REFERENCES

[1] Sri Lanka Telecom, Specification for OSP Material, Document No: MTID SPE 001, May 2009, Issued No: 03

[2] SLS 363:1975, Specification for Reinforced Concrete Poles for telecommunication lines, Sri Lanka Standards Institute

[3] BS 607: Part 2:1970, Specification for Concrete Poles for Electrical Transmission and Traction Systems.

[4] Precast/Pre-Stressed Concrete Institute, PCI Journal, Vol.42, No.06, November/December 1997, pp 101-120.

[5] BS 8110: 1997, Structural use of concrete - Part 1, 2 and 3

[6] BS 5328: 1997, Guide to specifying concrete - Part 1, 2 and 3

[7] Hurst, M.K., Pre-Stressed Concrete Design published in 1998 by E & FN Spon, an imprint of Routledge, 11 New Fetter Lane, London EC4P 4EE, Second edition, pp 6-75.

[8] Gilbert, R.L., and Mickleborough, N.C., Design of Pre-Stressed concrete.

[9] Ashraf M. Shalaby, Fouad H. Fouad, and Ronald Albanese, Strength and deflection behaviour of spun concrete poles with CFRP reinforcement.

[10] Guidelines on Documentation and Submission of theses and Dissertations by the University of Moratuwa, Sri Lanka

[11] SAP2000 software programme version 17 and documentation

[12] BS 12: 1996, Specification for Portland cement

[13] BS 5328: 1997 - Part 2, Methods for specifying concrete mixes

[14] Senaka Zenn (Pvt) Ltd., Report on load testing of 7.5 m length pre-stressed concrete spun cast circular type poles on 21st of October, 2014.

[15] ASTM, “Specification for general requirements for Pre-stressed concrete poles statically cast,” ASTM C 935-90,V.4.05,Americal Society for Testing and Materials,Philadelphia,PA,1992.

[16] ASTM, ”Standards Specification for spun cast pre-stressed concrete poles,” ASTM C 1089-88, V.4.05, American Society for Testing and Materials, Philadelphia, PA, 1992.

[17] Lin, T.Y., and Burns, Ned H., Design of Pre-stressed Concrete Structures, Third edition, John Wiley & Sons, New York, NY, 1981.

[18] ASCE, Design of Guyed Electrical Transmission Structures (1997).

[19] ACI Committee 318, "Building code requirements for structural concrete (ACI 318-95)," American concrete Institute, Farmington Hills, MI, 1995.

[20] Terrasi, G.P., and J.M.Lees, 2003, CFRP pre-stressed concrete lighting columns. In Filed applications of FRP reinforcement: Case studies, pp 55-74. Farmington Hills, MI: American Concrete Institute (ACI).

[21] AASHTO. "Standards specifications for structural supports for Highway Signs, Luminaires and Traffic Signals," AASHTO Subcommittee on Bridges and American Association of State Highway and Transportation Officials, Washington, D.C., 1994, 78pp.

[22] ACI Committee 318. "Building Code Requirements for Structural Concrete (ACI 318-95), "American Concrete Institute, Farmington Hills, MI, 1995.

[23] ANSI, C2 National Electrical Safety Code, 1990 Edition, American National Standards Institute, New York, NY, 1990.

[24] ASCE, "Guide of the Design and Use of Concrete Poles," prepared by Concrete Pole Task Committee, American Society of Civil Engineers, New York, NY, 1987,52pp.

[25] ASCE, Guidelines for Electrical Transmission Line Structural Loading, ASCE Manual No.74, American Society of Civil Engineers, New York, NY, 1991.

[26] ASCE, "Minimum Design Loads for Buildings and Other Structures," ASCE Standard 7-88 American Society of Civil Engineers, New York, NY, 1995.

[27] ASTM, " Specification for General requirements for Pre-Stressed Concrete Poles Statically Cast," ASTM C 935-90, V.4.05, American Society for Testing and Materials, Philadelphia, PA, 1992.

[28] ASTM, "Standards Specification for Spun Cast Pre-Stressed Concrete Poles," ASTM C 1089-88, V.4.05, American Society for Testing and Materials, Philadelphia, PA, 1992.

[29] Fouad, F. H. & Mullinax, Edward C., "Spun Concrete Distribution Poles An Alternative". Transmission & Distribution, Vol. 44, P. 52-58 (April 1992).

[30] Thomas E. Rodgers, Jr. "Pre-stressed Concrete Poles: State-of-the-Art". PCI Journal, Vol. 29, P. 52-103 (1984).

[31] ASCE Task Force/PCI Committee on Concrete Poles & PCI Committee on Pre-stressed Concrete Poles. "Guide for the Design of Pre-stressed Concrete Poles". PCI Journal No. 42, P. 94-134 (1997).

[32] Dilger, W. H., Ghali, A. & Rao, S. V. Krishna Mohan. “Improving the Durability and Performance of Spun-Cast Concrete Poles”. PCI Journal Vol. 41, (1996).

[33] BS 1881-207:1992, Testing concrete

[34] BS 5896:1980, Specification for high tensile steel wire and strand for the pre-stressing of concrete.

[35] BS 4449:1997, Specification for carbon steel bars for the reinforcement of concrete.

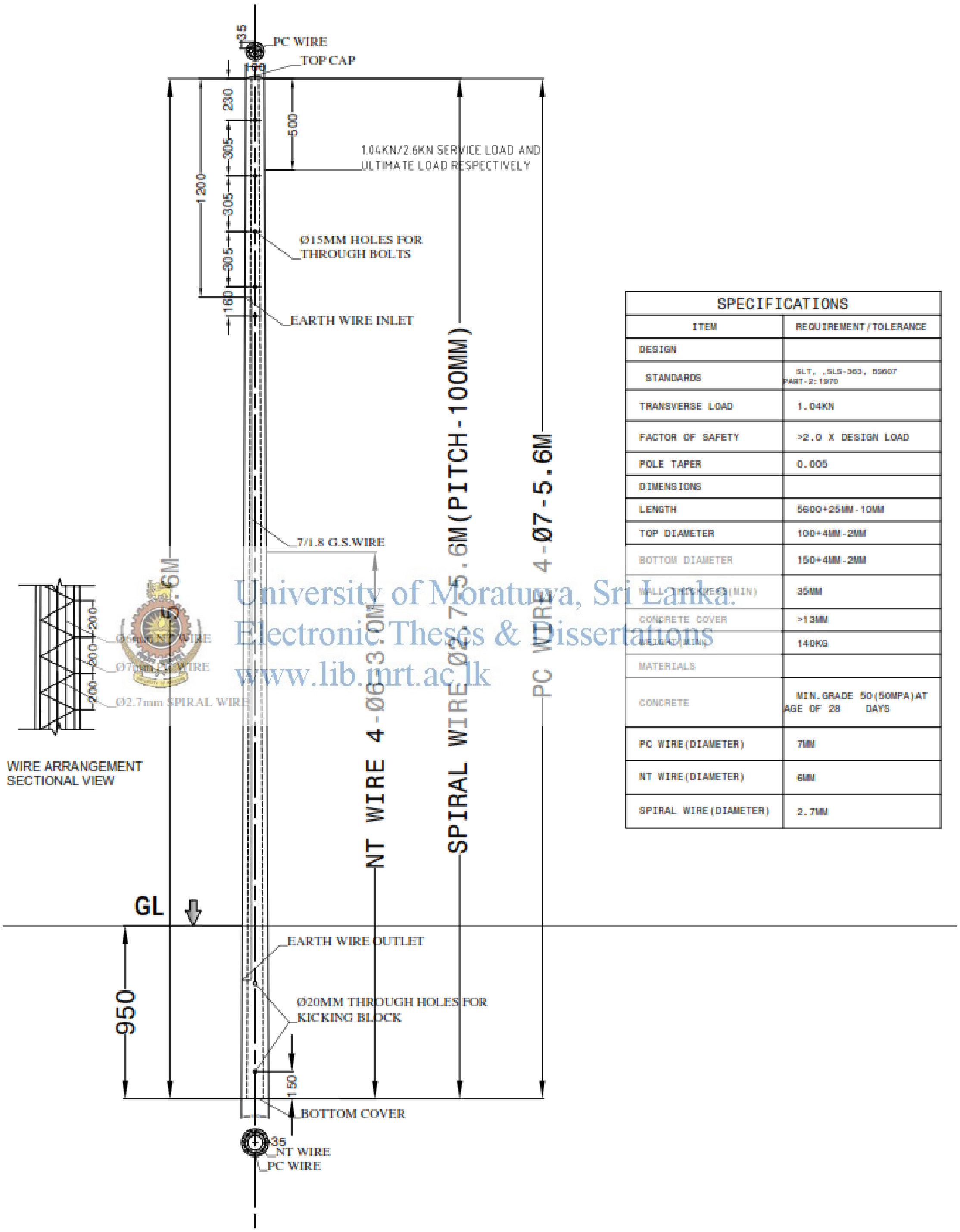
[36] BS 4466:1989, Specification for scheduling, dimensioning, bending and cutting of steel reinforcement for concrete.

[37] BS 4482:1985, Specification for cold reduced steel wire for the reinforcement of concrete.

[38] EIA, “Structural Standards for Steel Antenna Towers and Antenna Supporting Structures, “Electronic Industries Association, EIA/TIA-22-E, 1984.

