

Designing power line towers using circular hollow sections

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April 28, 2013

Abstract

It has become a challenging exercise to obtain land in order to further develop the electrical infrastructure in South Africa. The reason for this is that high voltage transmission towers visually impacts the surroundings and require a large servitude in order to accommodate these structures. The requirements for low visible towers with small foundation footprints may be achieved with double circuit power line towers.

However, the structural loading in tower member's increase drastically as a result of large conductor bundles, higher reliability, smaller foundation footprints and a increase in wind loading because of the taller structures. This limits the further economical use of standard angular hot rolled sections and requires that alternative cross sections are considered in the design of power line towers.

The aim of this research is to focus on the practical and cost-effective implementation of circular hollow sections (CHS) in power line towers. The design of a power line system consist of a family of tower structures which include a large number of structural and non-structural members as well as many connections resisting various combinations of loads. The outcome of this research proves that a feasible and practical way exist to implement circular hollow sections in power line tower design using current design software, current design standards and current manufacturing techniques for South African conditions.

It is recommended that connections between tower elements should be similar to *existing connection practices* where possible. This will reduce the requirements for specialized software or connection standards. This will also facilitate the design of hybrid tubular and angular member towers. Hence a review of current angular member and connection design practices are given for the reader.

Before the design of a tubular power line tower may be done, various hollow section connections and stability criteria are reviewed. The CIDECT manuals provide an excellent resource for hollow section connections for static and dynamic conditions. It is important to note that it is not the intention of the author to question or improve on the existing hollow section design formulae, but rather to show their ease of implementation in the power line industry.

A tubular tower was designed and fabricated in order to combine the theory and practical implementation thereof. In the design of this test tower, the author introduced a novel cross arm design. The new configuration cross arm has only three main chords compared with the conventional cross arm with four main chords. It is envisaged that this new cross arm configuration will reduce overall tower cost as well as construction cost.

An analytical and numerical structural analysis was used to design the test tower. An isolated analysis was also performed on the tower cross arm in order to compare and validate the use of less expensive structural software. The comparison considered a full finite element analysis (ANSYS) compared with a beam element analysis (Prokon). The results show that there is an excellent correlation between the two models given that specific, yet simple modeling techniques are used to model the tower elements.

In order to conclude the validity of the recommended design approach and the integrity of the test structure, physical testing was done at the Eskom tower test facility. The structure was securely fixed to the base of the test bed and strain gauges were fitted on several of the tower members. Steel wire ropes with load cells were fitted to the cross arms of the structure and three typical load cases were evaluated.

Comparing the physical test results with the Prokon model, a 10% variation between member loads were recorded. The loads in the test tower was in most cases higher compared with the Prokon model.

In summary, the design process proposed here may successfully be used to design and manufacture CHS power line towers. The design process uses current design software, current design standards and current manufacturing techniques.

Further investigation on full scale structures are required in order to study the economics of tubular towers versus angular member towers. This study

should include fabricators and construction experts in order to comprehend the impact on the power-line industry. The author suspects that the fabrication cost of CHS towers will be slightly higher but the construction cost will be significantly less.

Opsomming

Dit is 'n uitdagende taak om grond te bekom ten einde verdere ontwikkeling van die elektriese infrastruktuur in Suid-Afrika. Die rede hiervoor is dat die hoë spanning krag torings visueel 'n invloed op die omgewing het en vereis 'n groot serwituut ten einde hierdie strukture te akkommodeer. Die vereistes vir lae sigbare torings met 'n klein fondament voetspoor kan bereik word met 'n dubbel baan kraglyn toring.

Die aksiale kragte in toring elemente neem drasties toe as 'n gevolg van groot geleier bundels, hoër betroubaarheid, kleiner fondasie voetspore en 'n toename in die wind lading as gevolg van die groter strukture. Dit beperk die verdere ekonomiese gebruik van standaard hoek ysters en vereis dat alternatiewe dwarsnitte beskou moet word in die ontwerp van kraglyn torings.

Die doel van hierdie navorsing is om te fokus op die praktiese en koste-effektiewe implementering van ronde buis seksies in kraglyn torings. Die ontwerp van 'n kraglyn stelsel bestaan uit 'n familie van toring strukture wat insluit 'n groot aantal van die strukturele en nie-strukturele elemente sowel as 'n groot aantal verbindings wat blootgestel is aan verskillende kombinasies van laste. Die uitkoms van hierdie navorsing bewys dat dit moontlik is om 'n buis kraglyn toring met behulp van huidige ontwerp sagteware, huidige ontwerp standaarde en die huidige produksie tegnieke te ontwerp.

