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Vienna University of Technology

DIPLOMA THESIS

Development of a prototypical tower construction for northern Uganda

Development of a prototypical tower construction for northern Uganda
under specific consideration of local resources and the current situation
regarding their realistic practicability as a radio tower

Submitted in partial fulfillment of requirements for the degree of
Graduate engineer

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Abbreviations

ADSL	Asymmetric Digital Subscriber Line
BOSCO	Battery operated system for communal outreach
CHA	Cessation of Hostility Agreement
CTC	Catechist Center
FOSS	Free open Source Software
IDP	Internally Displaced People
IT	Information Technology
ITC	International Trade Center
LAN	Local Area Network
LRA	Lord Resistance Army
MoICT	Ministry of Information and Communications Technology
NGO	Non Governmental Organization
PRDP	Peace, Recovery and Development Plan for Northern Uganda
ToT	Training of Trainers
UCC	Uganda Communication Commission
UPDF	Uganda People Defense Force - Government Army of Uganda
UTL	Uganda Telecom
VoIP	Voice over Internet Protocol
WFP	World Food Program

Abstract

Subject of this thesis is the development of a construction plan for a radio mast in northern Uganda.

Almost all of the existing radio masts in Uganda are imported from abroad. This is due to the lack of architectural and engineering knowledge to plan such a tower whereas material and labor would be available. A development project called BOSCO is in need for such a radio mast to expand their rural network system in the recently war affected region of northern Uganda.

Aim of the thesis is to design a tower/mast construction which is technically equivalent to imported towers but made out of readily available materials and built by workers from the region. Consequently, the profit of the project stays within the region and, at the same time, costs could be economized in comparison to importing a readymade tower. As it is not clear yet on which site the mast will be erected and as the network layout is changing fast, a modular system is required. Therefore, another requirement of the tower/mast was to allow transportability and flexibility concerning its height.

Two study trips - one month each - were undertaken in order to investigate available materials and the local circumstances.

After extensive research, a slender lattice steel mast which is stabilized with a so-called “sailboat guy system” has been proposed as the suitable prototype. Eight modules, 3 meters high each, can be plugged together, thus providing flexible height. This system was chosen for the following reasons: to provide a material efficient solution which ensures reasonable coverage. Steel processing is widely known and with this material a stiff and at the same time light weight solution was possible. Joints are mainly welded as this is the most common processing method. All modules can be prefabricated entirely in the workshops whereby the quality of implementation increases. Only at the intersections of the modules bolts are required. In order to guarantee the transportability of the mast as well as static requirements a light weight foundation with ground screws has been designed. They can be prefabricated in workshops as well.

The entire mast construction can be transported to the site in prefabricated units. Any single module can be physically carried by one person. The different modules and units can be plugged together in horizontal position on site. The mast is connected with the foundation through a hinge. Once horizontally assembled, the entire mast can be lifted by a cable winch of a common pick up. Finally, the guy system has to be connected with the anchors.

The realization of the project is planned to be implemented as soon as the required funding is provided. In this case, a final verification of the construction plans can be realized.

1. INTRODUCTION AND OUTLINE OF THE PROBLEM

Everything started with a phone call from a close friend who was completing his civil service in Uganda. He has been working at a development project which is trying to provide wireless-LAN service to rural areas in northern Uganda – Gulu. The project is called BOSCO and will be described in more detail later on. BOSCO is in need of a radio tower/mast which transmits their signal to more distant areas.

We discussed that high rise constructions are usually imported from far away in the country or even from another continent. As a matter of fact, even NGOs in Africa tend to import technical advanced constructions from overseas. This would have been the solution for the BOSCO founders as well: ordering a prefabricated tower/mast abroad. Even though different materials like steel bars or constructional timber are available. Moreover there are workshops which provide common processing methods of such materials. So we started to think about why we should not try to build the tower/mast locally: The money for the construction would remain in the region, people involved in the process would have the opportunity to learn how to build such a construction, and finally, it would be cheaper than buying an existing professional ready-made solution from an overseas company. The only missing aspect was that nobody knew how to plan such a prototype. This was the starting point of this thesis.

