N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

REPORT N. **2013**

- INSTALLATION SITE: 0
- HIGH MAST HEIGHT: 20 m

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

SUMMARY

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

FOREWORD

The present document has been drafted according to the requirements of the Standards provided below.
Analysis, design and calculation has been drawn by the structural designer In accordance with best practice.

GENERAL DESCRIPTION OF THE STRUCTURE

The shaft of the high mast has a truncated cone shape with polygonal cross section (16 sides), cut from a press folded metal sheet longitudinally welded according to standard UNI EN ISO 3834 with type approval recognised by 'Istituto Italiano della Saldatura'.
The high mast consists of one or more sections to assemble on site with the 'slip-on-joint' method.
The bottom section is complete with a base plate for anchorage to the plinth through anchor bolts cast in place, it is also equipped with earthing device.
The shaft is made of S355 JR steel type according to standard UNI EN 10025.
The base plate is made of S355 JR steel type according to standard UNI EN 10025.
The whole frame is hot galvanized according to standard UNI EN ISO 1461-2009.

The mast is complete with a ladder with security cage, mass produced with a standard lenght of 3-5-6 m and fastened to the shaft with bolts.
As an alternative is installed a ladder with lock-slider, it is equipped with a resting platform placed every 10 m.
Masts with changing height from 12 to 20 m are complete with resting stage with size of 1000x620 mm.
The resting stage is equipped with anti-sleep floorboard, end-board, trap-door and banister 1 meter high.
The head platform, in the shape of the rectangular frame, is equipped with anti-sleep floorboard, end-board, trap-door and banister. Sometimes the banister is complete with the coupling devices for lanterns placement.
Otherwise on the top of the mast there is one or more cross bars for the positioning of lanterns.
As an alternative is installed a ladder with lock-slider, it is equipped with a resting platform placed every 10 m.

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

STANDARDS

. EN 1990	Eurocode : 'Basis of structural design'
. EN 1991-1-1	Eurocode 1: 'Actions on structure - Part. 1-1 General actions: densities, self-weight, imposed loads for buildings'
. EN 1991-1-4	Eurocode 1: 'Actions on structure - Part. 1-4' General actions: wind actions'
. EN 1993-1-1	Eurocode 3 : 'Design of steel structure - Part. 1-1 General rules and rules for buildings'
. EN 1993-1-8	Eurocode 3 : 'Design of steel structure - Part. 1-8 Design of joints'
. EN 1997-1	Eurocode 7: 'Geotechnical design'

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

MATERIALS PROPERTIES

▪ SHAFT SHEET: steel grade S355 JR (UNI EN 10025)

- f_{yk} =	355 N/mm²	nominal value of yeld strength
- f_{tk} =	510 N/mm²	nominal value of ultimate tensile strength
- E =	210.000 N/mm²	modulus of elasticity
- ρ =	7.850 Kg/m³	density
- v =	0.3	Poisson's ratio in elastic stage

▪ ANCHOR BOLT steel grade S355 JR (UNI EN 10025)

- f_{yk} =	355 N/mm²	nominal value of yeld strength
- f_{tk} =	510 N/mm²	nominal value of ultimate tensile strength
- E =	210.000 N/mm²	modulus of elasticity
- ρ =	7.850 Kg/m³	density
- v =	0.3	Poisson's ratio in elastic stage

▪ BASE PLATE: steel grade S355 JR (UNI EN 10025)

- f_{yk} =	355 N/mm²	nominal value of yeld strength
- f_{tk} =	510 N/mm²	nominal value of ultimate tensile strength
- E =	210.000 N/mm²	modulus of elasticity
- ρ =	7.850 Kg/m³	density
- v =	0.3	Poisson's ratio in elastic stage

▪ CARPENTRY: steel grade S235 JR (UNI EN 10025)

- f_{yk} =	235 N/mm²	nominal value of yeld strength
- f_{tk} =	360 N/mm²	nominal value of ultimate tensile strength
- E =	210.000 N/mm²	modulus of elasticity
- ρ =	7.850 Kg/m³	density
- v =	0.3	Poisson's ratio in elastic stage

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

▪ SAFETY MATERIAL FACTORS:

- γ_{MO} =	1	cracking safety factor
- γ_{M1} =	1	instability safety factor
- γ_{M2} =	1.25	fracture safety factor

▪ NUTS AND BOLTS: stainless steel A2 CLASS (UNI EN ISO 3506)

▪ WELDING: according to UNI EN ISO 3834
UNI EN ISO 15609-1

▪ PROTECTION: hot dip galvanizing according to UNI EN 1461

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

ASSESSMENTS OF LOADS

The following loads and overloads are examined:

. foundation and structure on elevation mass
. lantern with their support, possible ladder and accessories selfweight
. static and dynamic wind forces estimated according to EN 1991-1-1 and EN 1991-1-4
(areas exposed to wind of lanterns and accessories are considered, to computed area of the ladder exposed area of the shaft is increased of 6 cm/m)

CLASSIFICATION OF ACTIONS

Selfweight effects, vertical accidental loads into/out of alignement with mast are represented by a vertical forces system:
- concentrated (lantern, support and different accessories weight)
- distributed along the shaft (mast mass and possible ladder)

Wind effects are represented by a system of static equivalent horizontal forces (following the wind direction) according to EN 1991-1-4.
Each force is given by:

Fw = Ce · Cp · Cd · Qb · S

where
. Ce = exposure factor, as a function of terrain topography, category site, height of structure above ground
. Cp = shape factor, as a function of geometry and tipology structure and its wind direction
. Cd = through the dynamic coefficient, we consider the reductive effects linked to the non-contemporaneity of the maximum local pressure and of amplifying effects caused by the structural vibrations.
This coefficient is function of the vibration period, which is previously established:

Cd =	1.15		
where			
T =	2.08	s	period of vibration

. S = projected area on the vertical plane normal to the direction of the wind
. Qb = design wind pressure

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

MODELING OF THE STRUCTURE AND OF THE CONSTRAINTS

The structural analysis of the mast is conducted with the help of a computation code specifically drawn up to calculate this kind of structures.
The reliability of results has been validated by comparison with done by hand calculations and computer programs set up to solve static analysis of three dimensional structure.
The undertaken analysis is linear static.
The structural system is represented by a vertical cantilever, changing cross section along the shaft.
The internal forces, axial and shear forces and bending moments, due to characteristic values of the actions for the above loading cases are calculated.
This calculation report is based on limite state principles. Factored loads effects (design loads) are compared with the resistance of the structure (design strength) reduced by a safety factor.
The design value of the effects of action is calculated from the combinations of action in conformity with EN 1990.
The second order effects are also considered by means of bending moments caused by vertical loads and horizontal movement due to the wind.
Characteristic values of permanent and variable loads with corresponding partial factor are indicated below.