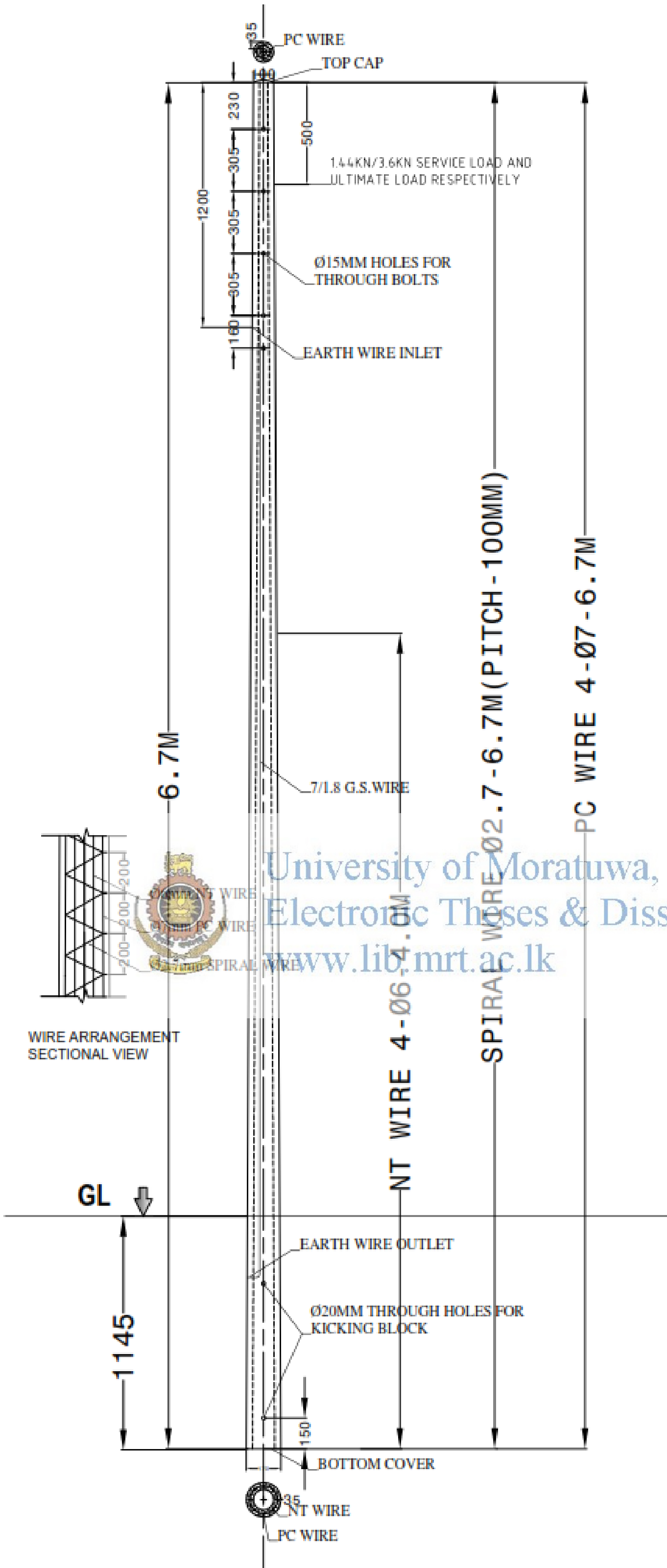
APPENDIXES

APPENDIX – A: Structural drawings of proposed pre-stressed concrete poles



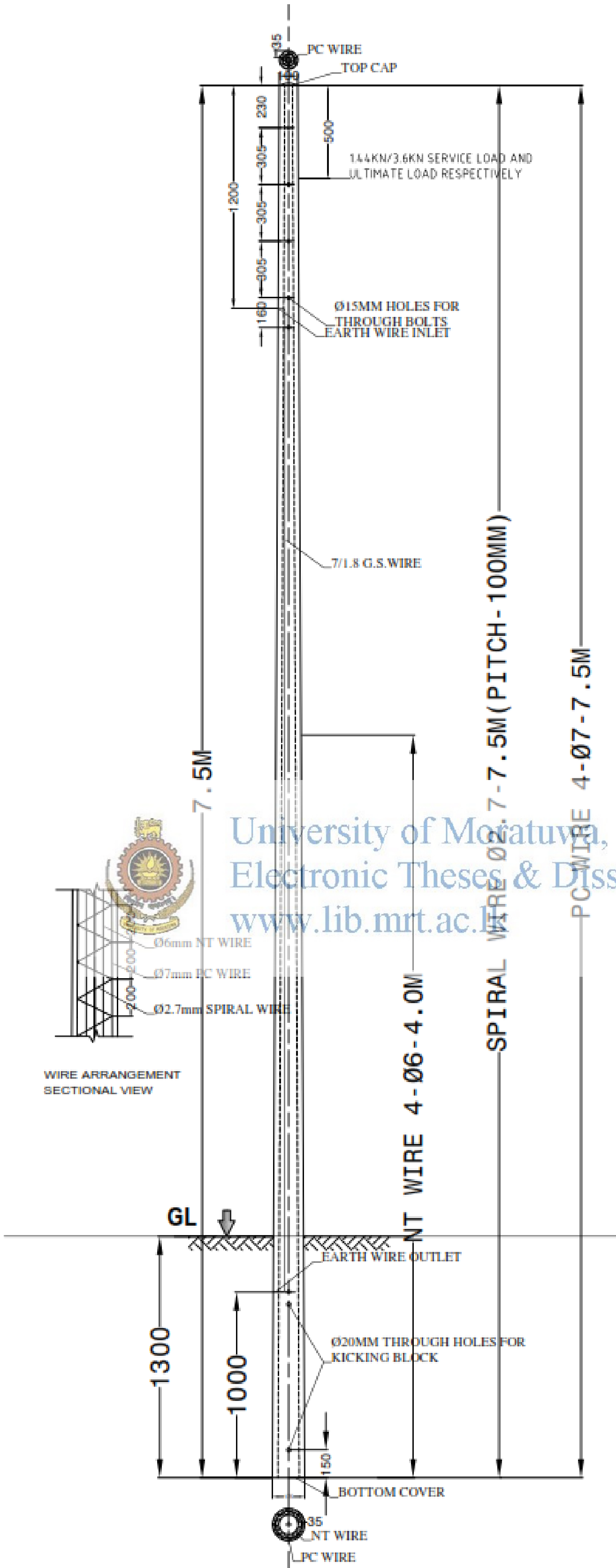
SPECIFICATIONS	
ITEM	REQUIREMENT/TOLERANCE
DESIGN	
STANDARDS	SLT, ,SLS-363, BS607 PART-2:1970
TRANSVERSE LOAD	1.04KN
FACTOR OF SAFETY	>2.0 X DESIGN LOAD
POLE TAPER	0.005
DIMENSIONS	
LENGTH	5600+25MM-10MM
TOP DIAMETER	100+4MM-2MM
BOTTOM DIAMETER	150+4MM-2MM
WALL THICKNESS(MIN)	35MM
CONCRETE COVER	>13MM
WEIGHT(MIN)	140KG
MATERIALS	
CONCRETE	MIN.GRADE 50(50MPA)AT AGE OF 28 DAYS
PC WIRE(DIAMETER)	7MM
NT WIRE(DIAMETER)	6MM
SPIRAL WIRE(DIAMETER)	2.7MM

PROPOSED DETAILS FOR THE
5.6M/140KG PRE-STRESSED SPUN CAST CONCRETE POLE



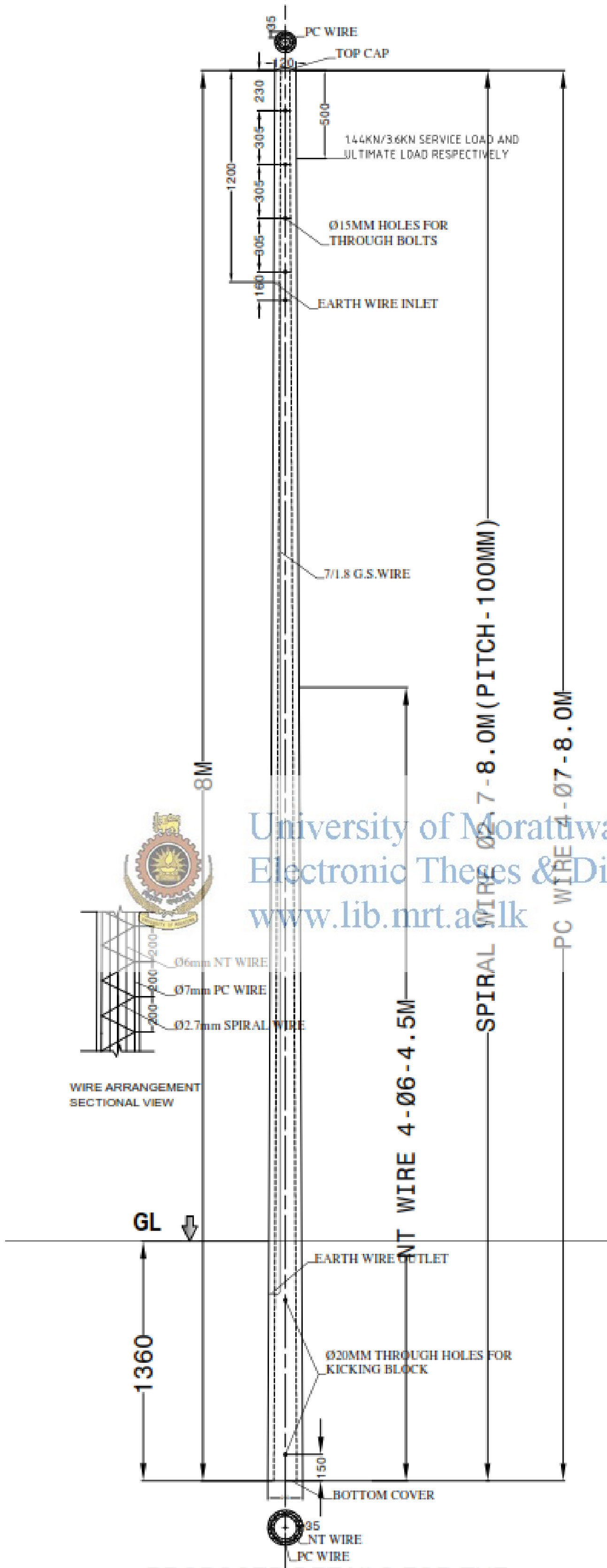
SPECIFICATIONS	
ITEM	REQUIREMENT/TOLERANCE
DESIGN	
STANDARDS	SLT, ,SLS-363, BS607 PART-2:1970
TRANSVERSE LOAD	1.44KN
FACTOR OF SAFETY	>2.0 X DESIGN LOAD
POLE TAPER	0.005
DIMENSIONS	
LENGTH	6700+25MM-10MM
TOP DIAMETER	100+4MM-2MM
BOTTOM DIAMETER	170+4MM-2MM
WALL THICKNESS(MIN)	35MM
CONCRETE COVER	>13MM
WEIGHT(MIN)	184KG
MATERIALS	
CONCRETE	MIN.GRADE 50(50MPA)AT AGE OF 28 DAYS
PC WIRE(DIAMETER)	7MM
NT WIRE(DIAMETER)	6MM
SPIRAL WIRE(DIAMETER)	2.7MM

PROPOSED DETAILS FOR THE
6.7M/184KG PRE-STRESSED SPUN CAST CONCRETE POLE



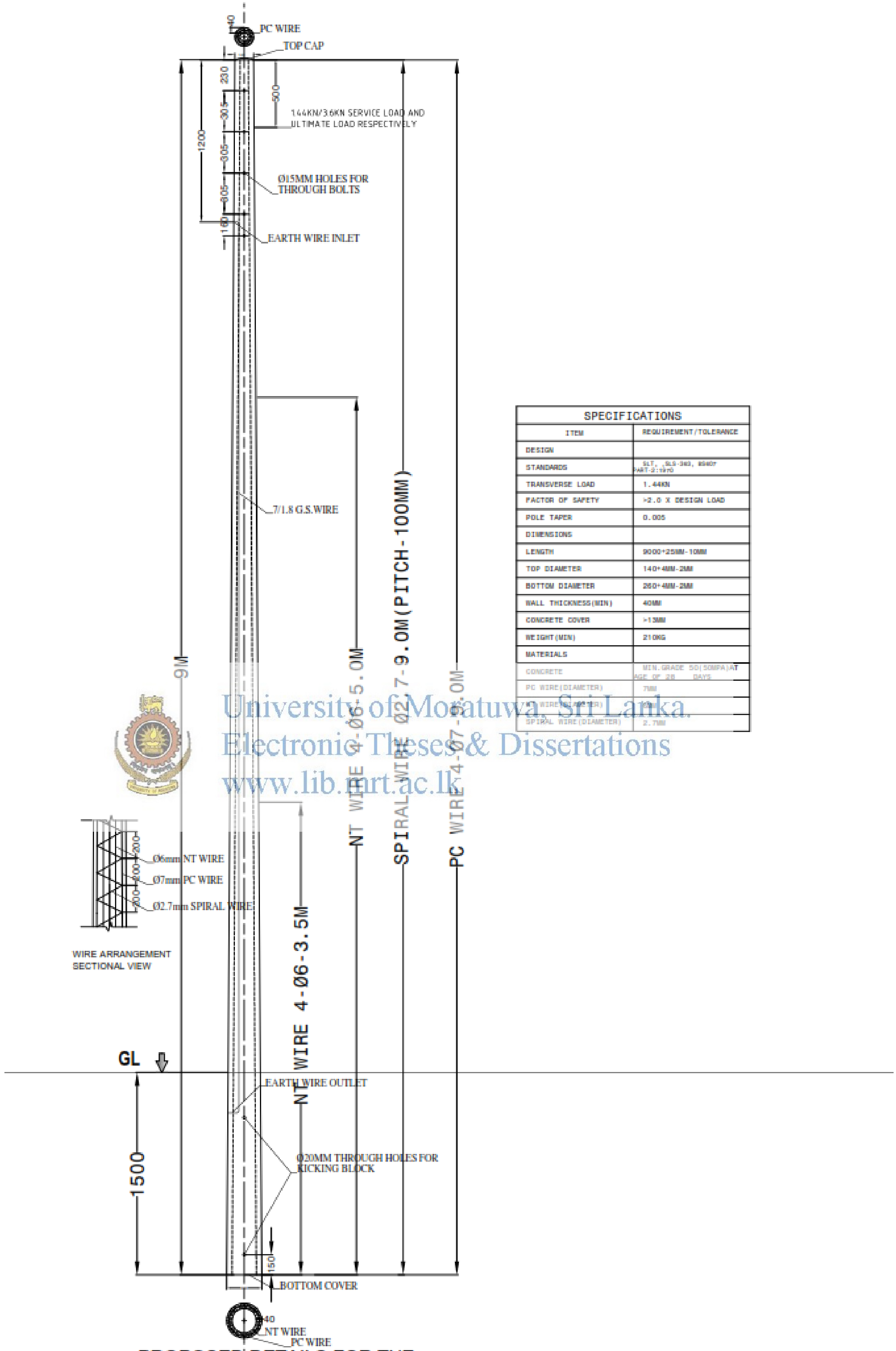
SPECIFICATIONS	
ITEM	REQUIREMENT/TOLERANCE
DESIGN	
STANDARDS	SLT, ,SLS-363, BS607 PART-2:1970
TRANSVERSE LOAD	1.44KN
FACTOR OF SAFETY	>2.0 X DESIGN LOAD
POLE TAPER	0.005
DIMENSIONS	
LENGTH	7500+25MM-10MM
TOP DIAMETER	100+4MM-2MM
BOTTOM DIAMETER	175+4MM-2MM
WALL THICKNESS(MIN)	35MM
CONCRETE COVER	>13MM
WEIGHT(MIN)	210KG
MATERIALS	
CONCRETE	MIN.GRADE 50(50MPA)AT AGE OF 28 DAYS
PC WIRE(DIAMETER)	7MM
NT WIRE(DIAMETER)	6MM
SPIRAL WIRE(DIAMETER)	2.7MM