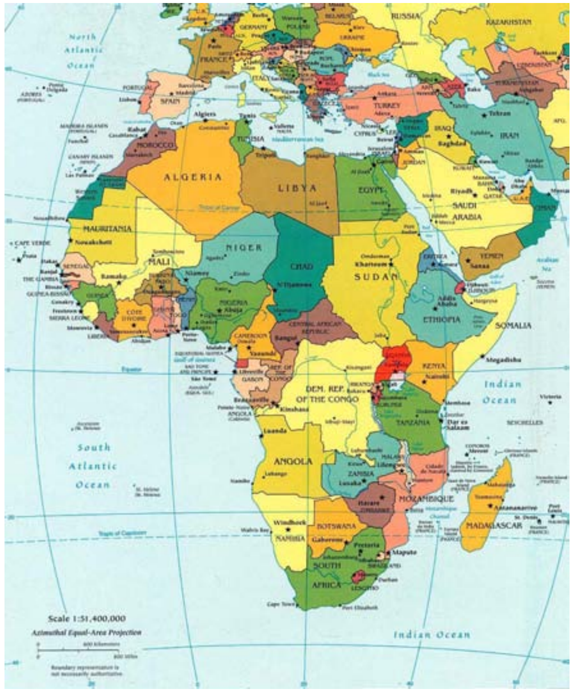
To fulfill this missing aspect it is necessary to have a close view on realistic conditions in Uganda and at the same time offering the architectural knowledge to plan such a tower. The challenge of this thesis will be to combine and provide both. These aspects are the reasons why I chose this project as the final thesis of my study. The challenge of dealing with the special circumstances of Uganda as project site was one motivation to choose this project. However another reason to choose this theme was the practical approach to plan such a construction under unusual circumstances. I am certain this will help to progress as an architect in the future. Already the research of background information and the probable realization of the construction in the future forced me to plan more realistic than I had to during my studies. Therefore I learned a lot throughout the project research and the planning process of this work. From there I will certainly benefit in my future work.

In the end this work should be a guide for people in Africa especially Gulu, Uganda, which provides technical aspects of how to build a locally produced and affordable construction. What is more, it aims to be a guideline for small companies, or NGOs, and other people around the world, who would like to extend their field of work and are interested in building affordable high rise constructions.

Nevertheless, this thesis does not intend to show up all technical possibilities of tower/mast constructions. However, it attempts to get a closer look on possible methods which are useful especially for the specific region. Finally, it tries to figure out a prototype which could be useful and probably applied in nearly every region around the world with medium effort. The case study in this thesis is a radio tower/mast of about 25 meters in height. Taking into account the requirements from BOSCO and the circumstances concerning material and technical equipment / possibilities in Uganda the construction of the tower should be the most efficient and sustainable way for this specific area. Of course there are newer kinds of technical solutions with high-tech materials and complex construction details. But in this case the construction plan focuses on places with poor resources of material and financial support.

At the beginning of this thesis a lot of necessary background information will be provided, starting with a description of the political situation in northern Uganda and an introduction of the client BOSCO. Furthermore the information of the on-site research, which was gathered during two study trips 2008/2009, will be described in order to give a complete picture of the conditions for the prospected site. With this information as well as a technical overview for tower/mast constructions, different examples regarding BOSCO's requirements will be statically compared. Finally a detailed elaboration of the most reliable and sustainable tower/mast will follow.

PART 1 - CONTEXT



ill. 1 - map of Africa

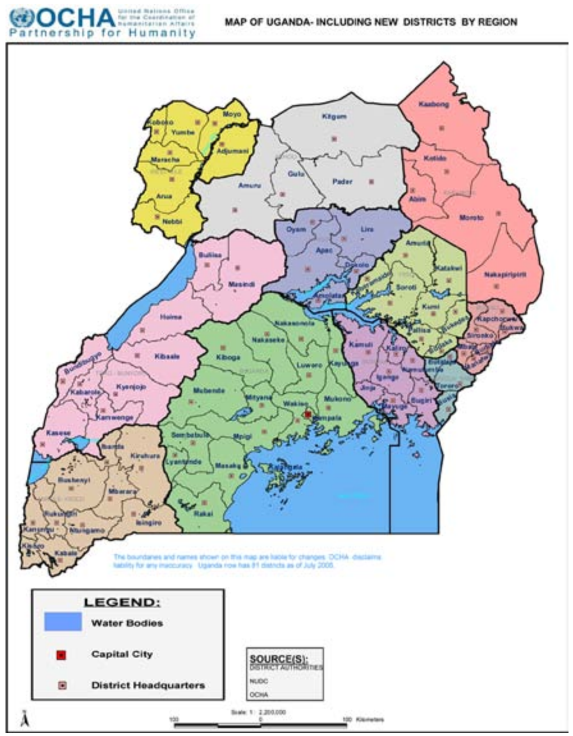
ill. 2/3 - IDP - camps in northern Uganda

2. UGANDA - GULU

2.1. War and displacement - peace and resettlement

The Districts of Gulu, Kitgum, Pader and Amuru in the Northern part of Uganda have been trapped in armed conflict between the Lord's Resistance Army (LRA) and the Government Army of Uganda (UPDF) for over 20 years[1]. The war has displaced over 2 million people into IDP camps (Internally Displaced People), resulting in a society completely depending on charity and welfare. Lack of security led most people to leave their agricultural and cattle-keeping lifestyles for one dependant on the World Food Program (WFP). Moreover, the security situation led to a strong isolation of the people as movement was heavily restricted and communication to areas outside the camp was nearly impossible.