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

DESIGN LOADS

COMBINATION OF ACTION (ULS verification): WIND

- $Ned = \gamma_G \cdot G + \gamma_P \cdot P$
- $Ved = \gamma_W \cdot W$
- $Med = \gamma_G \cdot M_G + \gamma_P \cdot M_P + \gamma_W \cdot M_W$

where

. Ned = design axial force
. Ved = design shear force
. Med = design bending moment
. γ_G = partial load factor = 1.35
. γ_P = partial load factor = 1.35
. γ_W = wind partial load factor = 1.5
. G = self weight
. P = dead load
. W = wind shear force
. M_G = self weight bending moment (2° order)
. M_P = dead load bending moment (1° e 2° order)
. M_W = wind bending moment

COMBINATION OF ACTION (SLS verification):

- $Ned = \gamma_G \cdot G + \gamma_P \cdot P$
- $Ved = \gamma_W \cdot W$
- $Med = \gamma_G \cdot M_G + \gamma_P \cdot M_P + \gamma_W \cdot M_W$

where

. Ned = design axial force
. Ved = design shear force
. Med = design bending moment
. γ_G = partial load factor = 1.0
. γ_P = partial load factor = 1.0
. γ_W = wind partial load factor = 1.0
. G = self weight
. P = dead load
. W = wind shear force
. M_G = self weight bending moment (2° order)
. M_P = dead load bending moment (1° e 2° order)
. M_W = wind bending moment

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

DESIGN STRENGTH

Design resistance, comparable with design forces indicated in the foregoing explanation, are defined by the following relations with a safety factor equal to 1.05 and with a characteristic yeld strength of the steel equal to 3550 daN/cmq.
To take into account local instability cases typical of cold formed section, steel yeld strength is reduced by a factor depending on diameter/thickness ratio:

$D / t < 16984 / fyk$	→	$\eta = 1$
$16984 / fyk \le D / t \le 89600 / fyk$	→	$\eta = 4546 / (D/t) + 0.4\ fyk$

- $Nrd = A \cdot \eta \cdot Fyk / \Upsilon_M$
- $Vrd = Av \cdot \eta \cdot Fyk / (\sqrt{3} \cdot \Upsilon_M)$
- $Mrd = W \cdot \eta \cdot Fyk / \Upsilon_M$

where
. Nrd = design axial strength
. Vrd = design shear strength
. Mrd = design bending strength
. Fyk = steel characteristic yeld strength = 3550 daN/cmq
. Υ_M = material partial factor = 1
. A = cross sectional area
. Av = shear cross sectional area
. W = elastic modulus of cross section
. η = strength reductive factor

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

VERIFICATION REPORTS

The bottom of every shaft section is checked for the main loads combination. The dominating variable action is wind.
The first check schematizes wind effects by static equivalent horizontal forces.
The second check takes into account stress and strain increase of the structure due to its vibration in wind direction by a dynamic factor.
Global buckling is taken into account by a buckling reduction factor.
Where the shear force is less than half the elastic shear resistance its effects on the moment resistance may be neglected.
In the case of the bending with compression, the verification for the Ultimate Limit State is carried out by using the following equation:

• Ned / (Nrd · χ) + K · Med/Mrd ≤ 1

where
. Ned = design axial force
. Nrd = design axial strength
. Med = design bending moment
. Mrd = design bending strength
. χ = buckling reduction factor
$\chi = 1 / (\Phi + \sqrt{(\Phi^2 - \lambda s^2)})$
$\lambda s = \lambda / 76.39$
$\lambda = Lo / i$ slenderness
$\lambda 1 = 93{,}9\ \varepsilon$ adimensional slenderness
$\varepsilon = \sqrt{}\ 235 / fyk$
$\Phi = 0.5\ [1 + \alpha\ (\lambda s - 0.2) + \lambda s^2]$
$\alpha = 0.49$ failure factor
. K = interaction factor
$K = \alpha\ [1 + 0.6\ \lambda s\ Ned\ \gamma_M / (\chi\ A\ Fyk)]$

• Ved ≤ 0.5 · Vrd

where
. Ved = design shear force
. Vrd = design shear strength

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

DEFORMABILITY CHECK

The maximum horizontal deflection under the action of the characteristic loads is calculated to control that all relevant serviceability criteria are satisfied.
For deflection calculations this is a serviceability limit state and partial load factor is taken as 1.0.
The maximum horizontal deflection shall not exceed $(0.04 \cdot H)$ where H is the nominal height of the mast, in according to European Standards EN40.

Deflection should be taken as:

$$\Sigma\, Sf\ (N) = Tf\ (N) \cdot (Hs/2)^3 / (3 \cdot E \cdot J(N)) + Mf\ (N) \cdot (Hs/2)^2 /(2 \cdot E \cdot J(N))$$

where

- N = mast sections number
- Hs = height of nth section
- Tf (N) = shear force of nth section
- Mf (N) = bending moment of nth section
- J (N) = moment of inertia of nth section

The value of Sf at the top gives the maximum deflection value.

PERIOD OF VIBRATION

The natural period of vibration T in seconds, is obtained by the Rayleigh method:

$$T = 2\pi \cdot (\Sigma\, Pi \cdot yi) / (g \cdot (\Sigma\, Pi \cdot yi))$$

- Pi = equipment and shaft mass concentrated in their centroid and horizontally acting
- yi = deflection related to each force
- g = gravity acceleration = 9,81 m/s^2

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

WIND CALCULATIONS

The wind action on the structure is represented by a simplified set of pressure or forces whose effects are equivalent to the extreme effects of the turbulent wind.
The wind actions are determined from the basic values of wind velocity and they are characteristic values having annual probabilities of exceedence of 0.02, which is equivalent to a mean return of 50 years.

