COMPARATIVE STUDY BETWEEN SELF-SUPPORTING AND GUYED TOWERS

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ABSTRACT

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The object of this report is to compare the following three types of tower used on a 735kV line for the James Bay project:

i) rigid (self-supporting)

ii) guyed-V

iii) chainette

The report will include a general description of the principal loading conditions as well as the characteristics of each tower for a specific line.

A comparative cost study will be made by taking a portion of one of the James Bay transmission lines and using the three types of tower in constructing the line.

Advantages and disadvantages of using each type of tower will be discussed. Some aspects which should be considered in the selections of tower type include engineering, schedule, construction considerations, security, maintenance, esthetics and right-of-way. Typical tower outlines as well as their respective foundations will be included as part of this report.

ACKNOWLEDGEMENTS

The author wishes to express his sincere thanks to his supervisor, Professor Cedric Marsh of Concordia University for his advice and suggestions for improving the text.

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1.0 INTRODUCTION

1.1 General

The use of electric power has become an increasingly important part of the economy of industrial countries. Electric transmission lines have evolved very rapidly during the twentieth century. The line voltage has increased from 69kV to 735kV and the weight of the suspended conductors per unit length of the line is about ten times that experienced at the beginning of the century.

At the beginning of the first world war, 115kV was considered high voltage. Since that time, load growth and transmission distances have increased to the point where facilities for 500kV and 735kV are being constructed, while still higher voltages as much as 1200kV are being studied for future use. Together with this EHV, it is necessary to accommodate heavy electrical currents in the order of several hundred amperes. The combination of EHV and heavy current has given rise to the need for relatively large structures, the design of which has become a challenging task.

It is the job of the civil engineer to design and construct transmission towers which will support heavy conductor loads with a high degree of reliability, and with safety to maintenance personnel as well as the general public. In doing this, he must also have constantly in mind that undue structure weight will ultimately affect the cost of electric power, for which that same public has to pay. Economy dictates that a variety of tower types be used.

1.2 Description of the Components of a Transmission Line

The purpose of a transmission line is to carry electric current from one point to another. The electricity carrying element consists of metallic cables of low resistivity. These cables, called conductors, are suspended from supports attached to the towers in order to isolate them from the ground. In the case where the support itself is made of a material that conducts electricity, insulators are placed between the cables and the towers. In addition, it is common to find at the tower peak a continuous cable that spans from one tower to the next, called ground wire or shield wire. Its unique function is to protect the conductor from lightning.

1.3 Loading Conditions

1.3.1 Heavy Loaded Region

case 1: 45mm of ice, no wind

case 2: 30mm of ice, 0.250kPa of wind on cables and 0.50kPa of wind on tower

case 3: no ice, 0.85kPa of wind on cables and 2.00kPa of wind on tower.

1.3.2 Medium Loaded Region

case 1: 30mm of ice, no wind

case 2: 25mm of ice, 0.20kPa of wind on cables and 0.45kPa of wind on tower

case 3: no ice, 0.75kPa of wind on cables and 1.80kPa of wind on tower

1.4 Conductor's Characteristics

Name: BERSFORT

Size: 1354.8MCM

Composition: 48/7 (48 strands of aluminum, 7 strands of steel)

Diameter: 3.56cm

Weight: 2.37kg/m

Ultimate strength: 18300kg

Final modulus of elasticity: 67500MPa

Coefficient of linear expansion: $20.30 \times 10^{-6}/°C$

Total steel area: $0.61cm^2$

Total aluminum area: $6.86cm^2$

N^o of aluminum layers: 3

Diameter of steel wire: 0.33cm

Diameter of aluminum wire: 0.43cm

Average steel diameter: 1.00cm

Electrical resistance @ 20°C: 0.0420ohms/km

1.5 Characteristics of Ground Wire

ground wire: 1.26cm galvanized steel, grade 1300

weight: 0.76kg/m

ultimate strength: 120kN

1.6 Conditions for Initial and Final Sags and Tensions

a) Maximum Loading Conditions:

load 1: 12.5mm of ice and 0.25kPa wind at 0°C load 2: 45mm of ice, no wind at 0°C

Final tension under load 1 not to exceed 50% RTS (9150kg)

Initial tension under load 2 not to exceed 75% RTS (13725kg)

b) Other Limiting Conditions

Initial unloaded tension at -18°C not to exceed 25% RTS (4575kg)

Final unloaded tension at 0°C not to exceed 20% RTS (3660kg)

where: RTS = Rated Tensile Strength

2.0 TECHNICAL SPECIFICATION FOR THE DESIGN OF GALVANIZED STEEL LATTICE TOWERS FOR TRANSMISSION LINES

The ultimate strength method is used throughout the design of towers and components.

2.1 Limiting Stresses: (kPa)

2.1.1 Structural Shapes

i) Axial tension: $F_t = F_y$

ii) Axial compression: $F_a = \left[1.0 - \frac{(\frac{K\ell}{r})^2}{2C_c^2}\right]F_{cr}$ ...... for $\frac{K\ell}{r} \leq C_c$

$F_a = \frac{1970 \times 10^6}{(\frac{K\ell}{r})^2}$ ...... for $\frac{K\ell}{r} > C_c$

where: $C_c = \pi\sqrt{\frac{2E}{F_{cr}}}$, $E = 200 \times 10^6$ kPa

$F_{cr} = F_y$ when $\frac{b}{t} \leq \frac{6500}{\sqrt{F_y}}$

$F_{cr} = \left[1.8 - \frac{0.8\frac{b}{t}}{6500/\sqrt{F_y}}\right]F_y$ when $\frac{6500}{\sqrt{F_y}} < \frac{b}{t} \leq \frac{9800}{\sqrt{F_y}}$

$F_{cr} = \frac{58000000}{(b/t)^2}$ when $b/t > \frac{9800}{\sqrt{F_y}}$

where: b = width of a projected element subjected to axial compressive stresses due to bending.

r = radius of gyration corresponding to the unsupported length "ℓ".

F_{cr} = critical compressive stress.

F_y = minimum specified yield point stress.

t = thickness of element.

F_t = limiting axial tensile stress.

2.1.2 Bolts

i) Axial tension: $F_t = F_y$

ii) Shear: for bolts to CSA B33.4, grade 2

$$F_V = 210\text{MPa}$$

(for all joint lengths up to 100cm)

for high strength bolts to CSA B33.4, grade 5 and 5.2

a) length of joint ≤ 35cm

$$F_V = 0.51F_U = 420\text{MPa}$$

b) length of joint > 35cm, ≤ 100cm

$$F_V = 0.42F_U = 350\text{MPa}$$

iii) Bearing in bolt holes: the lesser of $F_{Ph} = 2.05F_y$; $F_{Ph} = 1.50F_U$

iv) Bearing on bolt: a) for bolts to CSA B33.4, grade 2

$$F_p = 500\text{MPa}.$$

b) for high strength bolts to CSA B33.4, grades 5 and 5.2

$$F_p = 1.20F_U = 990\text{MPa}.$$

2.2 Effective Slenderness Ratio

For leg sections or post members bolted at connections in both faces, "K" shall be used as 1.0.

i) For members with concentric loading at both ends of the unsupported panel, $K\ell/r = \ell/r$ for values of ℓ/r up to and including 120.

ii) For members with concentric loading at one end and normal framing eccentricities at the other end of the unsupported panel,

$$\frac{K\ell}{r} = 30 + \frac{0.75\ell}{r}$$

for values of ℓ/r up to and including 120.

iii) For members with normal framing eccentricities at both ends of the unsupported panel,

$$\frac{K\ell}{r} = 60 + \frac{0.50\ell}{r}$$

for values of ℓ/r up to and including 120.

2.3 Limiting Slenderness Ratios

Slenderness ratios of members shall not exceed the values specified below:

main	120
secondary	200
cross-arm hangers	300
secondary tension	340

3.0 DESIGN CRITERIA FOR ANCHOR BARS

A common type of rock anchor consists of a steel structural shape anchored into rock with Portland cement grout or concrete. The ultimate strength of such a rock anchor is governed by several different modes of failure. First, the shear stress arising at the interface of the steel and grout might fail. The development length formula used in the ACI can be applied for this type of failure.

$$L_d = C \times (T/\sqrt{f'_c}) \times (2 - \frac{400}{F_y}) \times 1.33 \times 0.75$$

where: T = tension in the bar

f'_c = concrete strength

C = factor, 0.04 for #35 bars

L_d = anchor length

$(2 - \frac{400}{F_y})$ = correction factor for steel with yield strength greater than 400MPa

F_y = yield strength of bar

1.33 = correction factor for light-weight concrete

0.75 = correction factor for laterally supported bars, confined.

Second, the shear stress at the interface of the grout and rock.

$$L_a = \frac{T}{\phi \pi f}$$

L_a = length of bar

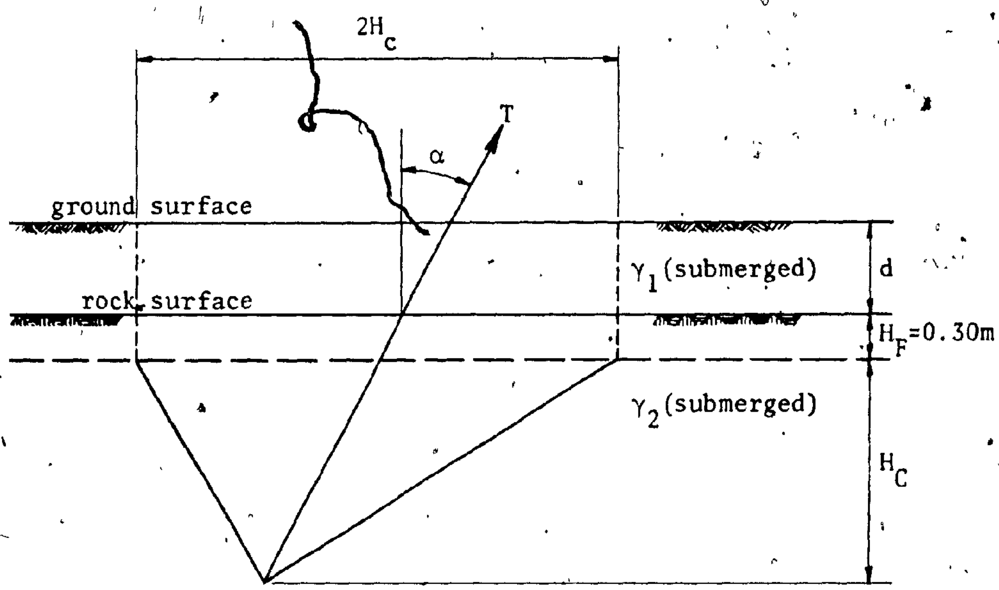
ϕ = diameter of drilled hole (70mm)

f = permissible shear stress (1400 kPa for solid rock and 700 kPa in fragmented rock and schiste)

T = tension in the bar

The third mode of failure is the cone type.

$$T = \frac{\pi H_c^2}{\cos \alpha} \left(d\gamma_1 + H_F\gamma_2 + \frac{H_c\gamma_2}{3}\right)$$



When rock is not encountered and only a good overburden soil is available, the anchor length is found by the following formula:

$$\ell = \frac{T}{36.5}$$

<u>where:</u> ℓ = length of anchor (m)

T = anchor load in "kN"

36.5 = permissible bond capacity between soil and grout (kN/m)

In evaluating the required lengths of anchors, adherence between grout and rock in the frost active zone as well as in the first 30 cm of rock is neglected.

4.0 SELF-SUPPORTING VERSUS GUYED TOWERS

4.1 Structural Aspects of Guyed Towers

Structurally, guyed towers have an advantage over self-supporting towers. This advantage relates to their flexibility and tolerance to deformation or displacement of the foundation structures. The guys are merely tension bearing elements of the structure which are installed with an initial tension of approximately 10% of their design load to eliminate "slack" in the structural system. This initial tension increases or diminishes progressively as a lateral load (transverse or longitudinal) is applied. Structurally, the effect of the initial tension in guys disappears when the tension in guys on the "non-loaded" side of the tower is reduced to zero. Hence the day-to-day guy load fluctuates over a range which is small relative to the design load. The range is a function of the day-to-day distribution of wind speeds and directions.

