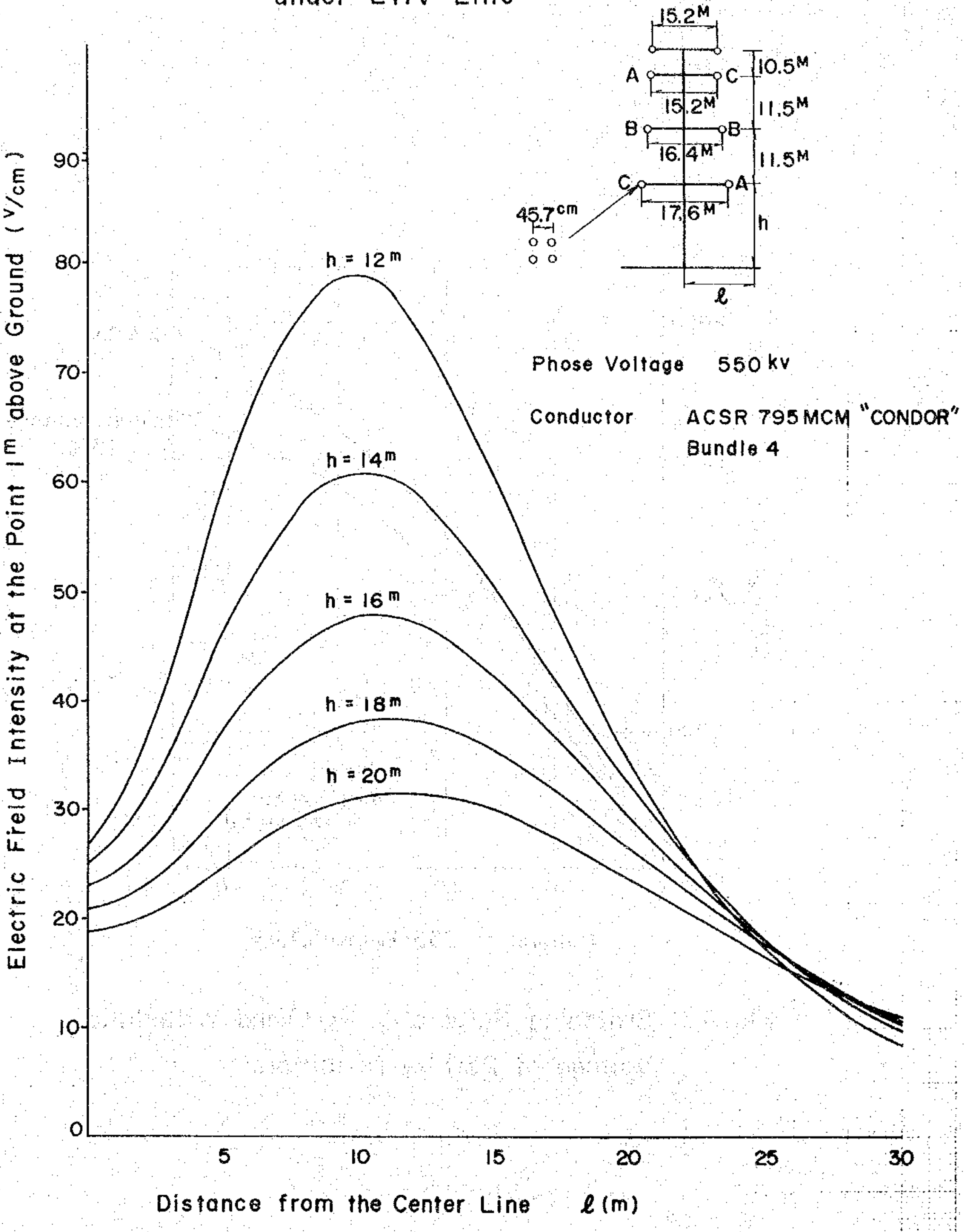


Fig. 5-5 Lateral Profile of Electric Field Intensity under EHV Line



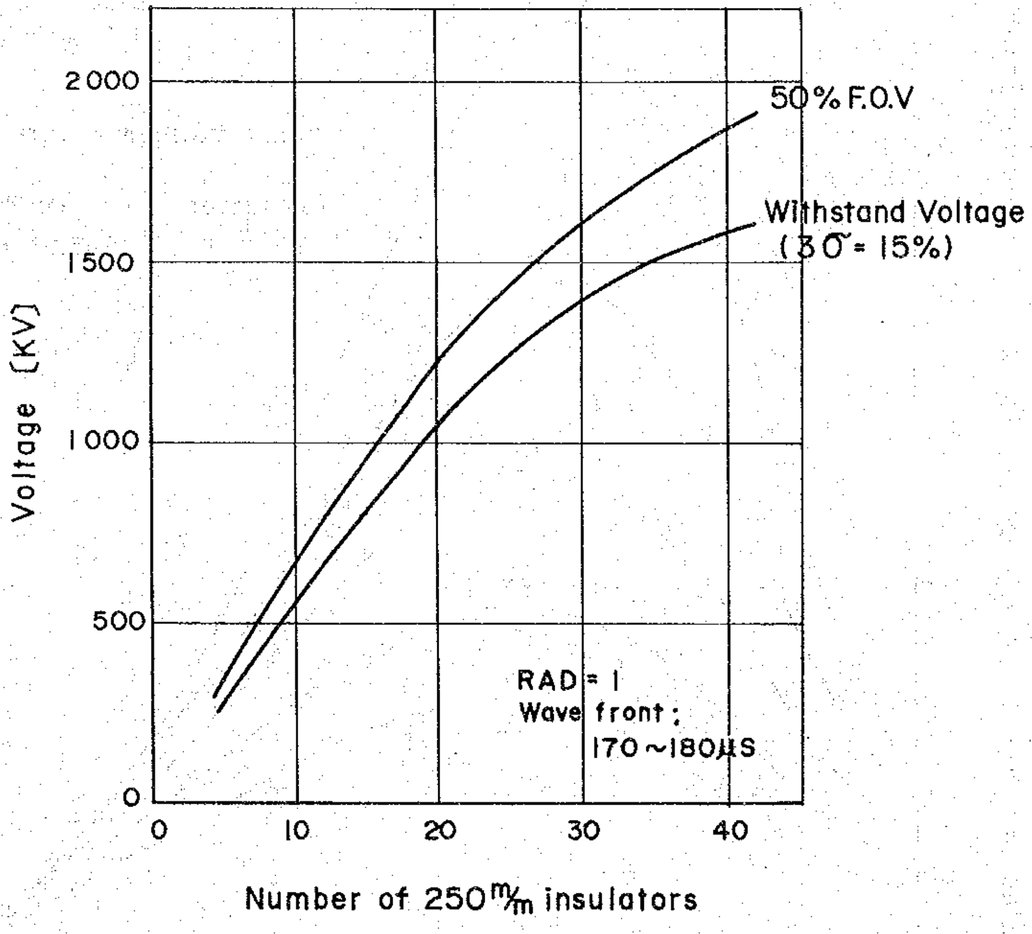


Fig. 5-6 Switching Surge 50% F.O.V and Withstand Voltage of 250 m/m Insulators

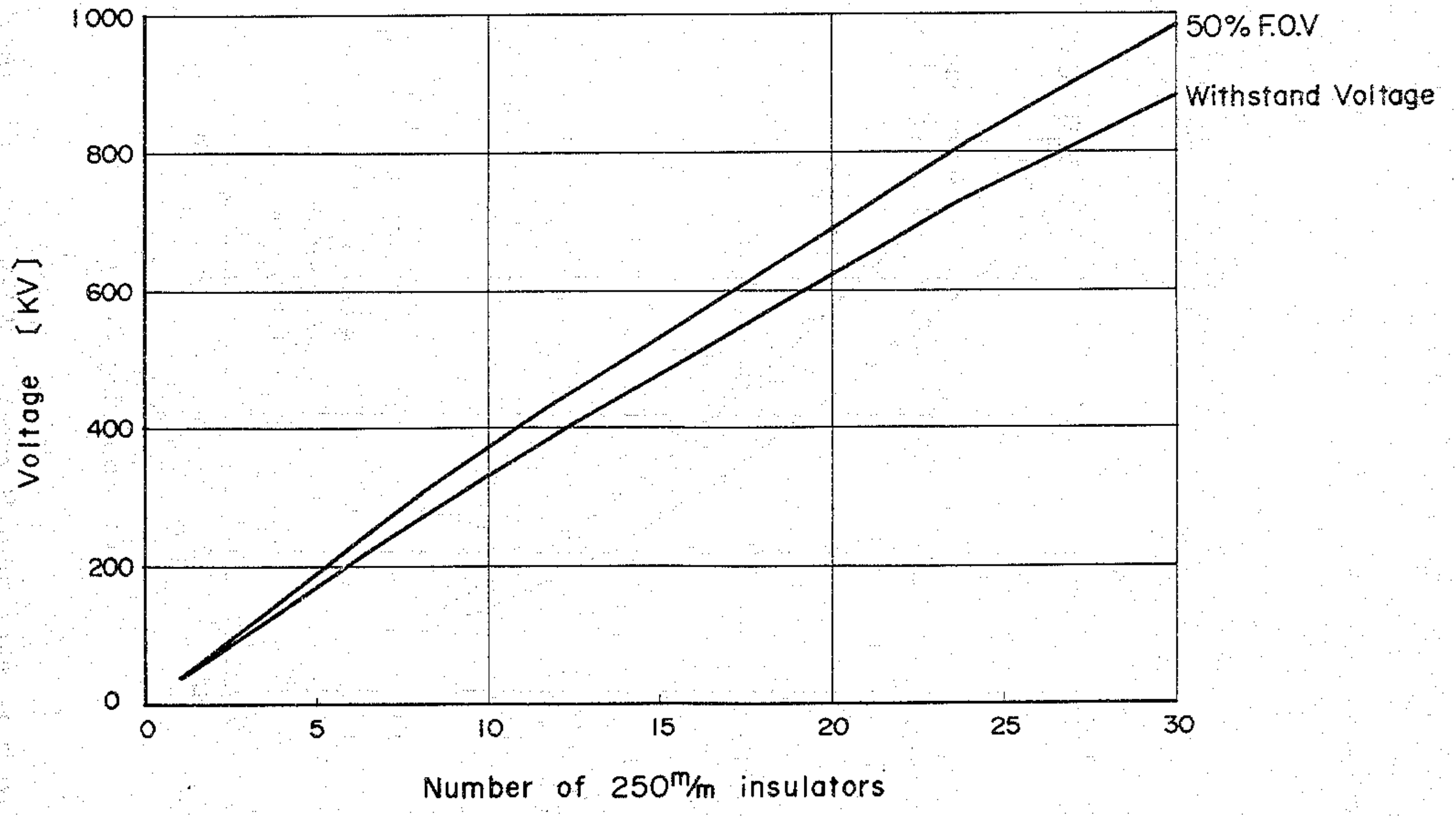


Fig.5-7 Power Frequency 50% F.O.V and Withstand Voltage of 250m/m Insulators (Wet)

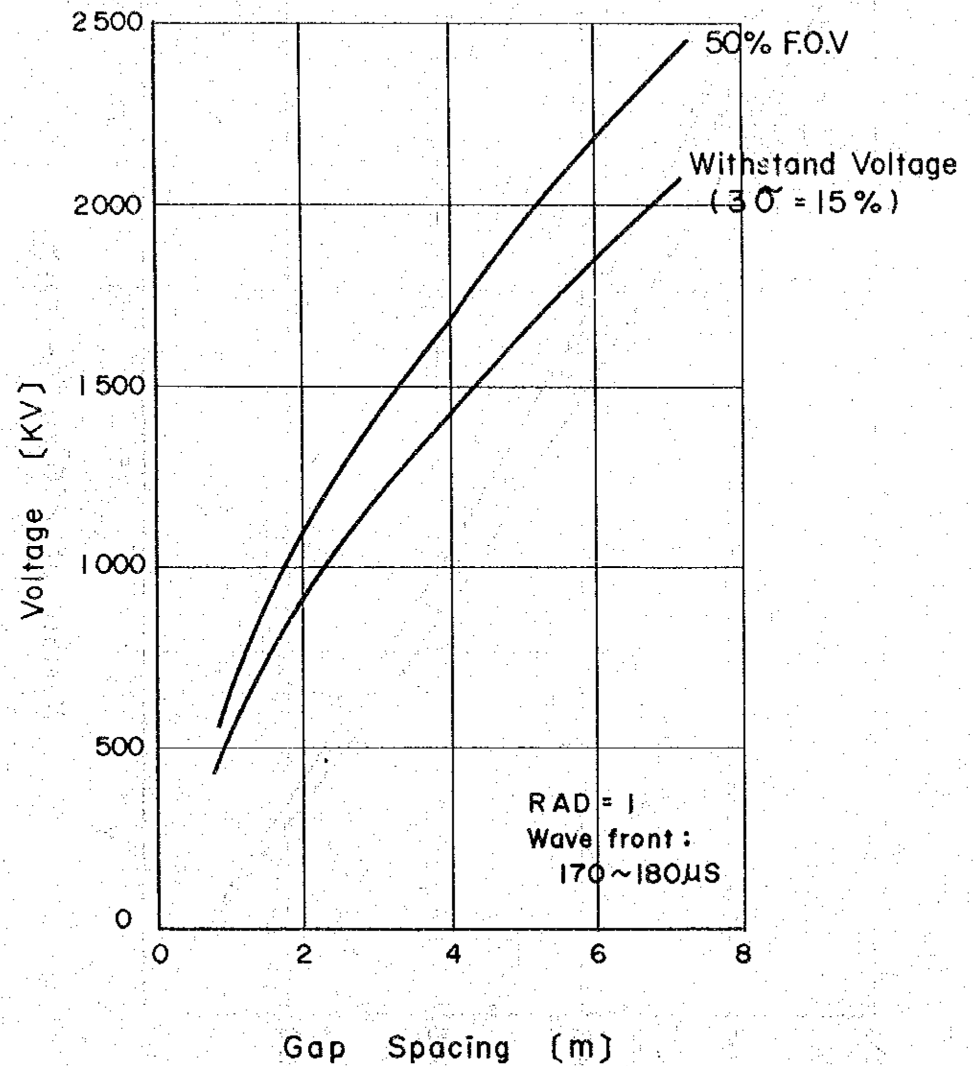


Fig. 5-8 Switching Surge 50% F.O.V and Withstand Voltage of Rod - Rod
(Positive polarity, Dry)

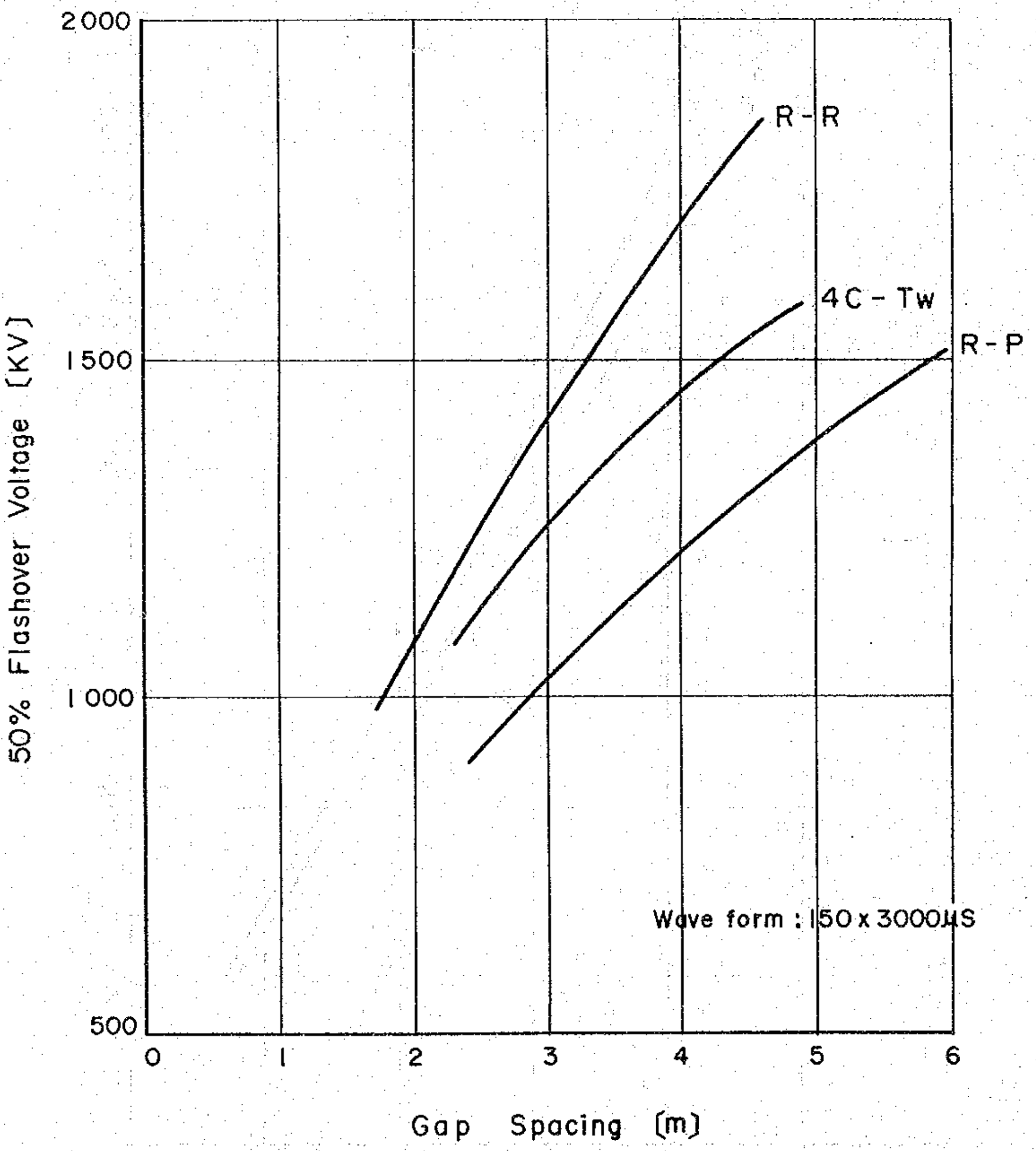


Fig. 5-9 Switching Surge 50% F.O.V of Rod-Rod, Rod-Plane and 4 Conductor-Tower

(Positive polarity, Dry)

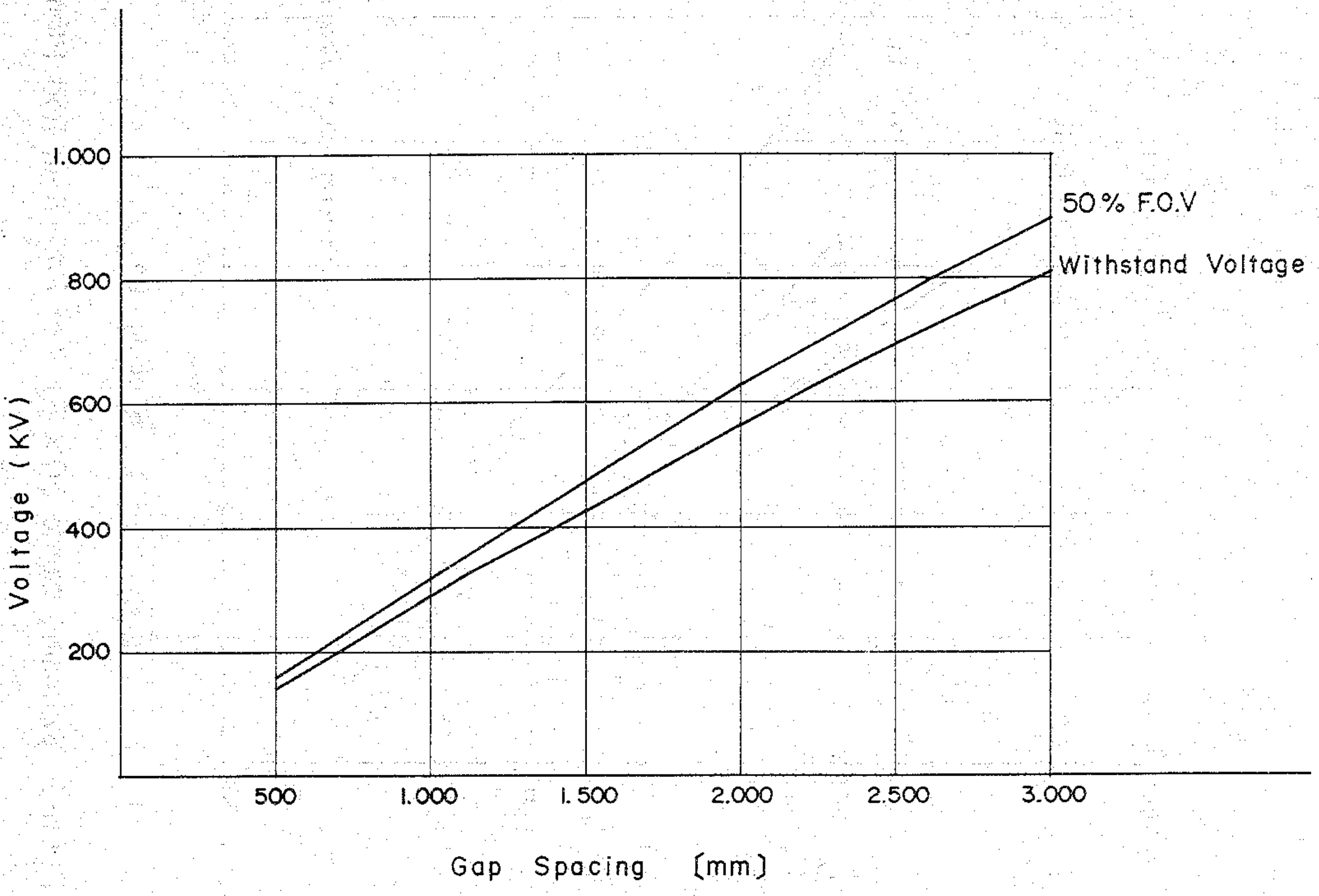


Fig. 5-10 Power Frequency 50% F.O.V and Withstand Voltage of Rod - Rod (Wet)