Fundamental value of the basic wind velocity $v_{b,o}$:

$v_{b,o}$ = **25.0** m/s

is the characteristic 10 minutes mean wind velocity with an annual risk of being exceeded of 0.02, irrespective of wind direction and time of year, at 10 m above ground level.
The fundamental value of the basic wind velocity may be given in the National Annex (wind maps).

Basic velocity pressure $q_b = \rho \cdot v_b^2 / 2$ = **39.1** daN/mq

where
$\rho = 1.25$ Kg/m³ is the air density

Peak velocity pressure $Q_b(H) = c_e(z) \cdot q_b$ = **109.8** daN/mq

where
. $c_e(z) = c_r(z)^2 + 7 \cdot K_r \cdot c_r(z)$ is the exposure factor = 2.81
. Terrain category (ref. Table 4.1) = **II**
→ Area with low vegetation such as grass and isolated obstacles (trees, buildings…) with separation of at least 20 obstacle heights

Wind velocity at z height:

$V(z) = \sqrt{(20 \cdot q_p(z) / \rho)}$ = **41.9** m/s → **151** Km/h

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

INPUT DATA:

. MAST HEIGHT ABOVE GROUND	H =	20	m
. HIGH MAST EMBEDDED LENGTH	H' =	0	m
. TILT OF THE SHAFT	% =	0.023	
. BASIC WIND VELOCITY (10 min mean velocity at 10 meters)	vref =	25	m/s
. WIND MAXIMUM VELOCITY	V =	151	Km/h
. PEAK VELOCITY PRESSURE	Qb =	110	daN/mq
. NUMBER OF LANTERNS	n =	13	
180° arranged			
. LANTERN MASS	p =	22	daN
. EXPOSED GLOBAL AREA OF LANTERNS	S =	3.3	mq
. CONTROL BOX MASS	p' =	0	daN
. EXPOSED AREA OF A CONTROL BOX	S1 =	0	mq
. ACCESSORIES MASS AND LIVE LOAD ON PLATFORM	p'' =	1710	daN
. EXPOSED GLOBAL AREA OF ACCESSORIES (control box included)	S2 =	2.55	mq
. SCREEN BARYCENTER POSITION (above ground level)	Hs =	20	m
. ACCESSORIES BARYCENTER POSI (above ground level)	Hs' =	20	m
. ECCENTRIC AXIAL LOAD 1	P1e =	0	daN
. X1 position	x1 =	0	m
. Y1 position	y1 =	0	m
. ECCENTRIC AXIAL LOAD 2	P2e =	0	daN
. X2 position	x2 =	0	m
. Y2 position	y2 =	0	m

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

THE HIGH MAST IS DIVIDED INTO N°2 SECTIONS

. 1° SECTION LENGTH	L1 =	10400	mm
. 2° SECTION LENGTH	L2 =	10400	mm
. 1° OVERLAP LENGTH	L1s =	800	mm
. GLOBAL SLENDERNESS		99	
. PERIOD OF VIBRATION T		2.08	sec
. MAXIMUM HORIZONTAL DEFLECTION		**532**	mm
. H/f RATIO		38	
. SHAFT MASS		1129	daN

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

FIRST SECTION:

. top diameter	220	mm
. bottom diameter	459	mm
. thickness	5	mm

SECOND SECTION:

. top diameter	431	mm
. bottom diameter	670	mm
. thickness	5	mm

BASE PLATE: steel S355 JR

. external diameter	860	mm
. internal diameter	620	mm
. thickness	25	mm
. pitch circle of anchor bolts	760	mm

STRAIGHT ANCHOR BOLT: [embedded length = 900 mm] N.16 M27 Lg. 1100 mm
TEMPLATE : width 120 mm thickness 12 mm S275 JR

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

The shaft is divided into 15 sections.
The following table shows the masse of every section and the force generated by the wind in every section.

Z	Ce(z)	Qw	A	D	Cp	F	P
(m)		(daN/mq)	(mq)	(m)		(daN)	(daN)
20.0	*2.810*	*109.8*	*3.25*	*-*	*1*	*356.7*	*286*
20.0	*2.810*	*109.8*	*2.55*	*-*	*1.2*	*335.9*	*1710.00*
20.00	2.810	109.8	0.000	0.220	1.20	0.0	0.00
19.33	2.787	108.9	0.363	0.235	1.20	47.5	51.81
18.00	2.738	107.0	0.403	0.265	1.20	51.8	56.75
16.67	2.686	104.9	0.443	0.295	1.20	55.8	61.68
15.33	2.630	102.8	0.483	0.325	1.20	59.6	66.61
14.00	2.570	100.4	0.523	0.355	1.20	63.0	71.54
12.67	2.504	97.8	0.563	0.385	1.15	63.4	76.48
11.33	2.432	95.0	0.603	0.415	1.10	63.1	81.41
10.00	2.352	91.9	0.643	0.445	1.05	62.2	86.34
8.67	2.262	88.4	0.683	0.475	1.00	60.5	91.27
7.33	2.159	84.3	0.723	0.505	0.95	58.1	96.21
6.00	2.037	79.6	0.763	0.535	0.90	54.9	101.14
4.67	1.889	73.8	0.803	0.565	0.85	50.6	106.07
3.33	1.698	66.3	0.843	0.595	0.80	45.0	111.00
2.00	1.423	55.6	0.883	0.625	0.76	37.1	115.93
0.67	1.423	55.6	0.923	0.655	0.71	36.3	120.87

. Z = height of center of gravity of the nth section
. Ce(z) = exposure coefficient of center of gravity of the nth section
. Qw = wind pressure of the nth section
. A = area exposed to wind of the nth section
. D = diameter of the nth section
. Cp = force coefficient of center of gravity of the nth section
. F = wind force on the nth section
. P = masse of the nth section