PROPOSED DETAILS FOR THE
7.5M/210KG PRE-STRESSED SPUN CAST CONCRETE POLE



SPECIFICATIONS	
ITEM	REQUIREMENT/TOLERANCE
DESIGN	
STANDARDS	SLT, ,SLS-363, BS607 PART-2:1970
TRANSVERSE LOAD	1.44KN
FACTOR OF SAFETY	>2.0 X DESIGN LOAD
POLE TAPER	0.005
DIMENSIONS	
LENGTH	8000+25MM-10MM
TOP DIAMETER	120+4MM-2MM
BOTTOM DIAMETER	200+4MM-2MM
WALL THICKNESS(MIN)	35MM
CONCRETE COVER	>13MM
WEIGHT(MIN)	305KG
MATERIALS	
CONCRETE	MIN.GRADE 50(50MPA)AT AGE OF 28 DAYS
PC WIRE(DIAMETER)	7MM
NT WIRE(DIAMETER)	6MM
SPIRAL WIRE(DIAMETER)	2.7MM

PROPOSED DETAILS FOR THE
8.0M/305KG PRE-STRESSED SPUN CAST CONCRETE POLE

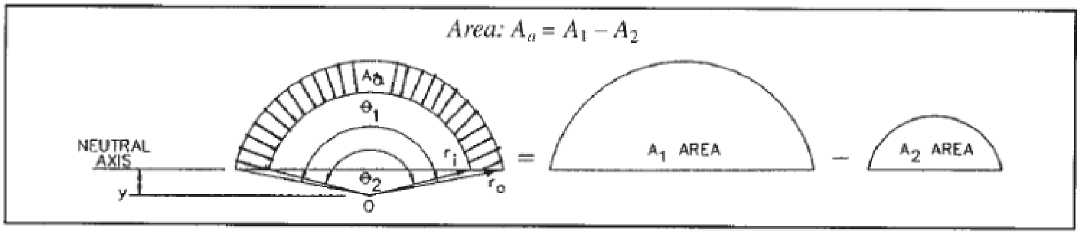


SPECIFICATIONS	
ITEM	REQUIREMENT/TOLERANCE
DESIGN	
STANDARDS	SLT, SLS-363, BS607 PART-2:1970
TRANSVERSE LOAD	1.44KN
FACTOR OF SAFETY	>2.0 X DESIGN LOAD
POLE TAPER	0.005
DIMENSIONS	
LENGTH	9000+25MM-10MM
TOP DIAMETER	140+4MM-2MM
BOTTOM DIAMETER	260+4MM-2MM
WALL THICKNESS(MIN)	40MM
CONCRETE COVER	>13MM
WEIGHT(MIN)	210KG
MATERIALS	
CONCRETE	MIN.GRADE 50(50MPA)AT AGE OF 28 DAYS
PC WIRE(DIAMETER)	7MM
NT WIRE(DIAMETER)	6MM
SPIRAL WIRE(DIAMETER)	2.7MM

PROPOSED DETAILS FOR THE
9.0M/502KG PRE-STRESSED SPUN CAST CONCRETE POLE

APPENDIX – B: Area and centroid of annulus [4]

AREA AND CENTROID OF ANNULUS



Area of Annulus

1. Determination of A_1 area.
Consider S, half of the area A_1:

$$r_o^2 = x^2 + y^2, \text{ hence } y = \sqrt{r_o^2 - x^2}$$

$$S = \int_d^{r_o} dA = \int_d^{r_o} y\,dx = \int_d^{r_o} \sqrt{r_o^2 - x^2}\,dx$$

Let: $x = r_o\cos\phi$ and $dx = (-r_o\sin\phi)d\phi$
Therefore:

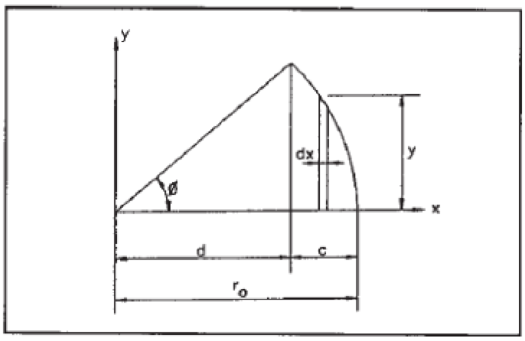
$$S = -\int_\phi^\alpha \sqrt{r_o^2 - r_o^2\cos^2\phi}\,(r_o\sin\phi)d\phi$$

$$= -\int_\phi^\alpha r_o^2 \sin\phi\sin\phi\,d\phi$$

$$= -r_o^2\int_\phi^\alpha \sin^2\phi\,d\phi$$

$$= -r_o^2\left(\frac{\phi}{2} - \frac{\sin^2\phi}{4}\right)^\alpha$$

$$A_1 = \frac{r_o^2}{2}(2\phi - \sin 2\phi) \text{ or } A_1 = \frac{r_o^2}{2}(\Theta_1 - \sin\Theta_1)$$



in which the central angle $\Theta_1 = 2\phi$:

$$\Theta_1/2 = \tan^{-1}\left(\sqrt{r_o^2 - y^2}/y\right)$$

2. Determination of A_2 area.

$$A_2 = \frac{r_i^2}{2}(\Theta_2 - \sin\Theta_2)$$

with radius r_i and central angle Θ_2:

$$\Theta_2/2 = \tan^{-1}\left(\sqrt{r_i^2 - y^2}/y\right)$$

Centroid of Annulus

The centroid of the annulus is the point of intersection of two axes which place the body in equilibrium. Axis 1 bisects the area of the annulus and Axis 2 divides the annulus into two equal areas.

Area of annulus:

$$A_a = \tfrac{1}{2}r_o^2(\Theta_1 - \sin\Theta_1) - \tfrac{1}{2}r_i^2(\Theta_2 - \sin\Theta_2)$$

where

$$\Theta_1/2 = \tan^{-1}\left(\sqrt{r_o^2 - y^2}/y\right)$$

and

$$\Theta_2/2 = \tan^{-1}\left(\sqrt{r_i^2 - y^2}/y\right)$$

Area above Axis 2:

$$A'_a = \tfrac{1}{2}r_o^2(\Theta_3 - \sin\Theta_3) - \tfrac{1}{2}r_i^2(\Theta_4 - \sin\Theta_4)$$

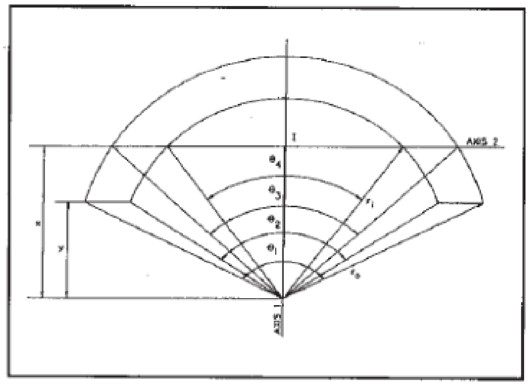
where

$$\Theta_3/2 = \tan^{-1}\left(\sqrt{r_o^2 - x^2}/x\right)$$

and

$$\Theta_4 = \tan^{-1}\left(\sqrt{r_i^2 - x^2}/x\right)$$

Since y is known, x is found by trial and error until $A'_a = \tfrac{1}{2}A_a$.



APPENDIX – C: Characteristic of pre-stressing steel [4]

Galvanized stress relieved strand

Nominal strand diameter mm	Nominal strand diameter in.	Grade MPa	Grade ksi	Minimum breaking load kN	Minimum breaking load lbs	Minimum load at 1 percent extension kN	Minimum load at 1 percent extension lbs	Nominal steel area* mm²	Nominal steel area* sq in.
9.53	3/8	1725	250	94.5	21,250	75.6	17,000	54.84	0.085
11.11	7/16	1725	250	127.7	28,700	102.1	22,950	74.19	0.115
12.70	1/2	1725	250	169.9	38,200	136.1	30,000	98.71	0.153
12.70	1/2	1860	270	183.7	41,300	156.1	35,100	98.71	0.153

* Steel area prior to galvanizing.

Uncoated stress relieved strand ASTM A416

Nominal strand diameter mm	Nominal strand diameter in.	Grade MPa	Grade ksi	Minimum breaking load kN	Minimum breaking load lbs	Minimum load at 1 percent extension: Normal relaxation kN	Normal relaxation lbs	Low relaxation kN	Low relaxation lbs	Nominal steel area mm²	Nominal steel area sq in.
7.94	5/16	1725	250	64.5	14,000	54.7	12,300	58.1	13,050	37.42	0.058
7.94	5/16	1860	270	71.2	16,000	60.5	13,600	64.1	14,400	38.06	0.059
9.53	3/8	1860	270	102.3	23,000	87.0	19,550	92.1	20,700	54.84	0.085
11.11	7/16	1860	270	137.9	31,000	117.2	26,350	124.1	27,900	74.19	0.115
12.70	1/2	1860	270	183.7	41,300	156.1	35,100	165.3	37,170	98.71	0.153
15.24	0.6	1860	270	260.7	58,600	221.5	49,800	234.6	52,740	140.00	0.217

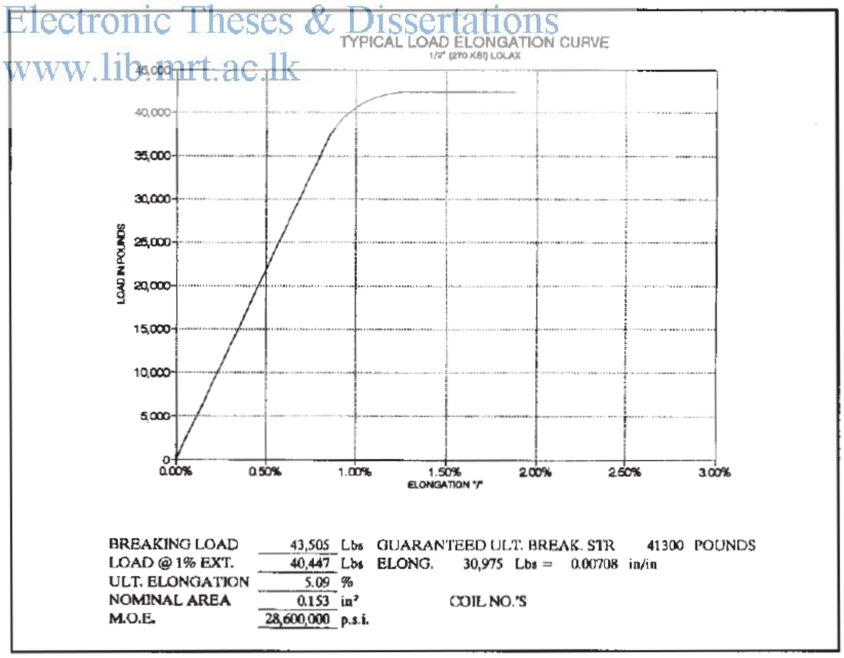
Uncoated stress relieved wire ASTM A421

Nominal wire diameter mm	Nominal wire diameter in.	Grade MPa	Grade ksi	Minimum breaking load kN	Minimum breaking load lbs	Minimum load at 1 percent extension kN	Minimum load at 1 percent extension lbs
5	0.196	1655	240	33.6	7550	28.6	6418
6.35	1/4	1655	240	52.4	11,780	44.5	10,013
7	0.276	1620	235	62.5	14,050	53.1	11,943