The signing of the Cessation of Hostility Agreement (CHA) between the government of Uganda and the LRA rebels on the 26th of August 2006 in Juba has marked the longest period of stability and relative peace in nearly 21 years of conflict in Northern Uganda. Although the Juba peace talks are still ongoing, Northern Uganda is currently facing a shift from short-term emergency to early recovery and long-term development efforts. People, who have been living in IDP-camps for many years are starting to return home or are moving to satellite camps closer to their original villages. Furthermore, the government has launched a Peace, Recovery and Development Plan for Northern Uganda (PRDP)[2] in order to support the reconstruction and reconciliation of peace in the region over the next three years.



ill. 4 - districts of Uganda

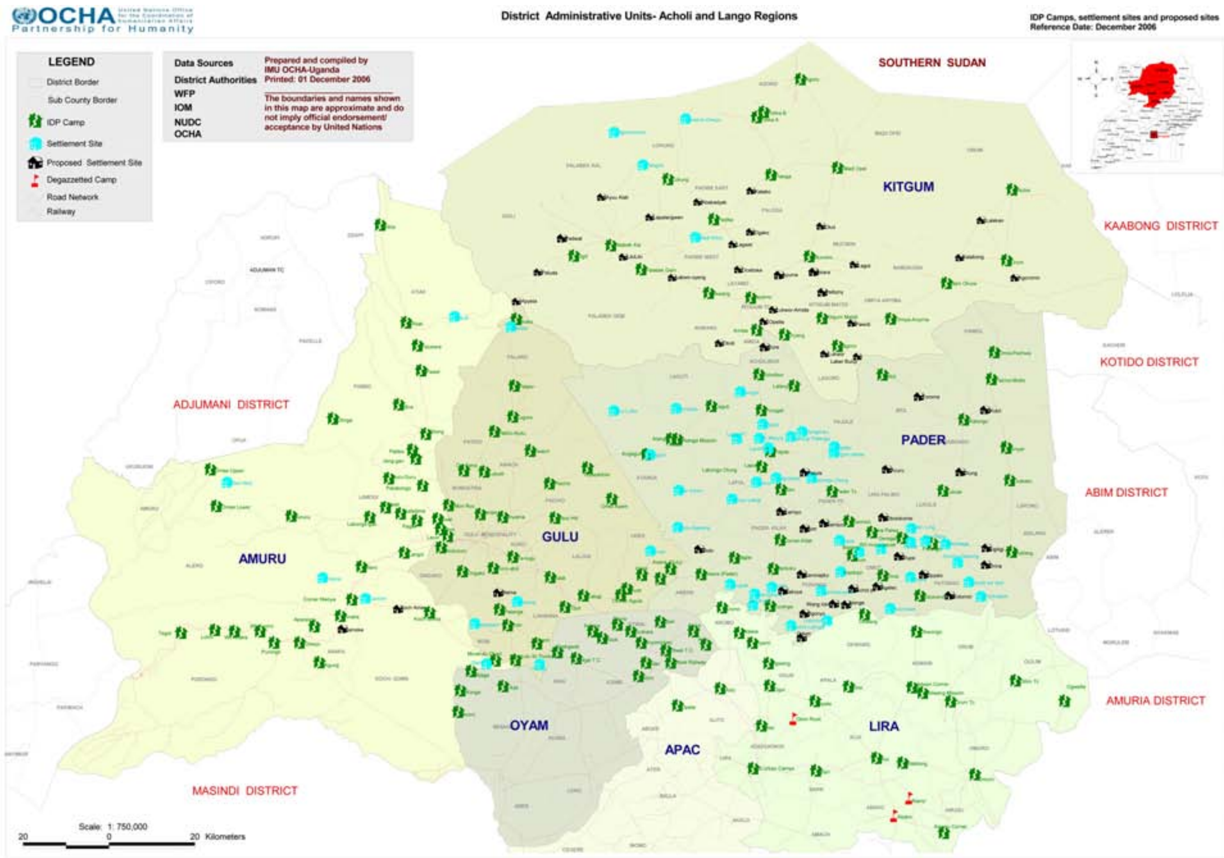
-1- The afterword for the book "Origins of Acholi", written by Professor Ronald R. Attkinson, provides a detailed but short overview of Ugandas political situation over the past 30 years especially in the northern part.

-2- Republic of Uganda, Peace, Recovery and Development Plan for Northern Uganda; (PRDP) 2007-2010, September 2007

2.2. Structural problems of rural communication in northern Uganda

Reestablishment of the infrastructure and enhancing economic growth are key areas of the planned recovery process. Therefore, the PRDP project considers communication and access to information as vital necessities for the ongoing development efforts in Northern Uganda. About 90% of the Acholi region consists of rural areas with limited infrastructure, no access to grid electricity and almost no access to information through internet and related communication facilities. In 2001, the Uganda Communication Commission (UCC)[3] published a Rural Communication Development Policy to develop and improve rural communication services, which led to a strong increase of mobile phone usage. Internet Points of Presence are not yet sufficiently available in the rural North.