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

DESIGN INTERNAL FORCES OF SECTIONS: STATIC CASE

Z	D	N	V	M1	Me	M2	Md	Vd	Nd
(m)	(m)	(KN)	(KN)	(KNm)	(KNm)	(KNm)	(KNm)	(KN)	(KN)
20.00	0.220	26.946	10.389	0.0	0.0	1.355	**1.36**	**10.39**	**26.95**
18.67	0.250	27.645	11.101	7.4	0.0	3.658	**11.06**	**11.10**	**27.65**
17.33	0.280	28.412	11.878	29.6	0.0	5.405	**35.05**	**11.88**	**28.41**
16.00	0.310	29.244	12.715	46.0	0.0	7.052	**53.09**	**12.71**	**29.24**
14.67	0.340	30.143	13.609	63.6	0.0	8.584	**72.17**	**13.61**	**30.14**
13.33	0.370	31.109	14.554	82.4	0.0	9.991	**92.36**	**14.55**	**31.11**
12.00	0.400	32.142	15.505	102.4	0.0	11.270	**113.68**	**15.50**	**32.14**
10.67	0.430	33.241	16.452	123.7	0.0	12.418	**136.13**	**16.45**	**33.24**
9.33	0.460	34.406	17.384	146.3	0.0	13.433	**159.70**	**17.38**	**34.41**
8.00	0.490	35.639	18.292	170.0	0.0	14.308	**184.36**	**18.29**	**35.64**
6.67	0.520	36.937	19.164	195.0	0.0	15.043	**210.06**	**19.16**	**36.94**
5.33	0.550	38.303	19.987	221.1	0.0	15.560	**236.68**	**19.99**	**38.30**
4.00	0.580	39.735	20.747	248.3	0.0	16.010	**264.29**	**20.75**	**39.73**
2.67	0.610	41.233	21.422	276.4	0.0	16.313	**292.70**	**21.42**	**41.23**
1.33	0.640	42.798	21.979	305.3	0.0	16.467	**321.79**	**21.98**	**42.80**
0.00	0.670	44.430	22.523	335.0	0.0	16.486	**351.48**	**22.52**	**44.43**

. Z = height of bottom diameter of the nth section
. D = bottom diameter of the nth section
. N = design axial force of the nth section
. V = design shear force of the nth section
. M1 = design bending moment of the 1° order of the nth section
. M2 = design bending moment of the 2° order of the nth section
. Me = design bending moment due to eccentric load of the nth section
. Md = global design bending moment of the nth section
. Vd = global design shear force of the nth section
. Nd = global design axial force of the nth section

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

DESIGN INTERNAL FORCES OF SECTIONS: DYNAMIC CASE

Z	D	N	V	M1	Me	M2	Md	Vd	Nd
(m)	(m)	(KN)	(KN)	(KNm)	(KNm)	(KNm)	(KNm)	(KN)	(KN)
20.00	0.220	26.946	11.947	0.0	0.0	1.355	**1.36**	**11.95**	**26.95**
18.67	0.250	27.645	12.765	8.5	0.0	3.658	**12.17**	**12.77**	**27.65**
17.33	0.280	28.412	13.658	34.1	0.0	5.405	**39.50**	**13.66**	**28.41**
16.00	0.310	29.244	14.621	52.9	0.0	7.052	**60.00**	**14.62**	**29.24**
14.67	0.340	30.143	15.649	73.1	0.0	8.584	**81.71**	**15.65**	**30.14**
13.33	0.370	31.109	16.736	94.7	0.0	9.991	**104.71**	**16.74**	**31.11**
12.00	0.400	32.142	17.830	117.8	0.0	11.270	**129.03**	**17.83**	**32.14**
10.67	0.430	33.241	18.918	142.3	0.0	12.418	**154.67**	**18.92**	**33.24**
9.33	0.460	34.406	19.990	168.2	0.0	13.433	**181.63**	**19.99**	**34.41**
8.00	0.490	35.639	21.034	195.5	0.0	14.308	**209.85**	**21.03**	**35.64**
6.67	0.520	36.937	22.037	224.3	0.0	15.043	**239.30**	**22.04**	**36.94**
5.33	0.550	38.303	22.983	254.3	0.0	15.560	**269.83**	**22.98**	**38.30**
4.00	0.580	39.735	23.857	285.5	0.0	16.010	**301.51**	**23.86**	**39.73**
2.67	0.610	41.233	24.634	317.8	0.0	16.313	**334.14**	**24.63**	**41.23**
1.33	0.640	42.798	25.274	351.1	0.0	16.467	**367.56**	**25.27**	**42.80**
0.00	0.670	44.430	25.899	385.2	0.0	16.486	**401.70**	**25.90**	**44.43**

. Z =	height of bottom diameter of the nth section
. D =	bottom diameter of the nth section
. N =	design axial force of the nth section
. V =	design shear force of the nth section
. M1 =	design bending moment of the 1° order of the nth section
. M2 =	design bending moment of the 2° order of the nth section
. Me =	design bending moment due to eccentric load of the nth section
. Md =	global design bending moment of the nth section
. Vd =	global design shear force of the nth section
. Nd =	global design axial force of the nth section

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

DESIGN STRENGTH OF SECTIONS

Z	D	s	D/s	Fydr	A	W	Nrd	Vrd	Mrd
(m)	(mm)	(mm)		(daN/cmq)	(cmq)	(cm³)	(KN)	(KN)	(KNm)
20.00	220	5	44.0	3550	33.6	179	**1192**	**438**	**64**
18.67	250	5	50.0	3489	38.3	232	**1335**	**491**	**81**
17.33	280	5	56.0	3343	43.0	293	**1436**	**528**	**98**
16.00	310	5	62.0	3225	47.6	360	**1536**	**565**	**116**
14.67	340	5	68.0	3128	52.3	435	**1637**	**602**	**136**
13.33	370	5	74.0	3047	57.0	516	**1737**	**639**	**157**
12.00	400	5	80.0	2978	61.7	604	**1837**	**675**	**180**
10.67	430	5	86.0	2919	66.4	699	**1938**	**712**	**204**
9.33	460	5	92.0	2867	71.1	802	**2038**	**749**	**230**
8.00	490	5	98.0	2822	75.8	911	**2138**	**786**	**257**
6.67	520	5	104.0	2782	80.4	1027	**2238**	**822**	**286**
5.33	550	5	110.0	2746	85.1	1150	**2338**	**859**	**316**
4.00	580	5	116.0	2714	89.8	1280	**2437**	**896**	**347**
2.67	610	5	122.0	2685	94.5	1417	**2537**	**933**	**381**
1.33	640	5	128.0	2659	99.2	1561	**2637**	**969**	**415**
0.00	670	5	134.0	2635	103.9	1712	**2737**	**1006**	**451**