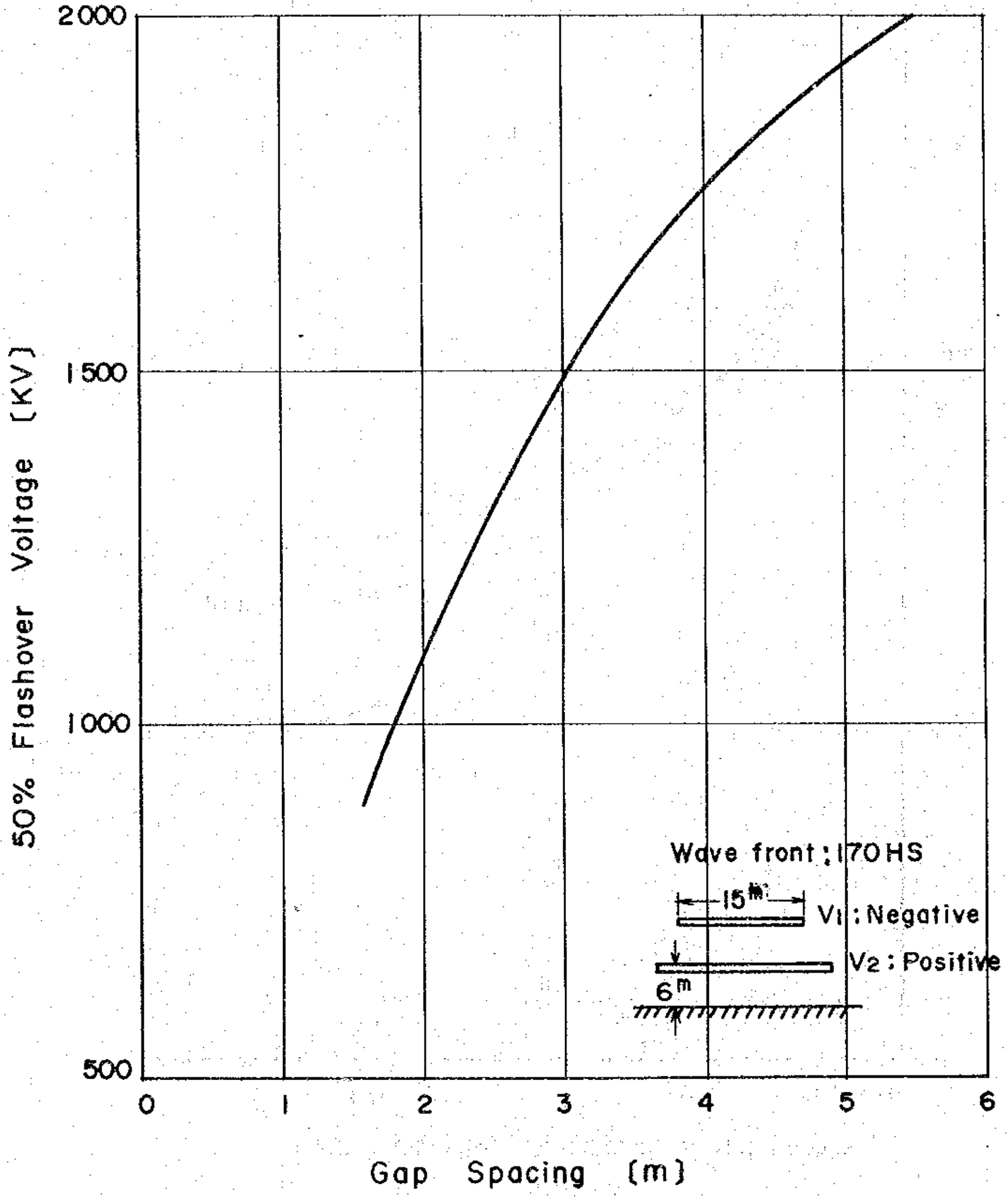


Fig. 5-11 Switching Surge 50% F.O.V of Parallel Conductors

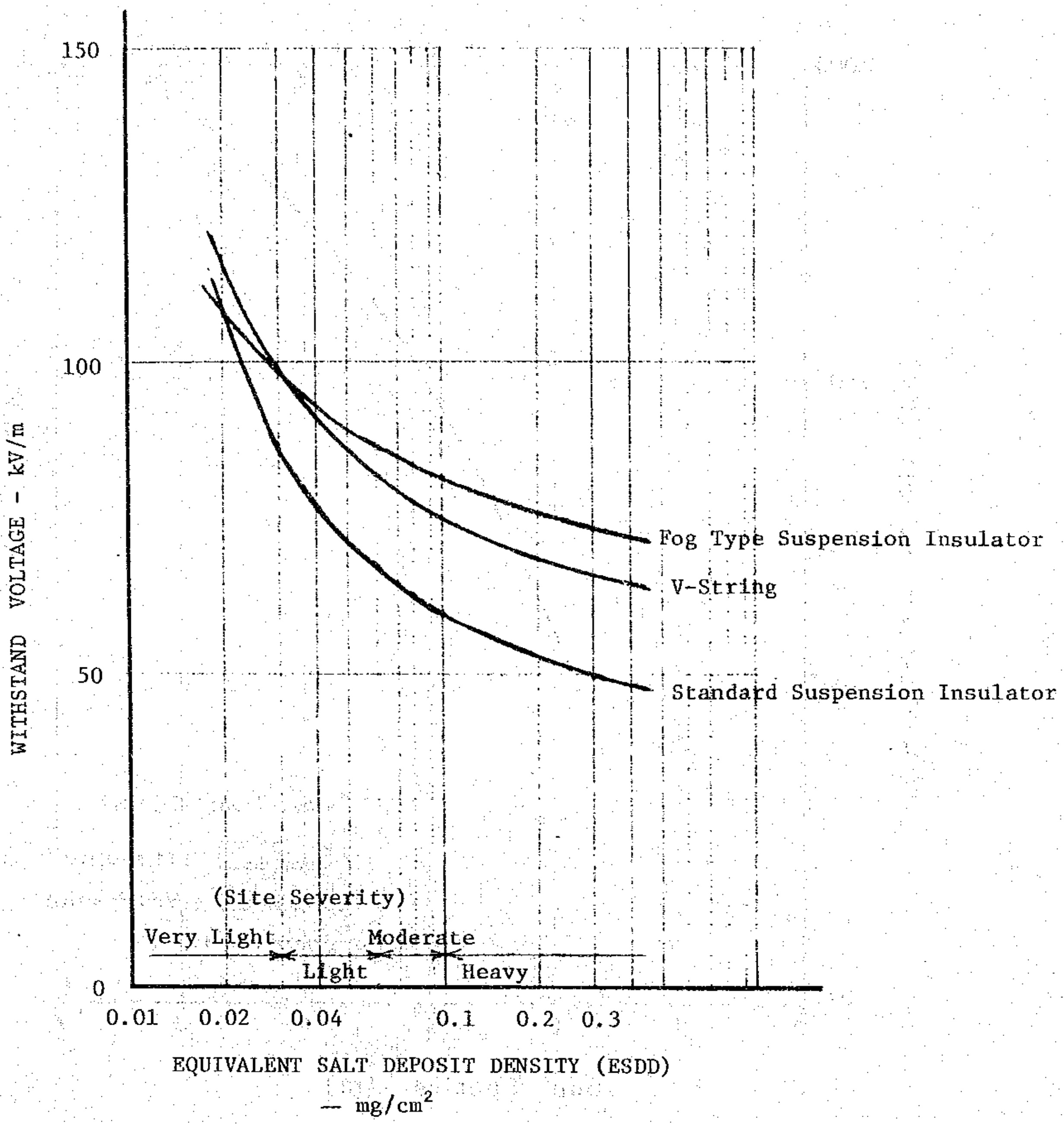


Fig. 5-12 Power Frequency Withstand Voltage of Contaminated Suspension Insulators in Fog.

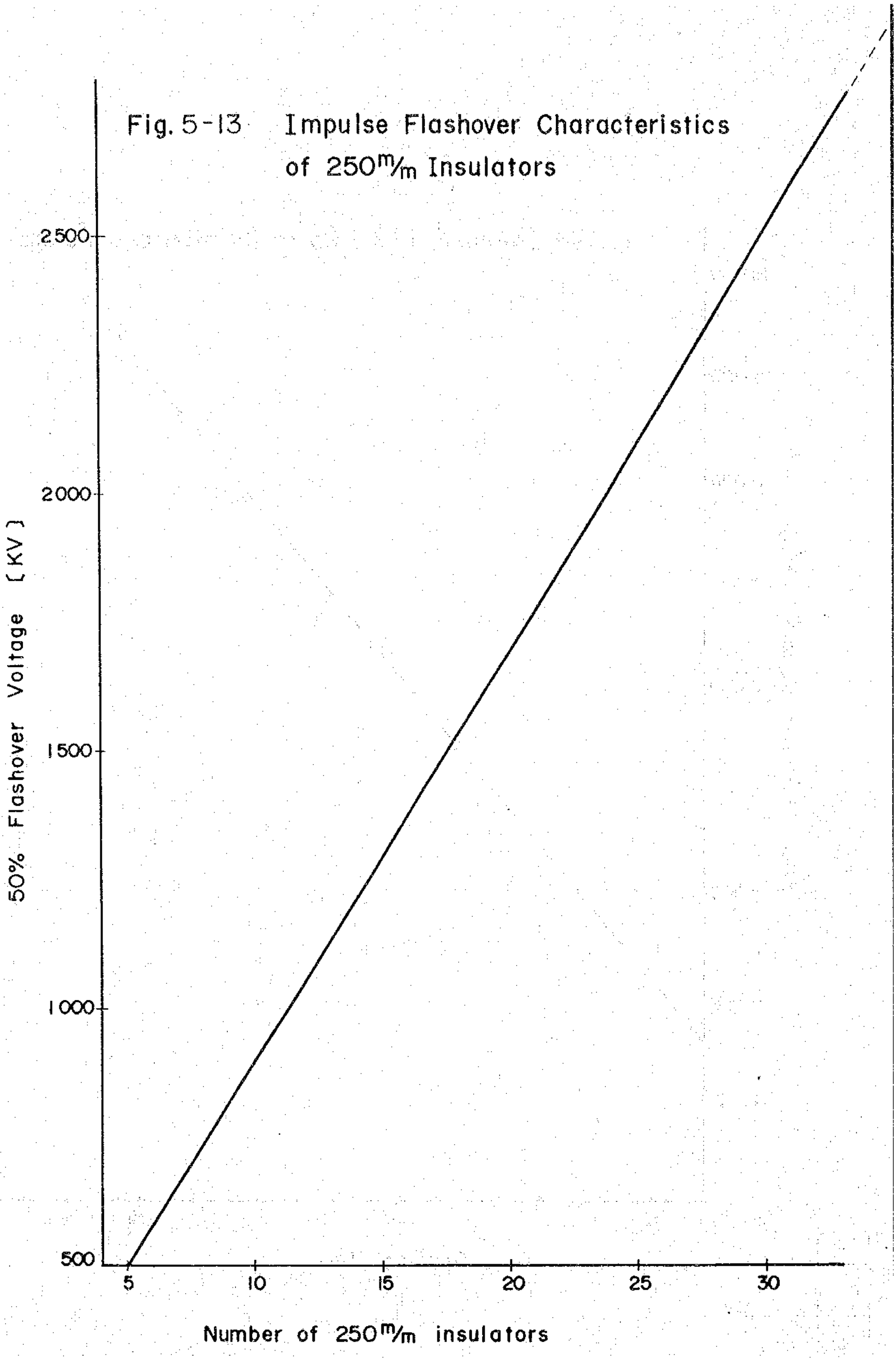


Fig. 5-13 Impulse Flashover Characteristics of 250$^m/_m$ Insulators

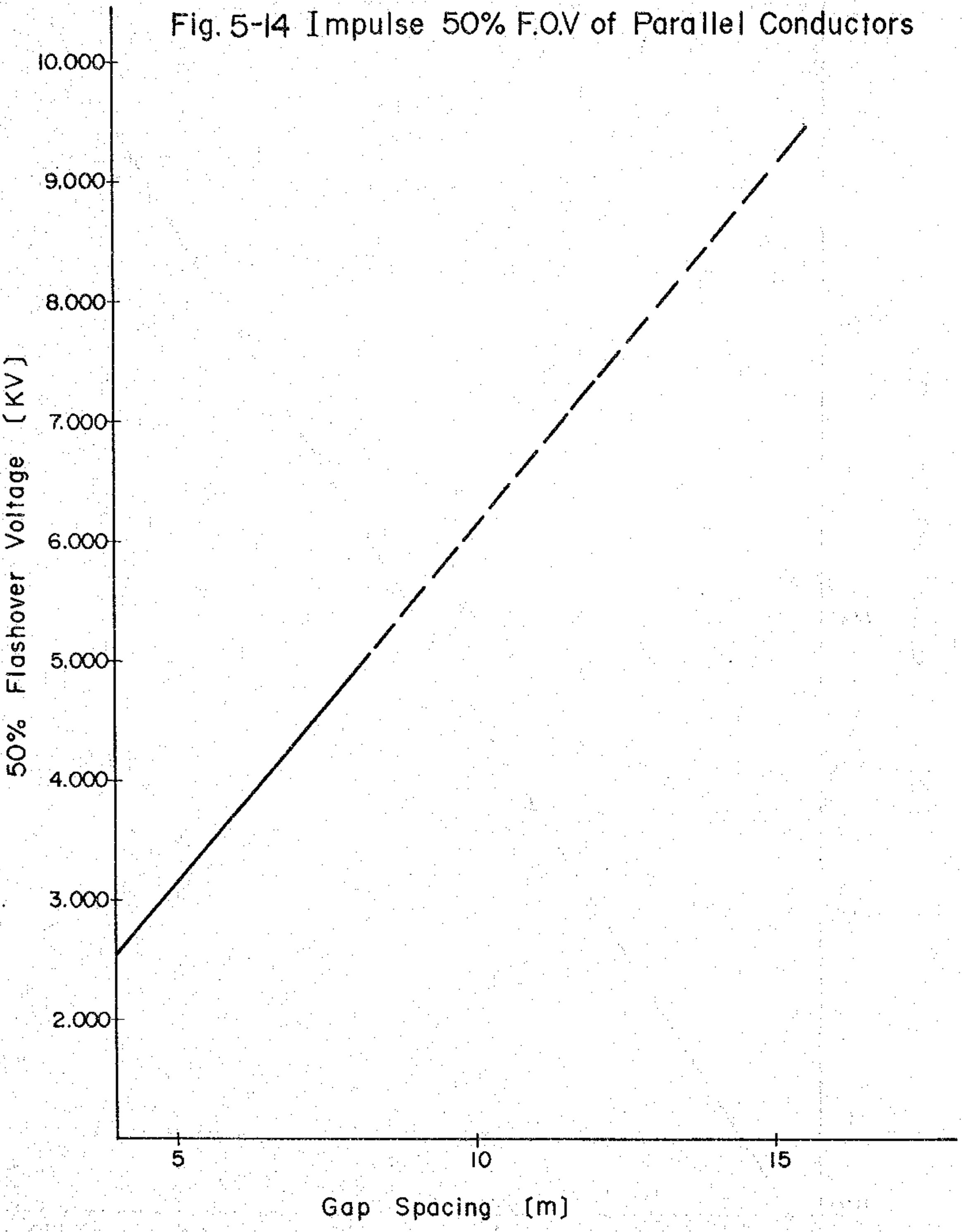
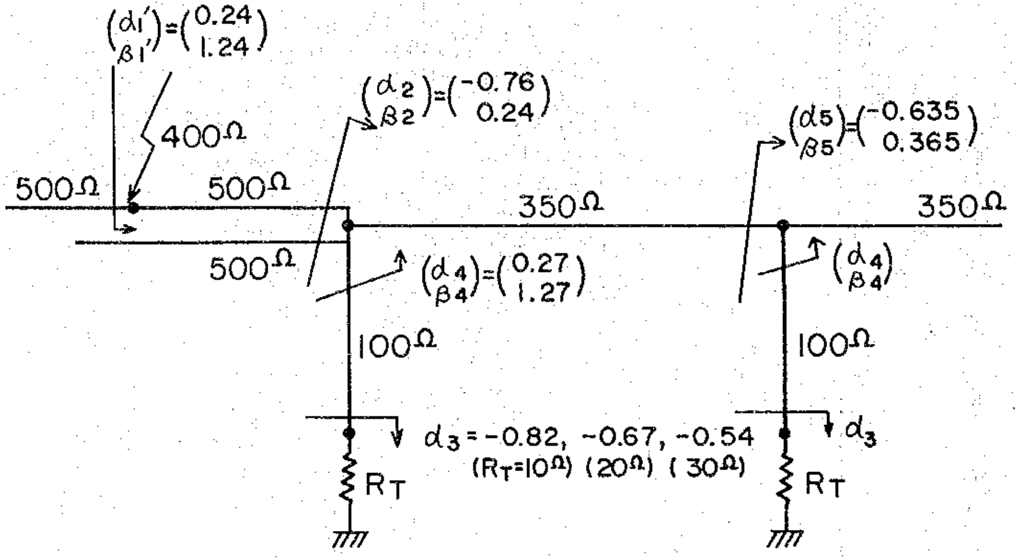


Fig. 5-14 Impulse 50% F.O.V of Parallel Conductors

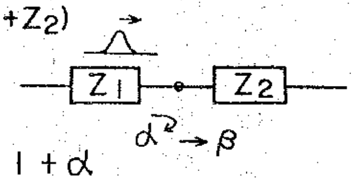
Fig. 5-15 Illustration of Calculation Conditions for Impedance Rise Caused by Lightning



Reflection coefficient $\alpha = (Z_2 - Z_1)/(Z_1 + Z_2)$

Transmission coefficient $\beta = 1 + \alpha$

$\alpha' = \alpha + \beta$, $\beta' = 1 + \alpha$



Calculation condilions

Impedance of lightning pass	400 Ω
Surge impedance of g.w.	500 Ω (1 line), 350 Ω (2 line)
Surge velocity	300 m/μs (g.w.), 210 m/μs (tower)
Damping constant	0.85 (g.w.), 0.9 (tower)
Duration of wave	4 μs
Initial impedance at midspan	$Z_m = 1/(1/400 + 1/500 + 1/500)$ $= 154\ \Omega$

Fig.5-16(1) Illustration of Grid Diagram Calculation for Lightning Surge Caused by Lightning Stroke at Midspan

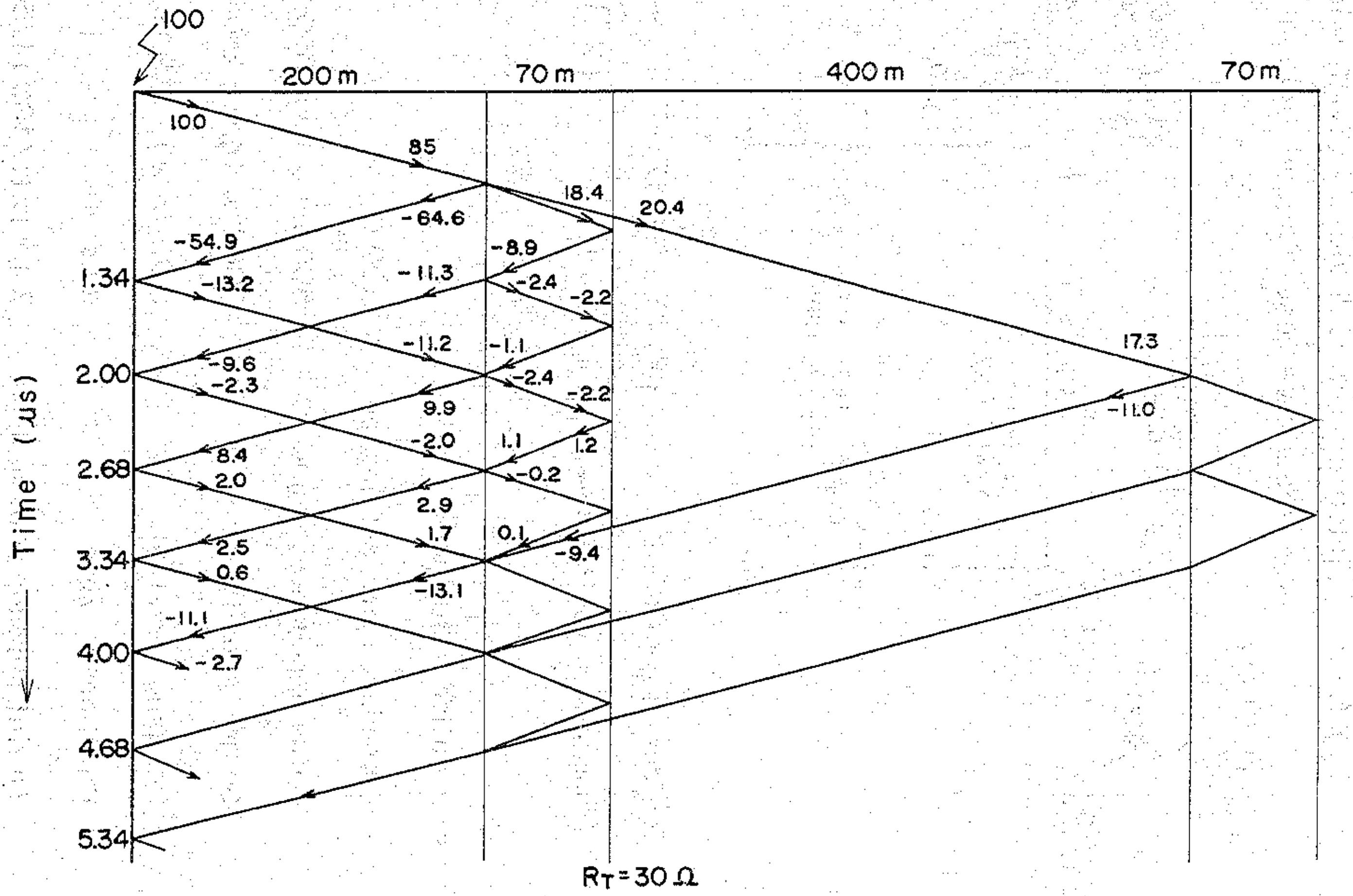


Fig.5-16(2) Illustration of Grid Diagram Calculation for Impedance Rise on Tower Top