Dit word aanbeveel dat die verbindings tussen die toring elemente soortgelyk moet wees aan *bestaande hoek yster verbindings* waar moontlik. Dit sal die vereistes vir gespesialiseerde sagteware of verbindings standaarde verminder. Dit sal ook die ontwerp van 'n hibriede buis en hoek yster torings vergemaklik. 'n Hersiening van die huidige ontwerp metodes vir hoek yster elemente en verbindings word gegee vir die leser. Voordat die ontwerp van 'n buis kraglyn toring gedoen kan word, is verskeie buis verbindings en stabiliteit kriteria hersien.

Die CIDECT handleidings gee 'n uitstekende bron vir hol buis verbindings vir statiese en dinamiese toestande. Dit is belangrik om daarop te let dat dit nie die bedoeling van die outeur is om betsaande buis ontwerp teorie te bevraagteken of te verbeter nie, maar eerder om te toon hoe maklik die uitvoering daarvan is in kraglyn torings.

'n Buis toring is ontwerp en vervaardigde om die teorie en praktiese implementering daarvan te kombineer. In die ontwerp van hierdie toets toring het die skrywer die geleendtheid gebruik om 'n oorspronklike kruis arm ontwerp voor gelê. Die nuwe konfigurasie kruis arm het net drie hoof stange in vergelyking met 'n konvensionele kruis arm met vier hoof stange. Dit word in die vooruitsig gestel dat hierdie nuwe kruis arm algehele toring koste sowel as boukoste sal verminder.

'n Analitiese en numeriese strukturele analise is gebruik om die toets toring te ontwerp. 'n Geïsoleerde analise is uitgevoer op die toring kruis arm om die geldigheid van die gebruik van goedkoper strukturele sagteware te bevestig. 'n Vergelykend analise is gedoen tussen 'n vol eindige element analise (ANSYS) en 'n balk element analise (Prokon). Die resultate toon dat daar 'n goeie korrelasie tussen die twee modelle is met spesifieke modelleringstegnieke.

Ten einde die geldigheid van die aanbevole ontwerp benadering en die integriteit van die toets struktuur te sluit, is 'n fisiese toets gedoen by die Eskom toring toetsfasiliteit. Die struktuur is stewig aan die basis van die toets bed geanker en rekstrookjies op verskeie elemente van die toring geplak. Staaltoustoppe met vrag selle is toegerus op die kruis arms van die struktuur waarna drie tipiese vrag gevalle geëvalueer is.

Die vergelyking van die fisiese toetsuitslae met die Prokon model, dui 'n 10% variasie in aksiale kragte tussen die verskeie toring element. Die ladinge in die toets-toring in die meeste gevalle was hoër in vergelyking met die Prokon model.

Ter opsomming, kan die ontwerp-proses wat hier voorgestel word suksesvol gebruik word om hol buis kraglyn torings te ontwerp en vervaardig. Die ontwerp maak gebruik van huidige ontwerp sagteware, huidige ontwerp standaarde en die huidige produksie tegnieke. Verdere ondersoek op volskaalse strukture word vereis ten einde die ekonomiese verskille tussen buis torings teenoor die hoek yster torings te bestudeer. Hierdie studie moet vervaardigers en konstruksie kundiges insluit om die impak op die kraglyn

bedryf ten volle te begryp. Die skrywer vermoed dat die vervaardiging koste van CHS torings effens hoër sal wees, maar die konstruksie koste aansienlik minder sal wees.