According to statistics, only 750.000 Ugandans are using Internet, equal to 2.5% of the overall population (ITC, 2006). Furthermore, about 70% of all internet usage is concentrated in urban areas leaving rural areas (and thus the majority of the population) with



ill. 5 - IDP camps, settlement sites and proposed sites very little access to communication services. Northern Uganda, being the target area of the proposed project, is significantly lower than the national average due to the above mentioned insurgency and 20 years of conflict in the region.

Already in 2001, a Rural Communications Development Policy for Uganda has been developed by the UCC. In line with the commitment of UCC to establish communication structures for rural areas in Uganda, the proposed project considers rural communication as a key area for further efforts to social and economic development.

Currently almost no rural school can offer any education related to Information Technology (IT) and computers. Although the usage of mobile phones is increasing rapidly, other means of information remain inaccessible or are just not affordable for the community. Basic service providers (such as schools, health centers, local government, local NGOs, etc.) have very limited access to information through the Internet, especially in rural areas outside the municipalities. Regarding the ongoing peace process, access to information remains one of the main obstacles for the current return and resettlement process as people are still waiting for a comprehensive peace agreement and any new results coming from the Juba peace talks. According to a survey carried out in Northern Uganda in December 2007, nearly three-quarters of the population are using radios as their main source of information[4]. At the same time almost half of the population does not feel well informed or just does not trust the information they get. Therefore, other means of accessing information and communication with the outside world remain essential for any further efforts to overcome the existing fears and restrictions of movement outside the IDP-camps. Furthermore, the lack of electricity and network infrastructure, especially in rural areas, limits the usage of computers and access points. Therefore, innovative facilities and technologies are needed, specifically addressing the constraints and necessities of rural areas: low power consumption, alternative energy and wireless connection through long distances.

ill. 6 - Gulu town

ill. 7 - IDP camp Pabo

-4- Berkley University / Tulane University, When the war ends - A population-based survey on attitudes about peace, justice and social reconstruction in Northern Uganda, 2007

3. INTRODUCTION OF THE CLIENT BOSCO

The client of the following specific case study is BOSCO. This small organization will be described in detail. Furthermore achievements will be outlined which have already taken place since BOSCO is running and the opportunities it offers for the people around Gulu so far.

3.1. Background of BOSCO

In 2004 Gus Zuehlke, a catechist from the US and a friend of Archbishop John Baptiste Odama, witnessed the misery and isolation of people living in the IDP-camps of northern Uganda. Together with Archbishop Odama they came to the conclusion that there was need of rural communication technologies to bridge needed communication gaps blocking peace building in northern Uganda. Inveneo, a social enterprise from the US[5] , specialized on solar powered wireless computer networks, was contracted to work out a concept to provide broadband Internet access and Voice over Internet Protocol (VoIP) communication for IDP-camps. This was the birth of the Battery Operated System for Community Outreach (BOSCO) project. On the 14th of December 2006 the Ministry of ICT (MoICT) issued a license to operate a private non-profit network, through UCC to the Catholic Archdiocese of Gulu[6] .

The BOSCO project itself is the first initiative started to bridge the already described lacks of information and rural communication.

-5- http://www.inveneo.org [accessed 2009 03 10]

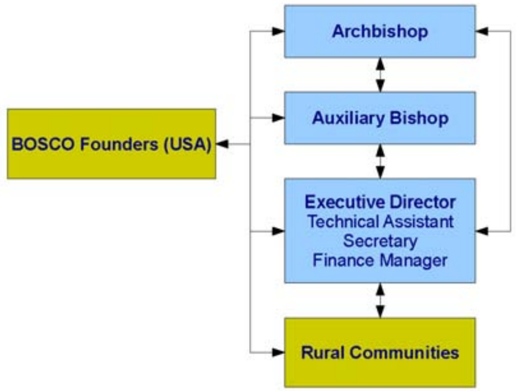
-6- http://www.archdioceseofgulu.org/ [accessed 2009 03 10]

3.2. Project management of BOSCO

The legal project holder of the BOSCO project is the archbishop of Gulu John Baptiste Odama. In December, a license to operate a private non-profit network was issued to the Catholic Archdiocese of Gulu through the Uganda Communications Commission. The executive director is Dr. Rev. Fr. Joseph Okumu also Director of the Catechist Training Center (CTC). The CTC staff is also contributing to the project as secretary and financial manager. A technical assistant is full time employed by the project at the moment. A group of Christians around Gus Zuehlke have been giving financial support to BOSCO and act as consultants to the project still. Rural communities play a consultant role in the project as well as they know best what their needs and interests are.