Time		Impedance
$0^{\mu s}$	100	154^{Ω}
1.34	- 68.1	-105
2.00	- 11.9	- 18
2.68	10.1	16
3.34	3.1	5
4.00	- 8.4	- 13

$R_T = 30\,\Omega$

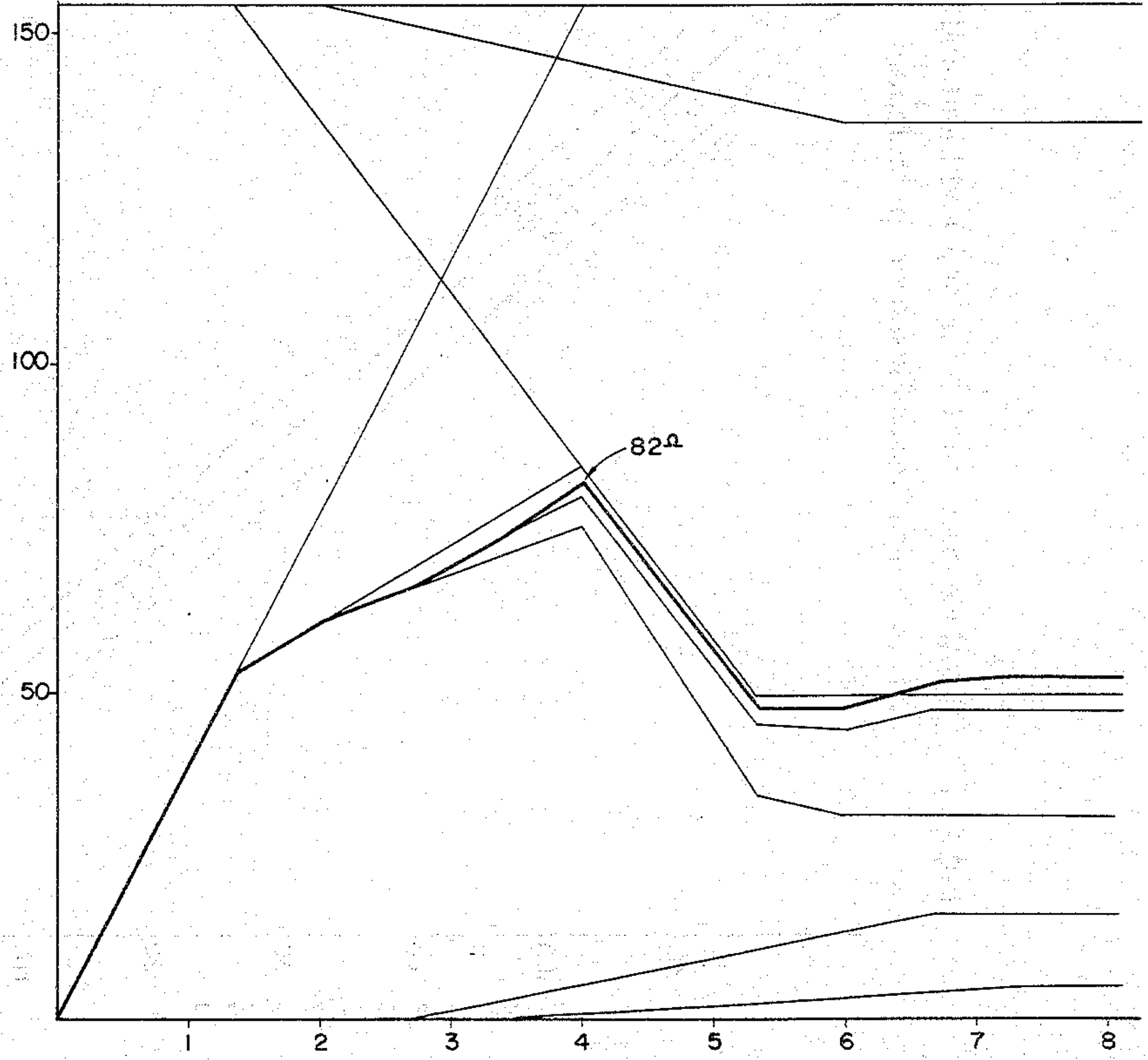
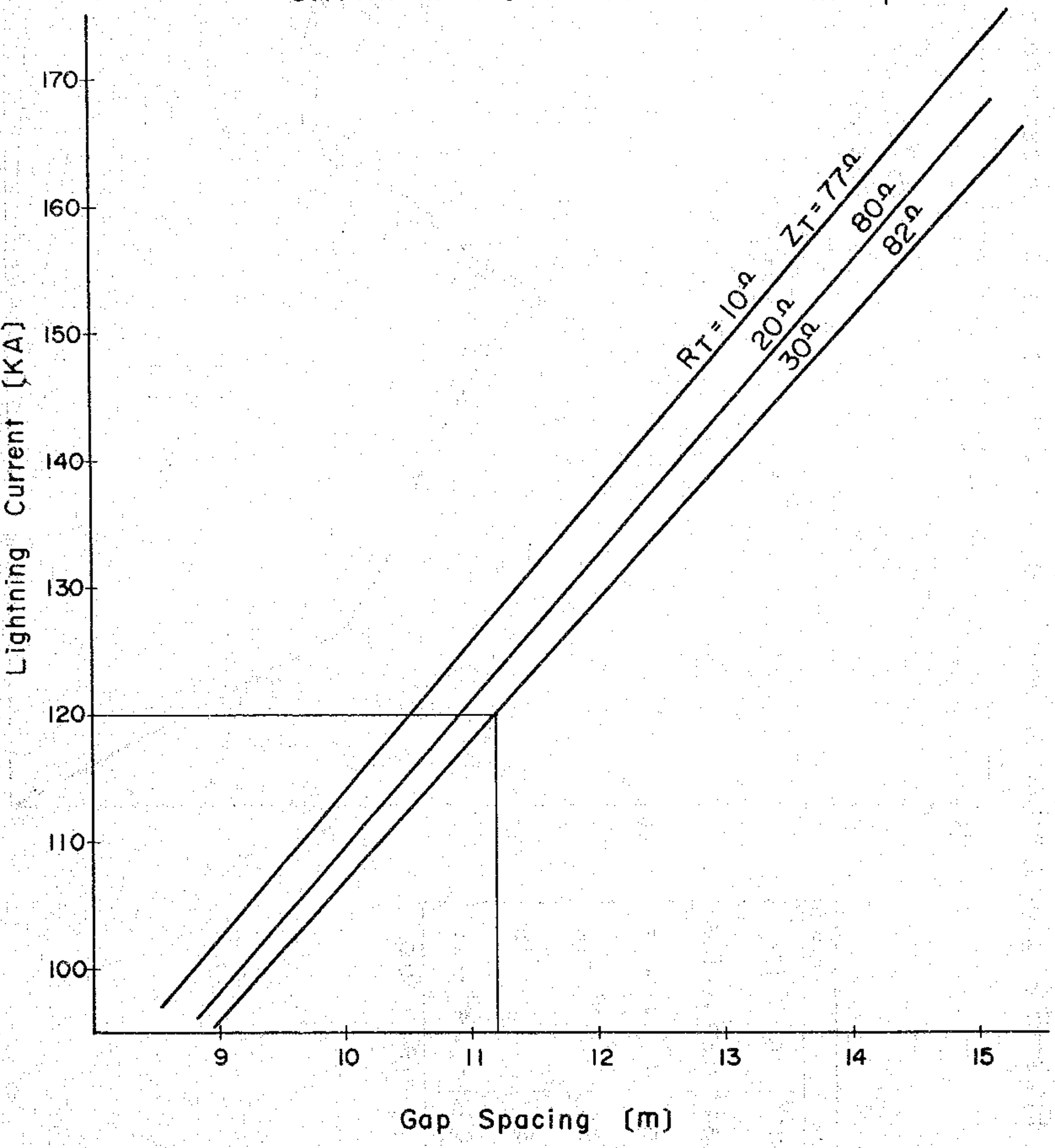


Fig. 5-17 Relations between Gap Spacing and Lightning Current which Causes Flashover at Midspan



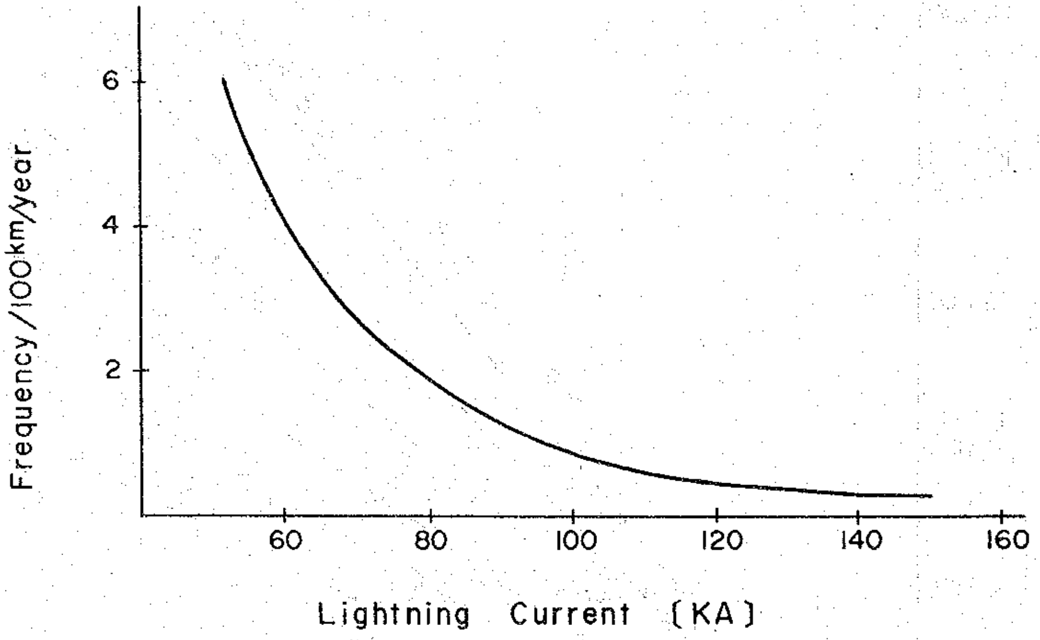


Fig.5-18 Lightning Current Frequency Curve

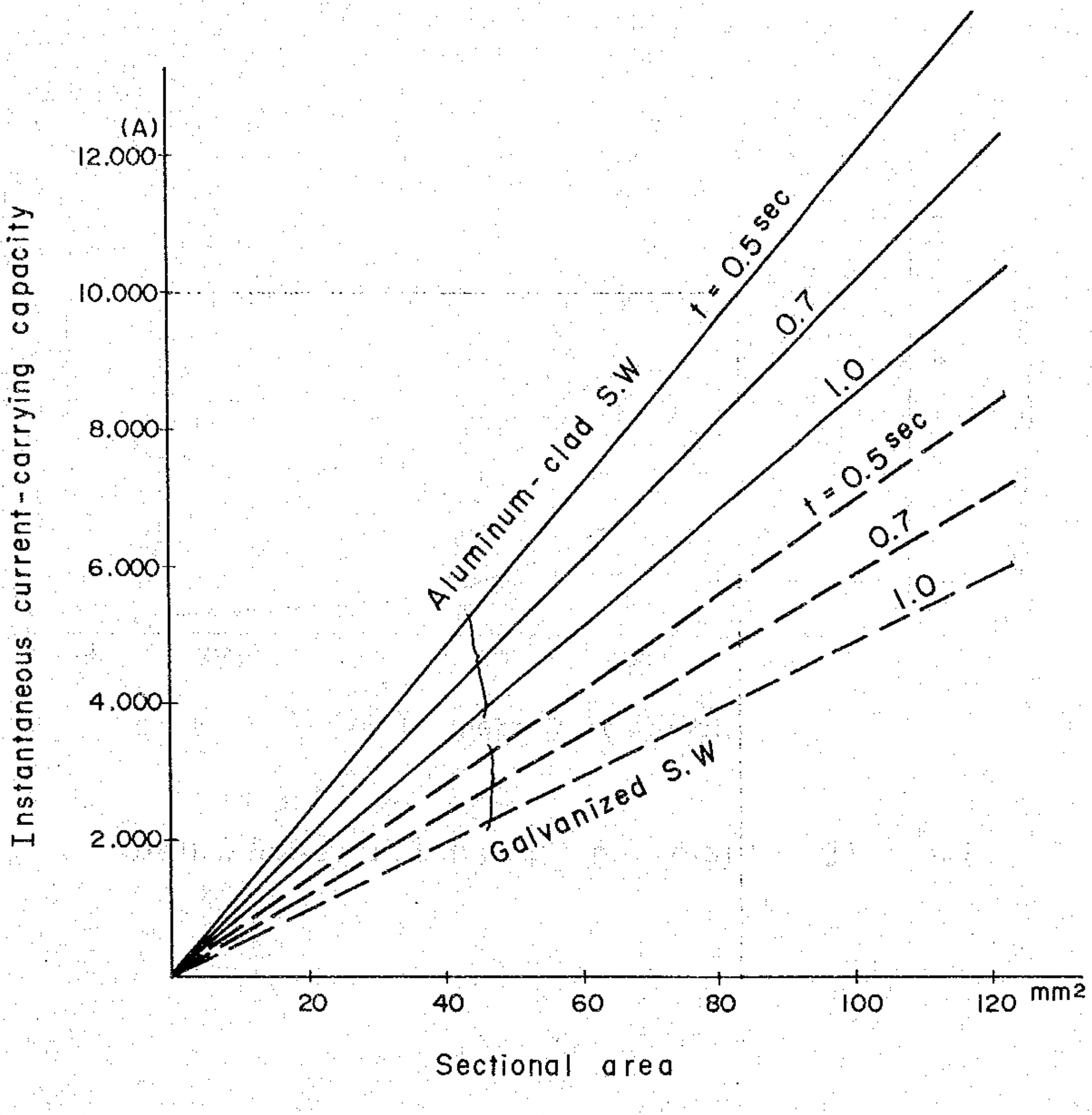


Fig. 5-19 Instantaneous Current-Carrying Capacity of Ground Wire

Fig.5-20 Relations Between Footing Resistance and Impedance Rise

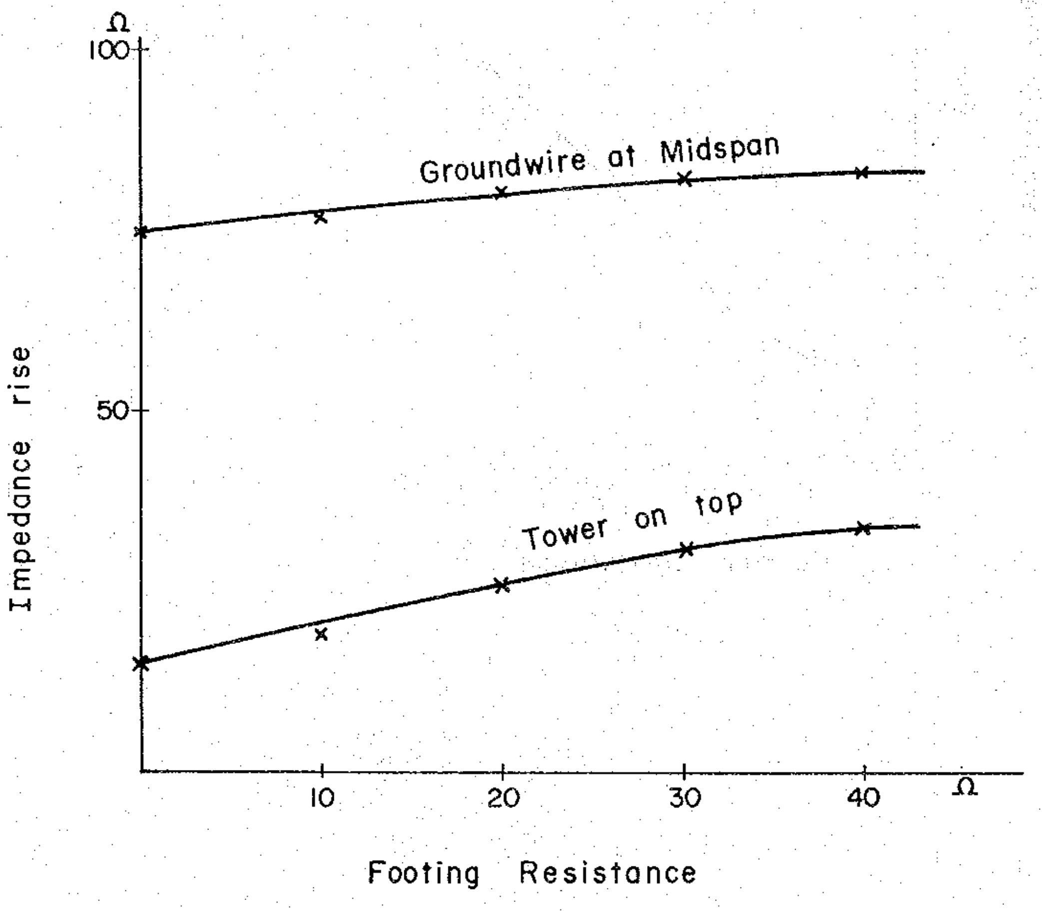


Fig. 5-21 Relation between Outage Rate and Footing Resistance in Luzon

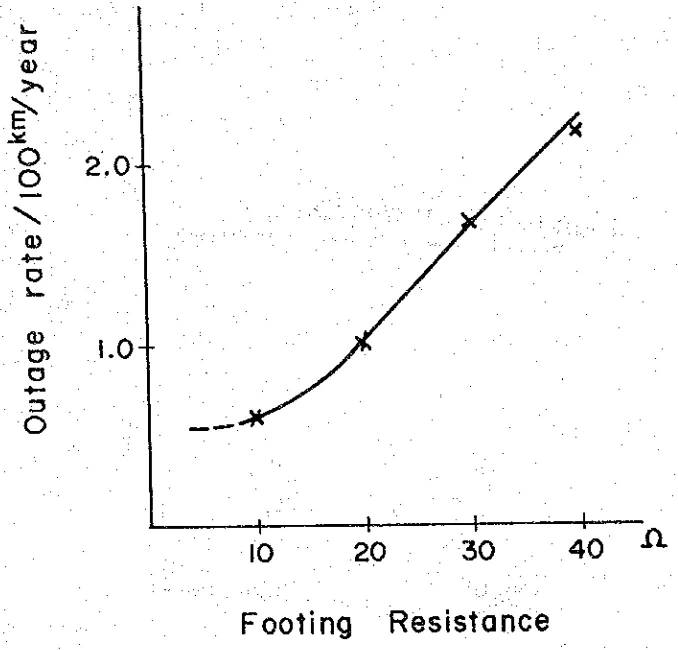
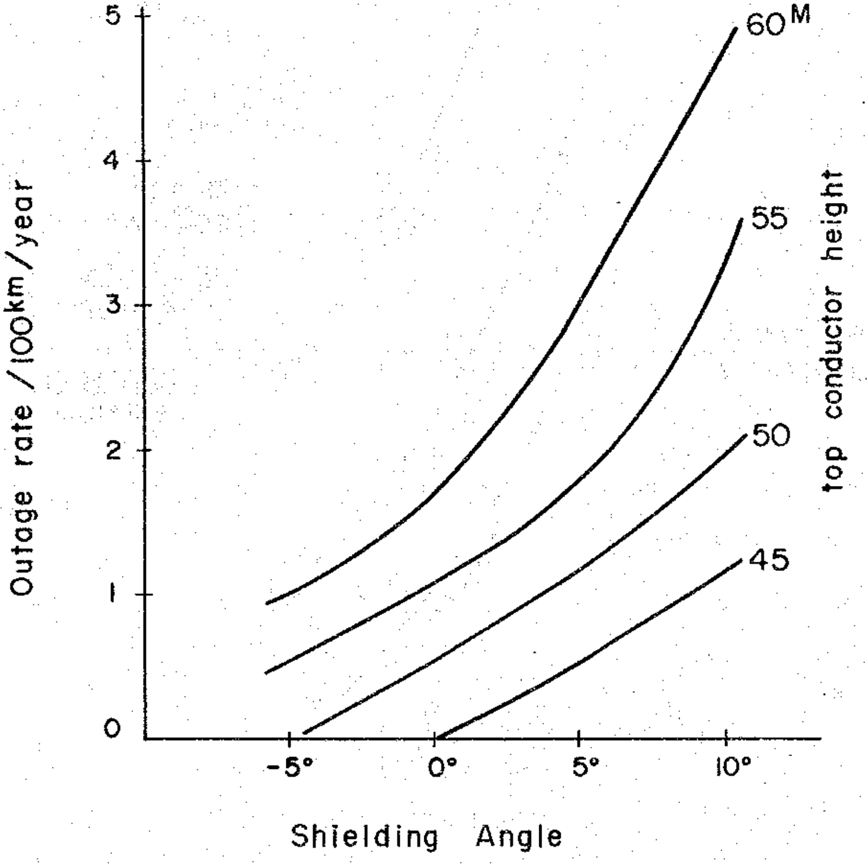