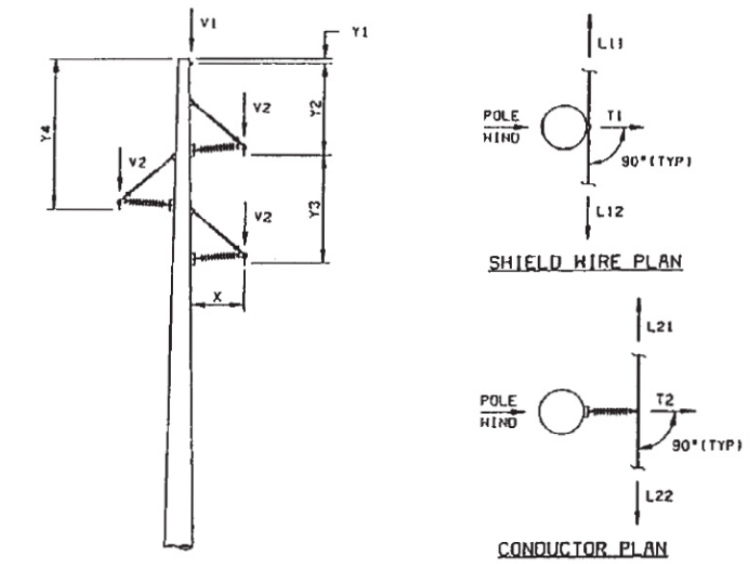
Table 3.2.2. Permissible stresses of prestressing steel.

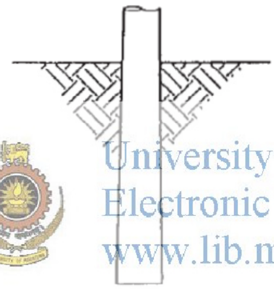
1	Due to jacking force but not greater than $0.80f_{pu}$ or maximum value recommended by manufacturer of prestressing steel or anchorages.	$0.94f_{py}$
2	Immediately after prestress transfer but not greater than $0.74f_{pu}$.	$0.82f_{py}$
3	Post-tensioning steel at anchorages and couplers immediately after anchorage.	$0.70f_{pu}$

Fig. 3.2.1. Load-elongation curve for 1/2 in. (12.7 mm) diameter stress-relieved seven-wire strand Grade 270.



APPENDIX – D: Typical load tree for concrete pole [4]





LOAD TABLE

LOAD DESCRIPTION	LOAD CASE 1	2	3	4	5
POLE WIND	0.036	0.023	0.026	0.000	0.009
TRANSVERSE LOAD - T1	0.51	0.33	[illegible]	0.08	0.15
VERTICAL LOAD - V1	[illegible]	0.25	[illegible]	0.50	0.17
LONGITUDINAL LOAD - L11	2.75	2.60	1.03	1.24	2.36
LONGITUDINAL LOAD - L12	2.75	2.60	1.03	1.44	2.36
TRANSVERSE LOAD - T2	1.42	0.86	0.86	0.04	0.38
VERTICAL LOAD - V2	0.51	0.69	0.46	2.80	0.46
LONGITUDINAL LOAD - L21	6.05	5.36	4.25	2.02	4.87
LONGITUDINAL LOAD - L22	6.05	5.36	4.25	2.02	4.87

CASE DESCRIPTION

CASE 1 - ASCE EXTREME WIND, VERTICAL OLF = 1.1
CASE 2 - NESC LIGHT, VERTICAL OLF = 1.50
CASE 3 - NESC EXTREME WIND, VERTICAL OLF = 1.0
CASE 4 - CONSTRUCTION LOAD, VERTICAL OLF = 1.0
CASE 5 - SPECIFIED CRACKING LOAD, VERTICAL OLF = 1.0

NOTES

1. WIRE LOADS ARE IN KIPS. POLE WIND IS IN KIPS PER SQUARE FOOT.
2. LOADS SHOWN INCLUDE OVERLOAD FACTORS.
3. EACH LOADING CASE SHALL BE CONSIDERED INDEPENDENTLY.

APPENDIX – E: Structural calculations for the 8m, 7.5m, 6.7m and 5.6m poles

8m high Pre-stressed Pole		
Analysis of critical section of the pole (at ground support position)		
r_1 (Radios of outer circle) =	100	mm
r_2 (Radios of inner circle) =	65	mm
Thickness of pole =	35.00	mm
Gross concrete area at base A_g	18,142.70	mm^2
Assume C= Neutral axis depth by trial and error	106.50	mm
β_1= Parameter to calculate rectangular concrete compressive stress block	0.69	
$\beta_1 C$ =	73.49	mm
f'_c = Concrete compressive strength	50.00	N/mm^2
$f_r=0.62\sqrt{f'_c}$ Modulus of rupture of concrete	4.38	N/mm^2
y_t = Distance from centroid axis to extreme tensile fibre	93.50	mm
I_g = Gross moment of inertia of the section	6.45E-05	m^4
Finding area of Annulus		
Φ_1 =	3.27	radians
Φ_2 =	3.34	radians
Area A_1 =	17,007.05	mm^2
Area A_2 =	7,480.20	mm^2
Therefore Annulus area $A_a = A_1 - A_2$	**9,526.84**	mm^2
Finding centroid of annulus A_a		
Assume distance to the centroid from the centre x=	15.00	mm
Φ_3 =	2.84	radians

Φ_4 =	2.68	radians
A'_a =	**8,015.19**	mm^2
Find the "x" so that $A_a \approx 2A'_a$		
Cross sectional area of Φ7mm strand A_{psi} =	38.48	mm^2
Number of strands	4	No's
Modulus of elasticity of pre-stressing steel E_s =	205.00	kN/mm^2
Modulus of elasticity of normal steel E_y =	200.00	kN/mm^2
Modulus of elasticity of concrete E_c =	31.75	kN/mm^2
f_{py} = Specified yield stress of pre-stressing steel	1620.00	N/mm^2
Total pre-stressing force per strand = F_{py}	62.34	kN
Minimum breaking load F_{pu} =	62.50	kN
Therefore permissible pre-stressing force per strand = lesser of $0.80f_{pu}$ and $0.94f_{py}$ (assume 10% loss due to relaxation)=	50.00	kN
Assessment of transmission length: $l_t = K_t\Phi/\sqrt{f_{ci}}$	593.97	mm
where K_t is a coefficient for tendons =	600.00	
Average diameter of the section	160.00	mm
Average cross sectional area of concrete	20106.19	mm^2
Exposed perimeter of the section	502.65	mm
Effective section thickness of concrete(under immersed conditions)	600.00	mm
Elastic deformation of concrete at the age of stress transfer	2.51	mm
Creep strain ε_{cc}=stress x ø/E_t	4.70E-04	
Therefore creep deformation of concrete	3.76	mm
where ø = creep coefficient	1.50	
E_t = Modulus of elasticity of concrete at the age of t = E_c		

Design as class 3 member with 0.1mm crack width at ultimate loading

For grade 50 concrete for limiting the crack width to 0.1mm

Design flexural stress for class 3 member f_r =	4.80	N/mm^2
Design compressive stress at extreme fibre should not exceed $0.5f_{ci}$		
where f_{ci} is the concrete strength at transfer		
$0.5\ f_{ci}$ =	25.00	N/mm^2
Concrete stresses due to effective pre-stresses = < $\lvert 0.5f_{ci} \rvert$	-11.02	N/mm^2
Concrete stresses due to bending: assume compression " - "		
Concrete compression at compression zone	-5.47	N/mm^2
Therefore maximum concrete compression = < $\lvert 0.5f_{ci} \rvert$	-16.49	N/mm^2
Maximum concrete tension for class 3 member f_r =	4.80	N/mm^2
Strain at extreme fibre at tension zone =	1.51E-04	
Calculation of steel stresses and moment about neutral axis :		
Area of pre-stressing strand =	38.48	mm^2
Strands stresses due to effective pre-stresses =	1299.22	N/mm^2
Strands stresses-1 due to bending at tension zone=	-2.15	N/mm^2
Moment about neutral axis	-0.65	kNm
Strands stresses-2 due to bending at tension zone=	25.19	N/mm^2
Moment about neutral axis	9.30	kNm
Normal steel stresses due to bending =	16.76	N/mm^2
Area of normal steel =	56.55	mm^2
Moment about neutral axis	0.05	kNm
Total moment about neutral axis due to steel tensions	**8.70**	kNm
Concrete compression $C_c = 0.85f_c'A_a$	404.89	kN
Centroid distance	21.50	mm
Moment about neutral axis due to concrete compression	**8.71**	kNm

Trial and error to find the value of "C" so that above two figures are almost equal		
Zero tension moment $M_0 = P\ I_g/(A_g\ y_t)$	**7.61**	kNm
Cracking moment $M_{cr} = P\ I_g/(A_g\ y_t)+f_r\ I_g/y_t$	**10.92**	kNm
Service moment of the pole =< M_{cr}	**10.80**	kNm
Therefore pole design is satisfactory for given service requirements		

7.5m high Pre-stressed Pole

Analysis of critical section of the pole (at ground support position)

r_1 (Radios of outer circle) =	87.5	mm
r_2 (Radios of inner circle) =	52.5	mm
Thickness of pole =	35.00	mm
Gross concrete area at base A_g	15,393.80	mm^2
Assume C= Neutral axis depth by trial and error	104.50	mm
β_1= Parameter to calculate rectangular concrete compressive stress block	0.69	
$\beta_1 C$ =	72.11	mm
f'_c = Concrete compressive strength	50.00	N/mm^2
$f_r=0.62\sqrt{f'_c}$ Modulus of rupture of concrete	4.38	N/mm^2
y_t = Distance from centroid axis to extreme tensile fibre	70.50	mm
I_g = Gross moment of inertia of the section	4.01E-05	m^4
Finding area of Annulus		
Φ_1 =	3.53	radians
Φ_2 =	3.80	radians
Area A_1 =	14,982.59	mm^2
Area A_2 =	6,082.80	mm^2
Therefore Annulus area $A_a = A_1 - A_2$	**8,899.78**	mm^2
Finding centroid of annulus A_a		
Assume distance to the centroid from the centre x=	-0.30	mm
Φ_3 =	3.15	radians
Φ_4 =	3.15	radians