Contents

Abstract	i
Opsomming	iv
Symbols	xv
1 Introduction	1
1.1 Background	1
1.2 Aim of this research	2
1.3 Research objectives	2
1.4 Outline of dissertation	3
2 Current Design Practice	5
2.1 Loading on power line towers	7
2.1.1 Vertical loads on towers	8
2.1.2 Transverse loads on towers	8
2.1.2.1 Wind load on conductors	8
2.1.2.2 Wind load on tower members	9
2.1.2.3 Transverse loads due to line angle	11
2.1.3 Longitudinal loads	11
2.1.4 Test tower loading	11
2.2 Typical tower members and fabrication methods	12
2.3 Current tower design methods	13
2.4 Full scale testing of towers	14
2.5 The limitations of angular tower members	16
2.6 Conclusion	17
3 CHS vs. Various Cross Sections	19
3.1 Structural efficiency	19
3.2 Reduced painting area	22
3.3 Economics of structural hollow sections	23

3.4	Tubular profiles and telecommunication structures	24
3.5	Conclusion	26
4	Layout of power line towers	28
4.1	Conclusion	35
5	Overview of the tubular test tower	37
5.1	A novel cross arm	37
5.2	Tower review	39
5.3	Conclusion	46
6	Member Design	47
6.1	The tubular test tower	48
6.2	Structural modeling of the test tower	50
6.3	Structural strength	53
6.4	Cross arm connection	54
6.5	Bolted end connections	58
6.6	Column splice connection	58
6.7	Gusset plate connections	60
6.8	Conclusion	61
7	Tower Cross Arm Numerical Analysis	63
7.1	Structural modeling of the tower cross arm	64
8	Physical Testing of the Structure	74
9	Conclusion	84
	Appendices	87
A	Load limit of angular members	88
B	Structural capabilities of angle iron members	90
B.0.1	Slenderness ratio	90
B.0.2	Width-to-thickness ratio	93
C	Angle iron member connections	94
C.0.3	End distance	95
C.0.4	Center-to-center spacing	96
C.0.5	Edge distance	96
D	Ratio of I_{CHS}/I_{ANG} without Class 3 requirements	97

<i>CONTENTS</i>	ix
E Ratio of I_{CHS}/I_{ANG} with Class 3 requirements	99
F Holo bolts capacities and installation details	101
G Huck bolt fasteners	103
H Design guidelines for truss design	105
I Failure modes in circular hollow section connections	108
J Welded CHS connection capacities	109
K Application of SANS 10162-1	111
K.1 Slenderness	111
K.2 Maximum slenderness ratio (Sec 10.4.2.1):	112
K.3 Cross-sectional strength (Sec 13.8.3a):	112
K.4 Overall member strength (Sec 13.8.3b):	114
K.5 Lateral torsional buckling strength (13.8.3c):	115
L Bolted end plate connections	116
M Design of gusset plate connections	121
M.1 Resistance in chord plastification, N_1Rd_{PL} :	121
M.2 In-plane moment resistance, $(M_{ip.Rd})$	122
M.3 In plane bending moment, (M_{ip})	122
M.4 Resistance in punching shear, N_1Rd_{Pu}	123
M.5 Punching force, N_{pu}	123
M.6 Punching Force, N_{Pu}	124
M.7 Resistance in punching shear, N_1Rd_{Pu}	125
M.8 Resistance in chord plastification, N_1Rd_{PL} :	125
M.9 In-plane bending strength	126
M.10 Out-plane bending strength	126

List of Figures

1.1	Effect of multiple power line circuits in a single corridor. The corridors transmit equivalent electrical power. Left: A corridor with four 400kV circuits. Middle: A corridor with two 765kV circuits. Right: A corridor with one 765kV double circuit.	1
1.2	Picture showing the fabricated tubular test tower.	4
2.1	132 kV wood pole structure typically used in distribution lines.	6
2.2	132 kV wood pole structure typically used in distribution lines.	6
2.3	400 kV running angle tower.	6
2.4	400 kV transposition tower.	6
2.5	400 kV suspension structures.	7
2.6	400 kV double circuit structure, left: lattice type, Right: monopole type	7
2.7	765 kV double circuit tower in Korea	7
2.8	Comparison between single and double circuit 765 kV towers, Left: 765 kV double circuit tower, Right: 765 kV single circuit tower.	8
2.9	Variation of characteristic wind speed with terrain, height and class of structure (Table 5 in <i>SABS 0160-1989:The general procedures and loadings to be adopted in the design of buildings</i> (1989)).	10
2.10	Standard angle iron tower members packed for transportation to site.	13
2.11	Typical tower views from PLS Tower.	14
2.12	Typical layout of tower test facility. Large latticed steel structures may be seen.	15
3.1	Typical details of a CHS cross-section(<i>The teal book - Structural hollow sections in South Africa</i> 2010).	20