Fig. 5-22 Outage Rate Caused by Shielding Failure



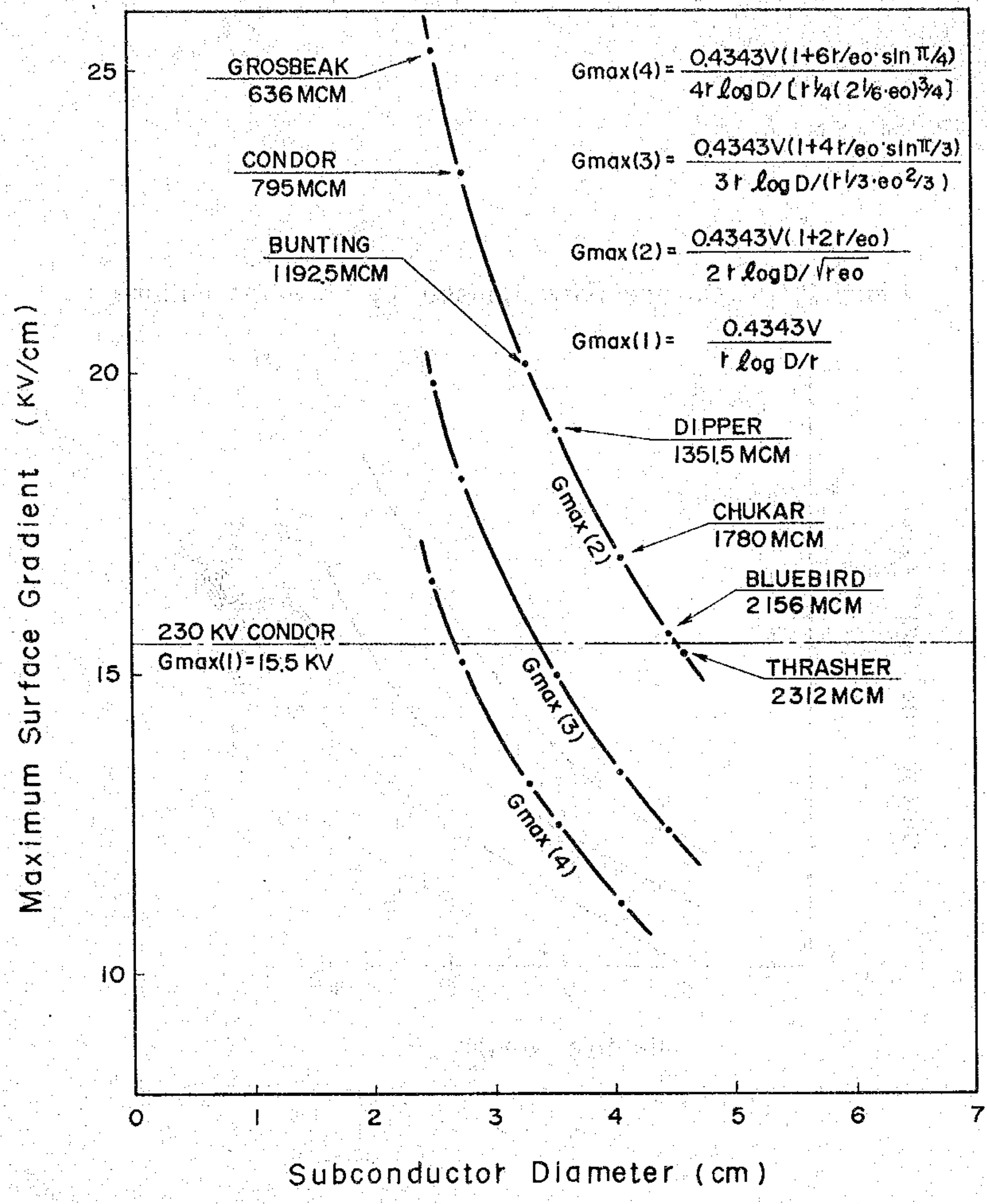


Fig 5-23 Maximum Conductor Surface Gradient versus Subconductor Diameter

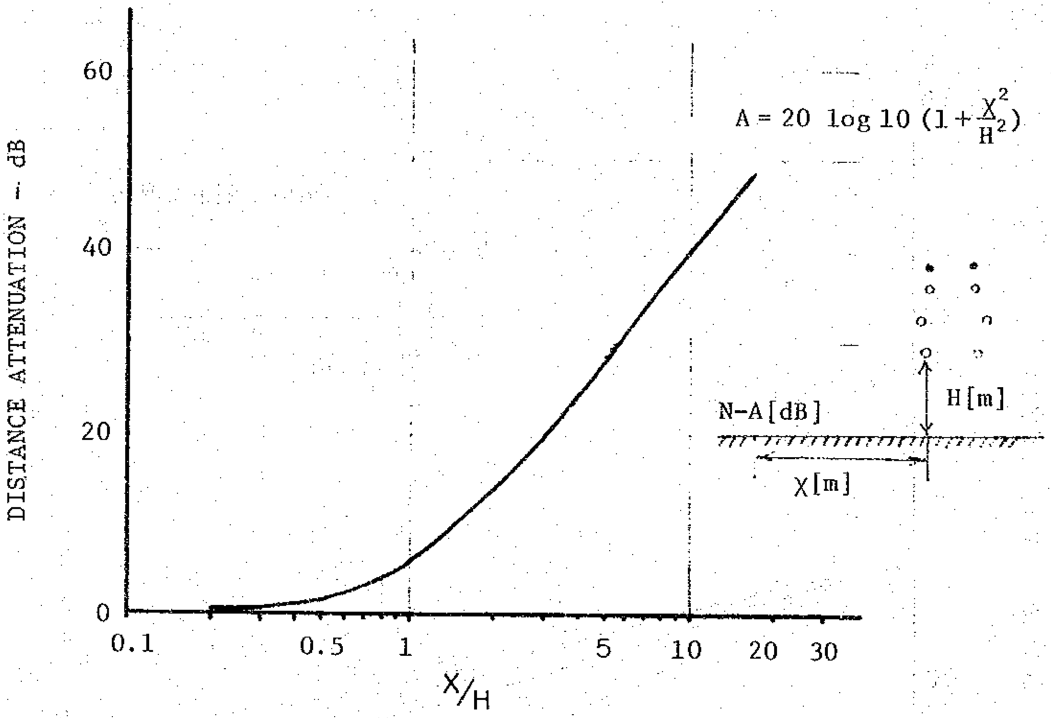
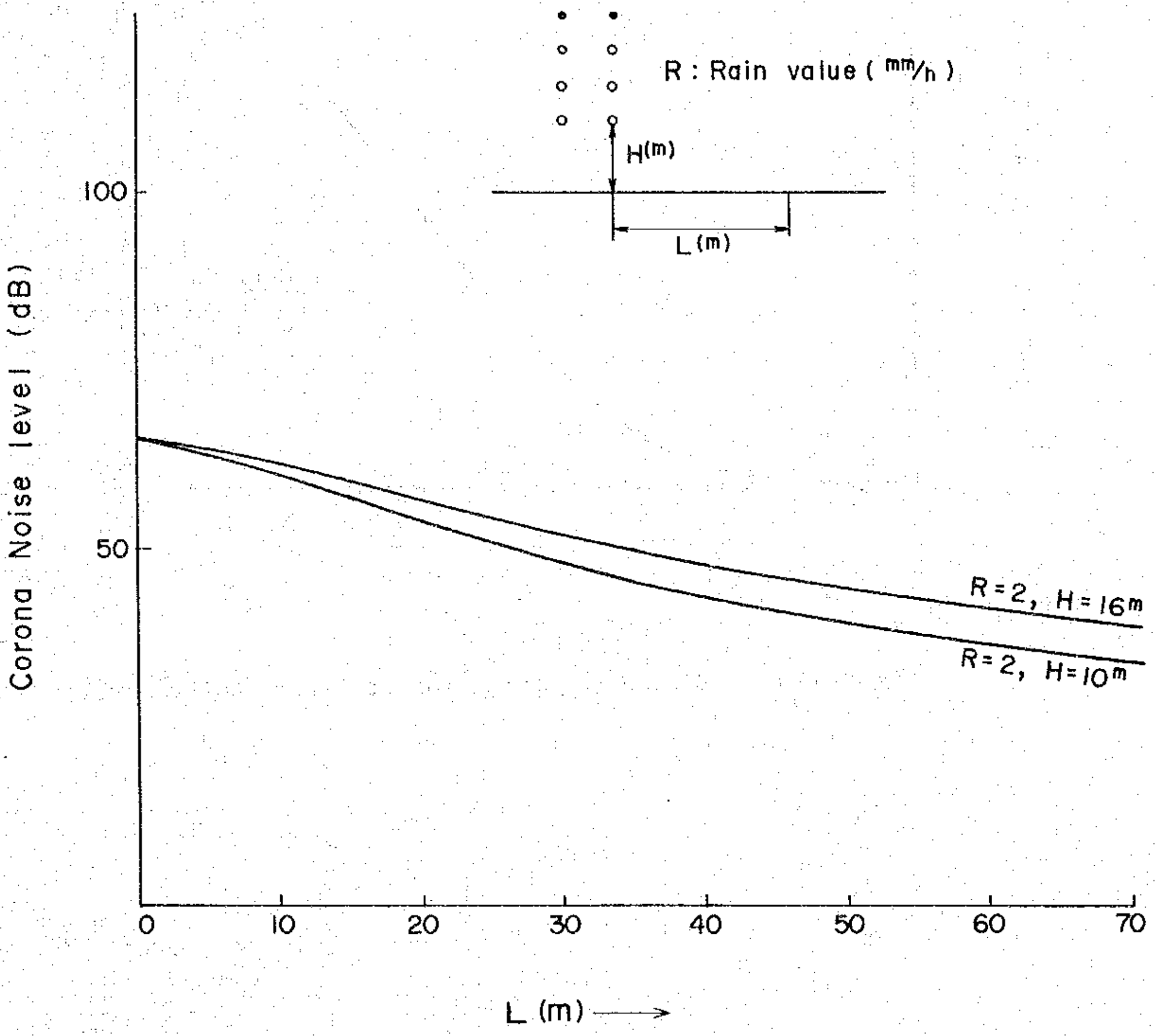


Fig. 5-24 Distance Attenuation of Corona Noise Level

Fig. 5-25   Corona Noise Level under EHV Line



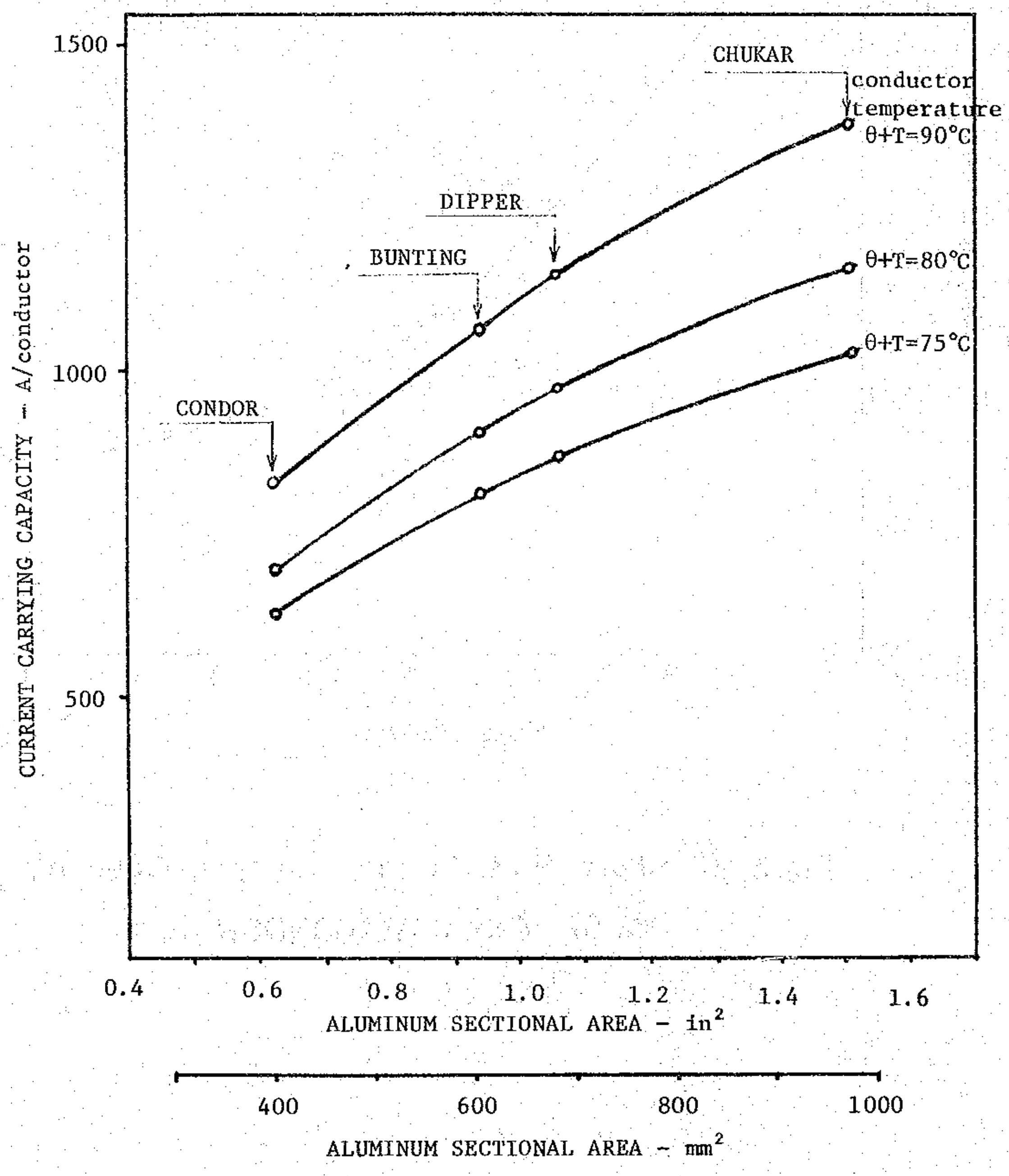


Fig. 5-26 Current Carrying Capacity of ACSR with Various Conductor Temperature

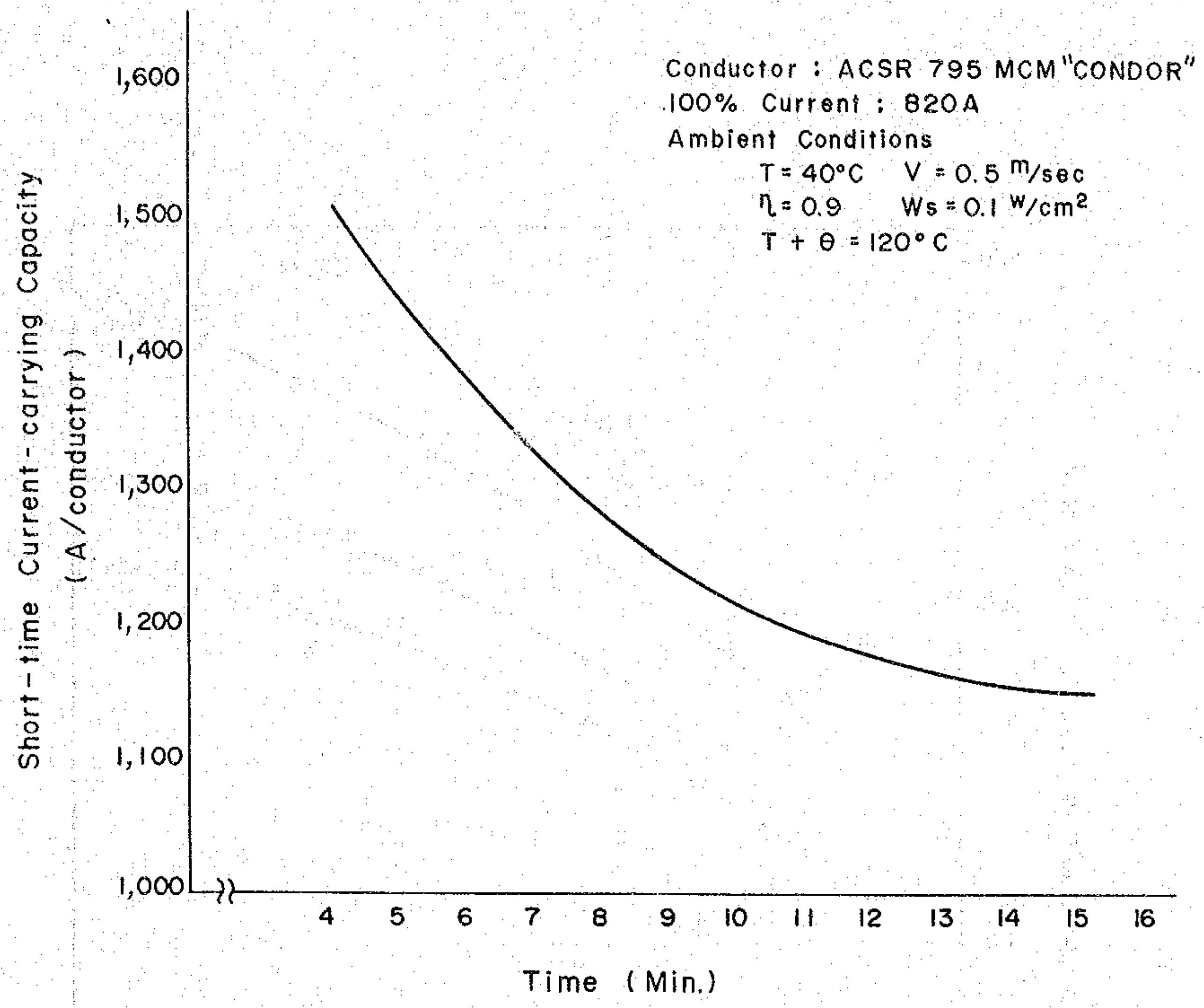


Fig. 5-27 Short-Time Current-Carrying Capacity
(ACSR 795 MCM "CONDOR")

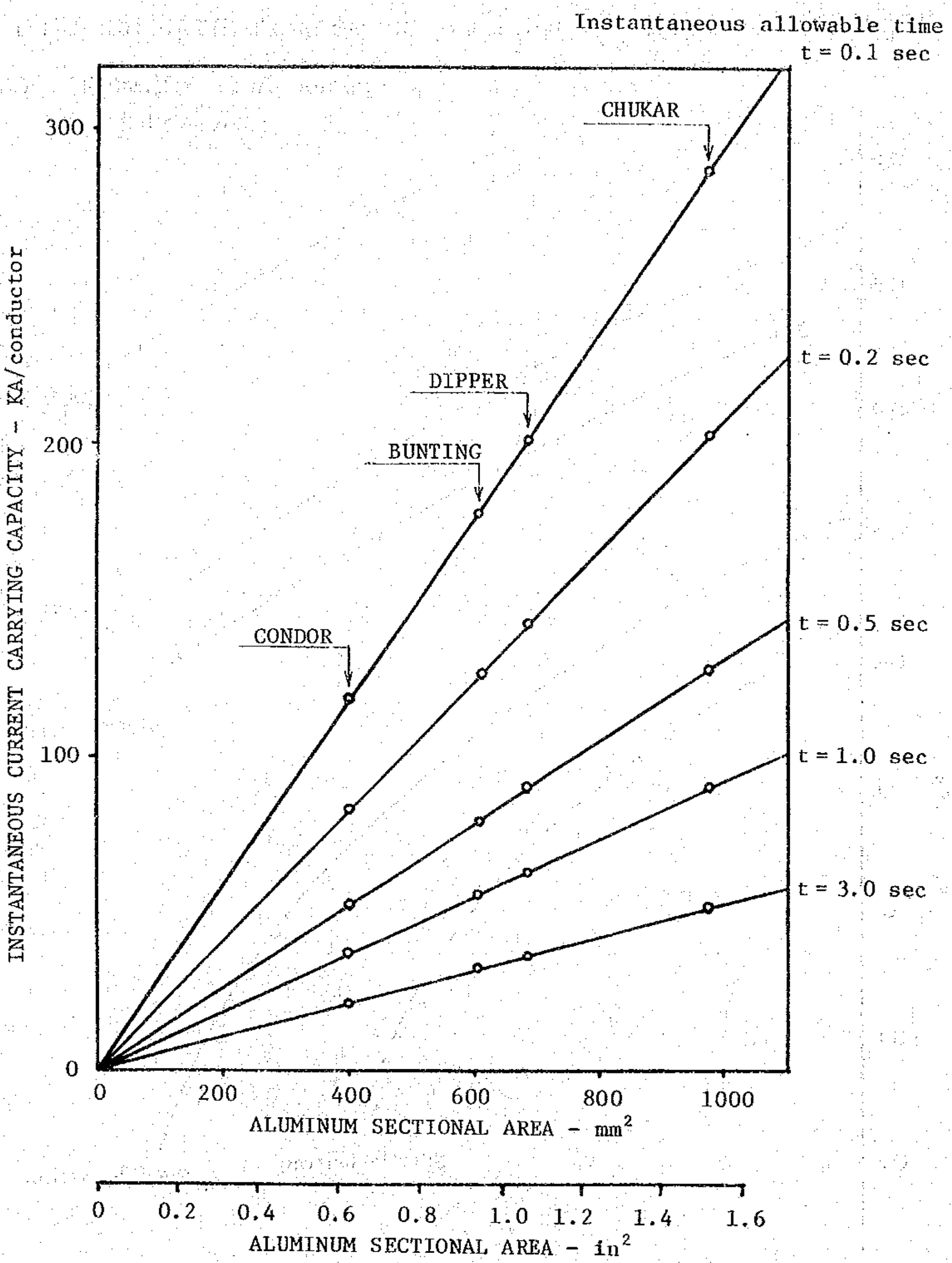


Fig. 5-28 Instantaneous Current Carrying Capacity of ACSR with Various Instantaneous Allowable Time