A'_a =	**7,717.90**	mm^2
Find the "x" so that $A_a \approx 2A'_a$		
Cross sectional area of Φ7mm strand A_{psi} =	38.48	mm^2
Number of strands	4	No's
Modulus of elasticity of pre-stressing steel E_s =	205.00	kN/mm^2
Modulus of elasticity of normal steel E_y =	200.00	kN/mm^2
Modulus of elasticity of concrete E_c =	31.75	kN/mm^2
f_{py} = Specified yield stress of pre-stressing steel	1620.00	N/mm^2
Total pre-stressing force per strand = F_{py}	62.34	kN
Minimum breaking load F_{pu} =	62.50	kN
Therefore permissible pre-stressing force per strand = lesser of $0.80f_{pu}$ and $0.94f_{py}$ = (assume 10% loss due to relaxation)	50.00	kN
Assessment of transmission length: $l_t = K_t\Phi/\sqrt{f_{ci}}$	593.97	mm
where K_t is a coefficient for tendons =	600.00	
Average diameter of the section	137.50	mm
Average cross sectional area of concrete	16198.84	mm^2
Exposed perimeter of the section	431.97	mm
Effective section thickness of concrete(under immersed conditions)	600.00	mm
Elastic deformation of concrete at the age of stress transfer	2.92	mm
Creep strain ε_{cc}=stress x ø/E_t	5.83E-04	
Therefore creep deformation of concrete	4.37	mm
where ø = creep coefficient	1.50	

E_t = Modulus of elasticity of concrete at the age of t = E_c

Design as class 3 member with 0.1mm crack width at ultimate loading

For grade 50 concrete for limiting the crack width to 0.1mm

Design flexural stress for class 3 member f_r =	4.80	N/mm^2
Design compressive stress at extreme fibre should not exceed $0.5f_{ci}$		
where f_{ci} is the concrete strength at transfer		
$0.5\ f_{ci}$ =	25.00	N/mm^2
Concrete stresses due to effective pre-stresses = < $\lvert 0.5f_{ci} \rvert$	-12.99	N/mm^2
Concrete stresses due to bending: assume compression " - "		
Concrete compression at compression zone	-7.11	N/mm^2
Therefore maximum concrete compression = < $\lvert 0.5f_{ci} \rvert$	-20.11	N/mm^2
Maximum concrete tension for class 3 member f_r =	4.80	N/mm^2
Strain at extreme fibre at tension zone =	1.51E-04	
Calculation of steel stresses and moment about neutral axis :		
Area of pre-stressing strand =	38.48	mm^2
Strands stresses due to effective pre-stresses=	1299.22	N/mm^2
Strands stresses-1 due to bending at tension zone=	-7.47	N/mm^2
Moment about neutral axis	-1.69	kNm
Strands stresses-2 due to bending at tension zone=	23.30	N/mm^2
Moment about neutral axis	8.02	kNm
Normal steel stresses due to bending =	13.94	N/mm^2
Area of normal steel =	56.55	mm^2
Moment about neutral axis	0.03	kNm
Total moment about neutral axis due to steel tensions	**6.35**	kNm
Concrete compression $C_c = 0.85f_c'A_a$	378.24	kN
Centroid distance	16.70	mm
Moment about neutral axis due to concrete compression	**6.32**	kNm

Trial and error to find the value of "C" so that above two figures are almost equal		
Zero tension moment $M_0 = P\, I_g/(A_g\, y_t)$	**7.38**	kNm
Cracking moment $M_{cr} = P\, I_g/(A_g\, y_t)+f_r\, I_g/y_t$	**10.11**	kNm
Service moment of the pole =< M_{cr}	**10.08**	kNm
Therefore pole design is satisfactory for given service requirements		

6.7m high Pre-stressed Pole		
Analysis of critical section of the pole (at ground support position)		
r_1 (Radios of outer circle) =	85	mm
r_2 (Radios of inner circle) =	50	mm
Thickness of pole =	35.00	mm
Gross concrete area at base A_g	14,844.03	mm^2
Assume C= Neutral axis depth by trial and error	97.00	mm
β_1= Parameter to calculate rectangular concrete compressive stress block	0.69	
$\beta_1 C$ =	66.93	mm
f'_c = Concrete compressive strength	50.00	N/mm^2
$f_r=0.62\sqrt{f'_c}$ Modulus of rupture of concrete	4.38	N/mm^2
y_t = Distance from centroid axis to extreme tensile fibre	73.00	mm
I_g = Gross moment of inertia of the section	3.61E-05	m^4
Finding area of Annulus		
Φ_1 =	3.42	radians
Φ_2 =	3.63	radians
Area A_1 =	13,382.21	mm^2
Area A_2 =	5,115.37	mm^2
Therefore Annulus area $A_a = A_1 - A_2$	**8,266.84**	mm^2
Finding centroid of annulus A_a		
Assume distance to the centroid from the centre x=	7.00	mm
Φ_3 =	2.98	radians
Φ_4 =	2.86	radians

A'_a =	**6,931.07**	mm^2
Find the "x" so that $A_a \approx 2A'_a$		
Cross sectional area of Φ7mm strand A_{psi} =	38.48	mm^2
Number of strands	4	No's
Modulus of elasticity of pre-stressing steel E_s =	205.00	kN/mm^2
Modulus of elasticity of normal steel E_y =	200.00	kN/mm^2
Modulus of elasticity of concrete E_c =	31.75	kN/mm^2
f_{py} = Specified yield stress of pre-stressing steel	1620.00	N/mm^2
Total pre-stressing force per strand = F_{py}	62.34	kN
Minimum breaking load F_{pu} =	62.50	kN
Therefore permissible pre-stressing force per strand = lesser of $0.80f_{pu}$ and $0.94f_{py}$ (assume 10% loss due to relaxation) =	50.00	kN
Assessment of transmission length: $l_t = K_t\Phi/\sqrt{f_{ci}}$	593.97	mm
where K_t is a coefficient for tendons =	600.00	
Average diameter of the section	135.00	mm
Average cross sectional area of concrete	14844.03	mm^2
Exposed perimeter of the section	424.12	mm
Effective section thickness of concrete(under immersed conditions)	600.00	mm
Elastic deformation of concrete at the age of stress transfer	2.84	mm
Creep strain ε_{cc}=stress x ø/E_t	6.36E-04	
Therefore creep deformation of concrete	4.26	mm
where ø = creep coefficient	1.50	
E_t = Modulus of elasticity of concrete at the age of t = E_c		

Design as class 3 member with 0.1mm crack width at ultimate loading

For grade 50 concrete for limiting the crack width to 0.1mm

Design flexural stress for class 3 member f_r =	4.80	N/mm^2

Design compressive stress at extreme fibre should not exceed $0.5f_{ci}$

where f_{ci} is the concrete strength at transfer

$0.5\ f_{ci}$ =	25.00	N/mm^2
Concrete stresses due to effective pre-stresses = < $\lvert 0.5f_{ci} \rvert$	-13.47	N/mm^2
Concrete stresses due to bending: assume compression " - "		
Concrete compression at compression zone	-6.38	N/mm^2
Therefore maximum concrete compression = < $\lvert 0.5f_{ci} \rvert$	-19.85	N/mm^2
Maximum concrete tension for class 3 member f_r =	4.80	N/mm^2
Strain at extreme fibre at tension zone =	1.51E-04	

Calculation of steel stresses and moment about neutral axis :

Area of pre-stressing strand =	38.48	mm^2
Strands stresses due to effective pre-stresses =	1299.22	N/mm^2
Strands stresses-1 due to bending at tension zone=	-5.09	N/mm^2
Moment about neutral axis	-1.20	kNm
Strands stresses-2 due to bending at tension zone=	23.56	N/mm^2
Moment about neutral axis	7.76	kNm
Normal steel stresses due to bending =	14.80	N/mm^2
Area of normal steel =	56.55	mm^2
Moment about neutral axis	0.03	kNm
Total moment about neutral axis due to steel tensions	**6.60**	kNm
Concrete compression $C_c = 0.85f_c'A_a$	351.34	kN
Centroid distance	19.00	mm
Moment about neutral axis due to concrete compression	**6.68**	kNm

Trial and error to find the value of "C" so that above two figures are almost equal

Zero tension moment $M_0 = P\, I_g/(A_g\, y_t)$	**6.66**	kNm
Cracking moment $M_{cr} = P\, I_g/(A_g\, y_t)+f_r\, I_g/y_t$	**9.03**	kNm
Service moment of the pole $=< M_{cr}$	**8.93**	kNm

Therefore pole design is satisfactory for given service requirements

5.6m high Pre-stressed Pole

Analysis of critical section of the pole (at ground support position)

r_1 (Radios of outer circle) =	75	mm
r_2 (Radios of inner circle) =	40	mm
Thickness of pole =	35.00	mm
Gross concrete area at base A_g	12,644.91	mm^2
Assume C= Neutral axis depth by trial and error	70.00	mm
β_1= Parameter to calculate rectangular concrete compressive stress block	0.69	
$\beta_1 C$ =	48.30	mm
f'_c = Concrete compressive strength	50.00	N/mm^2
$f_r=0.62\sqrt{f'_c}$ Modulus of rupture of concrete	4.38	N/mm^2
y_t = Distance from centroid axis to extreme tensile fibre	80.00	mm
I_g = Gross moment of inertia of the section	2.28E-05	m^4
Finding area of Annulus		
Φ_1 =	3.01	radians
Φ_2 =	2.89	radians
Area A_1 =	8,086.29	mm^2
Area A_2 =	2,114.32	mm^2
Therefore Annulus area $A_a = A_1 - A_2$	**5,971.97**	mm^2
Finding centroid of annulus A_a		
Assume distance to the centroid from the centre x=	33.50	mm
Φ_3 =	2.22	radians
Φ_4 =	1.16	radians

A'_a =	**3,790.47**	mm^2
Find the "x" so that $A_a \approx 2A'_a$		
Cross sectional area of Φ7mm strand A_{psi} =	38.48	mm^2
Number of strands	4	No's
Modulus of elasticity of pre-stressing steel E_s =	205.00	kN/mm^2
Modulus of elasticity of normal steel E_y =	200.00	kN/mm^2
Modulus of elasticity of concrete E_c =	31.75	kN/mm^2
f_{py} = Specified yield stress of pre-stressing steel	1620.00	N/mm^2
Total pre-stressing force per strand = F_{py}	62.34	kN
Minimum breaking load F_{pu} =	62.50	kN
Therefore permissible pre-stressing force per strand = lesser of $0.80f_{pu}$ and $0.94f_{py}$ (assume 10% loss due to relaxation)=	50.00	kN
Assessment of transmission length: $l_t = K_t\Phi/\sqrt{f_{ci}}$	593.97	mm
where K_t is a coefficient for tendons =	600.00	
Average diameter of the section	125.00	mm
Average cross sectional area of concrete	9817.48	mm^2
Exposed perimeter of the section	392.70	mm
Effective section thickness of concrete(under immersed conditions)	600.00	mm
Elastic deformation of concrete at the age of stress transfer	3.59	mm
Creep strain ε_{cc}=stress x ø/E_t	9.62E-04	
Therefore creep deformation of concrete	5.39	mm
where ø = creep coefficient	1.50	
E_t = Modulus of elasticity of concrete at the age of t = E_c		

Design as class 3 member with 0.1mm crack width at ultimate loading

For grade 50 concrete for limiting the crack width to 0.1mm

Design flexural stress for class 3 member f_r =	4.80	N/mm^2

Design compressive stress at extreme fibre should not exceed $0.5f_{ci}$

where f_{ci} is the concrete strength at transfer

$0.5\ f_{ci}$ =	25.00	N/mm^2
Concrete stresses due to effective pre-stresses = < $\lvert 0.5f_{ci} \rvert$	-15.82	N/mm^2
Concrete stresses due to bending: assume compression " - "		
Concrete compression at compression zone	-4.20	N/mm^2
Therefore maximum concrete compression = < $\lvert 0.5f_{ci} \rvert$	-20.02	N/mm^2
Maximum concrete tension for class 3 member f_r =	4.80	N/mm^2
Strain at extreme fibre at tension zone =	1.51E-04	

Calculation of steel stresses and moment about neutral axis :

Area of pre-stressing strand =	38.48	mm^2
Strands stresses due to effective pre-stresses =	1299.22	N/mm^2
Strands stresses-1 due to bending at tension zone=	1.94	N/mm^2
Moment about neutral axis	0.50	kNm
Strands stresses-2 due to bending at tension zone=	24.21	N/mm^2
Moment about neutral axis	6.75	kNm
Normal steel stresses due to bending =	17.25	N/mm^2
Area of normal steel =	56.55	mm^2
Moment about neutral axis	0.04	kNm
Total moment about neutral axis due to steel tensions	**7.29**	kNm
Concrete compression $C_c = 0.85f_c'A_a$	253.81	kN
Centroid distance	28.50	mm
Moment about neutral axis due to concrete compression	**7.23**	kNm

Trial and error to find the value of "C" so that above two figures are almost equal

Zero tension moment $M_0 = P\, I_g/(A_g\, y_t)$	**4.52**	kNm
Cracking moment $M_{cr} = P\, I_g/(A_g\, y_t) + f_r\, I_g/y_t$	**5.89**	kNm
Service moment of the pole =< M_{cr}	**5.30**	kNm

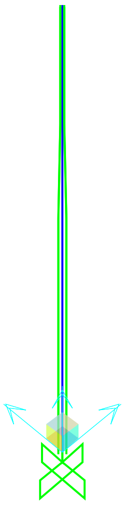
Therefore pole design is satisfactory for given service requirements

APPENDIX – F: SAP2000 Finite elements analytical results.