. Z = height of bottom diameter of te nth section
. D = bottom diameter of the nth section
. s = thickness of the nth section
. Fydr = reduced yeld strenght = $\mu \cdot Fyd / \gamma_{MO}$
. μ = reduced yeld strenght factor depending on D/s ratio
. γ_{MO} = partial factor for resistance of nth section
. A = area of the nth section
. W = elastic modulus of the nth section
. Nrd = design axial strenght of the nth section
. Vrd = design shear strenght of the nth section
. Mrd = design bending strenght of the nth section

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

CHECK: STATIC CASE

The following table summarises the outcome of the check for the nth section through the exploitation ratio η.
The structure is checked if $\eta \le 1$ for the nth section.

Z (m)	λ	λs	Φ	X	k	Nd/χNrd	kMd/Mrd	η	
20.00	0	0.000	0.451	1.109	0.900	0.020	0.019	**0.040**	OK
18.67	18	0.235	0.536	0.982	0.903	0.021	0.123	**0.144**	OK
17.33	32	0.419	0.641	0.887	0.905	0.022	0.324	**0.346**	OK
16.00	43	0.566	0.750	0.805	0.907	0.024	0.415	**0.438**	OK
14.67	53	0.687	0.856	0.733	0.909	0.025	0.483	**0.508**	OK
13.33	60	0.789	0.955	0.669	0.911	0.027	0.536	**0.562**	OK
12.00	67	0.874	1.048	0.616	0.913	0.028	0.577	**0.606**	OK
10.67	72	0.948	1.133	0.571	0.915	0.030	0.610	**0.641**	OK
9.33	77	1.012	1.211	0.533	0.917	0.032	0.637	**0.669**	OK
8.00	82	1.068	1.283	0.501	0.918	0.033	0.658	**0.692**	OK
6.67	85	1.118	1.350	0.475	0.919	0.035	0.676	**0.710**	OK
5.33	89	1.162	1.411	0.452	0.920	0.036	0.689	**0.725**	OK
4.00	92	1.201	1.467	0.433	0.920	0.038	0.700	**0.738**	OK
2.67	94	1.237	1.519	0.417	0.921	0.039	0.708	**0.747**	OK
1.33	97	1.269	1.567	0.402	0.922	0.040	0.715	**0.755**	OK
0.00	99	1.298	1.612	0.389	0.923	0.042	0.719	**0.760**	OK

. Z = height of bottom diameter of the nth section
. λ = slenderness
. λs = non dimensional slenderness
. Φ = $0.5\,[1 + \alpha\,(\lambda s - 0.2) + \lambda s^2]$ = value to determine the reduction factor
. α = 0.49 = imperfection factor
. χ = $1 / [\,\Phi + \sqrt{\Phi^2 + \lambda s^2}\,]$ = reduction factor for the relevant buckling curve
. k = $\alpha\,[1 + 0.6\,\lambda s \cdot Ned / (Nrd \cdot \chi)]$ = interaction factor
. η = exploitation ratio

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

CHECK: DYNAMIC CASE

The following table summarises the outcome of the check for the nth section through the exploitation ratio η.
The structure is checked if η ≤ 1 for the nth section.

Z (m)	λ	λs	Φ	X	k	Nd/χNrd	kMd/Mrd	η	
20.00	0	0.000	0.451	1.109	0.900	0.020	0.019	**0.040**	OK
18.67	18	0.235	0.536	0.982	0.903	0.021	0.135	**0.157**	OK
17.33	32	0.419	0.641	0.887	0.905	0.022	0.365	**0.387**	OK
16.00	43	0.566	0.750	0.805	0.907	0.024	0.469	**0.492**	OK
14.67	53	0.687	0.856	0.733	0.909	0.025	0.547	**0.572**	OK
13.33	60	0.789	0.955	0.669	0.911	0.027	0.607	**0.634**	OK
12.00	67	0.874	1.048	0.616	0.913	0.028	0.655	**0.683**	OK
10.67	72	0.948	1.133	0.571	0.915	0.030	0.694	**0.724**	OK
9.33	77	1.012	1.211	0.533	0.917	0.032	0.725	**0.756**	OK
8.00	82	1.068	1.283	0.501	0.918	0.033	0.750	**0.783**	OK
6.67	85	1.118	1.350	0.475	0.919	0.035	0.770	**0.804**	OK
5.33	89	1.162	1.411	0.452	0.920	0.036	0.786	**0.822**	OK
4.00	92	1.201	1.467	0.433	0.920	0.038	0.799	**0.836**	OK
2.67	94	1.237	1.519	0.417	0.921	0.039	0.809	**0.848**	OK
1.33	97	1.269	1.567	0.402	0.922	0.040	0.816	**0.857**	OK
0.00	99	1.298	1.612	0.389	0.923	0.042	0.821	**0.863**	OK

. Z = height of bottom diameter of the nth section
. λ = slenderness
. λs = non dimensional slenderness
. Φ = $0.5\,[1 + \alpha\,(\lambda s - 0.2) + \lambda s^2]$ = value to determine the reduction factor
. α = 0.49 = imperfection factor
. χ = $1 / [\,\Phi + \sqrt{\Phi^2 + \lambda s^2}\,]$ = reduction factor for the relevant buckling curve
. k = $\alpha\,[1 + 0.6\,\lambda s \cdot Ned / (Nrd \cdot \chi)]$ = interaction factor
. η = exploitation ratio

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

INTERNAL FORCES AT THE BOTTOM OF THE MAST

Calculated internal forces at the bottom of the mast are indicated above (ULS and SLS).
Static internal forces are calculated according to the relevant combination of actions (see pag. 9)
Dynamic internal forces take into account a magnification factor (see pag. 7).