Fig.5-29 Strength Diagram for Suspension Insulator Strings

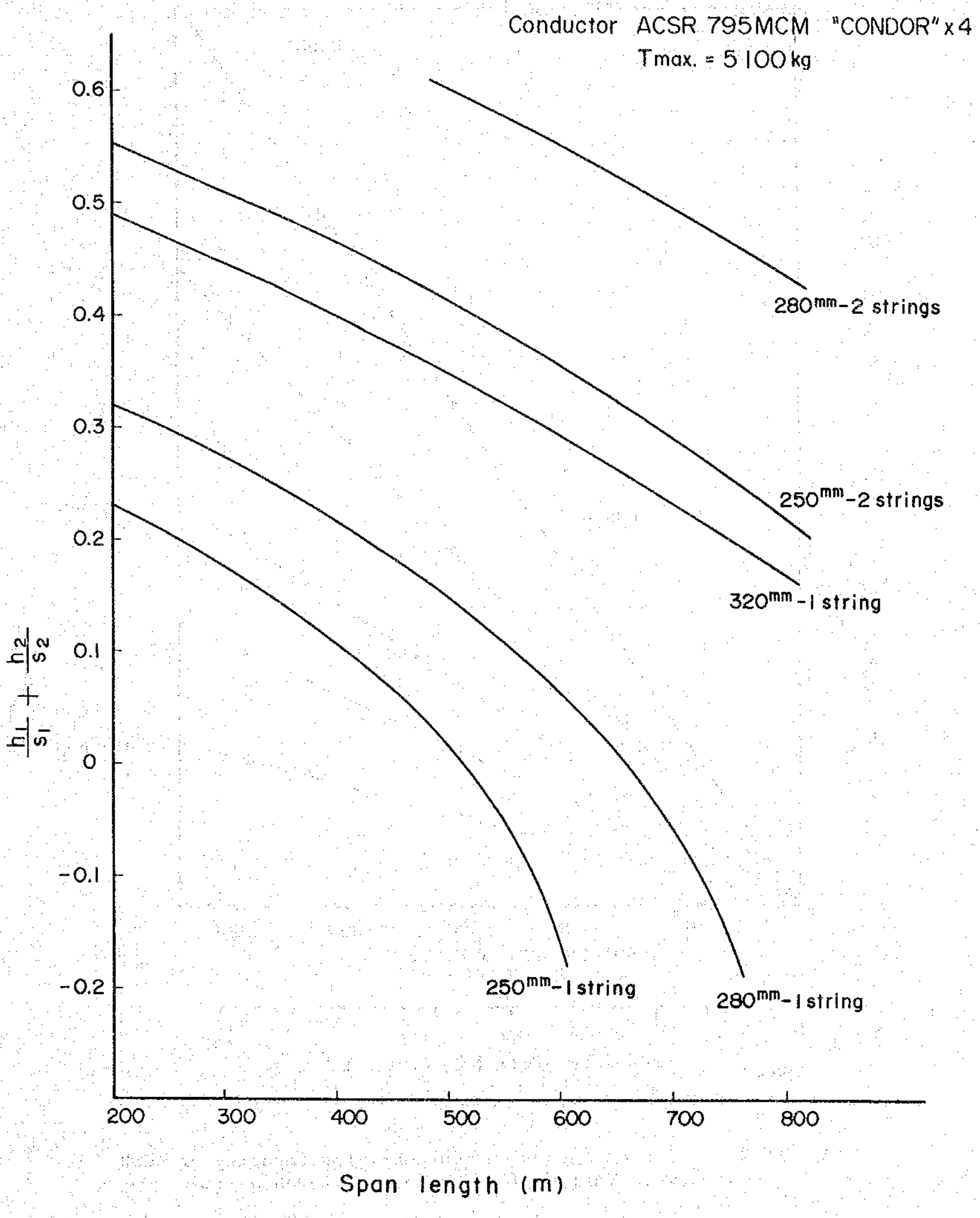


Fig.5-30 Comparison of Suspension Insulator Strings in Price

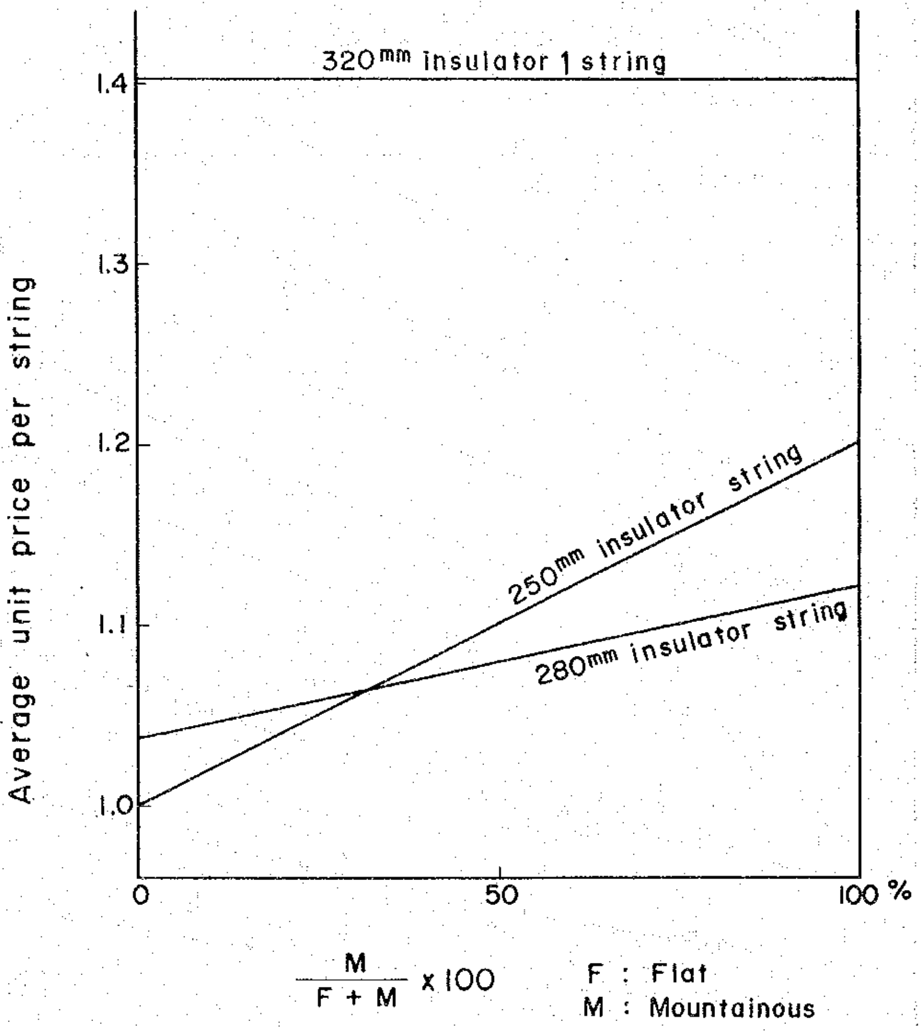
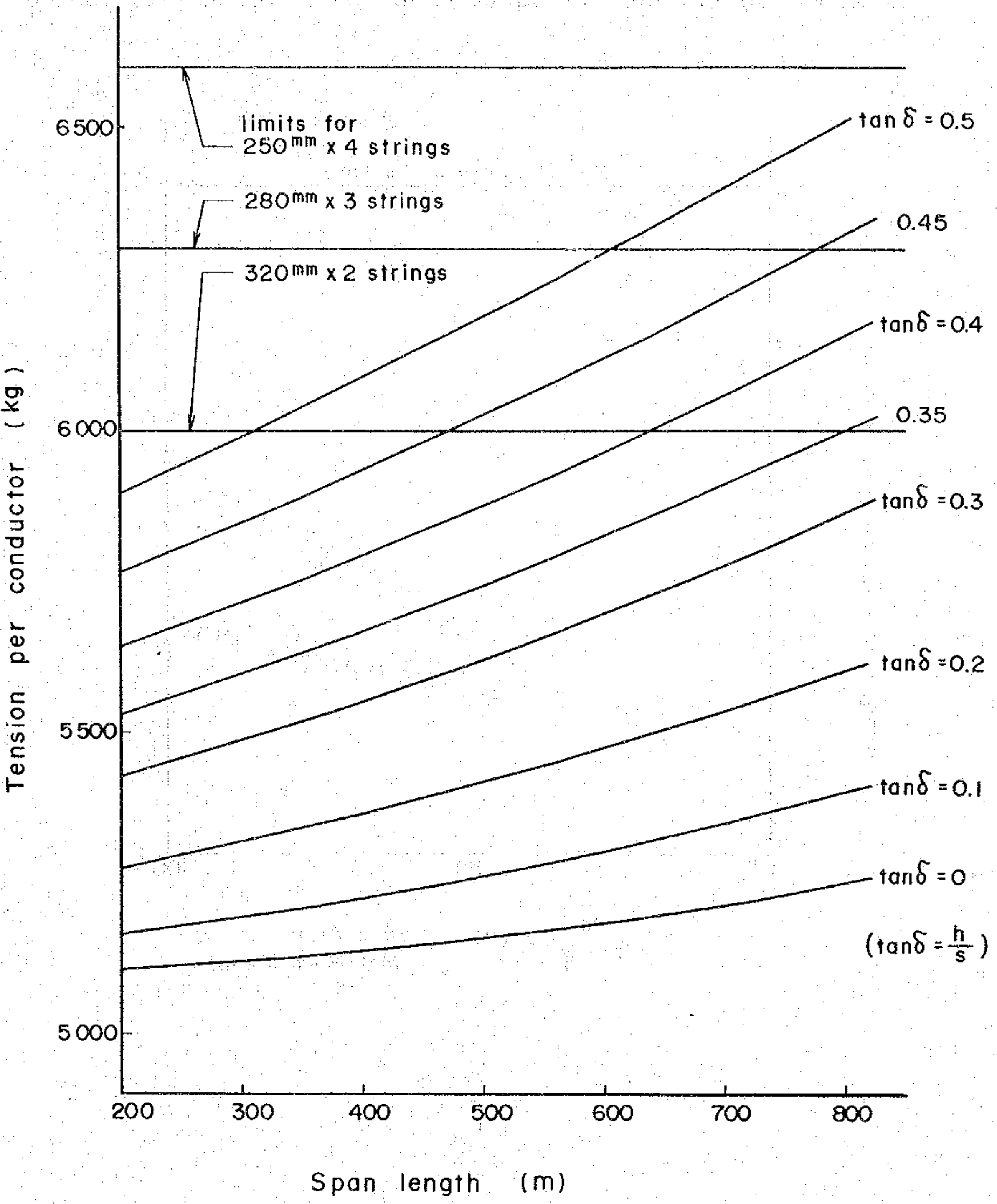
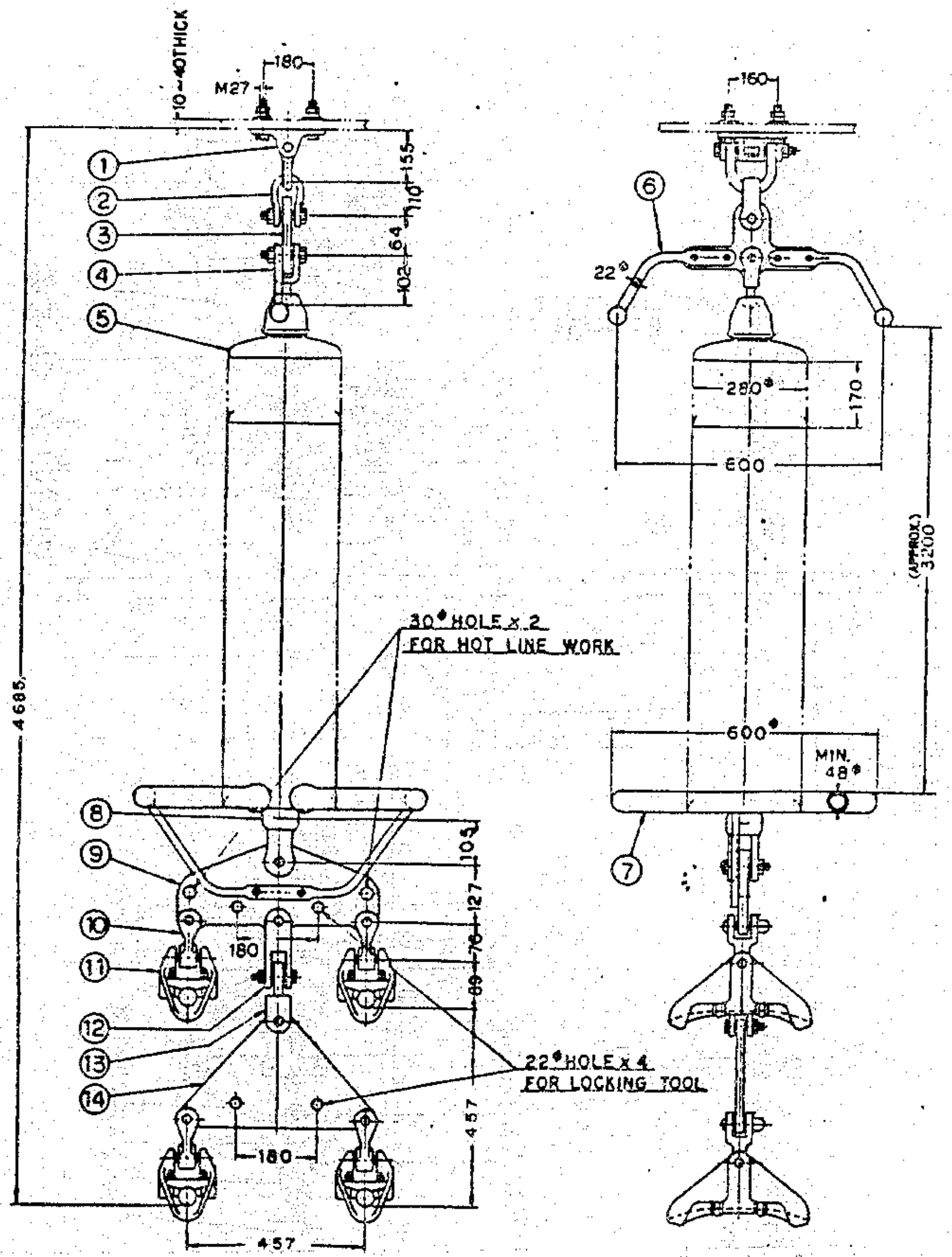


Fig. 5-31 Tension at Supporting Point of Insulator Strings in Worst Condition





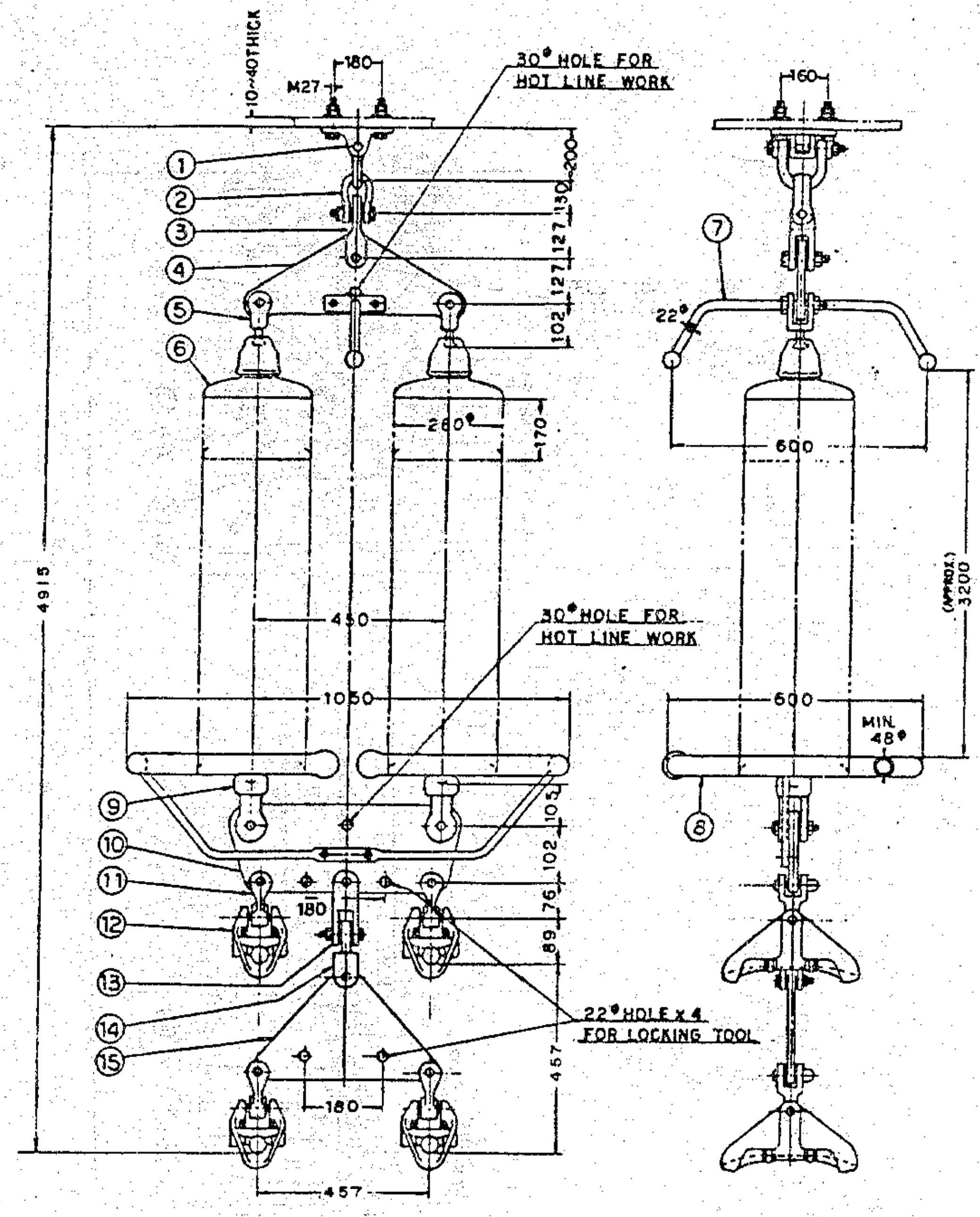
ITEM	DESCRIPTION	REQ'D	MIN BREAKING STRENGTH	MAIN MATERIAL	CAT. NO. (DRG. NO.)
①	TOWER FITTING	1	21000Kg	STEEL	
②	U-CLEVIS	1	21000Kg	STEEL	
③	HORN HOLDER	1	21000Kg	STEEL	
④	BALL CLEVIS	1	21000Kg	STEEL	
⑤	SUSPENSION INSULATOR	20	21000 Kg	PORCELAIN	
⑥	ARCING HORN	2	—	STEEL	
⑦	ARCING RING	1	—	STEEL	
(—)	—	—	—	—	—
⑧	SOCKET CLEVIS	1	21000Kg	MALLEABLE IRON OR DUCTILE IRON	
⑨	YOKE	1	21000Kg	STEEL	
⑩	CLEVIS EYE	4	12000Kg	STEEL	
⑪	SUSPENSION CLAMP	4	12000Kg	ALUMINIUM ALLOY	
⑫	90° CLEVIS-CLEVIS	1	12000Kg	STEEL	
⑬	90° CLEVIS EYE	1	12000Kg	STEEL	
⑭	YOKE	1	12000Kg	STEEL	
⑮	PREFORMED ARMOR RODS	4	—	ALUMINIUM ALLOY	
MIN BREAKING STRENGTH OF STRING				21000Kg	
SUITABLE CONDUCTOR SIZE OF CLAMP				ACSR 795MCM "CONDOR" WITH PREFORMED ARMOR RODS OD 43.5⌀	
TYPE OF BALL AND SOCKET PARTS				IEC 20mm	

NOTE: ALL LIVE FITTINGS ARE DESIGNED TO BE FREE FROM SHARP CORNERS AND PROJECTIONS IN ORDER TO PREVENT CORONA FORMATION.

PORCELAIN : BROWN GLAZED, ~~EXCEPT SURFACES MARKED LEFT UNGLAZED~~
FERROUS PARTS : HOT DIP GALVANIZED EXCEPT FEMALE THREAD & STAINLESS STEEL.

— FOR NORMAL ARER —

Fig.5-32(1) Insulator Assembly



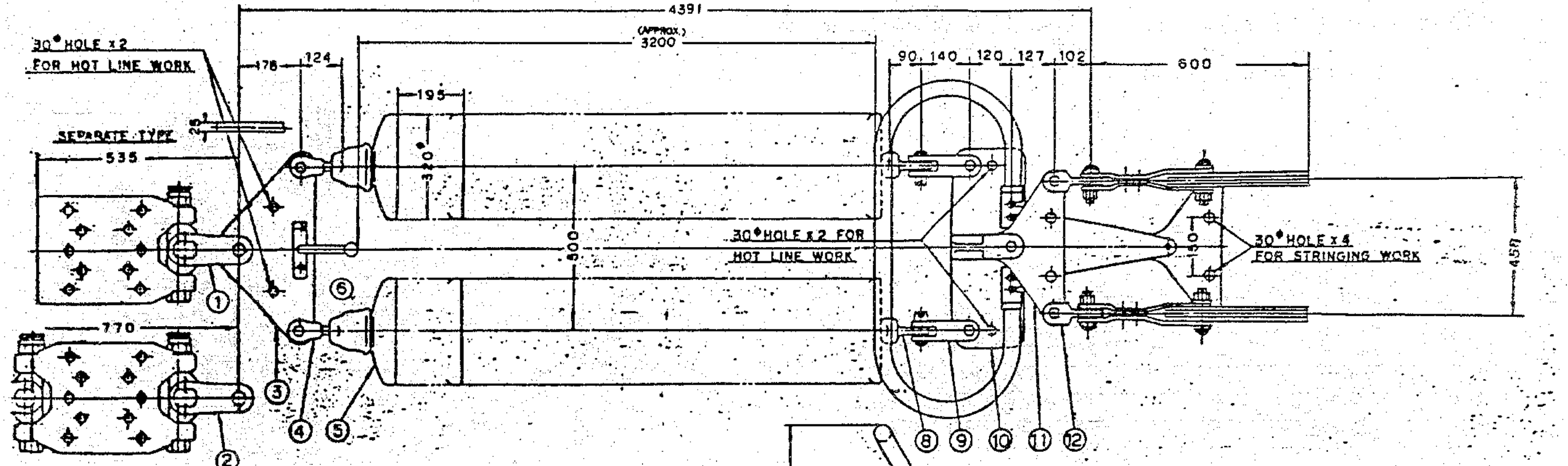
ITEM	DESCRIPTION	REQ'D	MIN BREAKING STRENGTH	MAIN MATERIAL	CAT. NO. (ORG. NO.)
①	TOWER FITTING	1	42000Kg	STEEL	
②	U- CLEVIS	1	42000Kg	STEEL	
③	90° CLEVIS EYE	1	42000Kg	STEEL	
④	YOKE	1	42000Kg	STEEL	
⑤	BALL CLEVIS	2	21000Kg	STEEL	
⑥	SUSPENSION INSULATOR	20x2	21000Kg	PORCELAIN	
⑦	ARCING HORN	2	—	STEEL	
⑧	ARCING RING	2	—	STEEL	
—	—	—	—	—	—
⑨	SOCKET-CLEVIS	2	21000Kg	MALLEABLE IRON OR DUCTILE IRON	
⑩	YOKE	1	42000Kg	STEEL	
⑪	CLEVIS EYE	4	12000Kg	STEEL	
⑫	SUSPENSION CLAMP	4	12000Kg	ALUMINIUM ALLOY	
⑬	90° CLEVIS-CLEVIS	1	21000Kg	STEEL	
⑭	90° CLEVIS EYE	1	21000Kg	STEEL	
⑮	YOKE	1	21000Kg	STEEL	
⑯	PREFORMED ARMOR RODS	4	—	ALUMINIUM ALLOY	
MIN BREAKING STRENGTH OF STRING				42000 Kg	
SUITABLE CONDUCTOR SIZE OF CLAMP				ACSR 795MCM "CONDOR" WITH PREFORMED ARMOR RODS O.D.43.5°	
TYPE OF BALL AND SOCKET PARTS				IEC 20mm	

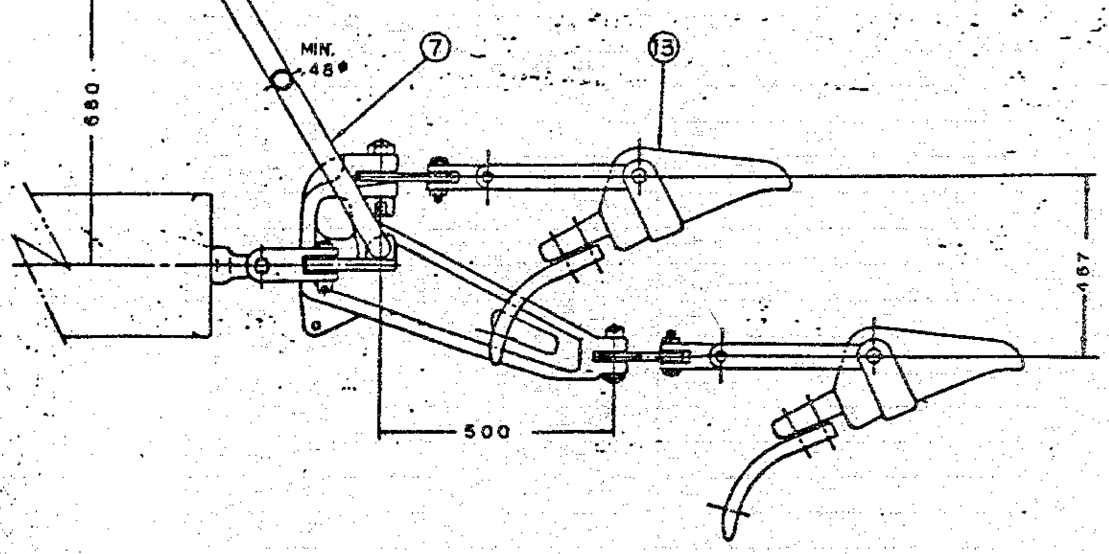
NOTE: ALL LIVE FITTINGS ARE DESIGNED TO BE FREE FROM SHARP CORNERS AND PROJECTIONS IN ORDER TO PREVENT CORONA FORMATION.