SAP2000 Analysis Report for 9m pre-stressed pole

Model geometry

This section provides model geometry information, including items such as joint coordinates, joint restraints, and element connectivity.



Finite element model

1.1. Joint coordinates

Table 1: Joint Coordinates, Part 1 of 2

Joint	CoordSys	CoordType	XorR mm	Y mm	Z mm	SpecialJt	GlobalX mm
1	GLOBAL	Cartesian	0.00	0.00	0.00	No	0.00
2	GLOBAL	Cartesian	0.00	0.00	9000.00	No	0.00

Table 1: Joint Coordinates, Part 2 of 2

Joint	GlobalY mm	GlobalZ mm	GUID
1	0.00	0.00	
2	0.00	9000.00	

1.2. Joint restraints

Table 2: Joint Restraint Assignments

Joint	U1	U2	U3	R1	R2	R3

Joint	U1	U2	U3	R1	R2	R3
1	Yes	Yes	Yes	Yes	Yes	Yes

1.3. Element connectivity

Table 3: Connectivity - Frame, Part 1 of 2

Frame	JointI	JointJ	IsCurved	Length mm	Centroid X mm	Centroid Y mm	Centroid Z mm
1	1	2	No	9000.00	0.00	0.00	4500.00

Table 3: Connectivity - Frame, Part 2 of 2

Frame	GUID
1	

Table 4: Frame Section Assignments, Part 1 of 2

Frame	SectionType	AutoSelect	AnalSect	DesignSect	MatProp
1	Nonprismatic	N.A.	Tapered	Tapered	Default

Table 4: Frame Section Assignments, Part 2 of 2

Frame	NPSectType	NPSectLen mm	NPSectRD
1	Default		

Table 5: Connectivity - Tendon

Tendon	JointI	JointJ	Length mm	GUID
2	1	2	9000.20	
3	1	2	9000.20	
4	1	2	9000.20	

Tendon	JointI	JointJ	Length mm	GUID
5	1	2	9000.20	

Table 6: Connectivity - Tendon

Tendon	JointI	JointJ	Length mm	GUID
2	1	2	9000.20	
3	1	2	9000.20	
4	1	2	9000.20	
5	1	2	9000.20	

2. Material properties

This section provides material property information for materials used in the model.

Table 7: Material Properties 02 - Basic Mechanical Properties

Material	UnitWeight N/mm3	UnitMass N-s2/mm4	E1 N/mm2	G12 N/mm2	U12	A1 1/C
A416Gr270	7.6973E-05	7.8490E-09	196500.60			1.1700E-05
A615Gr60	7.6973E-05	7.8490E-09	199947.98			1.1700E-05
A992Fy50	7.6973E-05	7.8490E-09	199947.98	76903.07	0.300000	1.1700E-05
Gr50	2.4000E-05	2.4473E-09	24855.58	10356.49	0.200000	9.9000E-06

Table 8: Material Properties 03a - Steel Data, Part 1 of 2

Material	Fy N/mm2	Fu N/mm2	EffFy N/mm2	EffFu N/mm2	SSCurveOpt	SSHysType	SHard	SMax
A992Fy50	344.74	448.16	379.21	492.98	Simple	Kinematic	0.015000	0.110000

Table 8: Material Properties 03a - Steel Data, Part 2 of 2

Material	SRup	FinalSlope
A992Fy50	0.170000	-0.100000

Table 9: Material Properties 03b - Concrete Data, Part 1 of 2

Material	Fc N/mm2	LtWtConc	SSCurveOpt	SSHysType	SFc	SCap	FinalSlope	FAngle Degrees
Gr50	50.00	No	Mander	Takeda	0.002219	0.005000	-0.100000	0.000

Table 9: Material Properties 03b - Concrete Data, Part 2 of 2

Material	DAngle Degrees	TimeType	TimeE	TimeCreep	TimeShrink	CreepType
Gr50	0.000	CEB-FIP 90	Yes	Yes	Yes	Full Integration

Table 10: Material Properties 03e - Rebar Data, Part 1 of 2

Material	Fy N/mm2	Fu N/mm2	EffFy N/mm2	EffFu N/mm2	SSCurveOpt	SSHysType	SHard	SCap
A615Gr60	413.69	620.53	455.05	682.58	Simple	Kinematic	0.010000	0.090000

Table 10: Material Properties 03e - Rebar Data, Part 2 of 2

Material	FinalSlope	UseCTDef
A615Gr60	-0.100000	No

Table 11: Material Properties 03f - Tendon Data

Material	Fy N/mm2	Fu N/mm2	SSCurveOpt	SSHysType	FinalSlope	TimeType	TimeRelax	RelaxType
A416Gr270	1689.91	1861.58	270 ksi	Kinematic	-0.100000	CEB-FIP 90	Yes	Full Integration

3. Section properties

This section provides section property information for objects used in the model.

3.1. Frames

Table 12: Frame Section Properties 01 - General, Part 1 of 6

SectionName	Material	Shape	t3 mm	t2 mm	tf mm	tw mm
140Dia	Gr50	SD Section				
260Dia	Gr50	SD Section				
Tapered		Nonprismatic				

Table 12: Frame Section Properties 01 - General, Part 2 of 6

SectionName	t2b mm	tfb mm	Area mm2	TorsConst mm4	I33 mm4	I22 mm4	I23 mm4
140Dia			12566.37	35970477.10	18221237.39	18221237.39	0.00
260Dia			27646.02	341054347.	172787595.9	172787595.9	0.00
Tapered							

Table 12: Frame Section Properties 01 - General, Part 3 of 6

SectionName	AS2 mm2	AS3 mm2	S33 mm3	S22 mm3	Z33 mm3	Z22 mm3	R33 mm
140Dia	9864.01	9864.01	260303.39	260303.39	417285.43	417285.43	38.079
260Dia	19334.73	19334.73	1329135.35	1329135.35	1938528.53	1938528.53	79.057
Tapered							

Table 12: Frame Section Properties 01 - General, Part 4 of 6

SectionName	R22 mm	ConcCol	ConcBeam	Color	TotalWt N	TotalMass N-s2/mm	FromFile
140Dia	38.079	No	No	Gray8Dark	0.00	0.000	No
260Dia	79.057	No	No	Magenta	0.00	0.000	No
Tapered				Blue			

Table 12: Frame Section Properties 01 - General, Part 5 of 6

SectionName	AMod	A2Mod	A3Mod	JMod	I2Mod	I3Mod	MMod

140Dia	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
260Dia	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
Tapered							

Table 12: Frame Section Properties 01 - General, Part 6 of 6

SectionName	WMod	GUID	Notes
140Dia	1.000000		Added 5/5/2015 4:24:24 PM
260Dia	1.000000		Added 5/5/2015 3:29:11 PM
Tapered			Added 5/5/2015 4:27:35 PM

Table 13: Frame Section Properties 05 - Nonprismatic, Part 1 of 2

SectionName	NumSegments	SegmentNum	StartSect	EndSect	LengthType	AbsLength mm
Tapered	1	1	260Dia	140Dia	Absolute	9000000.00

Table 13: Frame Section Properties 05 - Nonprismatic, Part 2 of 2

SectionName	VarLength	EI33Var	EI22Var
Tapered		Linear	Linear

3.2. Tendons

Table 14: Tendon Section Definitions, Part 1 of 4

TendonSect	ModelOpt	PreType	Material	Specify	Diameter mm	Area mm2	TorsConst mm4	I mm4
PC7	Elements	Prestress	A416Gr270	Diameter	7.000	38.48	235.72	117.86

Table 14: Tendon Section Definitions, Part 2 of 4

TendonSect	AS mm2	Color	TotalWt N	TotalMass N-s2/mm	AMod	A2Mod	A3Mod	JMod
PC7	34.64	Magenta	106.64	0.011	1.000000	1.000000	1.000000	1.000000

Table 14: Tendon Section Definitions, Part 3 of 4

TendonSect	I2Mod	I3Mod	MMod	WMod	GUID
PC7	1.000000	1.000000	1.000000	1.000000	

Table 14: Tendon Section Definitions, Part 4 of 4

TendonSect	Notes
PC7	

4. Load patterns
This section provides loading information as applied to the model.

4.1. Definitions

Table 15: Load Pattern Definitions

LoadPat	DesignType	SelfWtMult	AutoLoad	GUID	Notes
DEAD	DEAD	1.000000			
LIVE	LIVE	0.000000			
PRESTRESS	PRESTRESS	0.000000			

5. Load cases

This section provides load case information.

5.1. Definitions

Table 16: Load Case Definitions, Part 1 of 3

Case	Type	InitialCond	ModalCase	BaseCase	DesTypeOpt	DesignType	DesActOpt
DEAD	LinStatic	Zero			Prog Det	DEAD	Prog Det
MODAL	LinModal	Zero			Prog Det	OTHER	Prog Det
LIVE	LinStatic	Zero			Prog Det	LIVE	Prog Det
PRESTRESS	LinStatic	Zero			Prog Det	PRESTRESS	Prog Det

Table 16: Load Case Definitions, Part 2 of 3

Case	DesignAct	AutoType	RunCase	CaseStatus	GUID
DEAD	Non-Composite	None	Yes	Finished	
MODAL	Other	None	Yes	Finished	
LIVE	Short-Term Composite	None	Yes	Finished	
PRESTRESS	Long-Term Composite	None	Yes	Finished	

Table 16: Load Case Definitions, Part 3 of 3

Case	Notes
DEAD	
MODAL	
LIVE	
PRESTRESS	

5.2. Static case load assignments

Table 17: Case - Static 1 - Load Assignments

Case	LoadType	LoadName	LoadSF
DEAD	Load pattern	DEAD	1.000000
LIVE	Load pattern	LIVE	1.000000

Case	LoadType	LoadName	LoadSF
PRESTRESS	Load pattern	PRESTRESS	1.000000

5.3. Response spectrum case load assignments

Table 18: Function - Response Spectrum - User

Name	Period Sec	Accel	FuncDamp
UNIFRS	0.000000	1.000000	0.050000
UNIFRS	1.000000	1.000000	

6. Load combinations

This section provides load combination information.