Although it is necessary to provide four guys to accommodate the complete range of possible tower load, only two or three of the four are required for structural stability at any time. It can be shown that, except for extreme loadings, the failure of one load bearing guy (or anchor) will not necessarily result in tower collapse as the flexibility of the tower will permit deformation to proceed to the point where another guy in conjunction with a ground wire will accept the load required for structural stabilisation. This was first demonstrated in full scale tests by Alcan in 1959 and has been borne out in practice at Churchill Falls where failure of the guy hardware on two separate occasions has caused no structural problems. It should also be noted that the structural system is unaffected by a relative displacement of several inches between the tower footing and any guy anchor.

4.2 Guy Anchors and Hardware

In the 735kV Hydro-Quebec lines, it has been the practice to physically test most if not all guy anchors up to at least the guy design load and, although this is prompted by the lack of homogeneity of foundations, it offers a comforting degree of assurance.

Turnbuckles of threaded U-bolts which form part of the guy hardware permit the adjustment necessary for simplifying the guy installation, for setting guy tension and for the adjustment of guys to compensate for any displacements which may occur during the life of the structures.

This degree of flexibility is not available in a rigid tower which may be subjected to significant unforeseen internal stresses in the event that differential displacement occurs between footings.

4.3 Effect of Vibrations on Guys

Insofar as vibrations and their effect on guys and anchors are concerned, it has been shown theoretically and experimentally that this presents no problem when everyday tension is not high. It can be reported that this has presented no problem whatsoever in the first nine (9) years of operation of the Churchill Falls 735kV guyed tower lines. Apart from those lines, there are many miles of guyed tower lines of lower capacity which have been in service in Canada for longer periods of time and there have been no problems related to vibration of guys and anchors.

4.4 Additional Considerations

4.4.1 Engineering

The engineering effort necessary to specify the steelwork and footing (s) is approximately the same for both guyed and self-supporting towers. In the case of guyed structures, some additional engineering is required for the specification of guys, guy hardware and anchors and in the case of the chainette tower, the cross-ropes and their specific hardware.

4.4.2 Schedule

i) The potential advantages of guyed towers over self-supporting towers with respect to schedule are:

a) The fact that they are simple and lighter should minimize any problems of having them fabricated in time to meet the required delivery dates.

b) Once the contractor's staff has become familiar with the installation techniques, they can be assembled and erected much more quickly. Although tower erection time is not normally a critical item in the overall schedule, it could become so if there are delays in the preparation of foundations or delivery of materials.

ii) The potential disadvantages of guyed towers are:

a) Canadian experience has shown the initial (approximately first six months) construction progress to be slow as the contractor learns the new techniques and develops efficient procedures. Once the learning period is over however, the rate of progress seems to be at least as good as with self-supporting towers.

b) More special construction equipment is necessary, hence there is more exposure to major delays due to equipment breakdown. For this reason, it is prudent to insist that, in the case of critical items, the contractor makes satisfactory arrangements to have backup equipment reasonably available.

4.4.3 Construction

Guyed towers have the advantages that they can be assembled almost completely on the ground, which is safe and minimises the need for workers qualified to climb and work at considerable heights.

A disadvantage is that initially, contractors unfamiliar with erecting guyed structures may include excessive contingency in their bid prices to compensate for the "unknown" (to them).

The tower type has no influence on the costs of other elements of the transmission line such as conductors, insulators, etc.

4.4.4 Security

Under the conditions prevailing along the route chosen for this report, well designed towers of either the guyed, chainette or the self-supporting variety should prove equally reliable, considering both natural hazards and sabotage.

With respect to sabotage, it is often thought that guyed structures are more vulnerable because it would be easy to collapse them by cutting a guy. However, it is difficult and time-consuming task to cut one of these large diameter high strength steel cables without sophisticated tools, and furthermore it is necessary to cut at least two guys to cause the tower to fall under normal conditions. It would be at least as easy to unbolt and remove members from a self-supporting tower. If dynamite is used, then the three types of tower seem equally vulnerable.

In the event a tower did collapse for some reason, it would be necessary to mobilise more special equipment (i.e. gin poles and winches or a crane) to re-erect a guyed structure. If guyed towers are used, the saving should far more than offset the cost of maintaining such special equipment readily available, and it should be possible to mobilise the equipment at least as quickly as the tower repair material.

Another concern sometimes expressed about guyed towers is that a flashover from the conductor to the guy will burn the guy to such an extent that it will fail structurally. With such large guys, this theory does not seem very credible, and in one case that there was a flash to a loose guy (the guy hardware having failed) no burning was reported. In this particular instance, the 735kV line tripped and then reclosed, and in due course the guy was repaired. The tower was not damaged.

4.4.5 Maintenance

Canadian utilities report that there is virtually no difference between lines with self-supporting and guyed towers with respect to normal maintenance, including hot line work.

4.4.6 Appearance

Although largely a matter of personal preference, it is generally considered that the comparatively slender guyed towers are more pleasing in appearance than self-supporting structures.

4.4.7 Right-of-way

As far as electrical requirements and deforestation are concerned, the width of right-of-way is not affected by the choice of self-supporting or guyed towers.

With respect to land use, in some instances self-supporting structures are preferred and in other cases guyed structures are favoured.

4.4.8 Experience

Self-supporting towers of course have been used very successfully around the world for many years at voltages up to and including the 700kV class.

However, in recent years, the cost saving available through the use of guyed structures, particularly for heavy EHV lines, has resulted in this type of tower being selected for many important applications, and the results have generally proved most satisfactory.

The following partial listing provides some idea of the extent to which guyed towers are now being used for major lines.

300 - 500kV class

Hydro-Quebec

Ontario Hydro

B.C. Hydro

Bonneville Power Administration

Virginia Electric Power Co.

Pacific Gas and Electric

City of Los Angeles Department of Water and Power

Brazil*

700kV class

Hydro-Quebec

Churchill Falls Labrador Corp.

American Electric Power Co.

USSR 750kV line

Brazil*

Guyed tower lines are also used in Sweden, Finland, France, Chile and Argentina.

4.5 Description of Foundation

4.5.1 Overburden

A post type foundation employing a steel grillage is used for the James Bay project, see figure 5. The foundations for guyed-V towers

*In design stage

consist of two columns, 1.0m apart, rigidly connected at top and bottom by channels bolted to the columns forming a rigid frame. The grillage comprises of a series of wide flange beams spaced at approximately 250mm c/c. These beams are attached directly to the lower channels. The steel members used for the grillage are spaced in a manner such that the stress on the soil directly in contact with the grillage members does not surpass the design bearing capacity by more than 50%, while the nominal bearing stress is calculated using the gross area of the grillage.

4.5.2 Rock

A small grillage type foundation, using several very short grillage beams, is used on rock, see figure 6. Four rock anchors grouted directly into the rock below, solidly anchor the rock footing enabling it to resist all adfreeze and overturning forces. The small grillage is also set in a cushion of fine aggregate concrete to assure that no heaving forces can act from underneath. The columns supporting the tower can be adjusted to any height in order to accommodate the different depths encountered, between 0.0 and 3.2m. This is achieved by including several sets of bolt holes along the length of the column and simply cutting off, in the field, that part of the column not required. The cut end is then protected with a corrosion resistant paint.

4.5.3 Pile

Pile foundations are required when very low bearing capacities are found below the normal setting depths for overburden foundations. These conditions are normally found in low lying areas where swamps, peat bogs, soft clay and silt are found. The foundations are formed with a concrete pile cap fixed to three (3) piles arranged in a triangular pattern which transmit the tower loads to the lower layers of soil or rock.

The required length of piles is dependent on the types of supporting soil encountered, or the depth to the rock layer, as well as the maximum load to be carried by each pile.

4.5.4 Design Considerations

The grillage footings have been designed considering that an inclination of the foundation of 1° may occur thus creating an excentricity of as much as 50 mm subjected to the tower loading. The soil backfill is not considered to resist any lateral loading except to provide enough lateral support against buckling forces in the structural members.. In this manner steel sections are able to work to full design potential.

Forces due to adfreeze are considered on all members located in the frost penetration zone and both members and connections are checked to insure that they will resist the maximum heaving force. The minimum daily loading condition is considered when calculating the effects of adfreeze forces. A value of adfreeze of 100kPa applied over the full depth of frost penetration has been derived for foundations having their grillages set below the maximum frost penetration.

5.0 COST ANALYSIS OF SELF-SUPPORTING VS GUYED TOWERS

5.1 Introduction

The portion of a transmission line that was chosen for this analysis is the section between Chibougamau-Chamouchouane. The type of terrain and topography encountered in this zone, is representative for all the James Bay project. Most of the terrain is composed of silty till. The total length of this line is 200km.

5.2 Repartition of Towers

The tower type and quantity were divided as follows:

A) Guyed towers

Type	N°	N°/km	%
GV-0°	370	1.85	85.2
GV-5°	48	0.24	11.0
GM-60(0-30)	12	0.06	2.8
GM-60(30-60)	2	0.01	0.5
GM-DE	2	0.01	0.5
Total	434	2.17	100

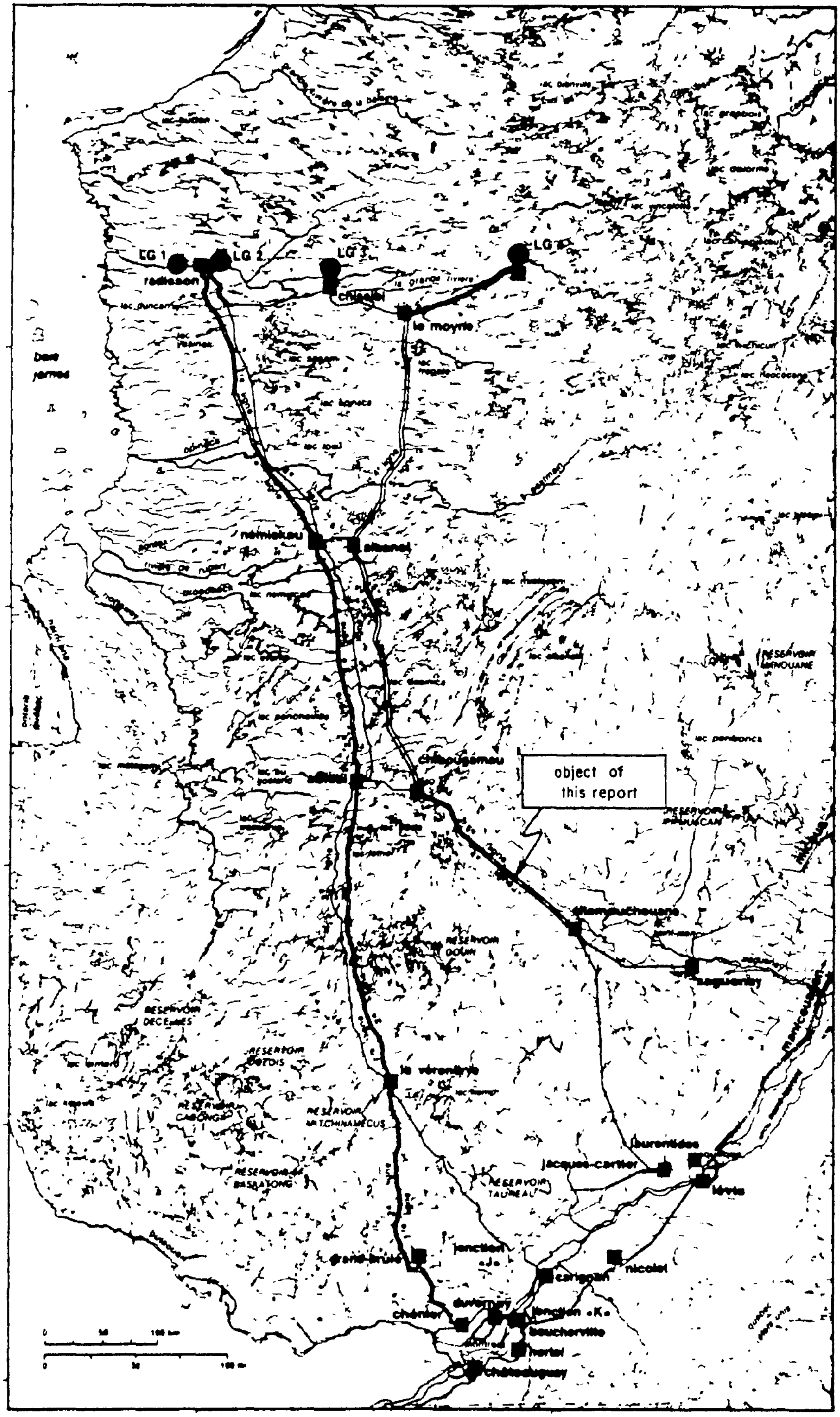
Average span: 462m.

