Chapter 5

Overview of the tubular test tower

This chapter gives an overview of a new proposed tower cross arm and also discusses the connections used in the design and fabrication of the tubular test tower. The test tower is a scaled version of the top section of a power line tower but includes all the major connections that would typically be found in a complete structure. The manufacturing process should also closely resemble the actual process that will be used to construct a full scale power line tower.

Throughout this section, it is the intention of the author to marry thorough understanding of hollow section theory with practical modeling and manufacturing techniques that suit the South African manufacturing climate, seeing that manufacturing very much relies on skilled artisans compared with more developed countries that focuses more on automated processes for fabrication.

These techniques should prove that connections between CHS and gusset plates are easily incorporated in power line structures and that the interaction between CHS members and conventional angle members is done effortlessly when designing hybrid power line structures.

5.1 A novel cross arm

A specific design enhancement for the transmission tower cross arm configuration is proposed with this research project. The proposal is a three main
member cross arm (figure 5.1) compared to the conventional four member cross arm (figure 5.2). This cross arm concept will be discussed in a later section.

Figure 5.1: New proposed cross arm - three main members.

Figure 5.2: Conventional tower cross arm - four main members.

As mentioned previously, the overall geometry and the outline of power line towers has been unchanged. Even the bracing systems have been unchanged for the various tower configurations. This lack of development in tower geometry has created the opportunity for novel improvements. The author proposes a new tripod type cross arm (figure 5.3).

Figure 5.3: A view from the side of the test tower showing the proposed tripod cross arm.

First of all, the use of CHS members in the tripod cross arm allows for the selection of long slender members with no or little redundant bracing
members. Figures 5.4 and 5.5 shows the difference between the conventional type cross-arm and the new proposed cross-arm. The effect of bracing on the visual impact can clearly be seen. There is also a 60% reduction in weight by using the new tripod cross-arm. Conservatively, a saving between 35% and 60% could be expected, depending on the type of tower. Secondly, there is one less main member in the cross arm compared to the conventional cross arm. Other than the saving in weight per cross arm, it is one less member to fabricate, galvanize, transport and assemble. The exact financial benefit of the tripod cross arm has not yet been studied and should form part of a series of economic studies based around CHS towers and conventional angle member structures.

Figure 5.4: Conventional tower cross-arm model with bracing and four main members: 258Kg.

Figure 5.5: New proposed cross-arm model with no bracing and three main members: 102 Kg.

5.2 Tower review

The test tower that has been designed for this particular research topic can be seen in figure 5.6 and figure 5.7. Where figure 5.6 shows the 3D CAD model of the tower from which the manufacturing drawings were created, and figure 5.7 is a photo of the final product. Each feature of the tower, ranging from the cross arm to the bracing will be looked at individually.

Considering the tubular tower developed (figure 5.7) for testing purposes, it is not possible to fully implement all the factors which influence the design of a power line tower (full economic impact, effect of varying tower base
width etc.). This should be done using a full scale tower comparison.

The tubular test tower uses a flanged (column splice) connection (figure 5.8 and figure 5.9) to fix the tower to the foundation. Conventional power line towers have a protruding stub shaft extending out from the foundation. The flanged base plate will allow easier layout of foundations compared to the conventional stub shaft. Column splices will also be the preferred method for joining tower leg members throughout the rest of the tower.

Typically, all bracing members will be connected to the main members with gusset plate connections (figure 5.10 and figure 5.11). The reason for using longitudinal plate to CHS column connections for bracing member is
that it has a low impact on cost when it comes to fabrication compared to CHS-to-CHS stub connections. Also, the gusset plate connections ensure that the bolted connection design is synonymous with conventional angular member connection design making it more convenient to adopt CHS tower designs in industry. Additionally, the connection should prevent punching shear and local yielding of the CHS member.

The diaphragm bracing system, used to keep the tower square, also uses gusset plate connections (figure 5.12 and figure 5.13).

Figure 5.10: Typical fabricated gusset plate connection on the side of the tower.

Figure 5.11: Gusset plate connection from 3D CAD model.

Figure 5.12: Typical fabricated diaphragm bracing to absorb torsional loads.