Table 19: Combination Definitions, Part 1 of 3

ComboName	ComboType	AutoDesign	CaseType	CaseName	ScaleFactor	SteelDesign
COMB(ULS)	Linear Add	No	Linear Static	DEAD	1.400000	None
COMB(ULS)			Linear Static	LIVE	2.500000	
COMB(ULS)			Linear Static	PRESTRESS	1.000000	
COMB(SLS)	Linear Add	No	Linear Static	DEAD	1.000000	None
COMB(SLS)			Linear Static	LIVE	1.000000	
COMB(SLS)			Linear Static	PRESTRESS	1.000000	
ENV(ULS)	Envelope	No	Response Combo	COMB(ULS)	1.000000	None
ENV(SLS)	Envelope	No	Response Combo	COMB(SLS)	1.000000	None

Table 19: Combination Definitions, Part 2 of 3

ComboName	CaseName	ConcDesign	AlumDesign	ColdDesign
COMB(ULS)	DEAD	None	None	None
COMB(ULS)	LIVE			
COMB(ULS)	PRESTRESS			
COMB(SLS)	DEAD	None	None	None

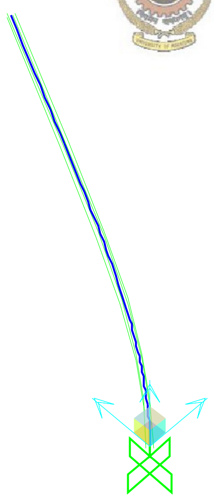
ComboName	CaseName	ConcDesign	AlumDesign	ColdDesign
COMB(SLS)	LIVE			
COMB(SLS)	PRESTRESS			
ENV(ULS)	COMB(ULS)	Strength	None	None
ENV(SLS)	COMB(SLS)	None	None	None

Table 19: Combination Definitions, Part 3 of 3

ComboName	CaseName	GUID	Notes
COMB(ULS)	DEAD		
COMB(ULS)	LIVE		
COMB(ULS)	PRESTRESS		
COMB(SLS)	DEAD		
COMB(SLS)	LIVE		
COMB(SLS)	PRESTRESS		
ENV(ULS)	COMB(ULS)		
ENV(SLS)	COMB(SLS)		

7. Structure results

This section provides structure results, including items such as structural periods and base reactions.



Finite element model deformed shape

7.1. Mass summary

Table 20: Assembled Joint Masses

Joint	MassSource	U1	U2	U3	R1	R2	R3

		N-s2/mm	N-s2/mm	N-s2/mm	N-mm-s2	N-mm-s2	N-mm-s2
1	MSSSRC1	0.049	0.049	0.049	0.00	0.00	0.00
2	MSSSRC1	0.025	0.025	0.025	0.00	0.00	0.00
~1	MSSSRC1	0.092	0.092	0.092	0.00	0.00	0.00
~2	MSSSRC1	0.083	0.083	0.083	0.00	0.00	0.00
~3	MSSSRC1	0.074	0.074	0.074	0.00	0.00	0.00
~4	MSSSRC1	0.065	0.065	0.065	0.00	0.00	0.00
~5	MSSSRC1	0.055	0.055	0.055	0.00	0.00	0.00
~6	MSSSRC1	2.266E-04	2.266E-04	2.266E-04	0.00	0.00	0.00
~7	MSSSRC1	4.531E-04	4.531E-04	4.531E-04	0.00	0.00	0.00
~8	MSSSRC1	4.531E-04	4.531E-04	4.531E-04	0.00	0.00	0.00
~9	MSSSRC1	4.531E-04	4.531E-04	4.531E-04	0.00	0.00	0.00
~10	MSSSRC1	4.531E-04	4.531E-04	4.531E-04	0.00	0.00	0.00
~11	MSSSRC1	4.531E-04	4.531E-04	4.531E-04	0.00	0.00	0.00
~12	MSSSRC1	2.266E-04	2.266E-04	2.266E-04	0.00	0.00	0.00
~13	MSSSRC1	2.266E-04	2.266E-04	2.266E-04	0.00	0.00	0.00
~14	MSSSRC1	4.531E-04	4.531E-04	4.531E-04	0.00	0.00	0.00
~15	MSSSRC1	4.531E-04	4.531E-04	4.531E-04	0.00	0.00	0.00
~16	MSSSRC1	4.531E-04	4.531E-04	4.531E-04	0.00	0.00	0.00
~17	MSSSRC1	4.531E-04	4.531E-04	4.531E-04	0.00	0.00	0.00
~18	MSSSRC1	4.531E-04	4.531E-04	4.531E-04	0.00	0.00	0.00
~19	MSSSRC1	2.266E-04	2.266E-04	2.266E-04	0.00	0.00	0.00
~20	MSSSRC1	2.266E-04	2.266E-04	2.266E-04	0.00	0.00	0.00
~21	MSSSRC1	4.531E-04	4.531E-04	4.531E-04	0.00	0.00	0.00
~22	MSSSRC1	4.531E-04	4.531E-04	4.531E-04	0.00	0.00	0.00
~23	MSSSRC1	4.531E-04	4.531E-04	4.531E-04	0.00	0.00	0.00
~24	MSSSRC1	4.531E-04	4.531E-04	4.531E-04	0.00	0.00	0.00
~25	MSSSRC1	4.531E-04	4.531E-04	4.531E-04	0.00	0.00	0.00
~26	MSSSRC1	2.266E-04	2.266E-04	2.266E-04	0.00	0.00	0.00
~27	MSSSRC1	2.266E-04	2.266E-04	2.266E-04	0.00	0.00	0.00
~28	MSSSRC1	4.531E-04	4.531E-04	4.531E-04	0.00	0.00	0.00
~29	MSSSRC1	4.531E-04	4.531E-04	4.531E-04	0.00	0.00	0.00
~30	MSSSRC1	4.531E-04	4.531E-04	4.531E-04	0.00	0.00	0.00
~31	MSSSRC1	4.531E-04	4.531E-04	4.531E-04	0.00	0.00	0.00
~32	MSSSRC1	4.531E-04	4.531E-04	4.531E-04	0.00	0.00	0.00
~33	MSSSRC1	2.266E-04	2.266E-04	2.266E-04	0.00	0.00	0.00

7.2. Modal results

Table 21: Modal Participating Mass Ratios, Part 1 of 3

OutputCase	StepType	StepNum	Period Sec	UX	UY	UZ	SumUX	SumUY
MODAL	Mode	1.000000	0.486022	0.59	3.903E-06	0.00	0.59	3.903E-06
MODAL	Mode	2.000000	0.486022	3.903E-06	0.59	0.00	0.59	0.59
MODAL	Mode	3.000000	0.102229	1.988E-03	0.22	0.00	0.59	0.81
MODAL	Mode	4.000000	0.102229	0.22	1.988E-03	0.00	0.81	0.81

OutputCase	StepType	StepNum	Period Sec	UX	UY	UZ	SumUX	SumUY
MODAL	Mode	5.000000	0.041583	2.964E-06	9.219E-02	0.00	0.81	0.90

Table 21: Modal Participating Mass Ratios, Part 2 of 3

OutputCase	StepType	StepNum	SumUZ	RX	RY	RZ	SumRX	SumRY
MODAL	Mode	1.000000	0.00	4.046E-06	0.61	0.00	4.046E-06	0.61
MODAL	Mode	2.000000	0.00	0.61	4.046E-06	0.00	0.61	0.61
MODAL	Mode	3.000000	0.00	0.12	1.086E-03	0.00	0.73	0.61
MODAL	Mode	4.000000	0.00	1.086E-03	0.12	0.00	0.73	0.73
MODAL	Mode	5.000000	0.00	0.11	3.467E-06	0.00	0.84	0.73

Table 21: Modal Participating Mass Ratios, Part 3 of 3

OutputCase	StepType	StepNum	SumRZ
MODAL	Mode	1.000000	0.00
MODAL	Mode	2.000000	0.00
MODAL	Mode	3.000000	0.00
MODAL	Mode	4.000000	0.00
MODAL	Mode	5.000000	0.00

7.3. Base reactions

Table 22: Base Reactions, Part 1 of 3

OutputCase	CaseType	StepType	GlobalFX N	GlobalFY N	GlobalFZ N	GlobalMX N-mm	GlobalMY N-mm	GlobalMZ N-mm
ENV(ULS)	Combination	Max	-3529.20	4.401E-14	197146.21	-2.344E-10	-29423259.9	3.763E-11
ENV(ULS)	Combination	Min	-3529.20	4.401E-14	197146.21	-2.344E-10	-29423259.9	3.763E-11
ENV(SLS)	Combination	Max	-1411.68	4.379E-14	195439.64	-2.332E-10	-11769304.0	1.505E-11

OutputCase	CaseType	StepType	GlobalFX N	GlobalFY N	GlobalFZ N	GlobalMX N-mm	GlobalMY N-mm	GlobalMZ N-mm
ENV(SLS)	Combination	Min	-1411.68	4.379E-14	195439.64	-2.332E-10	-11769304.0	1.505E-11

Table 22: Base Reactions, Part 2 of 3

OutputCase	StepType	GlobalX mm	GlobalY mm	GlobalZ mm	XCentroidFX mm	YCentroidFX mm	ZCentroidFX mm	XCentroidFY mm
ENV(ULS)	Max	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ENV(ULS)	Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ENV(SLS)	Max	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ENV(SLS)	Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 22: Base Reactions, Part 3 of 3

OutputCase	StepType	YCentroidFY mm	ZCentroidFY mm	XCentroidFZ mm	YCentroidFZ mm	ZCentroidFZ mm
ENV(ULS)	Max	0.00	0.00	0.00	0.00	0.00
ENV(ULS)	Min	0.00	0.00	0.00	0.00	0.00
ENV(SLS)	Max	0.00	0.00	0.00	0.00	0.00
ENV(SLS)	Min	0.00	0.00	0.00	0.00	0.00

Table 23: Joint Displacements, Part 2 of 2

Joint	OutputCase	StepType	R3 Radians
1	ENV(ULS)	Max	0.000000
1	ENV(ULS)	Min	0.000000
1	ENV(SLS)	Max	0.000000
1	ENV(SLS)	Min	0.000000
2	ENV(ULS)	Max	2.687E-19
2	ENV(ULS)	Min	2.687E-19
2	ENV(SLS)	Max	1.075E-19
2	ENV(SLS)	Min	1.075E-19
~1	ENV(ULS)	Max	-1.731E-20
~1	ENV(ULS)	Min	-1.731E-20
~1	ENV(SLS)	Max	0.000000
~1	ENV(SLS)	Min	0.000000
~2	ENV(ULS)	Max	-1.029E-19
~2	ENV(ULS)	Min	-1.029E-19
~2	ENV(SLS)	Max	-4.115E-20

Joint	OutputCase	StepType	R3 Radians
~2	ENV(SLS)	Min	-4.115E-20
~3	ENV(ULS)	Max	8.153E-20
~3	ENV(ULS)	Min	8.153E-20
~3	ENV(SLS)	Max	3.261E-20
~3	ENV(SLS)	Min	3.261E-20
~4	ENV(ULS)	Max	3.242E-19
~4	ENV(ULS)	Min	3.242E-19
~4	ENV(SLS)	Max	1.297E-19
~4	ENV(SLS)	Min	1.297E-19
~5	ENV(ULS)	Max	2.440E-19
~5	ENV(ULS)	Min	2.440E-19
~5	ENV(SLS)	Max	9.761E-20
~5	ENV(SLS)	Min	9.761E-20
~6	ENV(ULS)	Max	-2.113E-12
~6	ENV(ULS)	Min	-2.113E-12
~6	ENV(SLS)	Max	-8.602E-13
~6	ENV(SLS)	Min	-8.602E-13
~7	ENV(ULS)	Max	-2.113E-12
~7	ENV(ULS)	Min	-2.113E-12
~7	ENV(SLS)	Max	-8.602E-13
~7	ENV(SLS)	Min	-8.602E-13
~8	ENV(ULS)	Max	-2.113E-12
~8	ENV(ULS)	Min	-2.113E-12
~8	ENV(SLS)	Max	-8.602E-13
~8	ENV(SLS)	Min	-8.602E-13
~9	ENV(ULS)	Max	-2.113E-12
~9	ENV(ULS)	Min	-2.113E-12
~9	ENV(SLS)	Max	-8.602E-13
~9	ENV(SLS)	Min	-8.602E-13
~10	ENV(ULS)	Max	-2.113E-12
~10	ENV(ULS)	Min	-2.113E-12
~10	ENV(SLS)	Max	-8.602E-13
~10	ENV(SLS)	Min	-8.602E-13
~11	ENV(ULS)	Max	-2.113E-12
~11	ENV(ULS)	Min	-2.113E-12
~11	ENV(SLS)	Max	-8.602E-13
~11	ENV(SLS)	Min	-8.602E-13
~12	ENV(ULS)	Max	-2.113E-12
~12	ENV(ULS)	Min	-2.113E-12
~12	ENV(SLS)	Max	-8.602E-13
~12	ENV(SLS)	Min	-8.602E-13
~13	ENV(ULS)	Max	-0.000173
~13	ENV(ULS)	Min	-0.000173
~13	ENV(SLS)	Max	-0.000069
~13	ENV(SLS)	Min	-0.000069
~14	ENV(ULS)	Max	-0.000131
~14	ENV(ULS)	Min	-0.000131
~14	ENV(SLS)	Max	-0.000052
~14	ENV(SLS)	Min	-0.000052
~15	ENV(ULS)	Max	-0.000059
~15	ENV(ULS)	Min	-0.000059
~15	ENV(SLS)	Max	-0.000024
~15	ENV(SLS)	Min	-0.000024
~16	ENV(ULS)	Max	2.621E-08