People currently working on site at the BOSCO project are:

Executive Director - Fr. Dr.Joseph Okumu
Project coordinator - David Martin Aliker
Technical assistant - Alfred Kilama
Finance / Logistics Coordination - Sr. Betty
Consultant Horizont 3000 - Stefan Bock
Consultant BOSCO USA - Kevin Bailey



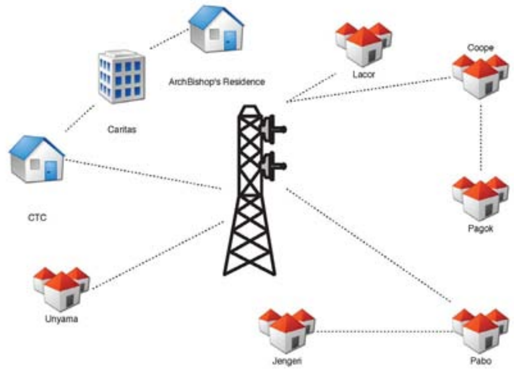
ill. 8 - Bosco Management Board

3.3. Technical layout of BOSCO

3.3.1. Network Layout

Until October 2008 antennas had been installed on an abandoned TV-Tower (Radio Maria Tower) in KatiKati distributing a signal to the camps. However, now the owner of the TV - Tower has removed all of their equipment without informing BOSCO. Until January 2009 they have not been able to transmit to the IDP camps. The network between the CTC, Archbishops Residence and Caritas is not dependent on the TV tower. But to provide the network in the IDP camps, furthermore to extend the system to other camps, it is more than necessary to get a tower to transmit the signal to the camps.

Efforts have been made to bridge this situation. They have been trying to rent a spot at an existing tower in Gulu, but the prices for this service are unbelievably high. At the Uganda Telecom Tower in Gulu it would cost US$ 2800 per month to install their equipment. A small self-made locally produced mast prototype – see description starting on page 133 [chapter 8] – has been constructed to bridge the situation. The quality of transmission is just at about 25% but at least the system is working and the camps have now been reconnected until March 2009. This solution will be used until the money for the construction of a main tower/mast has been raised.