3.2	Relative masses of axially loaded struts (<i>Southern African Structural Hollow Sections Handbook</i> 1996).	21
3.3	Paint area of various sections, per meter (<i>Southern African Structural Hollow Sections Handbook</i> 1996).	22
3.4	Drag coefficients for lattice triangular and square cross sections (Nielsen & Stottrup-Andersen 2006).	25
3.5	Ice buildup model for rime on circular and angular profiles (ISO 12492 2001) (Nielsen & Stottrup-Andersen 2006).	25
4.1	Typical tower geometry.	28
4.2	Layout of tubular test tower.	29
4.3	Lattice type tower.	30
4.4	220/330 kV power line structure.	31
4.5	Single circuit tower - delta configuration.	31
4.6	Double circuit tower - vertical configuration.	31
4.7	Various transmission tower bracing types. The solid lines represent main braces, while the dashed lines represent redundant members.	32
4.8	Various bracing systems typically used in power line towers.	33
4.9	Variation in intersection of leg members with resultant load.	34
4.10	Diaphragm bracing in the tower body that are used to take up torsional loads.	35
5.1	New proposed cross arm - three main members.	38
5.2	Conventional tower cross arm - four main members.	38
5.3	A view from the side of the test tower showing the proposed tripod cross arm.	38
5.4	Conventional tower cross-arm model with bracing and four main members: 258Kg.	39
5.5	New proposed cross-arm model with no bracing and three main members: 102 Kg.	39
5.6	3D Cad model of tubular tower.	40
5.7	Fabricated tubular tower from 3D model.	40
5.8	Fabricated column splice that would typically be used to join adjacent tower panels or that would be used for tower base plate connections.	40
5.9	Column splice from 3D CAD model used on the test tower.	40
5.10	Typical fabricated gusset plate connection on the side of the tower.	41
5.11	Gusset plate connection from 3D CAD model.	41
5.12	Typical fabricated diaphragm bracing to absorb torsional loads.	41

5.13	Diaphragm bracing from 3D CAD model.	41
5.14	Typical fabricated end plate bracing showing a continuous weld in order to minimize fatigue failures.	42
5.15	End plate bracing from 3D CAD model.	42
5.16	Tubular test tower cross arm tip. This is a typical example of how the conductor attachment can be constructed.	43
5.17	Cross arm tip from 3D CAD model.	43
5.18	Tubular test tower lower cross arm - hamper connection.	44
5.19	Lower cross arm - hamper connection from 3D CAD model.	44
5.20	Tubular test tower upper cross arm - hamper connection.	45
5.21	Upper cross arm - hamper connection from 3D CAD model.	45
5.22	Section through upper cross arm - hamper connection.	45
6.1	Dimensional outline of tubular test tower.	49
6.2	Structural model of the test tower.	50
6.3	Load tree of tubular test tower.	51
6.4	Members 71-95-51 resemble rigid links on the tower model to ensure that all bending moments are included in the structural analysis. These rigid links take into consideration the radius of the hollow section.	52
6.5	Pinned cross arm model with a single conductor attachment point.	53
6.6	Rigid cross arm model with a double conductor attachment point.	53
6.7	Cross arm end connection.	55
6.8	Dimension of flange connection of cross arm beam.	56
6.9	Flange connection of cross arm beam.	56
6.10	T-stub welded attachment (figure 6.10).	59
6.11	Slotted end plate welded attachment (figure 6.11).	59
6.12	Column splice connection.	60
6.13	Parameter f_3 for column splice connection design.	60
6.14	Gusset plate connection layout.	61
7.1	Photo showing the attachment of the load cells on the test structure cross arm.	66
7.2	Prokon model 1: Tripod cross arm model - pinned. This cross arm has three main members that are fixed at the support and pinned at the conductor attachment end.	66