— FOR NORMAL ARER —

PORCELAIN : BROWN GLAZED ~~EXCEPT SURFACES~~
~~MARKED LEFT UNGLAZED~~
FERROUS PARTS : HOT DIP GALVANIZED EXCEPT
FEMALE THREAD & STAINLESS STEEL

Fig. 5-32(2) Insulator Assembly





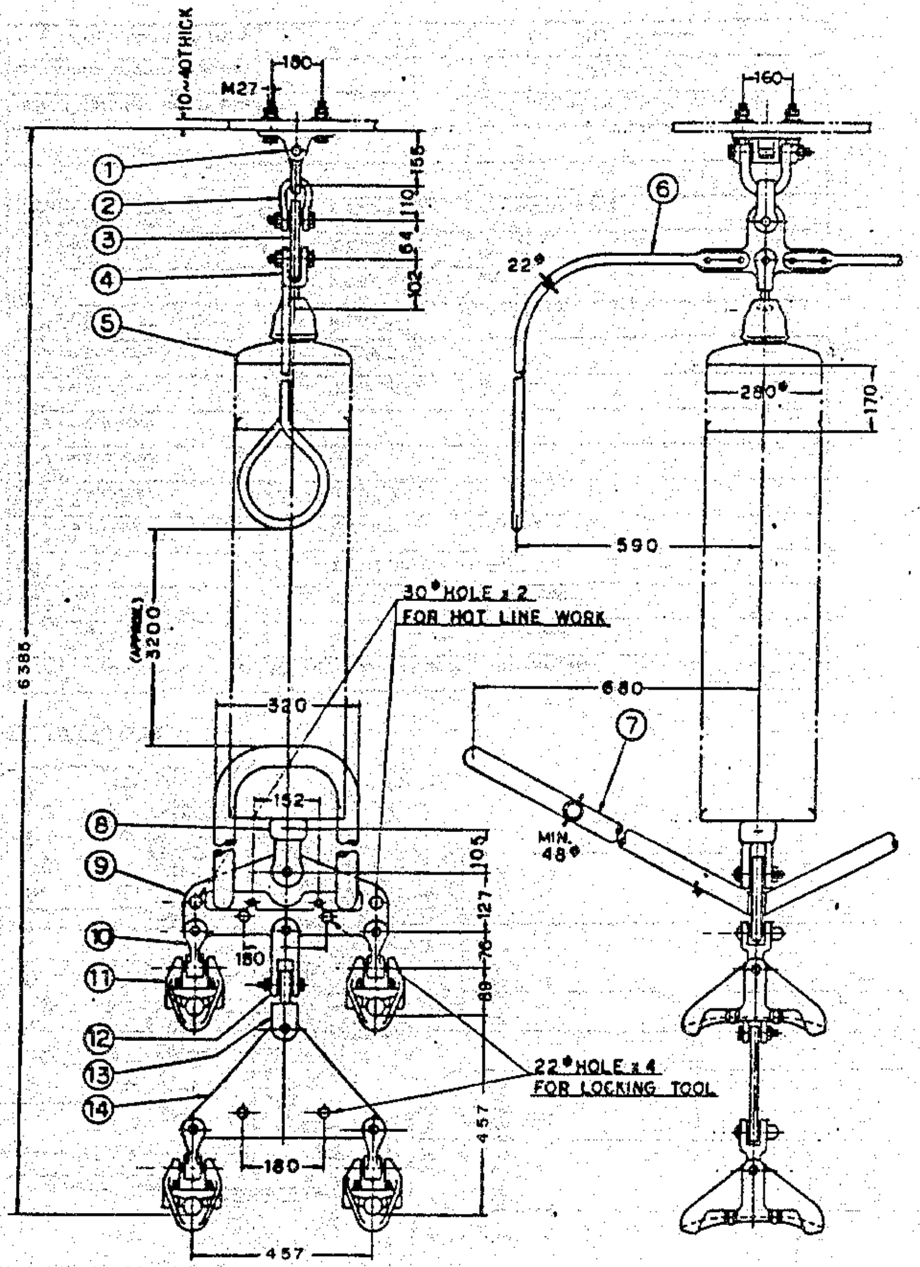
ITEM	DESCRIPTION	REQD	MIN BREAKING STRENGTH	MAIN MATERIAL	CAT. NO. (DWG. NO.)
①	SINGLE SUPPORT TOWER FITTING	1	60000Kg	DUCTILE IRON	
②	SINGLE SUPPORT TOWER FITTING	$\frac{1}{2}$	60000Kg	DUCTILE IRON	
③	YOKE	1	60000Kg	STEEL	
④	BALL-CLEVIS	2	30000Kg	HIGH TENSION STEEL	
⑤	SUSPENSION INSULATOR	18 x 2	30000Kg	PORCELAIN	
⑥	ARCING HORN	1	—	STEEL	
⑦	ARCING RING	1	—	STEEL	
⑧	SOCKET-EYE	2	30000Kg	MALLEABLE IRON OR DUCTILE IRON	
⑨	90° CLEVIS-CLEVIS	2	30000Kg	STEEL	
⑩	QUADRUPLE YOKE	1	60000Kg	DUCTILE IRON	
⑪	YOKE	2	30000Kg	STEEL	
⑫	90° CLEVIS EYE	4	16500Kg	DUCTILE IRON OR STEEL	
⑬	WEDGE TYPE TENSION CLAMP	4	12950Kg	ALUMINIUM ALLOY	
SUITABLE CONDUCTOR SIZE OF CLAMP				ACSR 795MCM 'CONDOR'	
MIN BREAKING STRENGTH OF STRING				60000Kg	
TYPE OF BALL AND SOCKET PARTS				IEC 24mm	

NOTE: ALL LIVE FITTINGS ARE DESIGNED TO BE FREE FROM SHARP CORNERS AND PROJECTIONS IN ORDER TO PREVENT CORONA FORMATION.

PORCELAIN : BROWN GLAZED. ~~EXCEPT SURFACES MARKED LEFT UNGLAZED.~~
FERROUS PARTS : HOT DIP GALVANIZED EXCEPT FEMALE THREAD & STAINLESS STEEL.

— FOR NORMAL ARER —

Fig.5-32 (3) Insulator Assembly



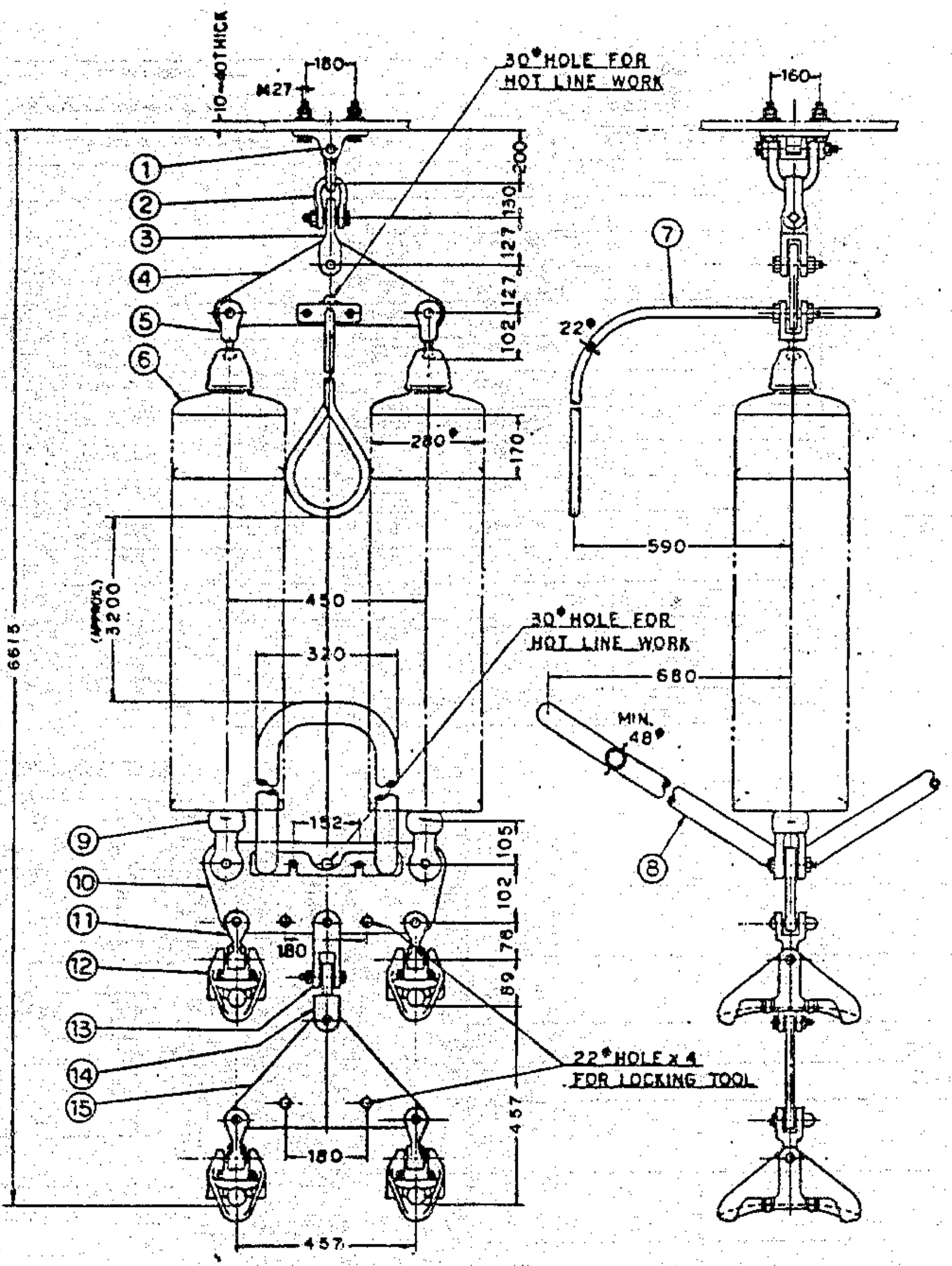
ITEM	DESCRIPTION	REQD	MIN BREAKING STRENGTH	MAIN MATERIAL	CAT. NO. (DRG. NO.)
①	TOWER FITTING	1	21000Kg	STEEL	
②	U-CLEVIS	1	21000Kg	STEEL	
③	HORN HOLDER	1	21000Kg	STEEL	
④	BALL-CLEVIS	1	21000Kg	STEEL	
⑤	SUSPENSION INSULATOR	30	21000Kg	PORCELAIN	
⑥	ARCING HORN	2	—	STEEL	
⑦	ARCING RING	2	—	STEEL	
⑧	SOCKET-CLEVIS	1	21000Kg	MALLEABLE IRON OR DUCTILE IRON	
⑨	YOKE	1	21000Kg	STEEL	
⑩	CLEVIS EYE	4	12000Kg	STEEL	
⑪	SUSPENSION CLAMP	4	12000Kg	ALUMINIUM ALLOY	
⑫	90° CLEVIS-CLEVIS	1	12000Kg	STEEL	
⑬	90° CLEVIS EYE	1	12000Kg	STEEL	
⑭	YOKE	1	12000Kg	STEEL	
⑮	PREFORMED ARMOR RODS	4	—	ALUMINIUM ALLOY	
MIN. BREAKING STRENGTH OF STRING				21000 Kg	
SUITABLE CONDUCTOR SIZE OF CLAMP				ACSR 795MCM "CONDOR" WITH PREFORMED ARMOR RODS O.D. 43.5φ	
TYPE OF BALL AND SOCKET PARTS				IEC 20mm	

NOTE: ALL LIVE FITTINGS ARE DESIGNED TO BE FREE FROM SHARP CORNERS AND PROJECTIONS IN ORDER TO PREVENT CORONA FORMATION.

PORCELAIN : BROWN GLAZED, ~~EXCEPT SURFACES MARKED ——— LEFT UNGLAZED.~~
FERROUS PARTS : HOT DIP GALVANIZED EXCEPT FEMALE THREAD & STAINLESS STEEL

— FOR POLLUTION AREA —

Fig. 5-32(4) Iusulator Assembly



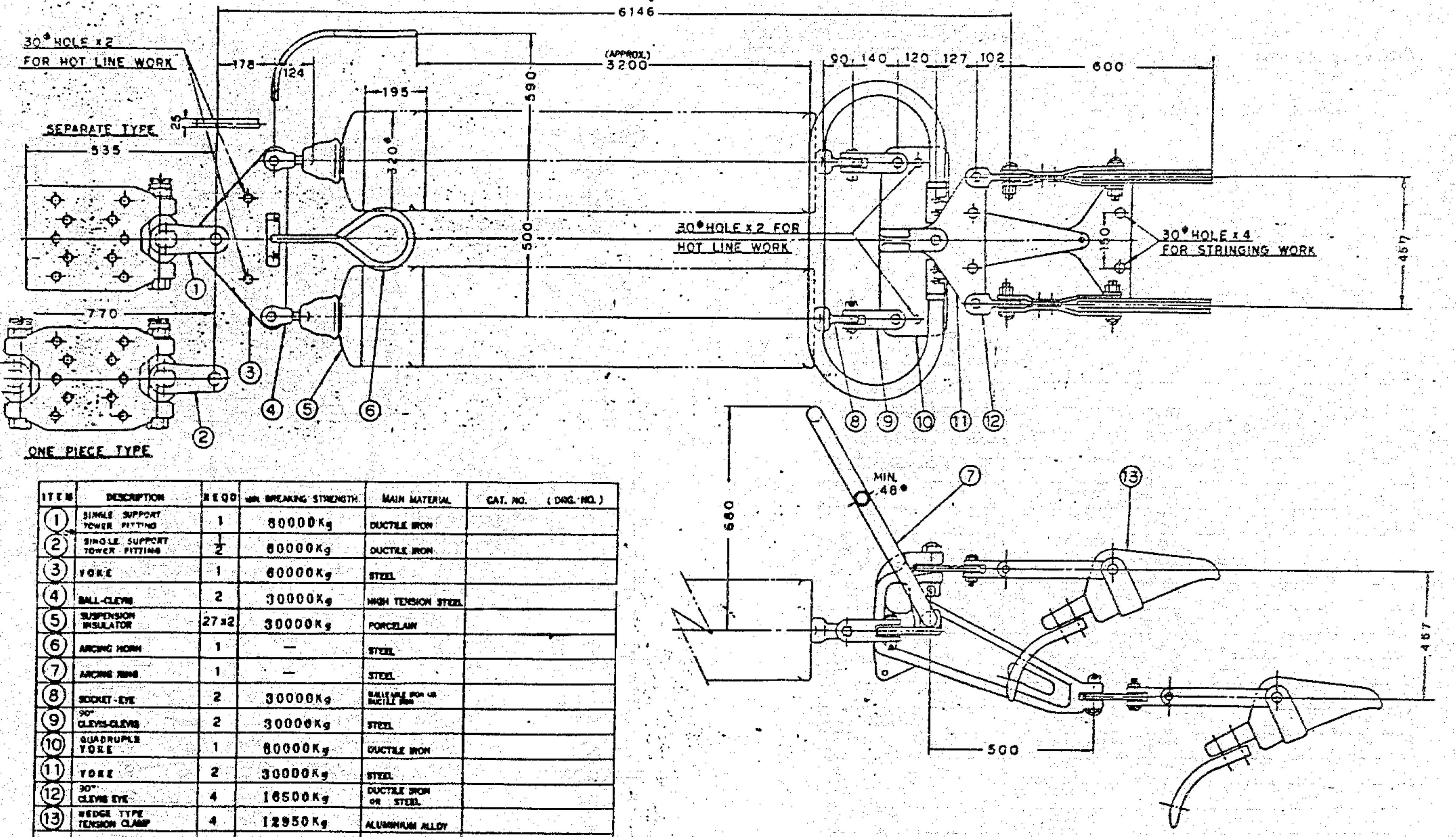
ITEM	DESCRIPTION	REQD	MIN. BREAKING STRENGTH	MAIN MATERIAL	CAT. NO. (DRG. NO.)
①	TOWER FITTING	1	42000Kg	STEEL	
②	U- CLEVIS	1	42000Kg	STEEL	
③	90° CLEVIS EYE	1	42000Kg	STEEL	
④	YOKE	1	42000Kg	STEEL	
⑤	BALL-CLEVIS	2	21000Kg	STEEL	
⑥	SUSPENSION INSULATOR	30×2	21000Kg	PORCELAIN	
⑦	ARCING HORN	2	—	STEEL	
⑧	ARCING RING	2	—	STEEL	
⑨	SOCKET-CLEVIS	2	21000Kg	MALLEABLE IRON OR DUCTILE IRON	
⑩	YOKE	1	42000Kg	STEEL	
⑪	CLEVIS EYE	4	12000Kg	STEEL	
⑫	SUSPENSION CLAMP	4	12000Kg	ALUMINIUM ALLOY	
⑬	90° CLEVIS-CLEVIS	1	21000Kg	STEEL	
⑭	90° CLEVIS EYE	1	21000Kg	STEEL	
⑮	YOKE	1	21000Kg	STEEL	
⑯	PREFORMED ARMOR RODS	4	—	ALUMINIUM ALLOY	
MIN. BREAKING STRENGTH OF STRING				42000Kg	
SUITABLE CONDUCTOR SIZE OF CLAMP				ACSR 795MCM "CONDOR" WITH PREFORMED ARMOR RODS OD. 43-5°	
TYPE OF BALL AND SOCKET PARTS				IEC 20mm	

NOTE: ALL LIVE FITTINGS ARE DESIGNED TO BE FREE FROM SHARP CORNERS AND PROJECTIONS IN ORDER TO PREVENT CORONA FORMATION.

PORCELAIN : BROWN GLAZED ~~EXCEPT SURFACES MARKED ——— LEFT UNGLAZED~~
FERROUS PARTS : HOT DIP GALVANIZED EXCEPT FEMALE THREAD & STAINLESS STEEL

— FOR POLLUTION AREA —

Fig. 5-32(5) Insulator Assembly



ITEM	DESCRIPTION	REQ'D	MIN BREAKING STRENGTH	MAIN MATERIAL	CAT. NO. (DRG. NO.)
①	SINGLE SUPPORT TOWER FITTING	1	60000Kg	DUCTILE IRON	
②	SINGLE SUPPORT TOWER FITTING	1 2	60000Kg	DUCTILE IRON	
③	YOKE	1	60000Kg	STEEL	
④	BALL-CLEVIS	2	30000Kg	HIGH TENSION STEEL	
⑤	SUSPENSION INSULATOR	27x2	30000Kg	PORCELAIN	
⑥	ARCING HORN	1	—	STEEL	
⑦	ARCING RING	1	—	STEEL	
⑧	SOCKET-EYE	2	30000Kg	MALLEABLE IRON OR DUCTILE IRON	
⑨	90° CLEVIS-CLEVIS	2	30000Kg	STEEL	
⑩	QUADRUPLE YOKE	1	60000Kg	DUCTILE IRON	
⑪	YOKE	2	30000Kg	STEEL	
⑫	90° CLEVIS EYE	4	16500Kg	DUCTILE IRON OR STEEL	
⑬	WEDGE TYPE TENSION CLAMP	4	12950Kg	ALUMINIUM ALLOY	
SUITABLE CONDUCTOR SIZE OF CLAMP				ACSR 795MCM "CONDOR"	
MIN BREAKING STRENGTH OF STRING				60000Kg	
TYPE OF BALL AND SOCKET PARTS				IEC 24mm	

NOTE: ALL LIVE FITTINGS ARE DESIGNED TO BE FREE FROM SHARP CORNERS AND PROJECTIONS IN ORDER TO PREVENT CORONA FORMATION.

PORCELAIN : BROWN GLAZED. ~~EXCEPT SURFACES~~
~~MARKED LEFT~~
FERROUS PARTS : HOT DIP GALVANIZED EXCEPT FEMALE THREAD & STAINLESS STEEL.