Figure 5.13: Diaphragm bracing from 3D CAD model.
The typical construction of a bracing member is done using a CHS main member and welded plate attachment. The welded plate attachment can take on any form or shape that allows safe connection of the bracing member. In the proposed tubular structure, two types of welded attachments are used. The first type is where a plate is shaped to fit around the CHS bracing member (figure 5.10). It is preferred to shape the plate compared to slotting the CHS member. The reason is that plate fabrication is less expensive than CHS fabrication or profiling. The second type of welded attachments is used for the main members in the tower cross arm and for connecting the main members in the tower hamper. They are constructed by welding a plate normal to the open end of the CHS member.

The main reason for this simple construction method is that it allows for a continuous circular weld that will minimize fatigue failures in the connection. (figure 5.14 and 5.15).

![Figure 5.14: Typical fabricated end plate bracing showing a continuous weld in order to minimize fatigue failures.](image1)

![Figure 5.15: End plate bracing from 3D CAD model.](image2)

It can be seen that both these type of bracing connections are simple to fabricate and could very easily be fabricated by automated welding processes in order to ensure consistent weld strengths. Seeing that in current power line tower connections no welding is used, the welded connections in power line tower fabricated with CHS members will require much more design attention. This will have a negative impact on the design cost of power line towers and also the design time that is needed to complete all the welded connection designs.
One of the more critical connections in the transmission tower is the connection formed at the tip of the cross arm (figure 5.16 and figure 5.17). This is where the conductors are attached. With conventional angular member towers, the layout of the cross arm is such that it minimizes the effect of secondary bending moments created by eccentricities in the connection. This is not always possible when using CHS members. The cross arm member must be designed for axial and bending loads which can then be redistributed through the body of the tower.

In the proposed cross arm tip connection, all the main members are joined with one main connecting plate (figure 5.17). This type of end plate connection ensures that the nett effect of eccentricity can easily be solved by conventional analytical methods. The analytical solution will be discussed in the next chapter.

The second connection that requires careful attention is where the cross arm joins with the tower hamper. Here is a lower and an upper connection. The lower connection is modeled as a beam-column connection (figure 5.18 and figure 5.19). This is done by using a fabricated I-Section connection to CHS members. Here, three main load carrying members join. It is thus important to carefully consider the fabrication method. It can be seen that continuous flange plates are used at the top and bottom. This allows for a continuous weld around the leg main member. Web plates and end plates
are then added in order to create the final connection. Cleats for the bracing members are then welded on the top flange. The connection components can be fabricated in a jig and then slides over the main leg member in order to complete the final flange weld. This will ensure that all the web and flange plates are fully welded in order to achieve full strength.

The second connection on the cross arm is where the single top member of the cross arm joins the tower hamper. The proposed connection (figure 5.20 and figure 5.21) is to pass a continuous plate (figure 5.22) through the horizontal hamper member. The reason for doing this is that the forces in the top cross arm member is very high and that a CHS member that is needed is impractical compared to the rest of the tower. The intention with the continuous plate is to transfer the load directly into the top diaphragm members that will then redistribute the loads into the rest of the tower.
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Figure 5.20: Tubular test tower upper cross arm - hamper connection.

Figure 5.21: Upper cross arm - hamper connection from 3D CAD model.

Figure 5.22: Section through upper cross arm - hamper connection.
From the above overview of the tower connections and the tremendous amount of connections typically found in large power line towers. It is the intention of the author to provide connections that can always be calculated with the use of classical analytical methods or proposed CHS connection design equations (CIDECT) in order to reduce the overall design time and cost associated with structural designs. A connection layout that requires advanced solution techniques such as finite element analysis should be avoided seeing that it is very costly and requires more specialized engineers and software.

5.3 Conclusion

The tubular test tower under review is a scaled version of a full scale tower cross arm and tower body section. The specific selection is done to ensure that all the possible connections that could be found throughout the structure will be included in this research. This chapter also discusses the type of connections that were selected and the reasoning behind it. More focus is placed on connections with gusset plate to CHS members. Very few fabrication facilities rely on automated fabrication processes; hence the selection of the type of connection should also be such that connections may be easily assembled by skilled and semi-skilled artisans.

A new tripod cross-arm has also been introduced. It is expected that this new type of cross-arm will reduce the weight of the conventional angular cross-arm by 35% to 60%, depending on the type of structure under consideration. There may also be a cost reduction as a result of implementing this cross-arm due to one less main member and no or little bracing members. This cost saving is achieved by having less members to fabricate, transport and construct. The exact cost saving has not been considered in this study.