STATIC INTERNAL FORCES (ULS):

. BENDING MOMENT	Md =	**351.48**	KNm
. SHEAR FORCE	Vd =	**22.52**	KN
. AXIAL FORCE	Nd =	**44.43**	KN

DYNAMIC INTERNAL FORCES (ULS):

. BENDING MOMENT	Md' =	**401.70**	KNm
. SHEAR FORCE	Vd' =	**25.90**	KN
. AXIAL FORCE	Nd' =	**44.43**	KN

Calculated internal forces for serviceability limit state are indicated above:

. Nrd =	G + P	axial force
. Vrd =	W	shear force
. Mrd =	Mg + Mp + Mw	bending moment

where serviceability partial safety factor have a value equal to unity (SLS).

. BENDING MOMENT	Ms =	**235.54**	KNm	static
. SHEAR FORCE	Ts =	**15.02**	KN	
. AXIAL FORCE	Ns =	**32.91**	KN	
. BENDING MOMENT	Ms' =	**269.02**	KNm	dynamic
. SHEAR FORCE	Ts' =	**17.27**	KN	
. AXIAL FORCE	Ns' =	**32.91**	KN	

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

VERIFICATION OF FRICTION JOINTS

(re 'Calculation of minimum overlap' / ENEL Unità specialistica sistemi e componenti)

The contact surface between the upper and lower section consists of 16 trapezoids, as many as sides of the section itself, each of which has area At and forms an angle αt with the axis of the pole.
The insertion force F to join the sections generates a pressure p in the overlap area, whose component Ft applied to single trapezoid is equal to $Ft = p \cdot At$ directed perpendicularly to it.
This force generates a friction force Rt acting on the level of the trapezoid itself equal to :

$$Rt = \mu \cdot Ft = \mu \cdot p \cdot At$$

with $\mu = 0{,}3$ = friction coefficient between contact surfaces of two sections (hot dip galvanized steel)
The components Rta which are parallel to the pole axis and applied to trapezoids barycentre, generate a resisting moment due to friction equal to

$$Mra = 2 \cdot Rta \cdot (a1 + a2 + a3 + a4) = \mu \cdot p \cdot Dm^2 \cdot i_{min} \cdot K1 \cdot K2$$

with

- $2 \cdot tg(\alpha)$ = pole conicity
- $tg(\alpha t) = tg(\alpha) \cdot \cos(180/16)$
- $At = (Dg + tg(\alpha) \cdot Lmin) \cdot Lmin \cdot \sin(180/16) / \cos(\alpha t)$
- $Rta = Rt \cdot \cos(\alpha t) = \mu \cdot p \cdot At \cdot \cos(\alpha t) = \mu \cdot p \cdot Dm \cdot \sin(180/16) \cdot Lmin$
- a1,a2,a3,a4 = distances between centres of application of Rta forces
- p = pressure generated by the lower section to the upper section in the overlap length
- Dm = diameter of circle circumscribed to the medium section of overlap length
- Lmin = minimum overlap length between two sections
- $K1 \cdot K2 = 0{,}9808$ = coefficients dependent on geometry

Referring to the bending moment Mf which acts in the medium area of overlap due to the combination of considered stresses, in order to verify the conditions of stability for friction relevant to the sections joint, therefore following formula will have to be verified: $Mra > Mf$.
As the stresses produced by Mf in the section are lower than the relevant allowed value, it follows that:

$$W \cdot \sigma \cdot am > Mf$$

in which, replacing the previously calculated value of Mra and taking into consideration that for a 16 sided poligonal section $W = 0{,}76 \cdot Dm \cdot Di \cdot s$, (with Di = internal circumscribed diameter) therefore we obtain that formula which guarantees joint stability is verified :

Lmin / Dm > 1,5 condition for joint stability

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

BASE PLATE CHECK

BASE PLATE CHARACTERISTICS

. external diameter:	860	mm
. internal diameter :	620	mm
. thickness :	25	mm
. pitch circle of anchor bolts:	760	mm
. drilling step :	149.2	mm
. number of bolts :	16	
. base plate steel grade :	S355 JR	
. number of ribs:	16	
. thickness of ribs:	10	mm
. ribs steel grade :	S235 JR	

DESIGN INTERNAL FORCES IN THE BASE PLATE

Mpd = Nrd · d =	8.52	KNm

where

. Nrd = design tensile strength		
= A · Fyk / ϒm :	19373	daN
. A = bolt cross section :	4.59	cmq
. fyk = characteristic yeld strength :	3550	daN/cmq
. ϒm = partial safety factor :	1.25	
. d = mean distance between rib and bolt :	5.06	cm

DESIGN STRENGTH OF THE BASE PLATE

Mrd = W · fyk / ϒm =	11.32	KNm

where

. W = base plate elastic modulus :	33.5	cm^3
. fyk = characteristic yeld strength :	3550	daN/cmq
. ϒm = partial safety factor :	1.25	

BASE PLATE CHECK

. ηp = Mpd / Mrd =	**0.752**	≤ 1	OK

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

SHAFT-BASE PLATE FILLET WELD CHECK

Geometrical characteristic of fillet weld:

. internal diameter of fillet weld	Ds =	670	mm
. minimum fillet weld leg size	Ss =	8	mm
. fillet weld throat thickness	Sg =	5.7	mm
. fillet weld area	As =	12007	mmq
. fillet weld elastic modulus	Ws =	2011531	mm3
. fillet weld tensile strength		5100	daN/cmq

Design stresses in fillet weld:

Static case:

. ns = Nds / As + Mds / Ws =	1784.3	daN/cmq
. ts = 2 Vds /As =	37.5	daN/cmq

Dynamic case:

. nd = Ndd / As + Mdd / Ws =	2034.0	daN/cmq
. td = 2 Vdd / As =	43.1	daN/cmq

Verification reports:

Static case:

. $\sqrt{(ns^2 + ts^2)}$ =	1785.5	daN/cmq	≤	β1 · fyk =	2485	daN/cmq
. ns + ts =	1821.8	daN/cmq	≤	β2 · fyk =	3018	daN/cmq

Dynamic case:

. $\sqrt{(nd^2 + td^2)}$ =	2035.4	daN/cmq	≤	β1 · fyk =	2485	daN/cmq
. nd + td =	2077.1	daN/cmq	≤	β2 · fyk =	3018	daN/cmq

where

. fyk =	3550	daN/cmq	characteristic yeld strength of base plate
. β1 =	0.7		factor
. β2 =	0.85		factor

The verification is checked

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

CHARACTERISTICS OF ANCHOR BOLTS **N.16 M27 Lg. 1100 mm**

HEADED ANCHOR BOLTS

. number of anchor bolts :	16	
. diameter of anchor bolts :	27	mm
. embedded length of anchor bolt :	900	mm
. total length of anchor bolt :	1100	mm
. steel grade of anchor bolt :	S355 JR	
. diameter of ring template :	760	mm
. thickness of ring template:	**12**	mm
. width of ring template:	**120**	mm
. steel grade of ring template :	S235 JR	

CHECK OF BASE PLATE AND BOLTS SYSTEM

The ultimate strength of section has been obtained by calculating the resultant of tensile and compression stress in the concrete and in the anchor bolts:

Mrd = Mrd,c + Mrd,s

where

. Mrd,c = Nc(yc) · ycg =	354.4	KNm	contribution of concrete
. Mrd,s = Σ Asi · σsi · (D/2 - ysi) =	559.6	KNm	contribution of reinforced bars

. Nc(yc) = contribution of concrete (stress block hypothesis)
. σsi = tension in reinforced bars
. ycg = distance between barycenter of compressed zone and cross section centre
. D = external diameter of base plate
. ysi = distance between bolt axis and compressed size

from which

. Mrd = ultimate resistance of base plate and anchor bolt system:	914.0	KNm
. ycg = distance barycenter of compressed zone and section centre:	323.7	mm

Static check:

ηs = Med / Mrd =	**0.481**	≤ 1	OK

Dynamic check :

ηd = Med' / Mrd =	**0.549**	≤ 1	OK

The verification is checked

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

DESIGN INTERNAL FORCES IN ANCHOR BOLT

Ndt = σd · A =	129.36	KN	axial force
Vdt = Vd / nt =	1.62	KN	shear force

where

. σd = Nd' / A ± Md' c / J =	281.83	N/mmq	anchor bolt stress
. A =	459	mmq	anchor bolt area
. nt =	16		anchor bolt number
. Nrd =	168.54	KN	axial design strength
. Vrd =	112.36	KN	shear design strength

Check:

Ndt / Nrd =	**0.768**	< 1	OK

EMBEDMENT LENGTH OF ANCHOR BOLTS

The force (Nrd - Ra) is absorbed by the ring template:

Rd =	79379	N	ring template resistance
Ra = π · fbd · Ø · La =	89166	N	design bond strength of anchor bolt

where

. Nrd =	168545	N	design strength of anchor bolt
. Ø =	27	mm	diameter of anchor bolt
. fbd = 0.32 √Rck / Yc =	1.168	N/mmq	design value ultimate bond stress
. Rck =	30	N/mmq	cubic compressive strength
. Yc =	1.5		safety material factor
. La =	900	mm	embedment lenght

The minimun thickness of ring template is:

a = [3p /(4 fyd)] ½ (Ld-Ø) =	12.00	mm	minimum thickness ring template

with

. p = Rd / (Ld · Ld) =	44.33	daN/cmq	design pressure on ring template
. Ld =	120	mm	width of ring template
. fyd =	275.0	N/mmq	design yeld strength of base plate
. Ø =	27	mm	diameter of anchor bolt

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

CHECK OF THE OPENING DOOR

The shaft is checked at the lower and upper section of the opening door.

INPUT DATA:

. bottom diameter of the shaft =	670	mm	
. tilt of the shaft =	0.023	%	
. embedment length of the shaft =	0	mm	
. opening door ground clearance =	400	mm	
. height of the opening door =	700	mm	

SHAFT DIAMETERS CORRESPONDING TO OPENING DOOR:

. shaft diameter lower end of the opening door =	660.8	mm	
. shaft diameter upper end of the opening door =	644.7	mm	

OPENING DOOR DATA:

. shaft diameter Dip =	660.8	mm	lower section
. shaft thickness sp =	5	mm	
. width of the opening door =	205	mm	

A dimensionless factor is introduced to consider the partialization of the resistant section; the factor is measured as the ratio of the opening distance p and the mean diameter of the section:

. factor α = p / (Dip - sp) = 0.3126

The opening door is reinforced with metal frame: 80x20 mm

. reinforcement width =	80	mm
. reinfordement thickness =	20	mm
. eccentricity =	0	mm
. steel grade =	S275 JR	

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

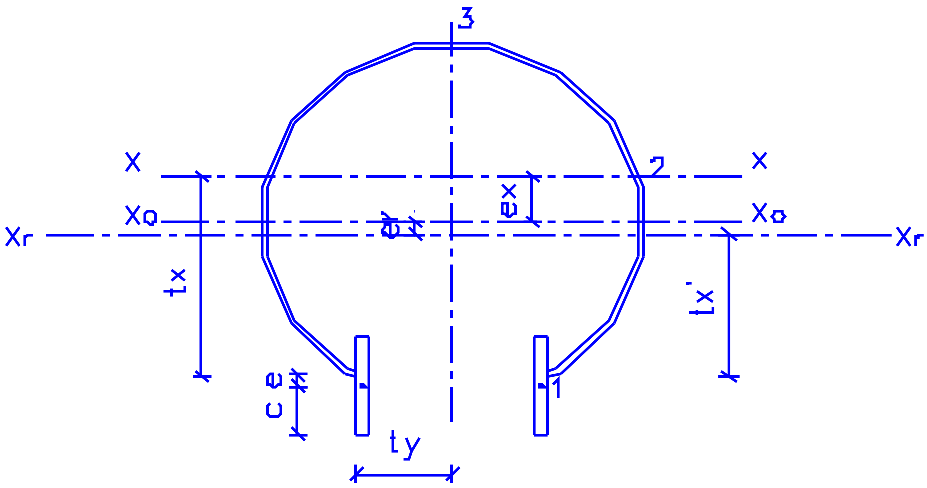
$0,1951 < \alpha < 0,5556$

CHARACTERISTICS OF NOT REINFORCED SECTION:

. ex =	37.4	mm
. A =	91.8	cm2
. Jx =	41646.6	cm4
. Jy =	53185.4	cm4
. tx =	343.1	mm
. ty =	102.5	mm
. Wx =	1213.9	cm3
. Wy =	1609.7	cm3
. reinforcement width =	80	mm
. reinforcement thickness =	20	mm

CHARACTERISTICS OF REINFORCED SECTION:

. At =	123.8	cm2
. x reinforcement =	0.0	mm
. tx' =	252.9	mm
. ty' =	102.5	cm4
. Jx' =	70703.5	cm4
. Jy' =	56558.1	cm4
. Wx1 = (shaft)	2795.8	cm3
. Wy2 = (shaft)	1711.8	cm3
. Wx3 = (shaft)	1845.3	cm3
. Wps = (reinforcement)	3321.1	cm3
. Wpi = (reinforcement)	2414.0	cm3
. er =	52.8	mm



N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

Maximum internal forces in the lower section:

. Npl =	4443	daN
. Mpl =	39146	daNm

Design strengths:

. Mrx = Wx · η · Fyk / γm =	32073	daNm	not reinforced
. Mry = Wy · η · Fyk / γm =	42533	daNm	not reinforced
. Nrd = (A· η · Fyk + Ar· Fyk') / γm =	330516	daN	
. Mrx1 = Wx1 · η · Fyk / γm =	73872	daNm	
. Mrx3 = Wx3 · η · Fyk / γm =	48758	daNm	
. Mry2 = Wy2 · η · Fyk / γm =	45230	daNm	
. Mrps = Wps · Fyk' / γm =	91331	daNm	
. Mrpi = Wpi · Fyk' / γm =	66385	daNm	

con

. Fyk =	3550	daN/cmq	shaft	S355 JR
. Fyk' =	2750	daN/cmq	reinforcement	S275 JR
. γm =	1		partial material factor	

Considering the ratio diameter / thickness = Dip / sp = 132.16 ; the reduction factor of the characteristic yeld strength is equal to:

η = [4546 / (Dip/sp) + 0.4 fyk] / 237 = 0.744

CHECK :

. Np / Nrd + Mp / Mrx1 =	**0.54**	≤ 1	OK
. Np / Nrd + Mp / Mrx3 =	**0.82**	≤ 1	OK
. Np / Nrd + Mp / Mry2 =	**0.88**	≤ 1	OK
. Np / Nrd + Mp / Mrpi =	**0.60**	≤ 1	OK

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

OPENING DOOR DATA:

. shaft diameter Dsp =	644.7	mm	upper section
. shaft thickness sp =	5	mm	
. width of the opening door =	205	mm	
. factor $\alpha = p / (Dsp - sp)$ =	0.3205		
. reinforcement width =	80	mm	
. reinfordement thickness =	20	mm	
. eccentricity =	0	mm	
. steel grade =	S275 JR		

$0,1951 < \alpha < 0,5556$

CHARACTERISTICS OF NOT REINFORCED SECTION:

. ex =	37.6	mm
. A =	89.3	cm2
. Jx =	38350.0	cm4
. Jy =	49335.7	cm4
. tx =	334.7	mm
. ty =	102.5	mm
. Wx =	1145.9	cm3
. Wy =	1530.5	cm3
. reinforcement width =	80	mm
. reinforcement thickness =	20	mm

CHARACTERISTICS OF REINFORCED SECTION:

. At =	121.3	cm2
. x rinforzo =	0.0	mm
. tx' =	244.8	mm
. ty' =	102.5	cm4
. Jx' =	65839.1	cm4
. Jy' =	52708.4	cm4
. Wx1 = (shaft)	2689.5	cm3
. Wy2 = (shaft)	1635.1	cm3
. Wx3 = (shaft)	1757.3	cm3
. Wps = (reinforcement)	3214.9	cm3
. Wpi = (reinforcement)	2311.8	cm3
. er =	52.3	mm

N.C.M. srl
POLES AND HIGH MASTS FOR LIGHTING
Via Bramante, 24 - 20020 MAGNAGO (MI) - Italy

Maximum internal forces in the upper section:

. Npu =	4443	daN
. Mpu =	37354	daNm

Design strengths:

. Mrx = Wx · η · Fyk / γm =	30425	daNm	not reinforced
. Mry = Wy · η · Fyk / γm =	40637	daNm	not reinforced
. Nrd = (A· η · Fyk + Ar· Fyk') / γm =	324991	daN	
. Mrx1 = Wx1 · η · Fyk / γm =	71410	daNm	
. Mrx3 = Wx3 · η · Fyk / γm =	46659	daNm	
. Mry2 = Wy2 · η · Fyk / γm =	43414	daNm	
. Mrps = Wps · Fyk' / γm =	88408	daNm	
. Mrpi = Wpi · Fyk' / γm =	63574	daNm	

where

. Fyk =	3550	daN/cmq	shaft	S355 JR
. Fyk' =	2750	daN/cmq	reinforcement	S275 JR
. γm =	1		partial material factor	

η = [4546 / (Dsp/sp) + 0.4 fyk] / 237 = 0.748 reduction factor

CHECK:

. Np / Nrd + Mp / Mrx1 =	**0.54**	≤ 1	OK
. Np / Nrd + Mp / Mrx3 =	**0.81**	≤ 1	OK
. Np / Nrd + Mp / Mry2 =	**0.87**	≤ 1	OK
. Np / Nrd + Mp / Mrpi =	**0.60**	≤ 1	OK