— FOR POLLUTION AREA —

Fig. 5-32 (6) Iusulator Assembly

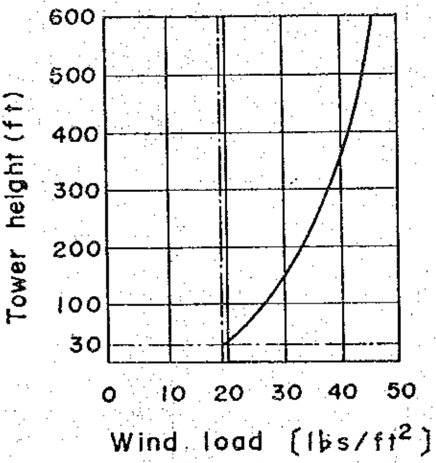
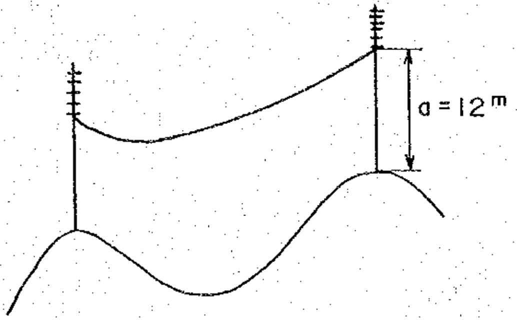


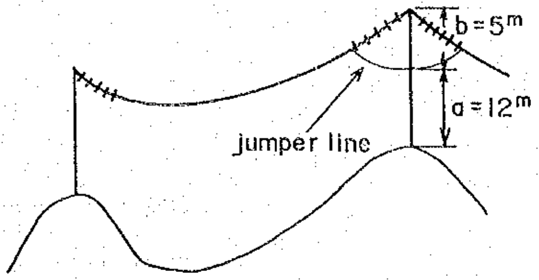
Fig. 5-33 Wind Load Curve

Fig.5-34 . Illustration of Estimation Process for Body Extension

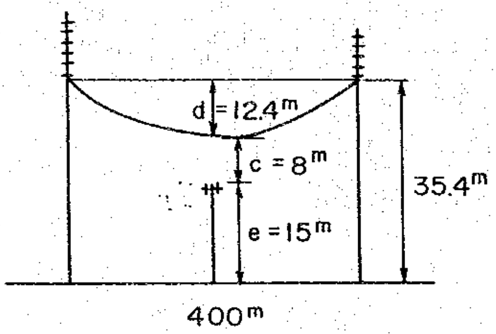
Suspension tower | Strain tower

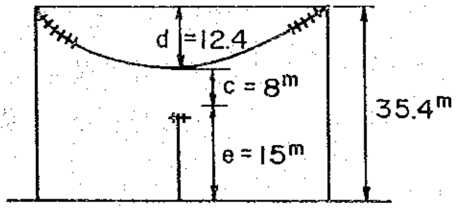
Minimum (O) extension





Required extension





Necessary extension

$35.4^m - 12^m = 23.4^m \rightarrow \underline{\underline{6^m \times 4}}$

$35.4^m - 17^m = 18.4^m \rightarrow \underline{\underline{6^m \times 4}}$

a : Necessary clearance above ground

b : Depth of jumper line

c : Necessary clearance between conductor and wires

d : Sag at 120°F no wind, 400^m span

e : Height of wires above ground

Fig.5-35 Relations between Width of Tower and Necessary Body Extension

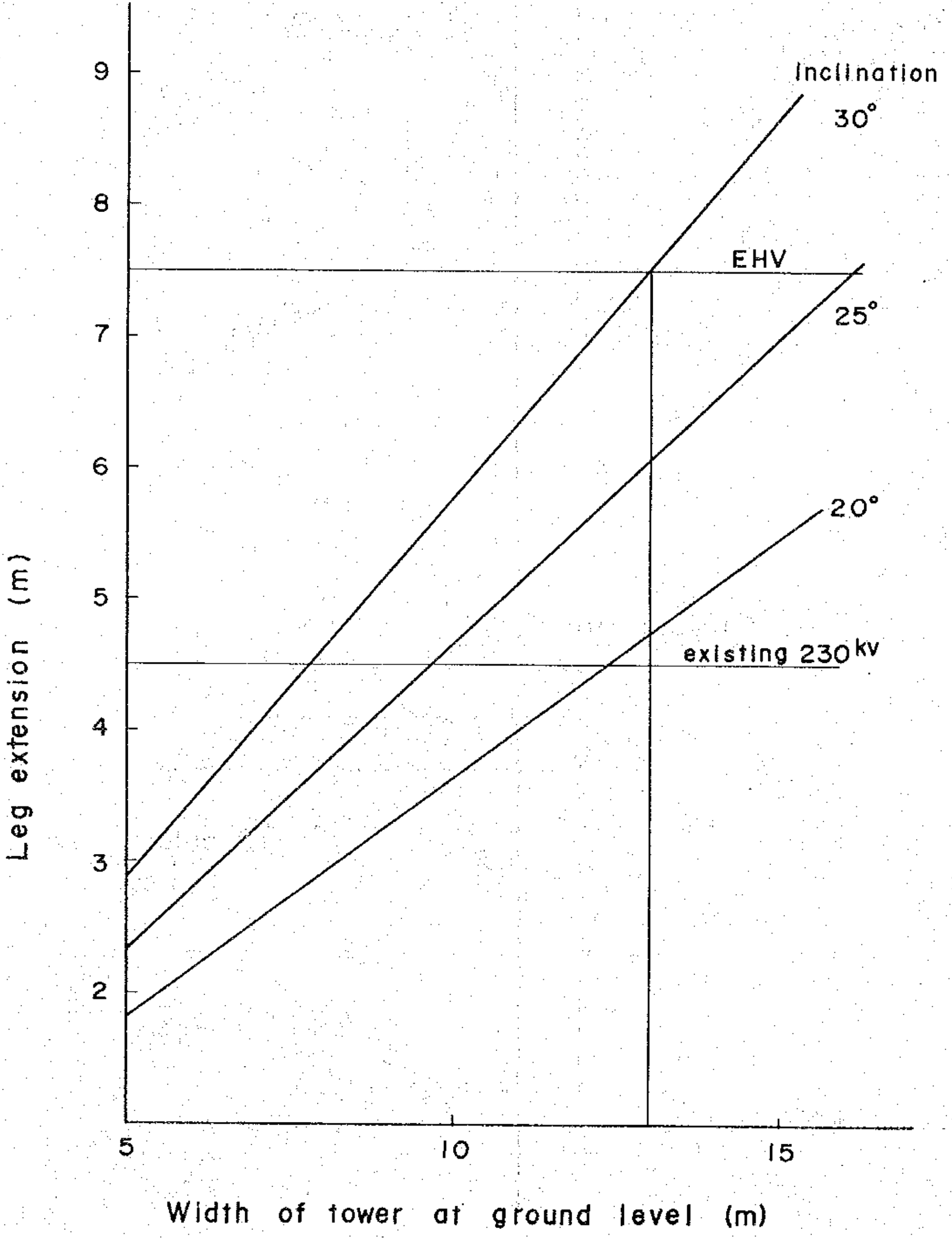
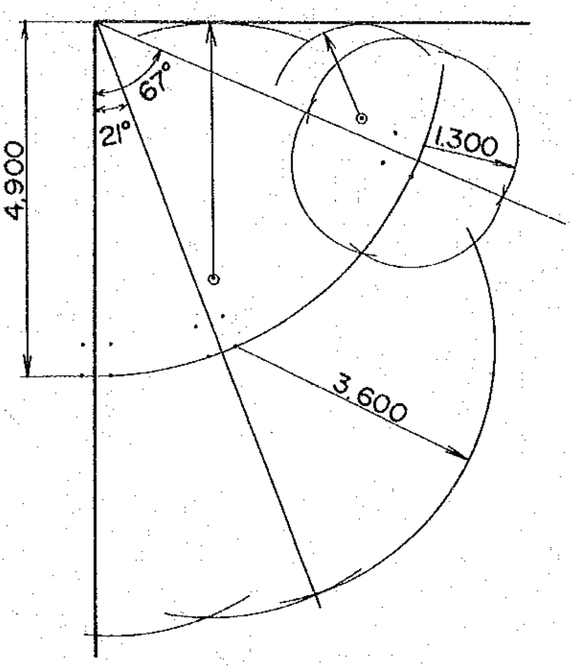


Fig. 5-36(1) Clearance Diagram

Suspension (1°) Standard Area



Suspension (5°)

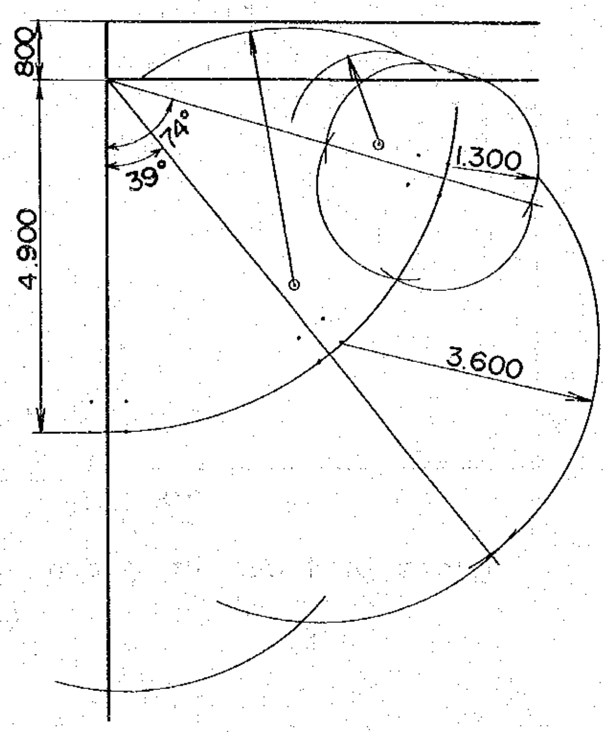


Fig.5-36(2) Clearance Diagram

Strain Standard Area

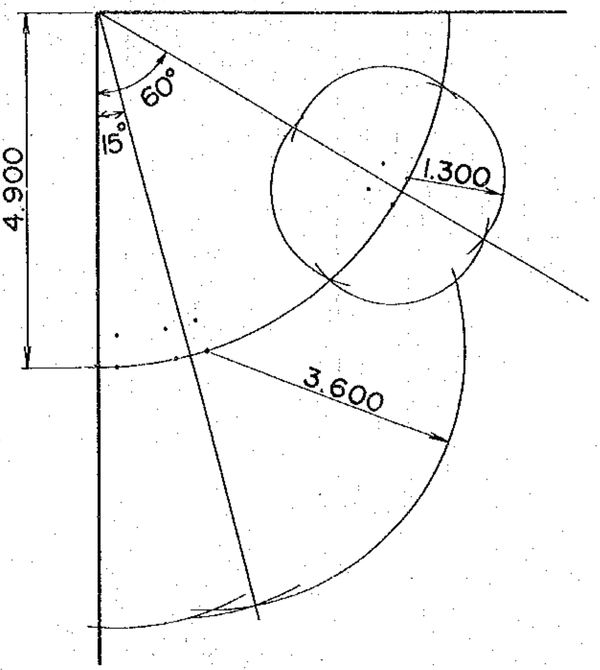
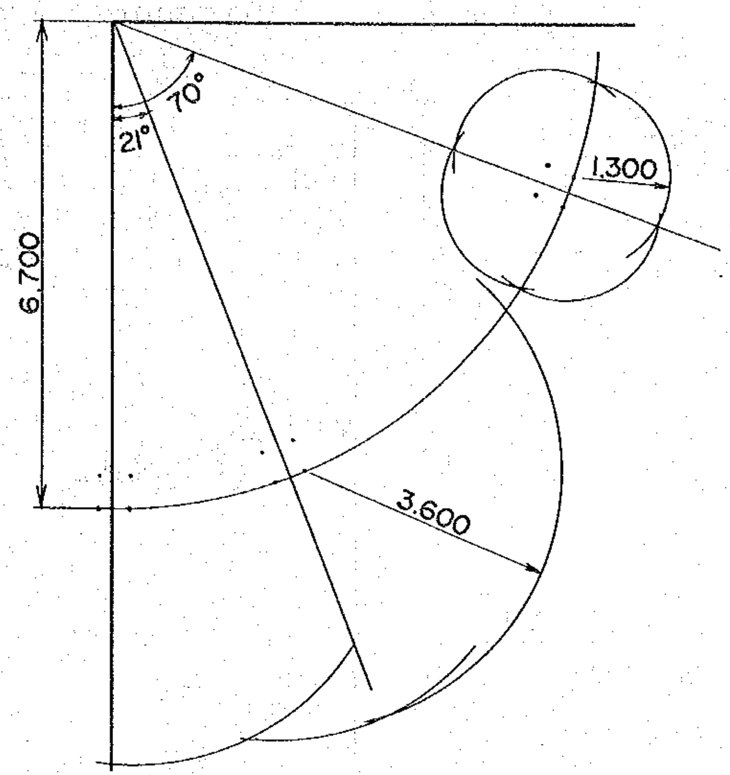


Fig. 5-36(3) Clearance Diagram

Suspension (1°) Contamination Area



Suspension (5°)

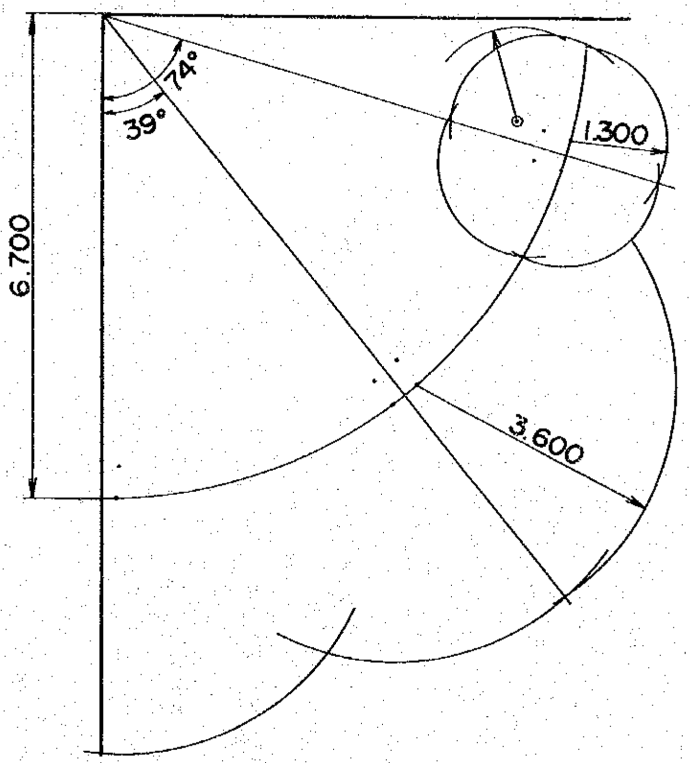


Fig. 5-36(4) Clearance Diagram

Strain ______ Contamination Area

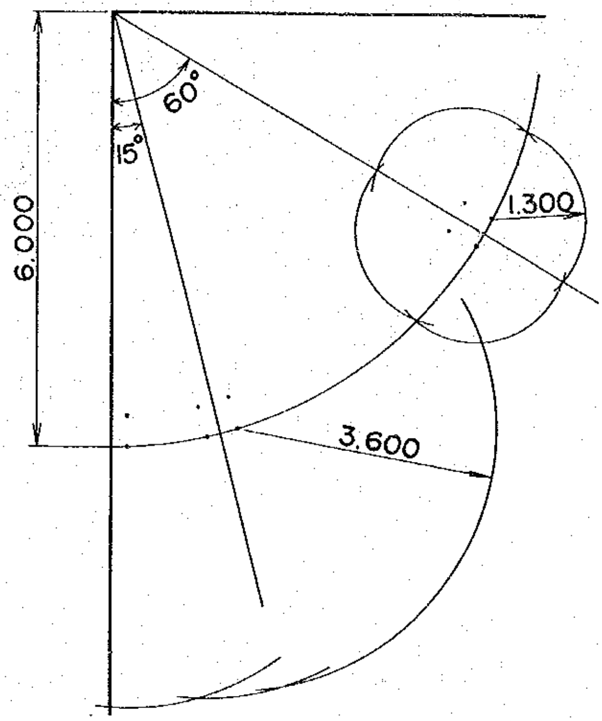


Fig. 5-37 (1)
Tower Configuration for Standard Area

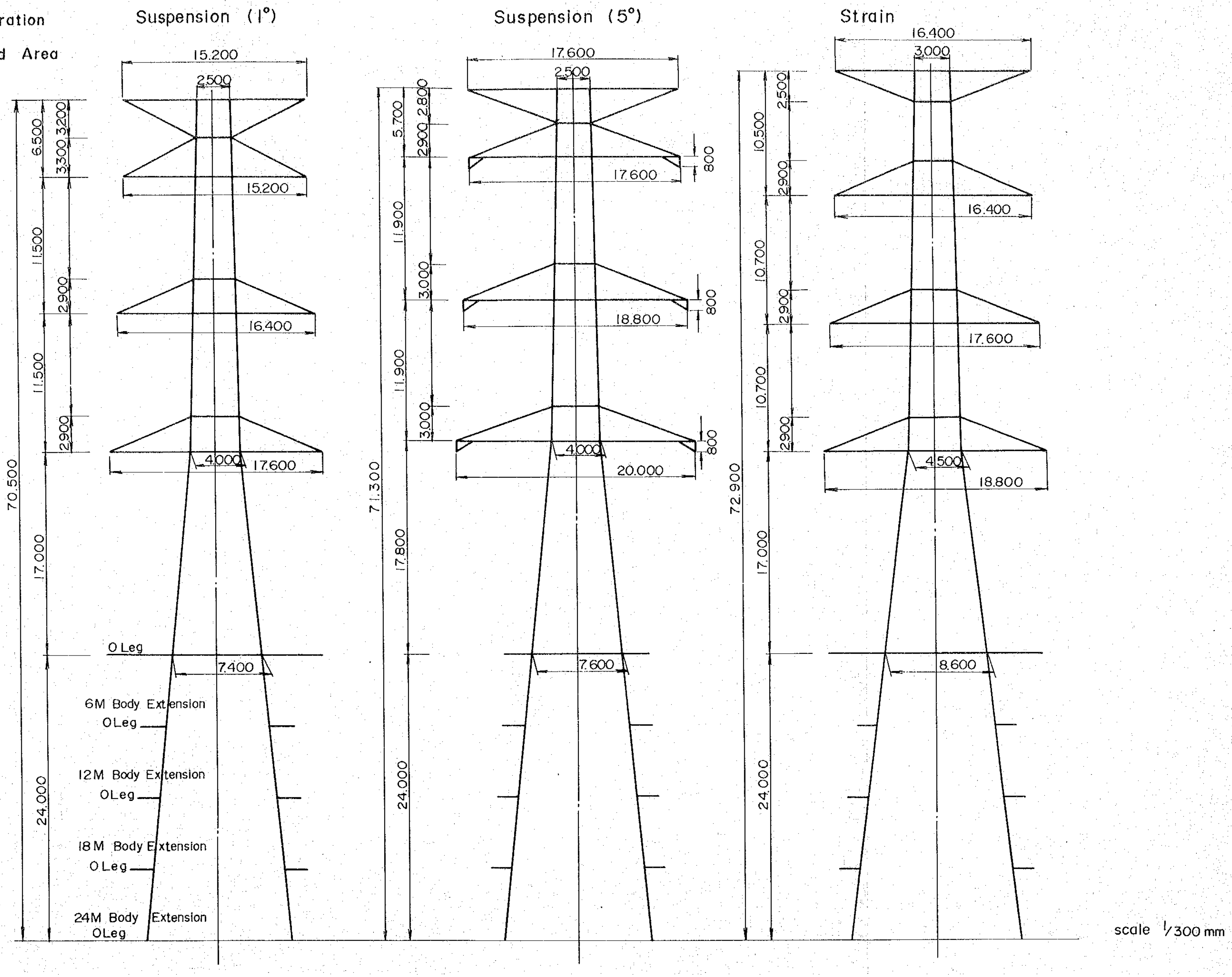


Fig. 5-37 (2)
Tower Configuration
for Contamination Area

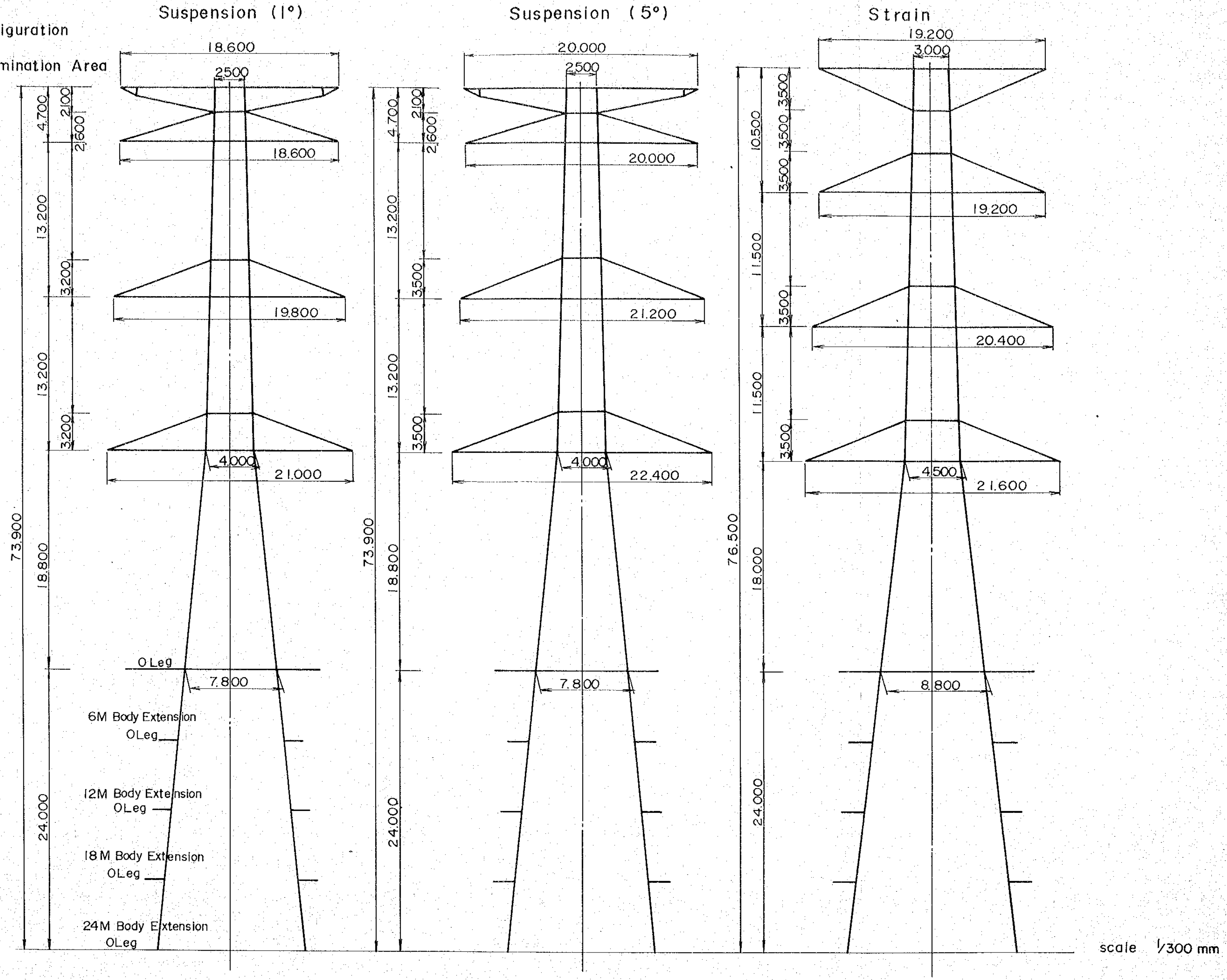


Fig. 5-38 Tentative Tower Weight Curve for EHV Line

(Standard area Tmax. = 5 100kg)