7.3	Prokon model 2: Improved cross arm model with specific end connection detail. The cross arm model consist of three main members that are fixed at the support and the conductor attachment end is more detailed with rigid links. Rigid represents only load transferring and not a structural member.	67
7.4	Finite element model of 3D cross arm.	67
7.5	Cross arm mesh control display after mesh refinement.	68
7.6	Revolute joint (Top 1A) indicating only rotation about the z-axis is permitted.	68
7.7	Reaction forces on revolute joint.	73
7.8	Graphical representation of reaction forces at a joint probe.	73
7.9	High stress gradient around hole joint.	73
8.1	Tubular test tower on test bed. Also visible are the covered load cells and steel ropes.	75
8.2	Isometric view indicating the position of the strain gauges that were fitted to the test tower.	76
8.3	Strain gauge fitted to tower member.	77
8.4	Prokon model of the test tower.	78
8.5	Graph of strain results - Cascade failure (the x-axis reports the seconds and the y-axis reports the strain in μm).	80
8.6	Graph of strain results - Broken cond. + No broken cond (the x-axis reports the seconds and the y-axis reports the strain in μm).	81
8.7	Graph of strain results - High transverse wind (the x-axis reports the seconds and the y-axis reports the strain in μm).	82
B.1	Angular cross section properties according to <i>Southern African Steel Construction Handbook</i> (2008).	90
B.2	Determination of w/t	93
C.1	Typical angle member connection detail.	94
F.1	Hollo Bolt capacities.	101
F.2	Hollo Bolt installation.	102
F.3	Hollo Bolt installation section view.	102
G.1	Huck BOM fastener.	103
G.2	Huck BOM fastener installation details.	104
G.3	Huck BOM fastener hand tool.	104
H.1	Noding eccentricity limits (Wardenier 2001).	106

H.2 Illustration of gap and overlap (Wardenier 2001). 107

I.1 Typical CHS failure modes (Wardenier 2001). 108

J.1 d_1/t_1 limits for compression bracing members (Wardenier 2001).109

J.2 Load capacities of welded CHS joints (Wardenier 2001). 110

L.1 T-stub welded attachment. 116

L.2 Slotted end plate welded attachment. 116

L.3 Load dispersion through T-stub connection. 119

Symbols

AC alternating current

ASCE American Society of Civil Engineers

A_e effective frontal area

B length of gusset plate

b_1 width of brace member

b_o width of chord member

CHS circular hollow sections

C_f overall force coefficient for lattice towers

C_u ultimate compressive load

C_r ultimate compressive resistance

C_{xc} drag coefficient of the conductor

C_c critical buckling factor

C_u ultimate compressive load

C_r ultimate compressive resistance

CIDECT International Committee for the Study and Development of Tubular Construction

c_o, c_1 coefficients

DC direct current

D diameter of circular hollow section member

d diameter of conductor

E modulus of elasticity

EMV extra high voltage

ERW electric resistance welding

e distance from center of hole to end of member

FEA finite element analysis

F_{cr} critical stress for local buckling

F_v design shear stress

F_u specific minimum tensile strength

F force acting on the tower panel (direct wind load)

F_y yield strength

F_a design compressive stress

F_b design bending stress

f distance from center of hole to edge of member

f(n') function to include additional loads such as chord loads

G_c combined wind factor for conductors

G_L span factor

H transverse load due to wire tension

HV high voltage

IEC International Electrotechnical Commission

K effective length factor

k strain gauge factor

k_p factor for converting wind speed into velocity pressure

kV kilo volt

L unbraced length, wind span, longitudinal load on tower cross arm

LV low voltage

M moment

M_f moment in flange

$M_{pl,f}$ plastic moment capacity of flange

M_r ultimate moment resistance

M_u ultimate moment

M_x moment reaction in the x-direction

M_y moment reaction in the y-direction

M_z moment reaction in the z-direction

m_p plastic moment per unit length

N_i applied axial force in member

N_o chord load

N_{pl} axial load capacity of a member

q uniformly applied load

q_0 dynamic wind pressure

q_z velocity pressure

RHS rectangular hollow section

R_x reaction force in the x-direction

R_y reaction force in the y-direction

R_z reaction force in the z-direction

r radius of gyration

SABS South African Bureau of Standard

s longitudinal center-to-center spacing (pitch) of any two consecutive holes

T transverse load on tower cross arm, wire tension

T_r ultimate tensile resistance

T_u ultimate tensile load

t thickness of element

t_f flange plate thickness

t_1 brace wall thickness

t_o chord wall thickness

U_A output voltage

U_E input voltage

V vertical load on tower cross arm

V_f shear load in flange

V_r ultimate shear resistance

V_u ultimate shear load

V_z characteristic wind speed at height z

$V_{pl,f}$ plastic shear capacity of flange

V_{pl} plastic shear capacity

ν Poisson's ratio

w flat width of element

θ line angle in degrees, angle between brace member and chord

λ non-dimensional slenderness ratio

Ω angle between the wind direction and the conductor