# Designing power line towers using circular hollow sections

Ian Ferreira

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 dwarssnitte 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 ontwerps 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 vergelykkend 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 rekstrookjes op verskeie elemente van die toring geplak. Staaltoustroppe 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 ladings 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 krag lyn 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 verkille 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

# List of Figures

# 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 guage 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

$\mathbf{t}$ 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

$\mathbf{V}$ 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

$\mathbf{v}$ Poison's ratio

$\mathbf{w}$ flat width of element

$\theta$ line angle in degrees, angle between brace member and chord

$\lambda$ non-dimensional slenderness ratio

$\Omega$ angle between the wind direction and the conductor