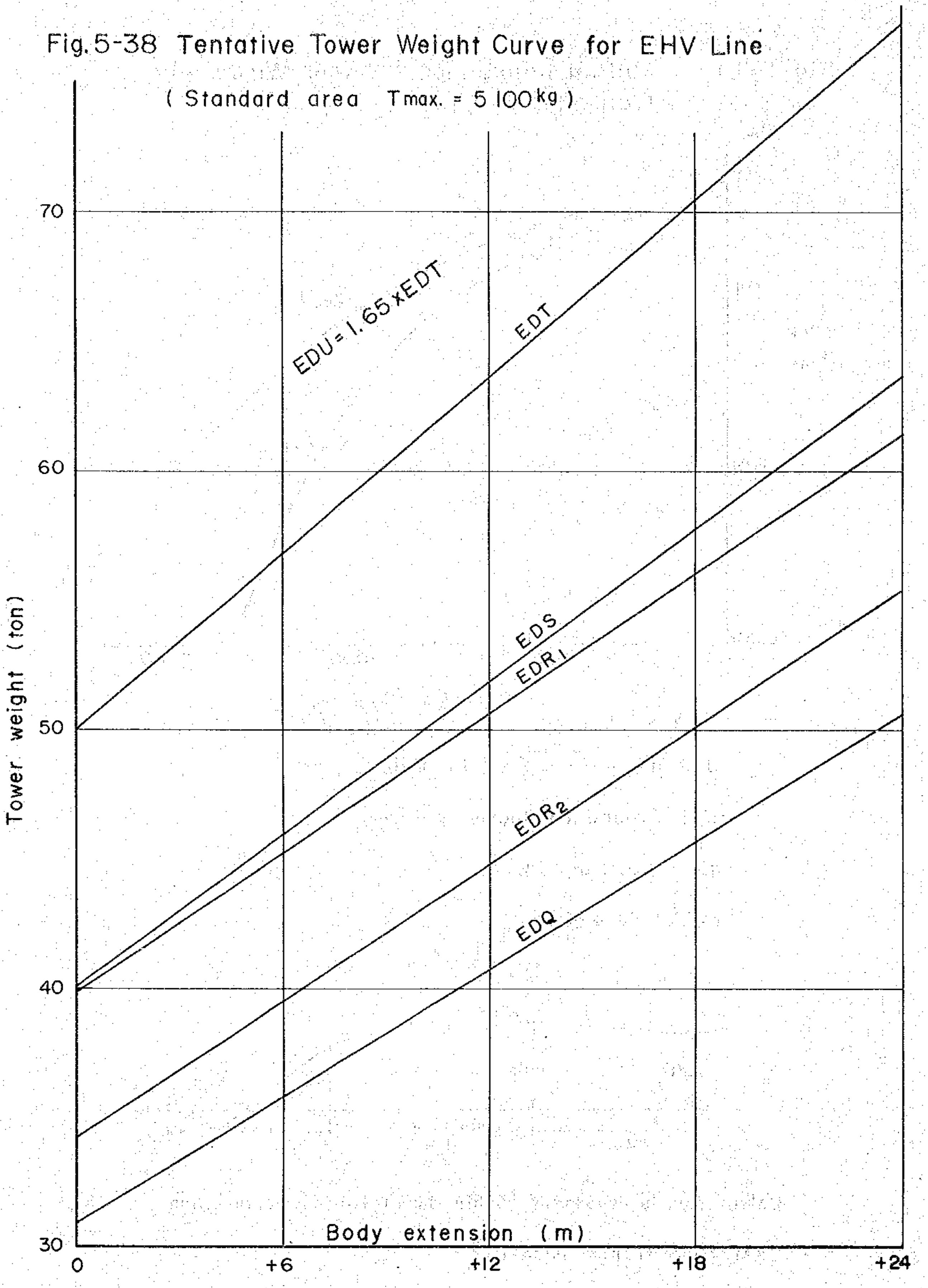
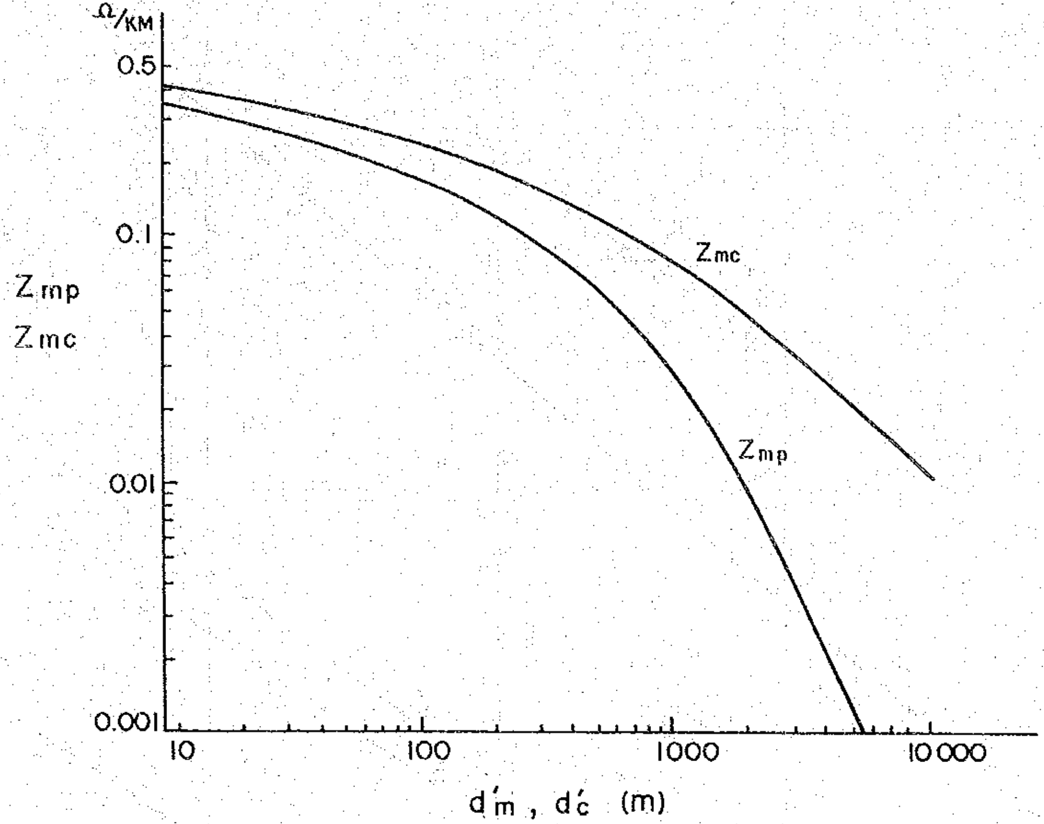


Fig. 5-39 Mutual Impedance between Wires and Transmission Line

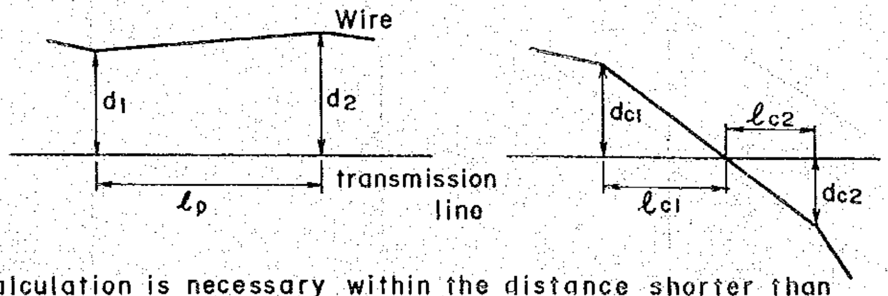


$d'_m,\ d'_c = \sqrt{100\,\sigma} \times (d_m \text{ or } d_c)$

σ : Ground conductivity (℧/m)

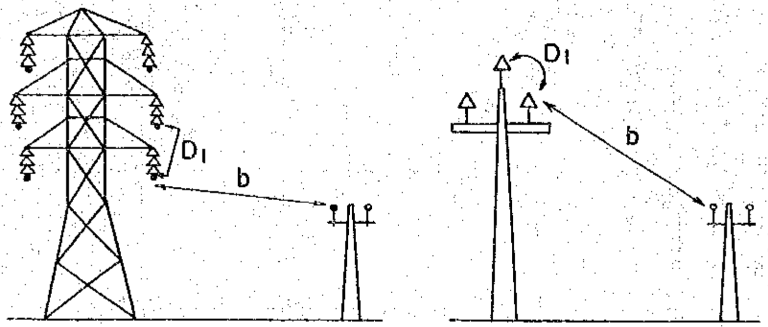
$d_m = (d_1 + d_2)/2$

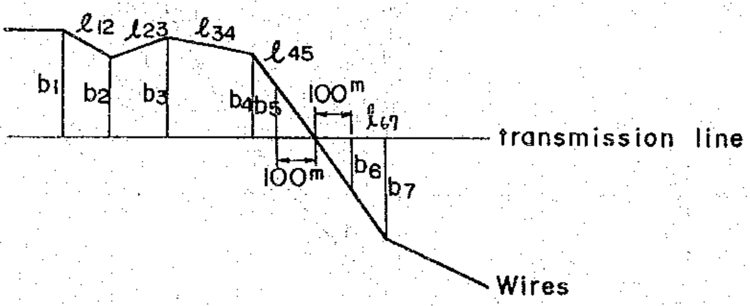
$d_c = (d_{c1} + d_{c2})/2$



Calculation is necessary within the distance shorter than 5KM from transmission line

Fig. 5-40 Explanatory Figures for the Calculation of Electromagnetic Induction Voltage





$$\sum \ell_{12}/b_1, b_2 = \ell_{12}/b_1, b_2 + \ell_{23}/b_2, b_3 + \ell_{34}/b_3, b_4 + \ell_{45}/b_4, b_5 + \ell_{67}/b_6, b_7 + \cdots\cdots$$

Calculation is necessary within the distance shorter than 500m from transmission line

Fig. 5-41 Electric Shock Caused by Released Impulse Current

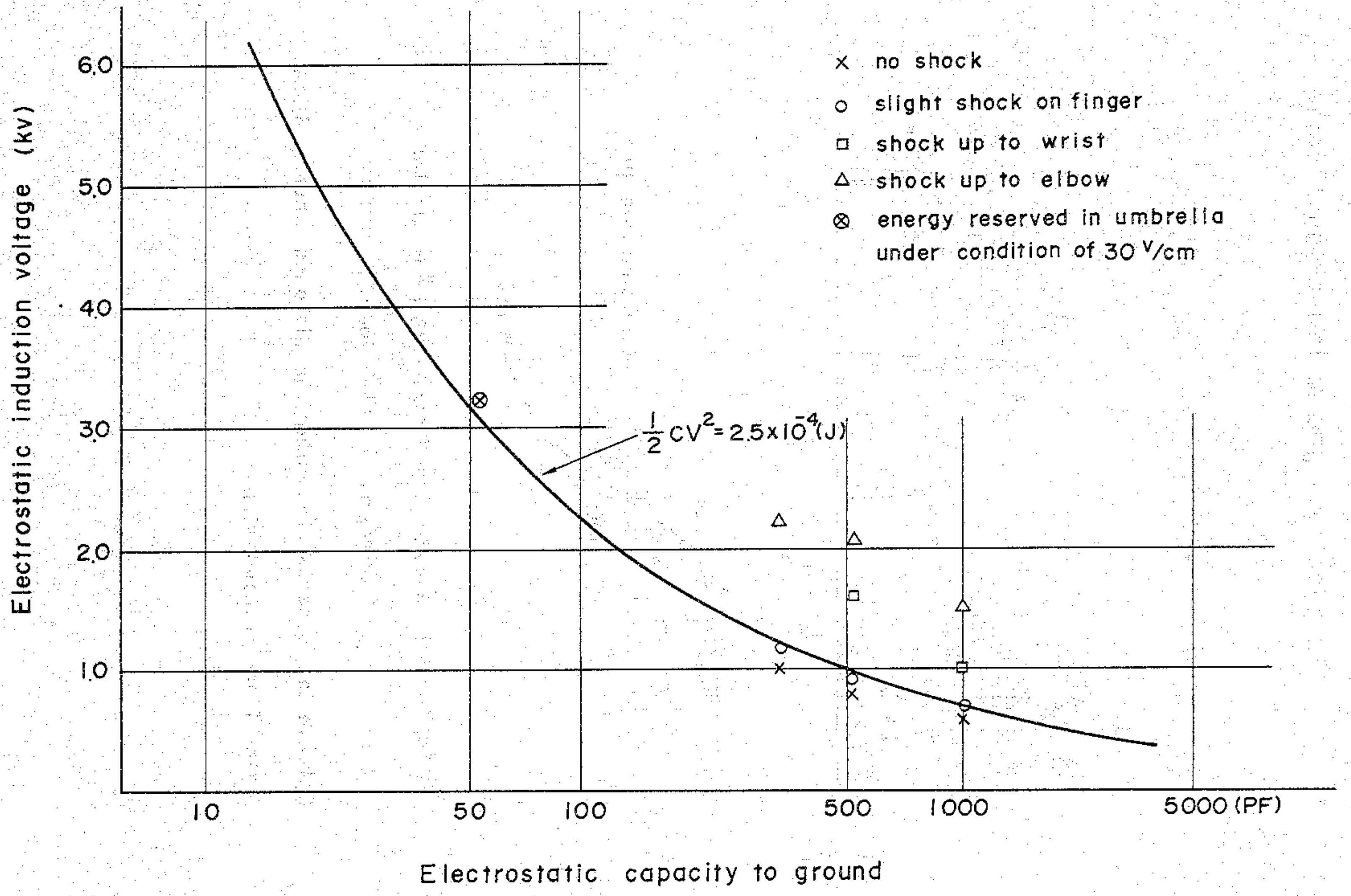
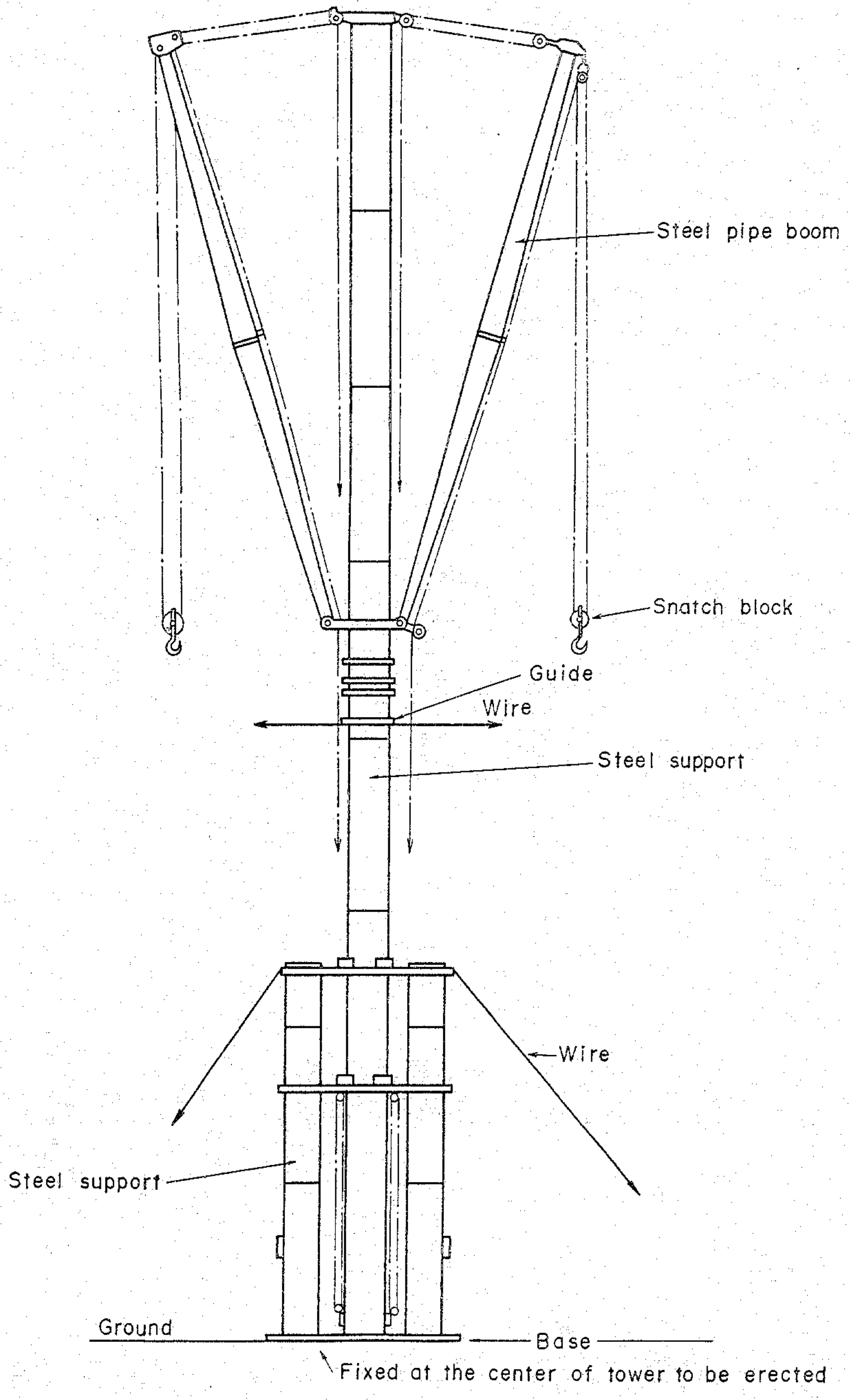


Fig.5-42 Thrust-up Type Derrick for Tower Erection



6. BASIC DESIGN OF SUBSTATION

6.1. Summary of Design Criteria

6.1.1. Insulation Coordination

Following basic insulation level shall be adopted for EHV substation in the Philippines after due consideration of IEC standards, actual records in the world and recent performance of arresters.

Nominal voltage	500 kV
Rated voltage	525 kV
Highest voltage for equipment	550 kV
Rated switching impulse withstand voltage (BSIL)	1,175 kV
Rated lightning impulse withstand voltage (BIL)	1,550 kV
AC withstand voltage	680 kV

In designing the equipment for pollution, Gened, Solano, San Jose and Kalayaan substations will be regarded to be located in the "light pollution area", and Naga and Legaspi substations to be in the "medium pollution area" based on IEC recommendation.

6.1.2. Seismicity and Other Criteria

Design Criteria for Seismic and Other Conditions:

(1) Seismic Condition

Lateral seismic force : 0.3 G static
Safety factor : same as existing practice

(2) Wind Condition

Maximum actual wind velocity : 185 KPH

(3) Electro-Static Induction:

Maintain the maximum potential gradient of 12 kV/m and 8 kV/m for substation yard and its vicinity, respectively.

(4) Ratio and TV Interference and Conductors for Bus:

In order to keep the EHV corona noise level equivalent to that of existing lines, the target value is 70 db or less, and consequently the minimum conductor sizes of 3 bundles of 660 mm^2 HAL will be adopted for EHV bus.

6.1.3. Others

(1) Bus Configuration:

1-1/2 CB bus configuration is recommendable for 500 kV substation.

(2) Method for Increasing Reliability

Methods for increasing system reliability are as follows:

° For EHV system two (2) cycles interrupting time circuit breaker will be applied.

° In order to shorten the relay operation time, solid-stage protective relay will be applied.

Duplication of main protective relays and the counter-measure for circuit breaker failures will be applied.

(3) Fire protection:

Fire protection measure should be provided for main transformers and shunt reactors.

(4) Standard capacities of main equipment:

Main transformer unit - 300 MVA
Shunt reactor unit - 70MVAR for 230kV - 500kV
35 MVAR for 69kV

6.2. Insulation Design

6.2.1. Basic Insulation Strength

IEC 38 (1975) recommends 525 kV as the highest voltage for the equipment. In the Philippines, however, the sending out voltage becomes more than 525 kV because of a long line length. It is, therefore, recommended to adopt 550 kV. The voltage rise of sound phase of EHV line at one line to ground fault was computed by electronic computer and the result was given on Fig.6-1. The highest value is 1.22 times and appeared at the southern Luzon system and it is lower in the order of the central Luzon and the northern Luzon systems.

Where the total load on the transmission line is shut off, the terminal voltage of generator reaches to the maximum level after one to two seconds, namely 1.2 to 1.3 times and the transmission line voltage rises by the Ferranti effect to 1.7 times in case the line length is 200 km. However, the stage of total load shut off will not occur at the substations because of 1-1/2 bus system. Even if it was assumed that such condition happened, the countermeasure, such as switching-off of the circuit at the terminal of generator, can be provided so that this may be considered to set the highest phase to ground voltage on the EHV system in the Philippines with some allowance to the value of 1.22 times.