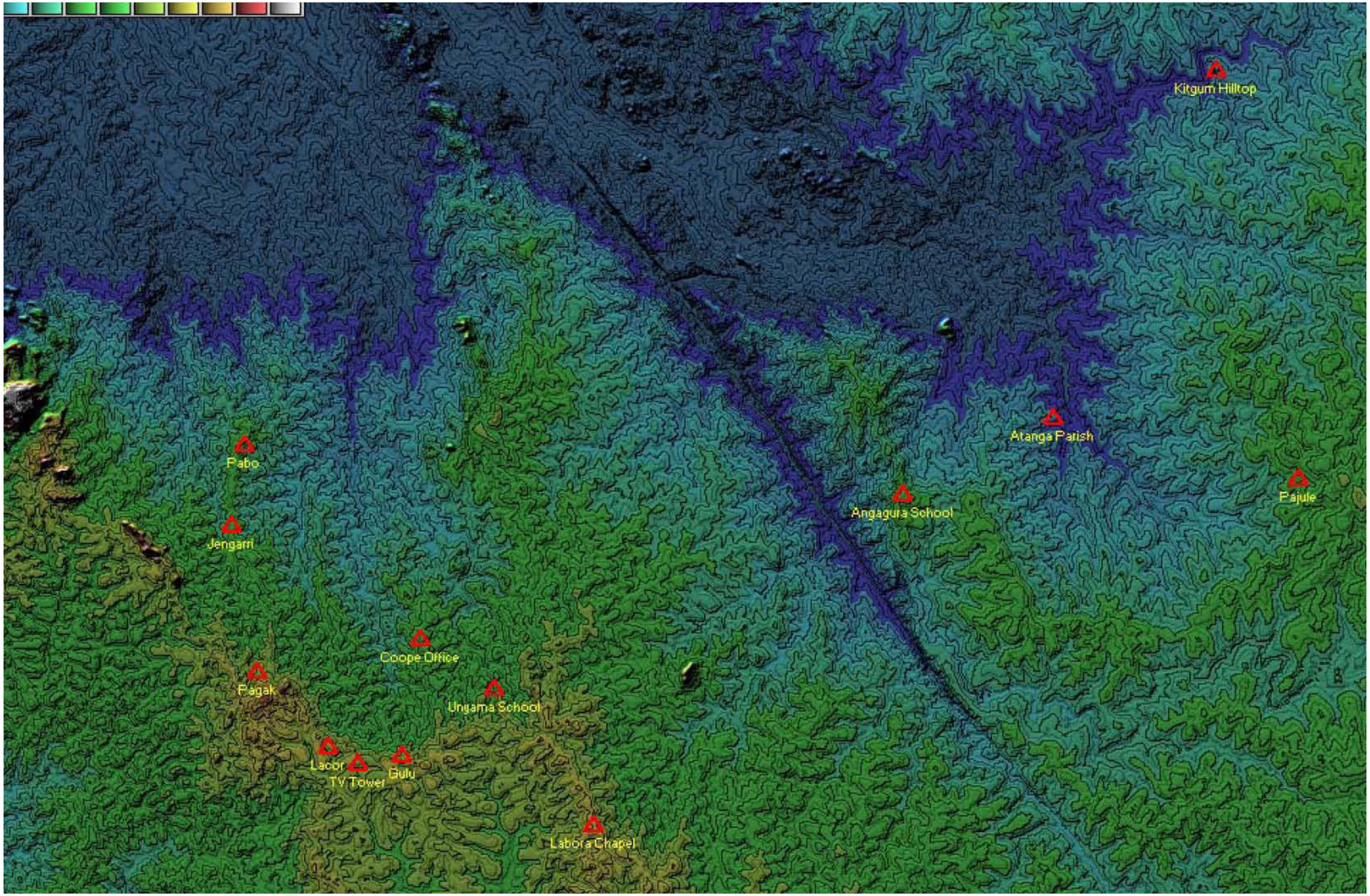


ill. 9 - Network Layout

The central server is located in the BOSCO office at the compound of Catechist Training Center (CTC) Gulu.

Communication stations are installed in:

- The Archbishops Residence, the legal project holder of BOSCO.
- Caritas Office Building Gulu.
- The Catechist Training Center (CTC) where the executive director, Fr. Joseph Okumu and the technical Assistant of BOSCO are managing the project.
- The IDP camps Lacor, Pagok, Unyama, Pabo, Jengeri and Coope.



ill. 10 - Topgraphical map of the network outreach of BOSCO including future sites

3.3.2. Hardware

All components of the network are designed for low-power consumption, using 12V Direct Current (DC) and are powered from a battery system that is either charged from the power grid where possible, or by solar panels. The use of low power components cuts the prices of the otherwise rather expensive solar equipment.

The main components of the network are:

- A server located in the Caritas building, providing the Broadband (256 Kb/s) ADSL internet up link and managing VoIP and file sharing services. An Apache[7] web server is used to serve a community homepage based upon Drupal Content Managing System[8]. The server is connected to a battery backup lasting for more than one week.

- Wireless routers operating on Tier Linux are used to establish the backbone links of BOSCO. Depending on the clearance of the line of sight, directional antennas can carry the signal over distances of up to 35 km.

ill. 11 - VoIP Telephone + Low Power PC

- Wireless access points are used for short range links inside a camp or a village.

- Communication stations consist of a low-power PC consuming approximately 20 Watts only and a telephone connected to a VoIP Router. The PCs are custom built products by Inveneo, designed to work in tropical environments. They have no internal hard disk or fan which makes them less sensitive to dust and humidity. Files are stored over the network on the server. A custom linux distribution with an intuitive user interface has been chosen as an operating system making them invulnerable to viruses.

ill. 12 - Antenna

ill. 13 - Antenna

-7- Apache - HTTP SERVER PROJECT - www.apache.org [accessed 2009 03 10]

-8- Drupal - an open source content management platform - http://drupal.org/ [accessed 2009 03 10]

3.3.3. Software

The system is using Free Open Source Software (FOSS) instead of highly expensive licenses:

- FOSS - as the name gives away - is free of charge. Thus, project costs do not need to cover the high prices of software licenses and the saved money can rather be invested in training educated personnel in the installation and operation of the used software.

- As 90% of the existing commercial software is developed in the industrialized world, the usage of FOSS can therefore be seen as an alternative for developing countries, fostering their independence and self reliance.

- In comparison to commercial software, FOSS is more easily adaptable. The used applications have consequently been adjusted and optimized for the specific needs and requirements of the used low-power equipment.

ill. 14 - IT tutoring

3.4. Evaluation of the process so far

BOSCO has been running for more than a year. During this time the equipment has been tested under the extreme environmental conditions of the area, including extraordinary heavy rain as well as dry and dusty heat. This pilot phase has seen many technical problems solved and much improvement of the technical equipment. Thus, the gathered knowledge provides a good foundation for the expansion of the network and the used components fulfill the necessary requirements of the network.

The system has to be adjusted all the time. During this first period BOSCO has been evaluating the progress through regular visits to the target areas as well as holding group discussions and interviews with the beneficiaries. The lessons learnt in the last year will serve as a basis for a culturally sensitive and successful second deployment for the BOSCO project team.

For getting an idea of what BOSCO means to its beneficiaries here are some quotes from people who already use and from some who would like to get the opportunity to use the BOSCO system.