B) Rigid towers

Type	N^o	N^o/km	%
R-0	363	1.815	85.2
R-5	47	0.235	11.0
R5-30	12	0.060	2.8
R30-60	2	0.01	0.5
R-DE	2	0.01	0.5
Total	426	2.13	100

Average span: 471m.

Le réseau de transport La Grande à 735 kV



centrale

poste

ligne

FIG. 1

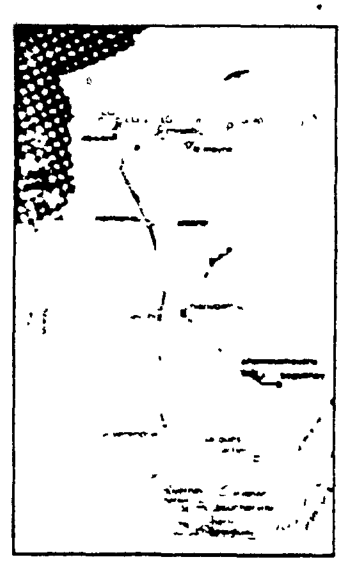
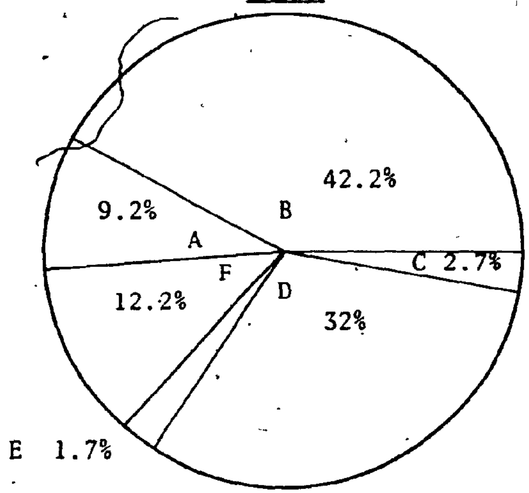


Table of Comparative Costs ($1000/km)

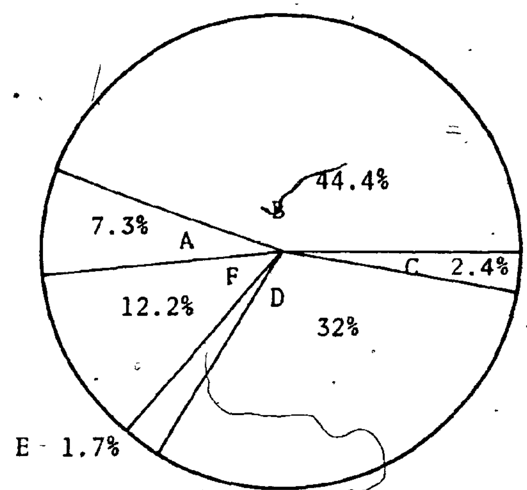
Description	guyed	rigid	difference (rigid-guyed)
Purchasing of material			
Conductor and accessories (except assemblies)	50.8	50.7	-0.1
ground wire and accessories	1.5	1.5	0.0
insulators and assemblies	12.4	11.2	-1.2
counter-weights and miscellaneous	0.1	0.1	0.0
sub-total	64.8	63.5	-1.3
tower's steel	20.0	34.4	+14.4
guys and accessories	4.3	0.0	-4.3
sub-total	24.3	34.4	+10.1
foundations and insulation	2.8	11.7	+8.9
anchors and hardware	1.6	0.0	-1.6
sub-total	4.4	11.7	+7.3
Total	93.5	109.6	+16.1(+17.2%)
Construction			
Stringing of conductors, ground wires and counter-weights	20.5	21.3	+0.8
erection of tower and installation of guys	19.2	30.4	+11.2
sub-total	39.7	51.7	+12.0
Foundations	8.9	27.0	+18.1
anchors	22.4	0.0	-22.4
sub-total	31.3	27.0	-4.3
Total	71.0	78.7	+7.7(+10.8%)
Right-of-way	6.0	6.0	0.0(0.0%)
Management	20.6	18.0	-2.6(-12.6%)
Total cost	191.1	212.3	+21.2(+11%)

Management, Material, Right-of-way, Construction, Administration and Interest

guyed

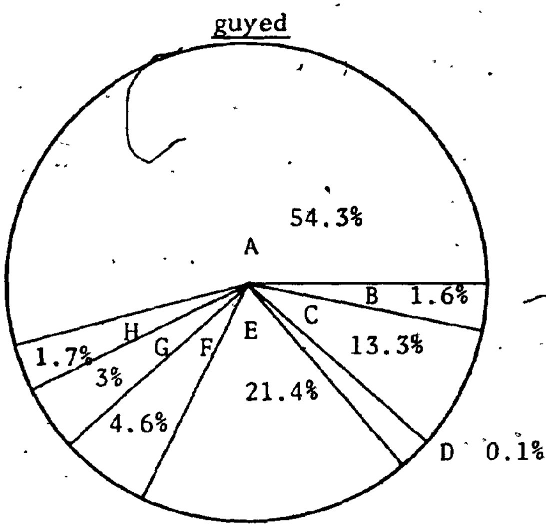


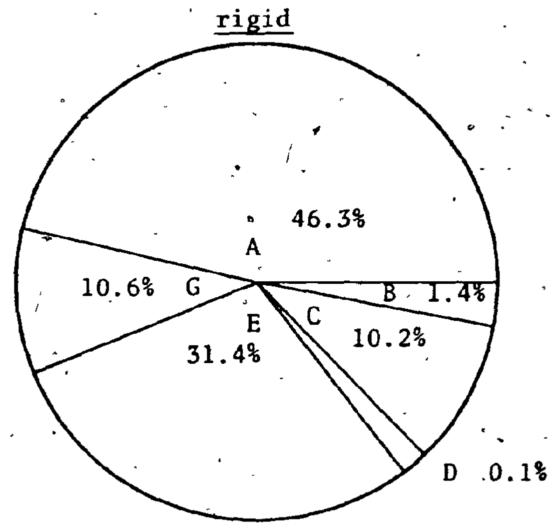
rigid



guyed $	guyed %		rigid $	rigid %
20550	9.2	A management	18000	7.3
93549	42.2	B material	109582	44.4
6000	2.7	C right-of-way	6000	2.4
70939	32.0	D construction	78723	32.0
3820	1.7	E administration	4246	1.7
27000	12.2	F interest	30000	12.2
221858	100	Total	246551	100

Purchasing of Material

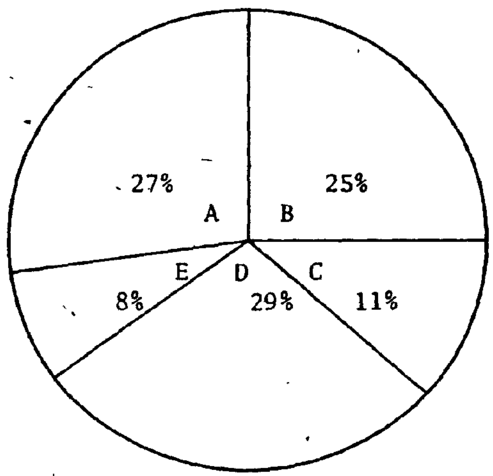




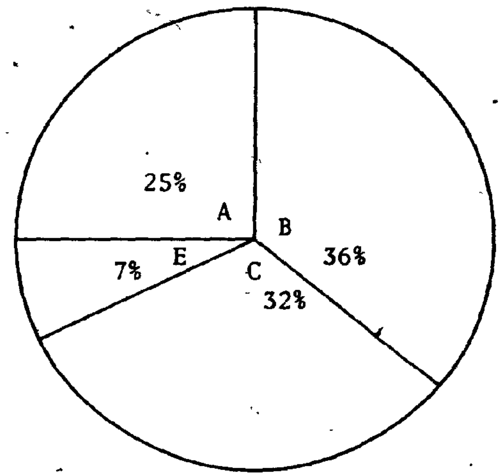
guyed $	guyed %			rigid $	rigid %
50830	54.3	A	conductors and accessories	50720	46.3
1518	1.6	B	ground wire and accessories	1509	1.4
12414	13.3	C	insulators and assemblies	11186	10.2
120	0.1	D	counterweights and miscellaneous	120	0.1
20027	21.4	E	tower steel	34379	31.4
4257	4.6	F	guys and accessories	0	0
2782	3.0	G	foundations	11668	10.6
1601	1.7	H	anchors and hardware	0	0
93549	100		Total	109582	100

Construction and Right-of-way

guyed



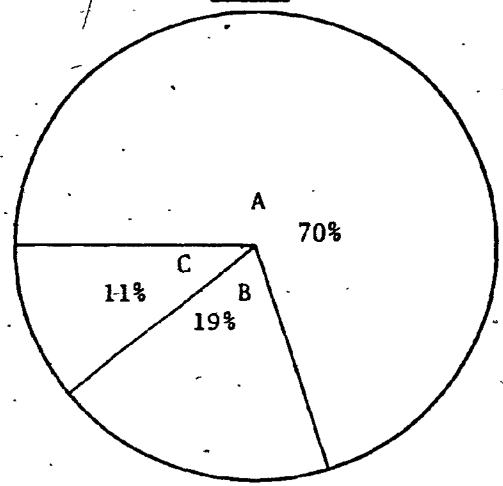
rigid



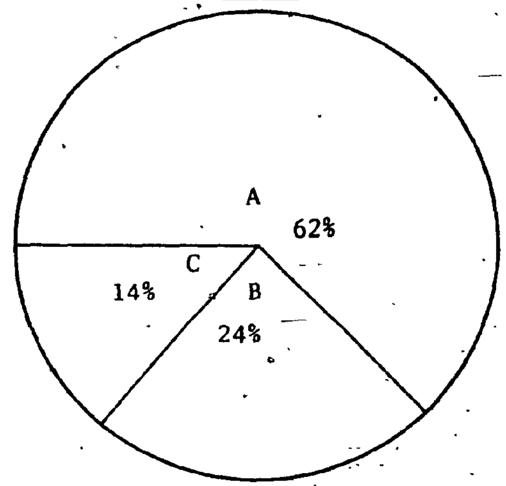
guyed $	guyed %			rigid $	rigid %
20530	27	A	stringing	21280	25
19170	25	B	eréction of tower and installation of guys	30416	36
.8871	11	C	foundations	27027	32
22368	29	D	anchoring of guys	0	0
6000	8	E	right-of-way	6000	7
76939	100		Total	84723	100

Management

guyed



rigid



guyed $	guyed %		rigid $	rigid %
14300	70	A work inspection	11200	62
4000	19	B operation of depots	4400	24
2250	11	C others	2400	14
20550	100	Total	18000	100

TABLE 1
Guyed-V and rigid towers
Cost detail related to length of line

Description	Units	Guyed Units/km	Guyed $/unit	Guyed $/km	Rigid Units/km	Rigid $/unit	Rigid $/km
i) Purchasing of material							
conductor	m	12100	3.90	47190	12100	3.90	47190
compression fittings for conductors	ea	5.7	22.50	128	5.7	22.50	128
spacer dampers	ea	45	75.00	3375	45	75.00	3375
sub-total				50693			50693
ground wire	m	2020	0.62	1252	2020	0.62	1252
compression fittings for ground wire	ea	0.66	7.00	5	0.66	7.00	5
sub-total				1257			1257
counter-weights and accessories	km	1	120.00	120	1	120.00	120
Total				52070			52070
ii) Construction							
stringing of conductors	km	1	17400	17400	1	18150	18150
stringing of ground wires	km	1	2200	2200	1	2200	2200
installation of counter-weights	km	1	930	930	1	930	930
Total				20530			21280
iii) Right-of-way	km	1	6000	6000	1	6000	6000
iv) Managing							
work supervision	km	1	14300	14300	1	11200	11200
operation of depots	km	1	4000	4000	1	4400	4400
miscellaneous	km	1	2250	2250	1	2400	2400
Total				20550			18000

TABLE 2

Cost detail for purchasing of material required for each type of guyed tower.