Joint	OutputCase	StepType	R3 Radians
~16	ENV(ULS)	Min	2.621E-08
~16	ENV(SLS)	Max	1.048E-08
~16	ENV(SLS)	Min	1.048E-08
~17	ENV(ULS)	Max	0.000055
~17	ENV(ULS)	Min	0.000055
~17	ENV(SLS)	Max	0.000022
~17	ENV(SLS)	Min	0.000022
~18	ENV(ULS)	Max	0.000096
~18	ENV(ULS)	Min	0.000096
~18	ENV(SLS)	Max	0.000038
~18	ENV(SLS)	Min	0.000038
~19	ENV(ULS)	Max	0.000111
~19	ENV(ULS)	Min	0.000111
~19	ENV(SLS)	Max	0.000044
~19	ENV(SLS)	Min	0.000044
~20	ENV(ULS)	Max	2.756E-16
~20	ENV(ULS)	Min	2.756E-16
~20	ENV(SLS)	Max	1.102E-16
~20	ENV(SLS)	Min	1.102E-16
~21	ENV(ULS)	Max	2.756E-16
~21	ENV(ULS)	Min	2.756E-16
~21	ENV(SLS)	Max	1.102E-16
~21	ENV(SLS)	Min	1.102E-16
~22	ENV(ULS)	Max	2.756E-16
~22	ENV(ULS)	Min	2.756E-16
~22	ENV(SLS)	Max	1.102E-16
~22	ENV(SLS)	Min	1.102E-16
~23	ENV(ULS)	Max	2.756E-16
~23	ENV(ULS)	Min	2.756E-16
~23	ENV(SLS)	Max	1.102E-16
~23	ENV(SLS)	Min	1.102E-16
~24	ENV(ULS)	Max	2.756E-16
~24	ENV(ULS)	Min	2.756E-16
~24	ENV(SLS)	Max	1.102E-16
~24	ENV(SLS)	Min	1.102E-16
~25	ENV(ULS)	Max	2.756E-16
~25	ENV(ULS)	Min	2.756E-16
~25	ENV(SLS)	Max	1.102E-16
~25	ENV(SLS)	Min	1.102E-16
~26	ENV(ULS)	Max	2.756E-16
~26	ENV(ULS)	Min	2.756E-16
~26	ENV(SLS)	Max	1.102E-16
~26	ENV(SLS)	Min	1.102E-16
~27	ENV(ULS)	Max	-5.407907
~27	ENV(ULS)	Min	-5.407907
~27	ENV(SLS)	Max	-2.163163
~27	ENV(SLS)	Min	-2.163163
~28	ENV(ULS)	Max	-5.407949
~28	ENV(ULS)	Min	-5.407949
~28	ENV(SLS)	Max	-2.163180
~28	ENV(SLS)	Min	-2.163180
~29	ENV(ULS)	Max	-5.408021
~29	ENV(ULS)	Min	-5.408021
~29	ENV(SLS)	Max	-2.163208

Joint	OutputCase	StepType	R3 Radians
~29	ENV(SLS)	Min	-2.163208
~30	ENV(ULS)	Max	-5.408080
~30	ENV(ULS)	Min	-5.408080
~30	ENV(SLS)	Max	-2.163232
~30	ENV(SLS)	Min	-2.163232
~31	ENV(ULS)	Max	-5.408135
~31	ENV(ULS)	Min	-5.408135
~31	ENV(SLS)	Max	-2.163254
~31	ENV(SLS)	Min	-2.163254
~32	ENV(ULS)	Max	-5.408176
~32	ENV(ULS)	Min	-5.408176
~32	ENV(SLS)	Max	-2.163270
~32	ENV(SLS)	Min	-2.163270
~33	ENV(ULS)	Max	-5.408191
~33	ENV(ULS)	Min	-5.408191
~33	ENV(SLS)	Max	-2.163276
~33	ENV(SLS)	Min	-2.163276

Table 24: Joint Reactions, Part 1 of 2

Joint	OutputCase	CaseType	StepType	F1 N	F2 N	F3 N	M1 N-mm	M2 N-mm
1	ENV(ULS)	Combination	Max	-3600.00	5.627E-14	6229.41	1.770E-09	-30600000.0
1	ENV(ULS)	Combination	Min	-3600.00	5.627E-14	6229.41	1.770E-09	-30600000.0
1	ENV(SLS)	Combination	Max	-1440.00	5.605E-14	4449.58	1.772E-09	-12240000.0
1	ENV(SLS)	Combination	Min	-1440.00	5.605E-14	4449.58	1.772E-09	-12240000.0

Table 24: Joint Reactions, Part 2 of 2

Joint	OutputCase	StepType	M3 N-mm
1	ENV(ULS)	Max	5.936E-11
1	ENV(ULS)	Min	5.936E-11
1	ENV(SLS)	Max	2.374E-11

Joint	OutputCase	StepType	M3 N-mm
1	ENV(SLS)	Min	2.374E-11

10. Material take-off
This section provides a material take-off.

Table 26: Material List 2 - By Section Property

Section	ObjectType	NumPieces	TotalLength mm	TotalWeight N
Tapered	Frame	1	9000.00	4342.94

APENDIX – G: Manufacturer's cost analysis for current pre-casting concrete poles

Rate analysis for the casting of conventional telecom post submitted to the Sri Lankan Telecom by one of the sub-contracting company on October 2012 are summarized below under different height categories of poles.

5.6m High Pole:

Description	Unit	Qty	Rate(Rs.)	Amount(Rs.)
Cement	bags	0.410	855.00	312.99
Metal(¾")	cube	0.014	7000.00	99.40
Sand	cube	0.007	10,000.00	70.00
¾" G.I Pipe	ft	0.50	101.60	50.80
Nuts & Bolts	each	1.00	80.00	80.00
Welding Rods	pkts	0.02	225.00	4.50
Mould Oil	ltrs	0.25	175.00	43.75
Cost of Mould	each	0.0005	75,000.00	37.50
Electricity and Water	Item	1.00	32.00	32.00
Welder	day	0.021	875.00	18.38
Curing 28Days	Item	1.00	32.00	32.00
12mm Tor Steel	ft	0.00	37.60	0.00
10mm Tor Steel	ft	109.00	25.91	2,521.60
6mm Mild Steel	kg	2.64	140.00	330.00
Binding Wire	kg	0.35	140.00	43.75
Bar Bender	hrs	1.50	196.87	295.31
Concreter	hrs	0.60	284.37	170.62
			Basic Cost per pole	**4,142.59**

6.7m High Pole:

Description	Unit	Qty	Rate(Rs.)	Amount(Rs.)
Cement	bags	1.15	855.00	877.90
Metal(¾")	cube	0.04	7000.00	280.00
Sand	cube	0.02	10,000.00	200.00
¾" G.I Pipe	ft	0.50	101.60	50.80
Nuts & Bolts	each	1.00	80.00	80.00
Welding Rods	pkts	0.02	225.00	4.50
Mould Oil	ltrs	0.30	175.00	52.50
Cost of Mould	each	0.0005	81,250.00	40.63
Electricity and Water	Item	1.00	32.00	32.00
Welder	day	0.021	875.00	18.38
Curing 28Days	Item	1.00	32.00	32.00
12mm Tor Steel	ft	88.15	37.60	2,959.32
10mm Tor Steel	ft	49.00	25.91	1,133.56
6mm Mild Steel	kg	5.20	140.00	650.00
Binding Wire	kg	0.40	140.00	50.00
Bar Bender	hrs	2.00	196.87	393.74
Concreter	hrs	0.80	284.37	227.50
			Basic Cost per pole	**7,082.82**

7.5m High Pole:

Description	Unit	Qty	Rate(Rs.)	Amount(Rs.)
Cement	bags	1.38	855.00	1,053.48
Metal(¾")	cube	0.05	7000.00	343.00
Sand	cube	0.025	10,000.00	250.00
¾" G.I Pipe	ft	0.50	101.60	50.80
Nuts & Bolts	each	1.00	80.00	80.00
Welding Rods	pkts	0.02	225.00	4.50
Mould Oil	ltrs	0.04	175.00	70.00
Cost of Mould	each	0.0005	81,250.00	40.63
Electricity and Water	Item	1.00	32.00	32.00
Welder	day	0.021	875.00	18.38
Curing 28Days	Item	1.00	32.00	32.00
12mm Tor Steel	ft	98.70	37.60	3,313.36
10mm Tor Steel	ft	58.00	25.91	1,341.54
6mm Mild Steel	kg	5.90	140.00	737.50
Binding Wire	kg	0.66	140.00	82.50
Bar Bender	hrs	2.50	196.87	492.18
Concreter	hrs	1.00	284.37	284.37
			Basic Cost per pole	**8,226.23**

8.0m High Pole:

Description	Unit	Qty	Rate(Rs.)	Amount(Rs.)
Cement	bags	1.51	855.00	1,152.72
Metal(¾")	cube	0.05	7000.00	378.00
Sand	cube	0.03	10,000.00	280.00
¾" G.I Pipe	ft	0.50	101.60	50.80
Nuts & Bolts	each	1.00	80.00	80.00
Welding Rods	pkts	0.02	225.00	4.50
Mould Oil	ltrs	0.40	175.00	70.00
Cost of Mould	each	0.0005	93,750.00	46.88
Electricity and Water	Item	1.00	32.00	32.00
Welder	day	0.021	875.00	18.38
Curing 28Days	Item	1.00	32.00	32.00
12mm Tor Steel	ft	105.00	37.60	3,525.00
10mm Tor Steel	ft	58.00	25.91	1,341.54
6mm Mild Steel	kg	6.45	140.00	806.25
Binding Wire	kg	0.75	140.00	93.75
Bar Bender	hrs	2.50	196.87	492.18
Concreter	hrs	1.00	284.37	284.37
			Basic Cost per pole	**8,688.59**

9.0m High Pole:

Description	Unit	Qty	Rate(Rs.)	Amount(Rs.)
Cement	bags	1.84	855.00	1,404.64
Metal(¾")	cube	0.06	7000.00	448.00
Sand	cube	0.034	10,000.00	340.00
¾" G.I Pipe	ft	0.50	101.60	50.80
Nuts & Bolts	each	1.00	80.00	80.00
Welding Rods	pkts	0.03	225.00	6.75
Mould Oil	ltrs	0.50	175.00	87.50
Cost of Mould	each	0.0005	106,250.00	53.13
Electricity and Water	Item	1.00	32.00	32.00
Welder	day	0.021	875.00	18.38
Curing 28Days	Item	1.00	32.00	32.00
12mm Tor Steel	ft	118.08	37.60	3,964.11
10mm Tor Steel	ft	71.76	25.91	1,660.09
6mm Mild Steel	kg	7.34	140.00	917.50
Binding Wire	kg	0.40	140.00	50.00
Bar Bender	hrs	3.00	196.87	590.61
Concreter	hrs	1.15	284.37	327.03
			Basic Cost per pole	**10,062.53**