Father Joseph Okumu: "*Now we can communicate all over the world with Skype. It makes it much easier to keep in contact with our friends. Funds can be collected with this possibility much easier. But most importantly the people in the camps, who had been disconnected from information, are now able to read daily newspapers on what is going on in Uganda. They can become more critical about the political situation in Uganda*."

Sister Kevin at the Archbishops Residence: „*We don't need to wait for hardcopies of emails any more. This makes us work much faster. And if I have an urgent question I can search the internet to get the answer. I hope that much more people in the camps will get this possibility soon*."

St. Patrizia: "*It is horrible now [the system had been down for several days] if the system is not running. We use it every day and without it we cannot work so efficient*."

David – teacher at IDP Camp Pagak: *"It's a great possibility for us and the students to get information. To blog on the Intranet and share information is a great opportunity. But we still need more training so that everybody can use it."*

Villager at IDP Camp Pagak: "*We also would like to use the computers. But as there is just one, it is restricted.*"

3.5. Extension of the system

After more than a year of successful running of BOSCO using the current TV-Tower (Radio Maria Tower), UTL Company[9] claimed the TV-Tower as their property and gave a deadline for removing the antennas and other equipment. This meant that suddenly everything stopped to work. BOSCO and the experts from INVENEO decided that the best solution would be to build a new tower/mast on a highly elevated point of Lacor Seminary - which belongs to a supporting organization of BOSCOS - taking the following considerations into account:

- BOSCO should serve the people and provide the means of communication independently from multinational companies. Therefore, the network should not rely on a partner like UTL.
- Paying a monthly rent of just 200 000 UGX (~100Dollar) would be more expensive after few years than building a tower themselves.
- Lacor Seminary will be able to receive the BOSCO signal as well and will be connected to the system.
- The place where the new tower should be built is owned by the Archdiocese of Gulu who is also the provider of the BOSCO system. It will be easier to secure the expensive equipment at the new tower and BOSCO will never again run into the trouble of having to pay for land or the usage of the TV-Tower.

3.5.1. Pre-requisites for the tower / mast construction

As mentioned before, Lacor Seminary would be a perfect location for the tower/mast. But even until February 2009 it has not been clear at all if it will be possible to use this site. Furthermore, it was not decided yet which kind of tower/mast BOSCO will need in the future. BOSCO did bridge the connection by using the guyed mast prototype - described on page 133 [chapter 8] - and mounting the antennas on lower existing positions to keep the system running. Nevertheless, this cannot be a solution for the future, as the quality of the transmission reaches just about 25% of their capacity.

During the trips to Gulu and at meetings of the BOSCO board, the topic of the tower construction has been in discussion all the time. Yet, it has not been decided if Lacor seminary really would be the best location and moreover how high the solution should be. There are two reasons for this situation.

BOSCO is trying to set up the tower at a site, which they own themselves or at least one of their supporting organizations – for example the archdiocese of Gulu. The site at Lacor seminary would fulfill these aspects, but it is still in discussion if this is the best position, to transmit the signal to the IDP camps. As a matter of fact they would like to be as independent as possible; setting up a tower on a site which they do not own would cause a lot of bureaucratic actions. Nonetheless, it is still

-9- http://www.utl.co.ug/ [accessed 2009 03 10] a necessary option for them, and furthermore they have to choose the sites depending on its possibility to transmit signals. However using a tower or site which doesn't belong to BOSCO or its supporters may cause problems similar to recent problems with the Radio Maria Tower. Therefore BOSCO would profit from a tower construction which is not fully dependent on the site.

As it isn't clear now on which site the tower construction can be set up the questions arises: *if it is possible to design a tower/mast construction system which can be set up or pulled down at any location?* In this case the whole construction, including the foundation has to be transportable.

The second question which arises is that every site has different circumstances regarding vegetation (like heights of buildings hills or trees around it). The height of the tower/mast depends on this circumstances at the prospected site. To have a most efficient solution regarding costs it is highly essential to build a tower at an adequate height for the prospected site. Setting up a much higher tower/mast at a position where half of the height would have been enough would be most inefficient. As BOSCO does not know where they are extending in the future, and what circumstances they can expect at the future sites it is necessary to provide a flexible height system, which can be used efficiently at any site.