ITEM	UNITS	GV-0°			GV-5°			GM-60° (0-30)			GM-60° (30-60)			GM-DE		
		UNIT/TOWER	$/UNIT	$/TOWER	UNIT/TOWER	$/UNIT	$/TOWER	UNIT/TOWER	$/UNIT	$/TOWER	UNIT/TOWER	$/UNIT	$/TOWER	UNIT/TOWER	$/UNIT	$/TOWER
tower steel (7.5m extension)	kg	10727	0.80	8582	14105	0.80	11284	20364	0.86	17513	20364	0.86	17513	25162	0.86	21639
secondary guys	m	—	—	—	—	—	—	206	3.74	770	206	3.74	770	206	4.23	871
principal guys	m	200	4.26	852	204	5.95	1213	261	7.80	2035	302	7.80	2356	457	10.86	4963
hardware for sec. guys	ea	—	—	—	—	—	—	6	191	1146	6	191	1146	6	220	1320
hardware for princ. guys	ea	4	220	880	4	247	988	6	311	1866	6	311	1866	9	480	4320
Total - guys				1732			2201			5817			6138			11474
suspension/dead-end assembly	ea	2	52	104	2	52	104	4	15	60	4	15	60	4	15	60
clamp for twin cable	ea	4	2.5	10	4	2.5	10	4	2.5	10	4	2.5	10	4	2.5	10
15° wedge for suspension clamp	ea	—	—	—	0.3	20	6	—	—	—	—	—	—	—	—	—
anchoring plate (GM)	ea	—	—	—	—	—	—	3	15	45	—	—	—	—	—	—
clamp for grounding	ea	—	—	—	—	—	—	2	2	4	2	2	4	2	2	4
N° 4 leather wire	m	6.1	1.0	6	6	1.0	6	—	—	—	—	—	—	—	—	—
Total - ground wire				120			126			119			74			74
I-suspension assembly of 36K	ea	0.60	250	150	0.60	250	150	—	—	—	—	—	—	—	—	—
I-suspension assembly of 50K	ea	1.40	250	350	1.40	250	350	6	1350	8100	6	1350	8100	3	1350	4050
V-suspension assembly of 25K	ea	0.45	435	196	0.45	435	196	3	278	834	3	278	834	3	278	834
V-suspension assembly of 36K	ea	0.55	450	248	0.55	450	248	—	—	—	—	—	—	—	—	—
insulators of 25k	ea	59.40	15	891	59.40	15	891	198	15	2970	198	15	2970	198	15	2970
insulators of 36K	ea	95.20	17	1618	95.20	17	1618	—	—	—	—	—	—	—	—	—

TABLE 2 (cont'd)

ITEM	UNITS	GV-0°			GV-5°			GM-60° (0-30)			GM-60° (30-60)			GM-DE		
		UNIT/TOWER	$/UNIT	$/TOWER	UNIT/TOWER	$/UNIT	$/TOWER	UNIT/TOWER	$/UNIT	$/TOWER	UNIT/TOWER	$/UNIT	$/TOWER	UNIT/TOWER	$/UNIT	$/TOWER
insulators of 50K	ea	78.40	20	1568	78.40	20	1568	672	20	13440	672	20	13440	336	20	6720
Total - insulators				5021			5021			25344			25344			14574
dead-end compression fittings	ea	—	—	—	—	—	—	24	39	936	24	39	936	12	39	468
spacer-dampers (extra)	ea	—	—	—	—	—	—	12	75	900	12	75	900	6	75	450
Total - conductors										1836			1836			918
foundation - rock	ea	0.40	663	265	0.40	782	313	1.20	584	701	1.20	584	701	1.20	603	724
- 300kPa	ea	0.25	1113	278	0.25	1538	385	0.75	1137	853	0.75	1137	853	0.75	1352	1014
- 200kPa	ea	0.10	1402	140	0.10	2017	202	0.30	1422	427	0.30	1422	427	0.30	1698	510
- 100kPa	ea	0.12	2169	260	0.12	2960	355	0.36	2085	751	0.36	2085	751	0.36	2828	1018
concrete pile cap	ea	0.13	230	30	0.13	230	30	0.39	690	269	0.39	690	269	0.39	800	312
insulation - stuffed	ea	0.42	17	7	0.42	17	7	0.84	17	14	0.84	17	14	0.84	17	14
- fitting	ea	0.20	15	3	0.20	15	3	0.42	15	6	0.42	15	6	0.42	15	6
- sheeting	m^2	2.42	5.37	13	2.42	5.37	13	7.26	5.37	39	7.26	5.37	39	7.26	5.37	39
piles - steel	m	5.6	29.30	164	5.6	29.30	164	12.4	33	410	12.4	33	410	12.4	33	410
Total - foundation				1160			1472			3470			3470			4047
anchor bars and hardware		—	—	704	—	—	755	—	—	1432	—	—	1432	—	—	1750
Total				17319			20859			55531			55807			54476

TABLE 3

Cost detail for the construction of each type of guyed tower

ACTIVITY	UNITS	GV-0°			GV-5°			GM-60° (0-30)			GM-60° (30-60)			GM-DE		
		UNIT/TOWER	$/UNIT	$/TOWER	UNIT/TOWER	$/UNIT	$/TOWER	UNIT/TOWER	$/UNIT	$/TOWER	UNIT/TOWER	$/UNIT	$/TOWER	UNIT/TOWER	$/UNIT	$/TOWER
rock excavation	m^3	1.0	350	350	1.3	350	455	3.3	350	1155	3.5	350	1225	5.0	350	1750
overburden excavation	m^3	19.2	27.5	528	25.6	27.5	704	68.0	27.5	1870	68.0	27.5	1870	60.0	27.5	1650
installation - 300kPa	ea	0.25	1600	400	0.25	1600	400	0.75	1600	1200	0.75	1600	1200	1.5	1600	2400
- 200kPa	ea	0.10	1700	170	0.10	1700	170	0.30	1700	510	0.30	1700	510	—	—	—
- 100kPa	ea	0.12	2200	264	0.12	2200	264	0.36	2200	792	0.36	2200	792	—	—	—
- rock	ea	0.40	2250	900	0.40	2250	900	1.2	2250	2700	1.2	2250	2700	1.2	2250	2700
granular material	m^3	0.56	100	56	0.74	100	74	2.0	100	200	2.0	100	200	1.8	100	180
regular backfill	m^3	18.2	7.9	144	23.3	7.9	184	65.0	7.9	514	65.0	7.9	514	57.5	7.9	454
backfill with borrowed material	m^3	1.3	92	120	2.7	92	248	7.5	92	690	10.0	92	920	10.0	92	920
Total - regular foundation				2932			3399			9631			9931			10054
pile - splices	ea	0.69	85	59	0.69	85	59	1.55	85	132	1.55	85	132	—	—	—
pile driving	m	5.9	69	407	5.9	69	407	13.2	69	911	13.2	69	911	—	—	—
concrete pile cap	ea	0.19	1500	285	0.2	1500	300	0.28	1500	420	0.28	1500	420	—	—	—
thermal insulation	m^2	2.42	32	77	2.42	32	77	7.26	32	232	7.26	32	232	—	—	—
Total - pile foundation				828			843			1695			1695			
drilling in overburden	m	29.1	210	6111	32.5	210	6825	97.4	210	20454	97.4	210	20454	121.8	210	25578
drilling in rock	m	12.5	210	2625	13.9	210	2919	41.8	210	8778	41.8	210	8778	52.2	210	10962
testing of overburden anchors	ea	3.52	165	581	3.52	165	581	5.28	165	871	5.28	165	871	7.92	165	1307
testing of rock anchors	ea	0.48	160	77	0.42	160	67	0.72	160	115	0.72	160	115	1.08	160	173
Total - anchor bars				9394			10392			30218			30218			38020

TABLE 3 (cont'd)

ACTIVITY	UNITS	GV-0°			GV-5°			GM-60° (0-30)			GM-60° (30-60)			GM-DE		
		Unit/Tower	$/Unit	$/Tower	Unit/Tower	$/Unit	$/Tower	Unit/Tower	$/Unit	$/Tower	Unit/Tower	$/Unit	$/Tower	Unit/Tower	$/Unit	$/Tower
erection of tower steel	t	10.73	700	7511	14.11	700	9877	20.37	700	14259	20.37	700	14259	25.16	700	17612
installation of guys	t	4	185	740	4	185	740	12	185	2220	12	185	2220	15	185	2775
Total - erection				8251			10617			16479			16479			20387
Total				21405			25251			58023			58323			68461

TABLE 4

Cost detail for the purchasing of material for each type of rigid tower

ITEM	UNITS	R-0° UNIT/TOWER	R-0° $/UNIT	R-0° $/TOWER	R-5° UNIT/TOWER	R-5° $/UNIT	R-5° $/TOWER	R5°-30° UNIT/TOWER	R5°-30° $/UNIT	R5°-30° $/TOWER	R30°-60° UNIT/TOWER	R30°-60° $/UNIT	R30°-60° $/TOWER	R-DE UNIT/TOWER	R-DE $/UNIT	R-DE $/TOWER
tower steel	kg	19230	0.80	15384	20700	0.80	16560	31200	0.95	29640	36000	0.95	34200	46800	0.95	44460
suspension and dead-end assembly	ea	2	52	104	2	52	104	4	15	60	4	15	60	4	15	60
clamp for twin cable	ea	4	2.5	10	4	2.5	10	4	2.5	10	4	2.5	10	4	2.5	10
grounding clamp	ea	—	—	—	—	—	—	2	2	4	2	2	4	2	2	4
N^{o} 4 leather wire	m	6	1.0	6	6	1.0	6	—	—	—	—	—	—	—	—	—
Total - ground wire				120			120			74			74			74
I-suspension assembly of 36K	ea	0.55	250	138	0.55	250	138	—	—	—	—	—	—	—	—	—
I-suspension or dead-end assembly of 50K	ea	1.45	250	362	1.45	250	362	—	—	—	6	1350	8100	3	1350	4050
25K V-suspension or jumper assembly	ea	0.40	435	174	0.40	435	174	—	—	—	3	278	834	3	278	834
36 or 50K V-suspension assembly	ea	0.60	450	270	0.60	450	270	3.0	450	1350	—	—	—	—	—	—
insulators of 25K	ea	52.8	15	792	52.8	15	792	—	—	—	198	15	2970	198	15	2970
insulators of 36K	ea	98.0	17	1666	98.0	17	1666	—	—	—	—	—	—	—	—	—
insulators of 50K	ea	81.2	20	1624	81.2	20	1624	336	20	6720	672	20	13440	336	20	6720
Total - insulators				5026			5026			8070			25344			14574
foundation - rock	kg	1591.6	0.95	1512	1711	0.95	1625	2630	0.95	2499	3183	0.95	3024	3235	0.95	3073
- overburden	kg	3222	0.95	3061	3465	0.95	3292	7364	0.95	6996	8683	0.95	8249	10000	0.95	9500
reinforcing steel	ea	0.10	920	92	0.10	944	94	0.08	1875	150	—	—	—	—	—	—
piles - steel	m	14.4	29.3	422	14.4	29.3	422	19.5	29.3	571	—	—	—	—	—	—
anchors for pile foundation	m	5.95	13.75	82	5.11	13.75	70	—	—	—	—	—	—	—	—	—

TABLE 4 (cont'd)

ITEM	UNITS	R-0°			R-5°			R5°-30°			R30°-60°			R-DE		
		UNIT/TOWER	$/UNIT	$/TOWER	UNIT/TOWER	$/UNIT	$/TOWER	UNIT/TOWER	$/UNIT	$/TOWER	UNIT/TOWER	$/UNIT	$/TOWER	UNIT/TOWER	$/UNIT	$/TOWER
thermal insulation	ea	0.05	1320	66	0.05	1320	66	0.04	2293	92	—	—	—	—	—	—
Total - foundations				5235			5569			10308			11273			12573
dead-end compression assembly	ea	—	—	—	—	—	—	—	—	—	24	39	936	12	39	468
spacer dampers (extra)	ea	—	—	—	—	—	—	—	—	—	12	75	900	6	75	450
Total - conductors													1836			918
Total				25765			27275			48092			72727			72599

TABLE 5

Cost detail for the construction of rigid towers

ACTIVITY	UNITS	R-0°			R-5°			R5°-30°			R30°-60°			R-DE		
		UNIT/TOWER	$/UNIT	$/TOWER	UNIT/TOWER	$/UNIT	$/TOWER	UNIT/TOWER	$/UNIT	$/TOWER	UNIT/TOWER	$/UNIT	$/TOWER	UNIT/TOWER	$/UNIT	$/TOWER
excavation - rock	m^3	8.3	130	1079	8.9	130	1157	17.6	130	2288	31.5	130	4095	34	130	4420
- overburden	m^3	114	47	5358	123	47	5781	242	47	11374	430	47	20210	470	47	22090
granular material	m^3	1.7	100	170	1.8	100	180	3.5	100	350	6.5	100	650	7	100	700
backfill with borrowed material	m^3	5.51	92	507	5.93	92	546	12.1	92	1113	21.5	92	1978	23.5	92	2162
concreting	m^3	1.5	525	788	1.55	525	814	2.5	525	1313	1.0	525	525	1.0	525	525
drilling of anchors	m	43.1	33	1422	46.3	33	1528	58	33	1914	70	33	2310	70	33	2310
pile driving	m	13.2	62	818	13.2	62	818	18	62	1116	—	—	—	—	—	—
pile - splices	ea	1.54	85	131	1.54	85	131	3.46	85	294	—	—	—	—	—	—
drilling of pile foundation anchors	m	4.8	350	1680	4.8	350	1680	—	—	—	—	—	—	—	—	—
installation of thermal insulation	m^2	8.64	32	276	7.43	32	238	—	—	—	—	—	—	—	—	—
Total - foundations				12229			12873			19762			29768			32207
erection of tower	t	19.23	570	10961	20.7	570	11799	31.2	570	17784	36.0	570	20520	46.8	570	26676
installation of foundations	t	4.86	570	2770	5.2	570	2964	10.04	570	5723	11.87	570	6766	13.24	570	7547
Total - erection				13731			14763			23507			27286			34223
Total				25960			27636			43269			57054			66430

TABLE 6

Cost summary of guyed towers

ITEM	GV-0° 1.85Tower/km		GV-5° 0.24Tower/km		GM-60° (0-30) 0.06Tower/km		GM-60 (30-60) 0.01Tower/km		GM-DE 0.01Tower/km		Total cost per km RESPECT TO TYPE OF TOWER	RESPECT TO THE LINE	TOTAL
	$/tower	$/km	$/tower	$/km	$/tower	$/km	$/tower	$/km	$/tower	$/km	$/km	$/km	$/km
i) Purchasing													
conductor and accessories	—	—	—	—	1836	110	1836	18	918	9	137	50693	50830
ground wire and accessories	120	222	126	30	119	7	74	1	74	1	261	1257	1518
insulators and hardware assembly	5021	9289	5021	1205	25344	1521	25344	253	14574	146	12414	—	12414
counter-weight and miscellaneous	—	—	—	—	—	—	—	—	—	—	—	120	120
tower steel	8582	15877	11284	2708	17513	1051	17513	175	21639	216	20027	—	20027
guy and accessories	1732	3204	2201	528	5817	349	6138	61	11474	115	4257	—	4257
foundation (steel and insulation)	1160	2146	1472	353	3470	208	3470	35	4047	40	2782	—	2782
anchors and hardware	704	1302	755	181	1432	86	1432	14	1750	18	1601	—	1601
sub-total	17319	32040	20859	5005	55531	3332	55807	557	54476	545	41479	52070	93549
ii) Construction													
stringing of conductor, ground wire	—	—	—	—	—	—	—	—	—	—	—	20530	20530
erection of tower and guys	8251	15264	10617	2548	16479	989	16479	165	20387	204	19170	—	19170
foundation (installation and excavation)	3760	6956	4242	1018	11326	680	11626	116	10054	101	8871	—	8871
anchoring of guys	9394	17379	10392	2494	30218	1813	30218	302	38020	380	22368	—	22368
sub-total	21405	39599	25251	6060	58023	3482	58323	583	68461	685	50409	20530	70939

TABLE 6 (cont'd)

ITEM	GV-0° 1.85Tower/km		GV-5° 0.24Tower/km		GM-60° (0-30) 0.06Tower/km		GM-60 (30-60) 0.01Tower/km		GM-DE 0.01Tower/km		Total cost per km		
											RESPECT TO TYPE OF TOWER	RESPECT TO THE LINE	TOTAL
	$/tower	$/km	$/tower	$/km	$/tower	$/km	$/tower	$/km	$/tower	$/km	$/km	$/km	$/km
iii) Managing													
work inspection	—	—	—	—	—	—	—	—	—	—	—	14300	14300
operation of depots	—	—	—	—	—	—	—	—	—	—	—	4000	4000
others	—	—	—	—	—	—	—	—	—	—	—	2250	2250
sub-total												20550	20550
iv) Right-of-way	—	—	—	—	—	—	—	—	—	—	—	6000	6000
Total	38724	71639	46110	11065	113554	6814	114130	1140	122937	1230	91888	99150	191038

TABLE 7

Cost summary of rigid towers

ITEM	R-0° 1.82Tower/km		R-5° 0.24Tower/km		R5°-30° 0.06Tower/km		R30°-60° 0.01Tower/km		R-DE 0.01Tower/km		Total cost per km: Respect to type of tower	Total cost per km: Respect to the line	Total cost per km: Total
	$/tower	$/km	$/tower	$/km	$/tower	$/km	$/tower	$/km	$/tower	$/km	$/km	$/km	$/km
i) **Purchasing**													
conductor and accessories	—	—	—	—	—	—	1836	18	918	9	27	50693	50720
ground wire and accessories	120	218	120	28	74	4	74	1	74	1	252	1257	1509
insulators and hardware assembly	5026	9122	5026	1181	8070	484	25344	253	14574	146	11186	—	11186
counter-weights and miscellaneous	—	—	—	—	—	—	—	—	—	—	—	120	120
tower steel	15384	27922	16560	3892	29640	1778	34200	342	44460	445	34379	—	34379
foundations (steel and installation)	5235	9502	5569	1309	10308	618	11273	113	12573	126	11668	—	11668
sub-total	25765	46764	27275	6410	48092	2884	72727	727	72599	727	57512	52070	109582
ii) **Construction**													
stringing of conductor and ground wire	—	—	—	—	—	—	—	—	—	—	—	21280	21280
erection of tower	10961	19894	11799	2773	17784	1067	20520	205	26676	267	24206	—	24206
erection of foundations	2770	5028	2964	696	5723	343	6766	68	7547	75	6210	—	6210
foundation (installation and excavation)	12229	22196	12873	3025	19762	1186	29768	298	32207	322	27027	—	27027
sub-total	25960	47118	27636	6494	43269	2596	57054	571	66430	664	57443	21280	78723

TABLE 7 (cont'd)

ITEM	R-0° 1.82Tower/km		R-5° 0.24Tower/km		R5°-30° 0.06Tower/km		R30°-60° 0.01Tower/km		R-DE 0.01Tower/km		Total cost per km		
	$/tower	$/km	$/tower	$/km	$/tower	$/km	$/tower	$/km	$/tower	$/km	Respect to type of tower $/km	Respect to the line $/km	Total $/km
iii) Managing													
work inspection	—	—	—	—	—	—	—	—	—	—	—	11200	11200
operation of depots	—	—	—	—	—	—	—	—	—	—	—	4400	4400
others	—	—	—	—	—	—	—	—	—	—	—	2400	2400
sub-total												18000	18000
iv) Right-of-way	—	—	—	—	—	—	—	—	—	—	—	6000	6000
Total											114955	97350	212305

6.0 GUYED VERSUS CHAINETTE TOWERS

6.1 Introduction

A study of existing guyed towers revealed that, for extra-high voltages, fifty (50) percent of the weight of steel of the tower is in its crossarm and that, as voltages increase, much heavier crossarms have to be installed at much greater heights. For instance, at 230kV, the crossarm weighing only one ton has to be installed at 25 meters, while at 315kV, a two ton crossarm has to be installed at 35 meters and at 735kV, a five ton crossarm has to be installed at 45 meters. For extra-high voltages, this makes the raising of guyed towers very difficult, and dictates the type of erection equipment to be used. Moreover, the weight of the crossarm of a 735kV tower makes it economically unsuitable for an helicopter operation.

6.2 Description of Chainette Tower

The chainette tower solved the above problem since it consists of a steel wire cable system that suspends the three phases between two masts which are anchored on the outside by guys from their top to the ground. For large phase spacings, this design makes very efficient use of structural materials, specializing the role of each member into tension and compression member. The weight of steel for the crossarm of a 735kV tower is reduced to only 10% of the total weight, and the total weight is reduced by about 40% compared with the guyed V-tower. This type of tower was invented by Brian Herbert White, in the 1950's, who convinced Hydro-Quebec to adopt it. By coincidence a Mr. Hubert designed a similar line of towers in France, also in the 50's, but the

French didn't develop the idea any further.

The outline and main dimensions of the chainette tower are shown in figure 4. Each mast weighs only 3700kg at maximum height. The arrangement at the top of the mast is shown in figure 11. The cable attachments are similar to the ones used in a suspension bridge and the ground wire is locked in a permanent pulley by means of a preformed grip. Temporary outriggers are added for the stringing of the ground wire by helicopter.

6.3 Construction

This tower opens up all the possibilities related to construction by helicopter, since all component weights are kept within the lift limits of a medium size machine. This allows the transfer of assembly work from the tower site, back to a yard, where mass production techniques can be applied. This type of tower appears very interesting, in view of the isolation of the James Bay network, as well as the working conditions to which men and equipment will be exposed. With a design as simple as this, assembly work could be carried out within a shelter, allowing men to work efficiently in a comfortable environment. In addition, tower erection by conventional construction methods is simplified. Since there are no heavy crossarms in the tower, it can easily be raised by the use of only one gin pole and a tractor from ground level.

6.4 Sensitivity Due to Foundation Movements

6.4.1 Affecting the Structure

Due to the flexibility of the cross-rope assembly, the structure is practically insensitive to foundation movements. For example, a 15cm upward movement of one foundation will cause only a 3% increase in stress levels in the guys and a 5% increase in the masts. The tower is also insensitive to movements of foundations in transversal and longitudinal directions. Insensitivity of the tower to settlement or uplift makes is possible to use surface foundations installed at a depth not exceeding one meter, even in regions (like the James Bay area) where frost reaches 3 meters.

6.4.2 Electrical Clearances

Both a theoretical and an experimental study of the geometrical changes in the structure revealed that electrical clearances will not be greatly affected by foundation movements. In the case of a 15cm settlement of both foundations, which is more than one would expect, electrical clearances to the masts are reduced by only 3.5% at the zero swing position of the outside phase, and by 5% at the extreme swing position of 19 degrees. Electrical clearances to the ground are decreased by only 70cm at the centre phase, where the effect is the greatest.

6.5 Special Design Criteria

All members of the cross-rope suspension system must be maintained under tension at all times in order to avoid impact loads on the hardware. This became a design criteria in the shaping of the cross-rope suspension system, and a requirement in the spotting criteria of the towers.

6.6 Right-of-way

It has to be recognized that the chainette tower occupies a large area at its base and, consequently, in some populated areas, this may make its use less attractive. In remote places, such as the upper part of the James Bay project however, it should not present any problems while in scenic areas, its reduced visual impact will be a positive asset. The required clearing is the same as for other types of line except at the actual tower sites.

6.7 Description of Foundation

The overburden foundation is similar to the one for the guyed V-tower, see figures 5 and 7. In the case of surface rock, the foundation consists of a grouted deformed bar topped with a steel plate, see figure 9. For both these types of foundation, a spherical plate is added to insure a good articulation of the mast.

6.8 Weight Comparison

The previously mentioned structural efficiency of the concept is significantly reflected in the total weight of the tower. The list below showing the evolution of 735kV towers designed by Hydro-Quebec, illustrates this point:

Type	Year	Weight (tons/km)
self-supporting	1965	65
self-supporting	1974	42
guyed-V	1976	31
chainette	1978	19

6.9 Economic Benefits

There is a significant economy regarding purchase of materials, as well as assembly and erection. The light weight of the masts, the more generous tolerances in construction of foundations, the easy assembly due to the reduced number of different members, and the I-configuration of the insulator strings, are among the factors tending to reduce construction costs. The only negative economic aspect concerns the foundations. The cost of guy anchors being the same for both types of tower, it is the need to build two footings rather than only one for the guyed-V tower that makes the latter more advantageous in this regard. The possibility of erecting the tower by helicopter is also very advantageous in remote areas, or in the case of a very tight schedule, for example in the event of a collapse.

7.0 COST ANALYSIS OF GUYED VS CHAINETTE TOWERS

A cost study similar to the one found in this report was carried out for a line with either guyed or chainette towers. It was concluded that a savings of about 5% could be obtained when using chainette towers. This percentage could easily be increased if surface foundations could be used.

8.0 CONCLUSION

In the case of a mechanical breakage, damage should be more limited for the chainette than for a more rigid tower and it should be possible, in some cases, to temporarily operate the damaged line. The flexibility of the chainette tower should also reduce the risk of progressive line collapse (cascade) in disastrous circumstances. Its insensitivity to foundation or anchor movements cuts down maintenance costs and eventually would make the use of surface foundations economically advantageous.

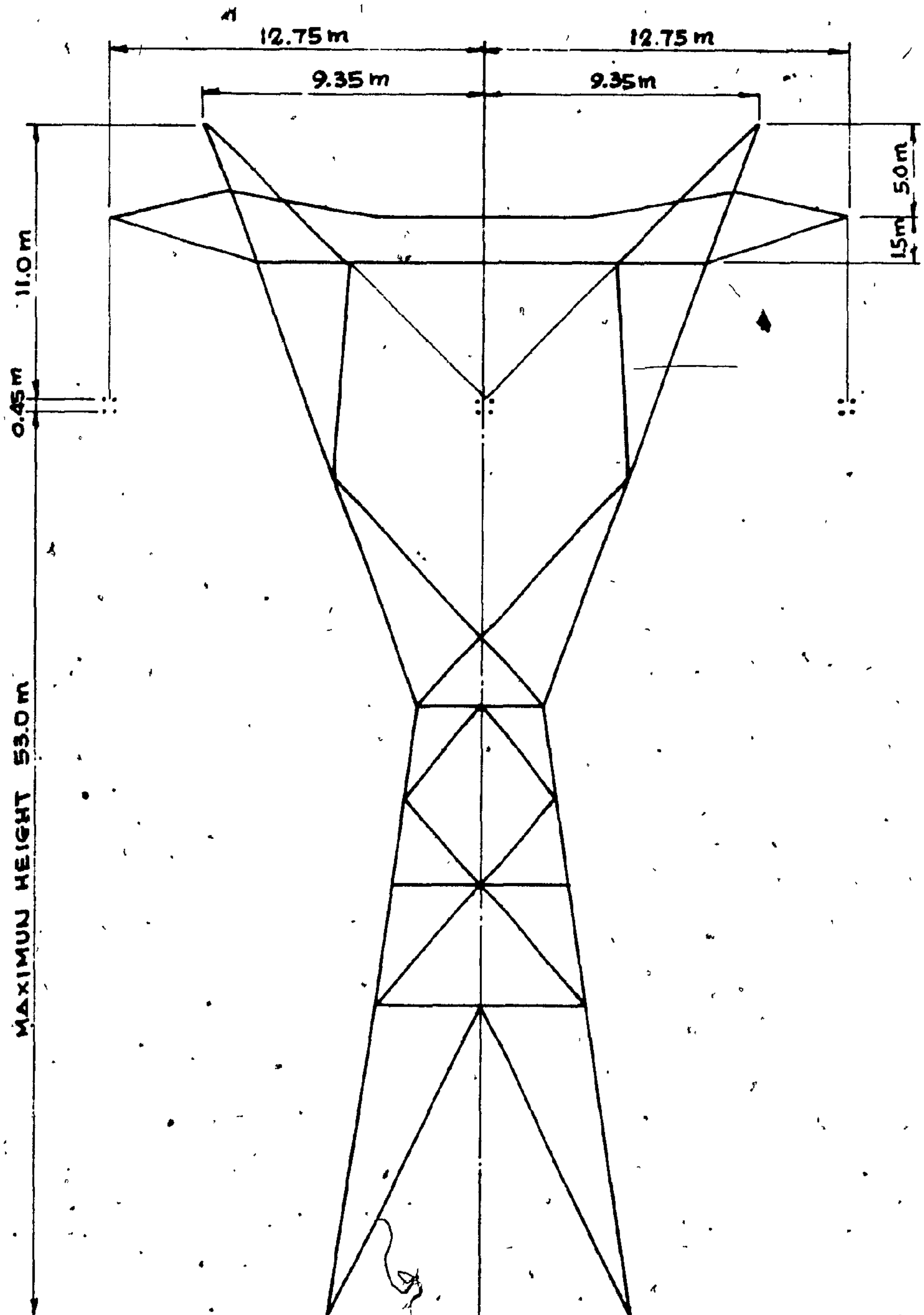
Construction and live-line maintenance are easier for the chainette tower than for the guyed-V or the self-supporting, due to its simple structure, the reduced number of the components and its light weight.

The validation program, made on an experimental line built by Hydro-Quebec, has clearly established that construction, operation and maintenance of chainette towers on a 735kV transmission line are not only feasible but also offer advantages over alternatives.

The cost analysis of the self-supporting versus the guyed towers (included in this report) and the analysis of the guyed versus chainette towers taken from reference [1], show that a line built with guyed towers is 11% less expensive than the self-supporting; and the chainette is 5% less expensive than the guyed towers.

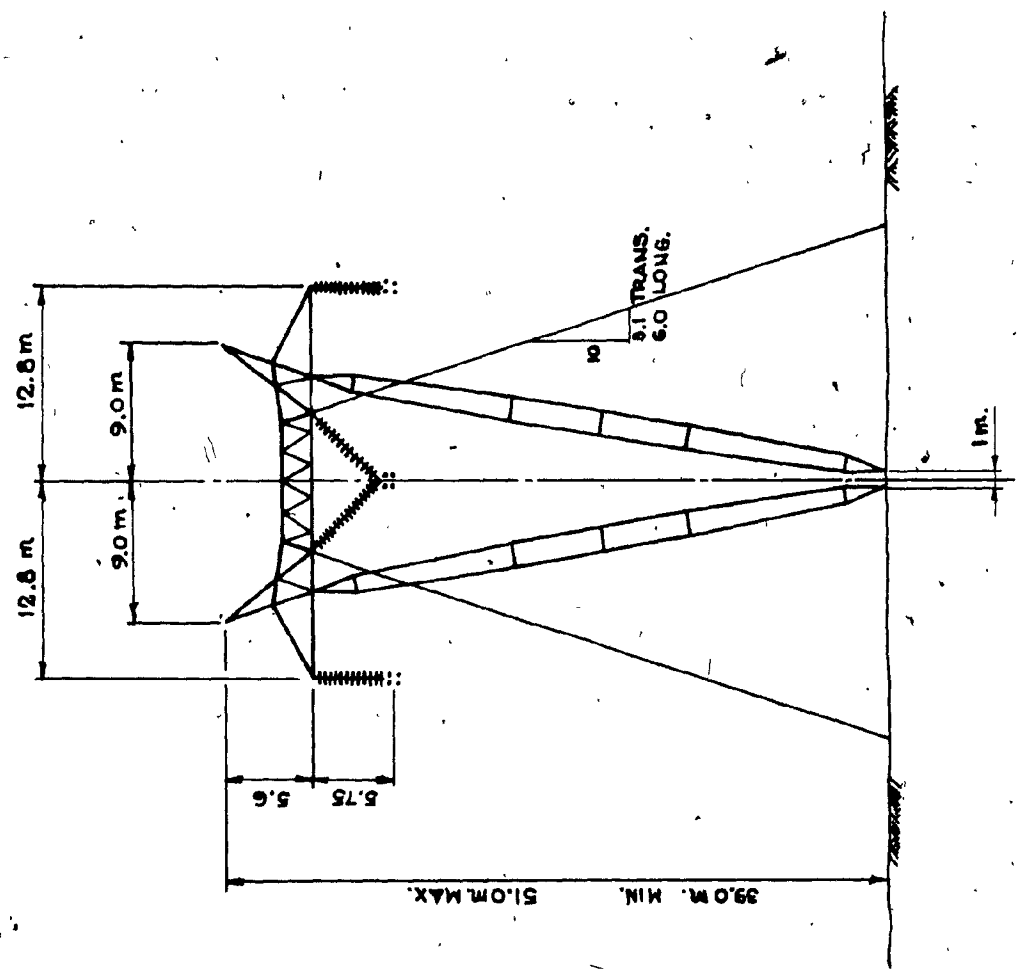
This report also shows that when an angle tower (45° or greater) is needed in the line, a rigid angle tower is less expensive than a guyed angle. The main reason being that the guyed angle tower has more insulators (the conductors are suspended on the rigid angle tower while they are dead-ended on the guyed angle). Therefore, one may conclude that when designing for the most economic transmission line, guyed or chainette should be used as suspension towers and self-supporting should be used for angle (greater than 45°) or dead-end towers.

The guyed-V as a tangent tower and the guyed mast as an angle or dead-end tower was used in the comparative study. When doing a complete cost study of the most economical type of tower to be used for a specific line, one should take into consideration other types of tower. For example, the guyed-Y tower, which is widely used in Ontario and the United States should be taken into account.



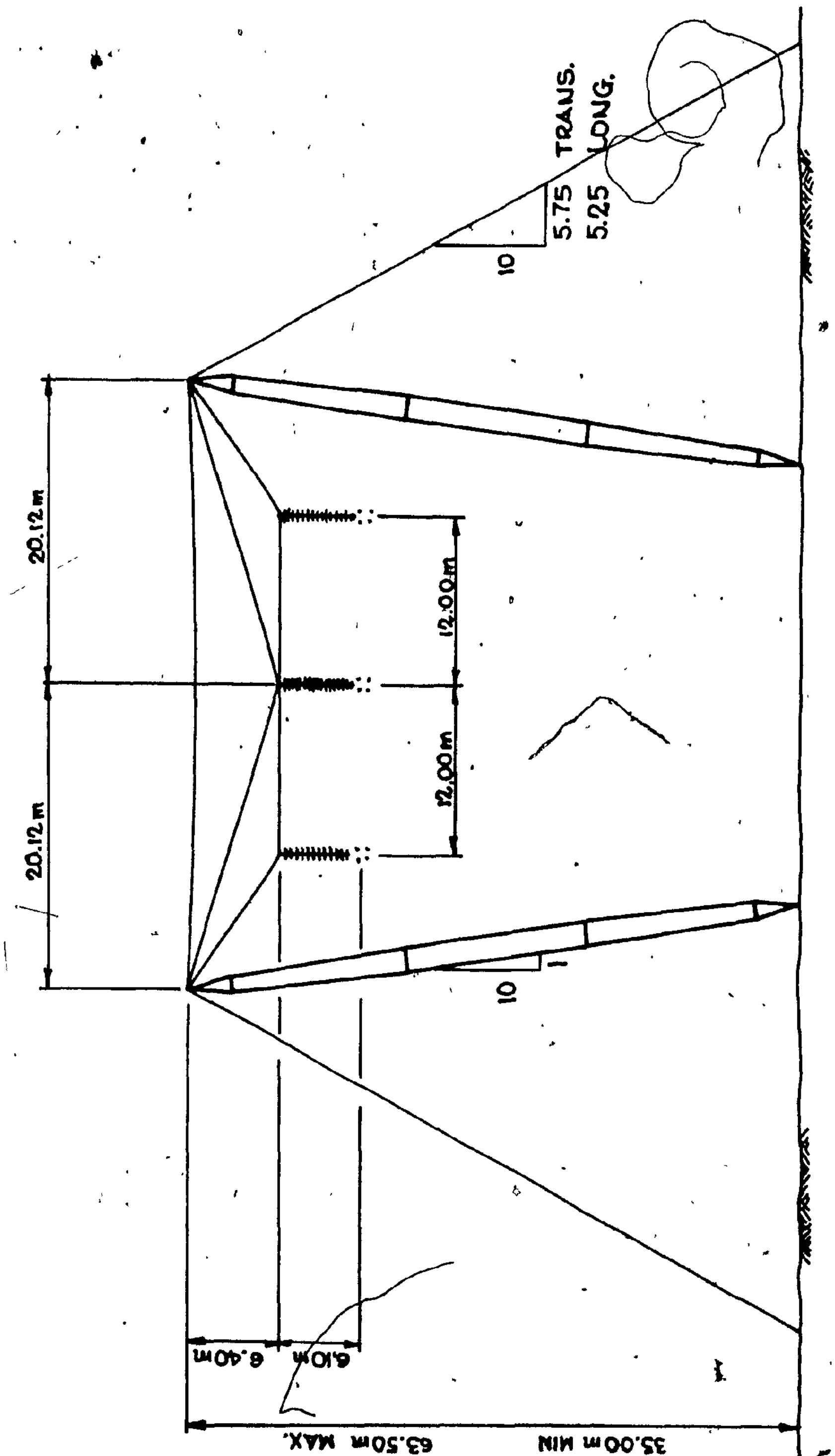
SELF-SUPPORTING TOWER

FIG. 2



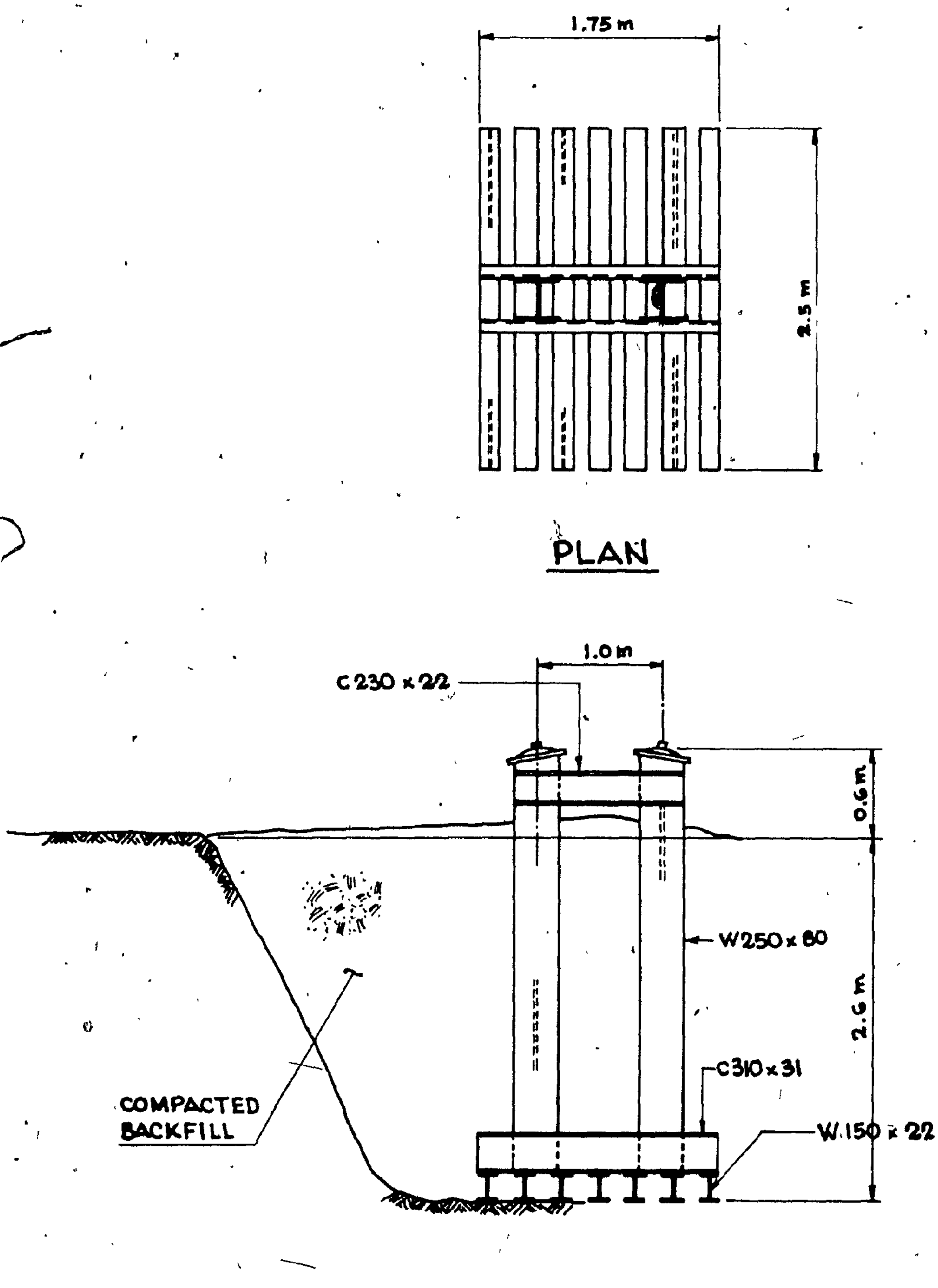
GUYED-V TOWER

FIG. 3



CHAINETTE TOWER

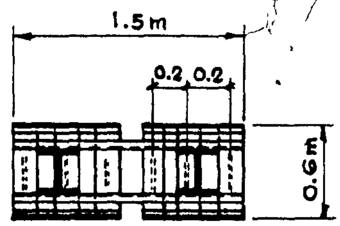
FIG. 4



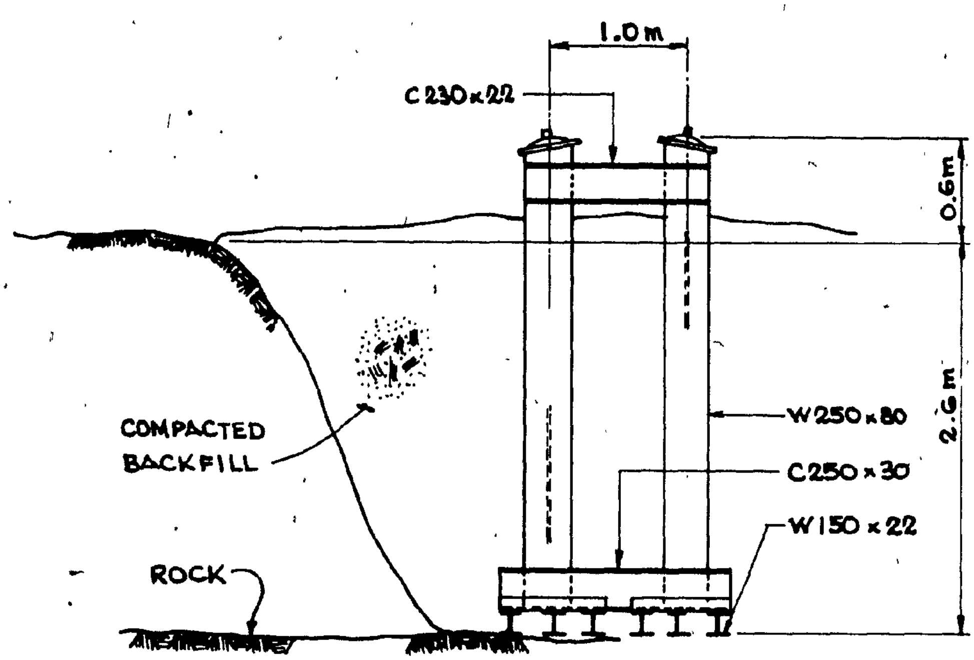
ELEVATION

OVERBURDEN FOUNDATION FOR GUYED-V TOWER

FIG. 5



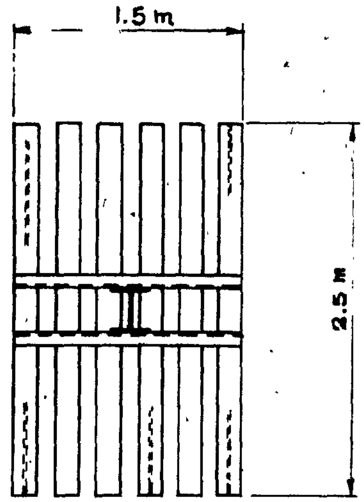
PLAN



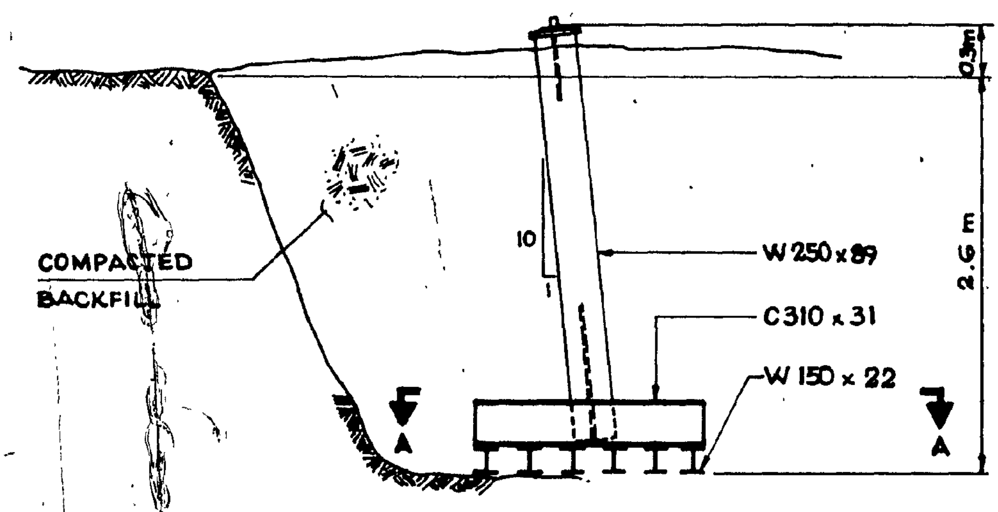
ELEVATION

ROCK FOUNDATION FOR GUYED-V TOWER

FIG. 6



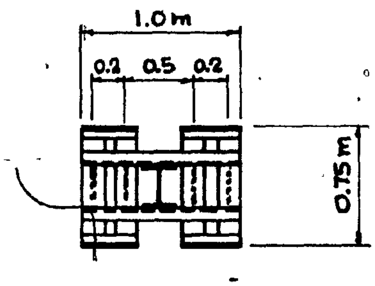
SECTION A-A



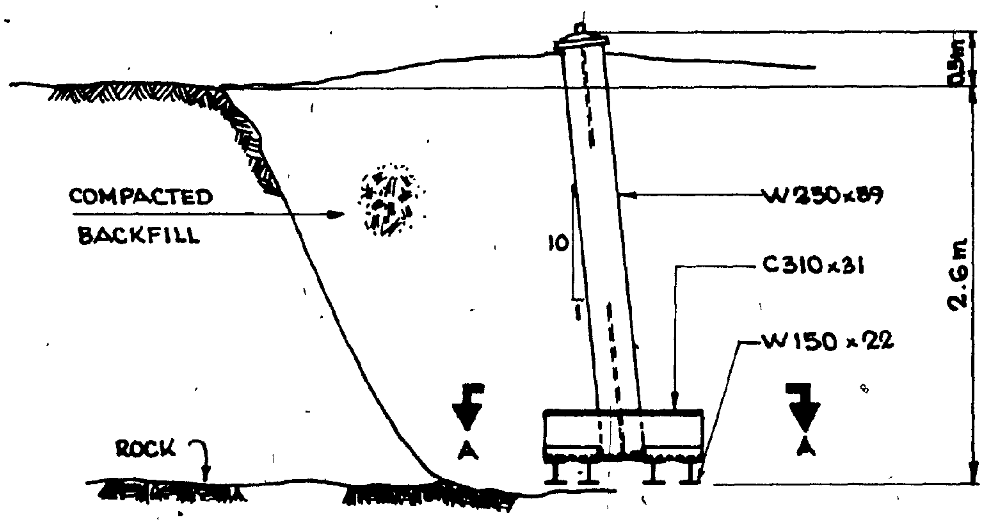
ELEVATION

OVERBURDEN FOUNDATION FOR CHAINETTE TOWER

FIG. 7



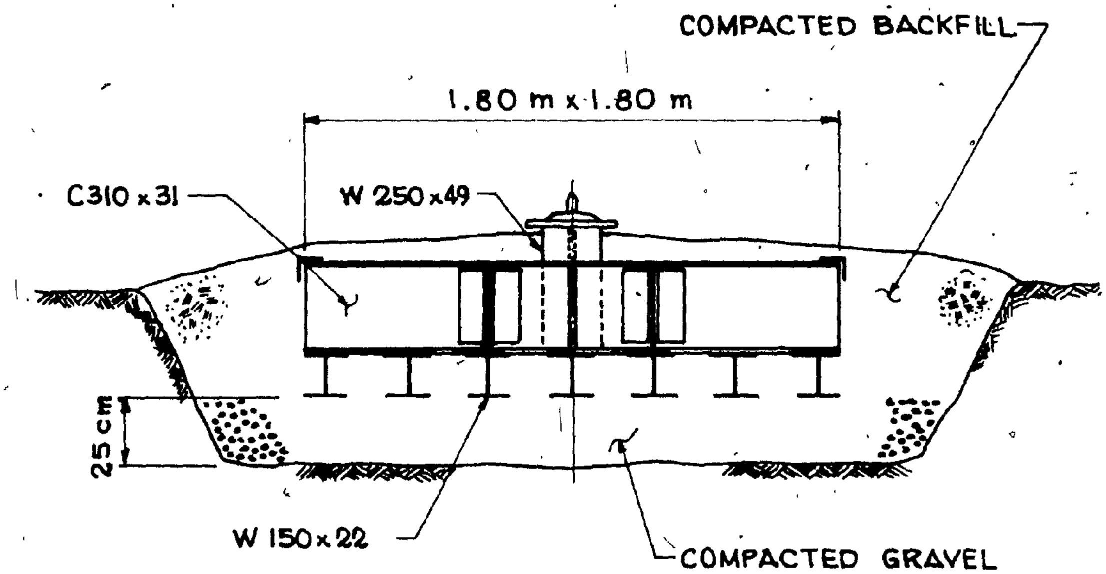
SECTION A-A



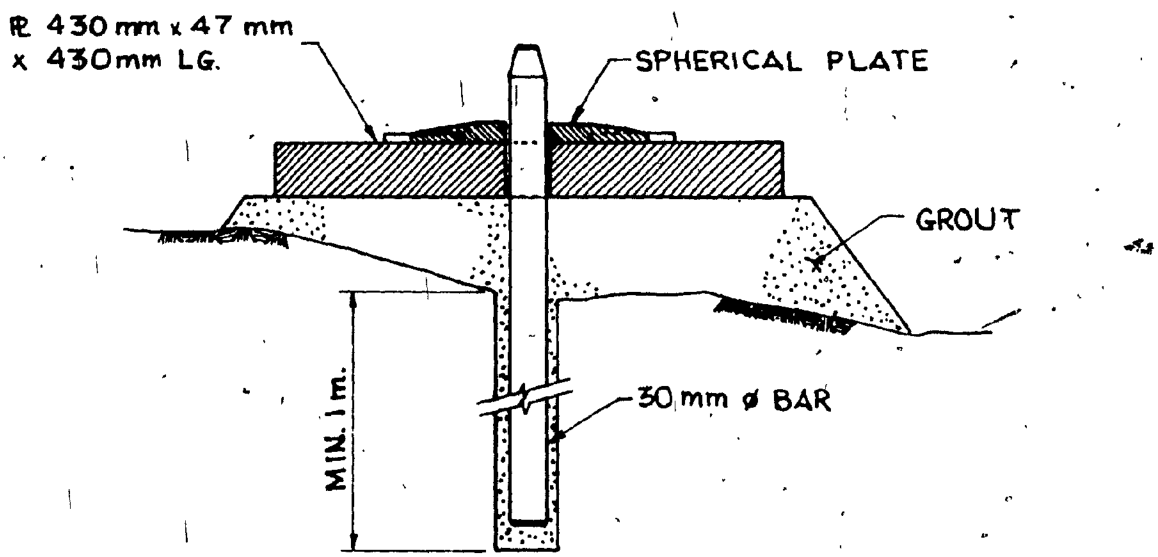
ELEVATION

ROCK FOUNDATION FOR CHAINETTE TOWER

FIG. 8



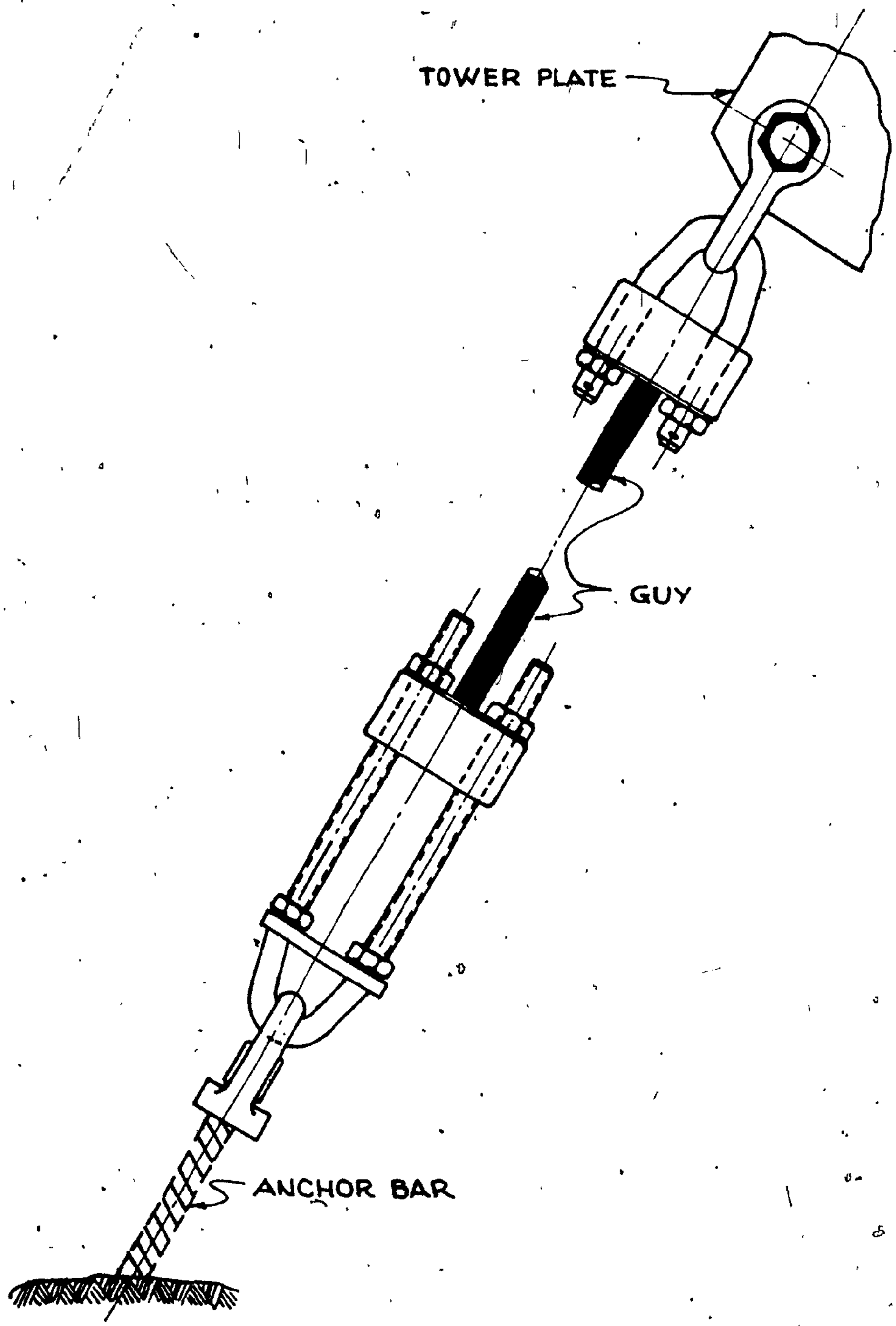
OVERBURDEN



ROCK

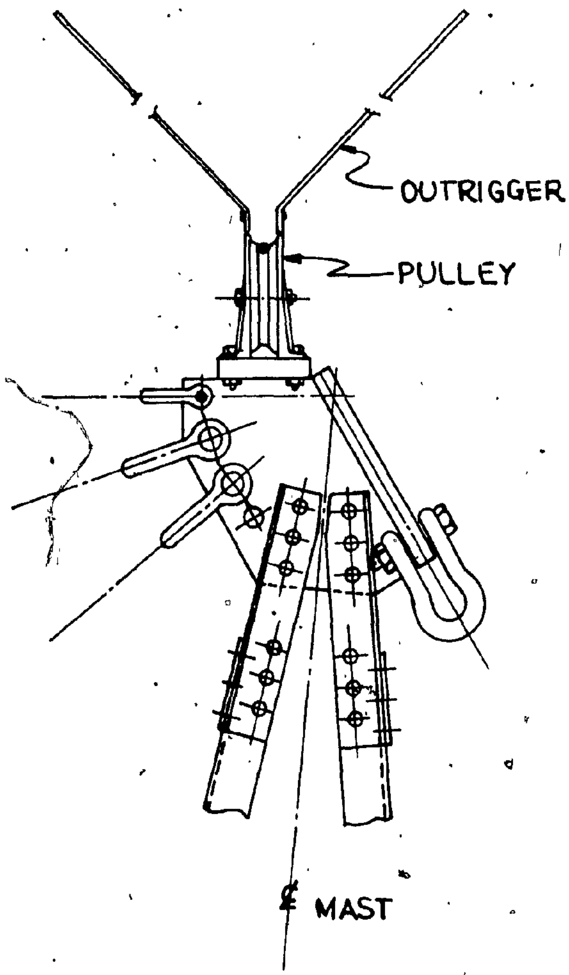
SURFACE TYPE - FOUNDATIONS FOR CHAINETTE TOWER

FIG. 9

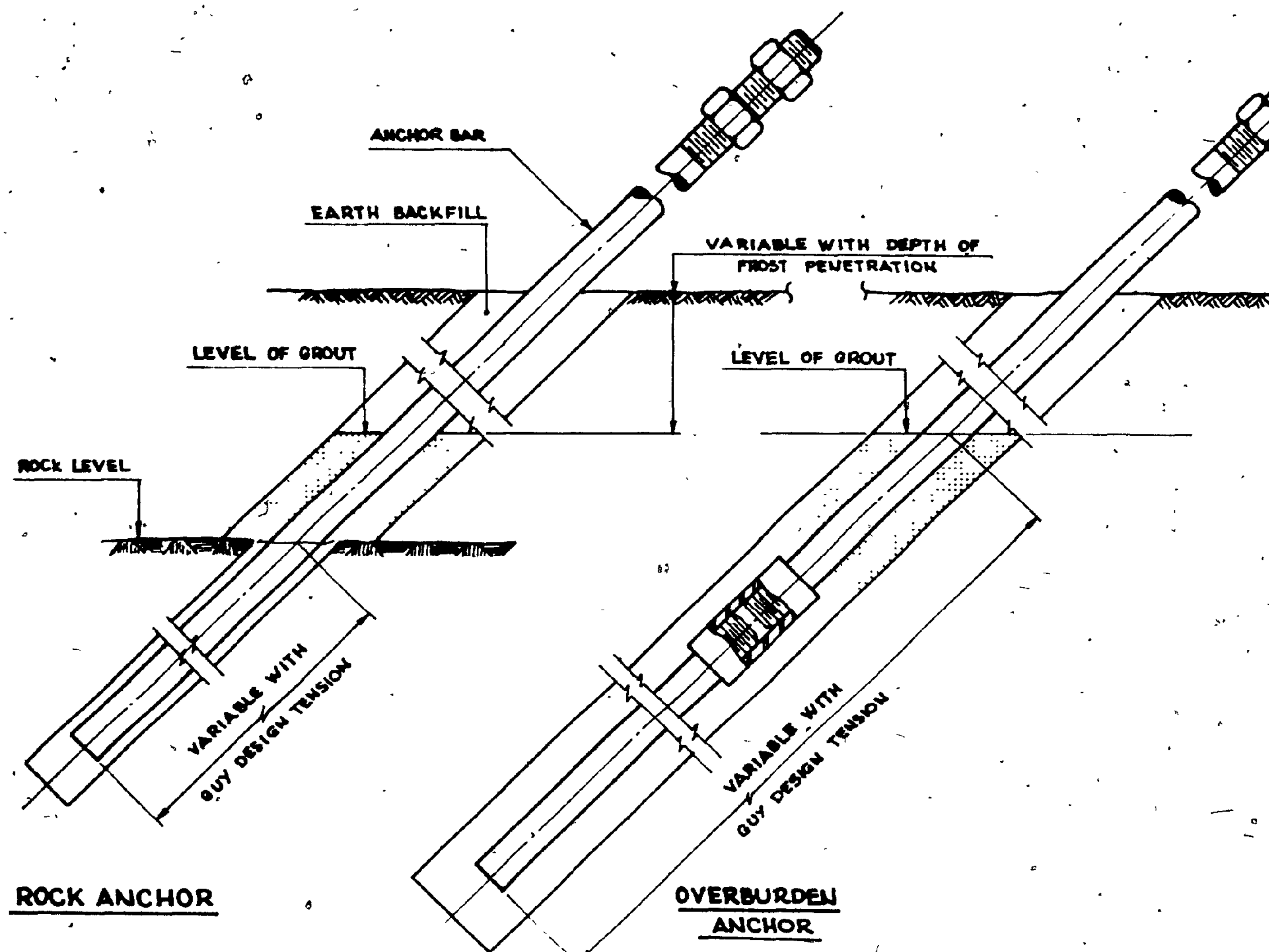


CONNECTION DETAIL FOR GUY

FIG. 10



CONNECTION DETAIL FOR THE CHAINETTE ROPES
FIG. 11



DETAIL OF ANCHOR BAR FOR GUYS

FIG. 12

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