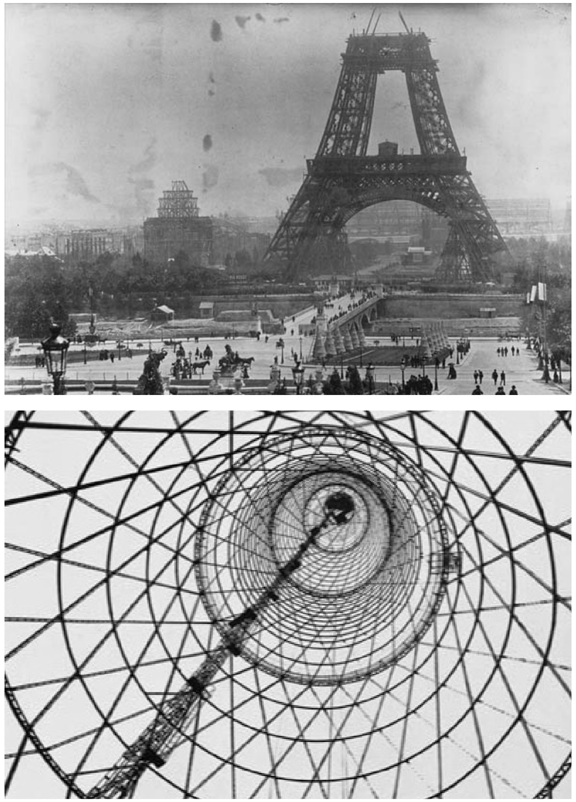
The combination of these two design aspects should give BOSCO flexibility regarding sites and heights. As it requires testing the signal at the projected site BOSCO should be able to adjust the tower according to their needs. So the construction and deconstruction process has to be easy to serve these aspects.

What is more, one must take into account that BOSCO is a low funded project. It is a small organization and the money for the tower/mast should be used as resourceful as possible by any means. The construction has to be cheap and reproduce-able. Father Joseph Okumu told: "*We do not have a lot of money. Our system should help the whole community which also includes that people in Gulu should learn how to do such a construction to get more independent.* "This is the most interesting aspect of this project for an architect.

This thesis's aim is to offer the knowledge to construct a tower in this rural area. Getting away from the dependency of international companies is in my opinion the key to do sustainable development work. It is not a given fact, that in such areas there are no possibilities to do technical advanced constructions. Of course material varieties are less and workshops are not as well equipped and trained as in other countries but with construction plans which take care of the conditions on site it is certainly possible to build a tower. Technical advanced details have to be transformed to a certain degree in order to be reproducible even in rural areas.

PART 2 - BASE ESTIMATES

ill. 15/16 - Impressions from Gulu



ill. 17/18 - Eiffel tower / Shabolovka tower

4. DETAILED ON-SITE INFORMATION ON RELEVANT ASPECTS FOR TOWER CONSTRUCIONS

The following chapter outlines first the genius loci. Intensive field studies have been made to understand the situation and requirements of BOSCO. Secondly, technical base elements of towers/masts will be explained.

The information in this chapter has been researched during two study trips, one from July to August 2008 and the other from February to March 2009. The prices listed for salaries and material and the conditions of the workshops are as of these dates. Almost all of the information has been gathered by speaking with shop owners or local villagers in Gulu directly, or from interviewing developments workers who have worked or still work in Uganda.

When reading the research's information one has to take following aspects into account: Northern Uganda is changing quite fast these days as peace is coming to the region. Progress takes place: for example, the road from Kampala to Gulu, in really poor condition in summer 2008, has been completely renewed until spring 2009.

The choice of material is less, prices are higher and salaries are lower in Gulu than in other regions of Uganda. It will take some time until Gulu will become equal to other big cities like Fort Portal or Kabale which have nearly the same infrastructure and prices as Kampala. Nevertheless, Kampala being the biggest city offers better conditions regarding any aspect than in the rest of the country.

Besides that Legal context and administration differs a lot from what is usual in European countries or western countries in general. Therefore this information has to be described more extensive than we are used to in Europe. In the following parts administration context as well as technical data of the region will be presented. Furthermore average knowledge in architecture and structural engineering will be analyzed in order to get an idea of what can be expected from the people in Gulu concerning the comprehension of a construction plan as they will be the ones who put into practice the plans of the thesis in the end.

4.1. Legal context – administration

4.1.1. Permission to construct a tower in Gulu

Construction permissions can be a critical aspect at many building sites usually. High rise constructions have to be permitted from technically authorized persons. For the district of Gulu the District Engineer – Olal Andrew Obong – is responsible.

David Martin Aliker - the project coordinator of BOSCO - told me in advance: *"Actually we are the first ones who have been looking for contact with the District Engineer before the construction starts. All other towers in Gulu like UTL and MTN did start building without asking the local authority."* Obviously it is not as strict to construct a tower around Gulu as it is in Europe.

In Fact District Engineer Olal Andrew Obong confirmed: *"As long as the tower is built to support the community, it won't cause any problems. I am most concerned about the environment. Nowadays companies come to ask for permission to destroy huts and cut a lot of trees for a small street. This will not be tolerated. But if you have the confirmation from the Sub County and reliable constructions plans everything should work out well!"* David afterwards added: *"If the District engineer is against the tower it will not be possible anywhere. But as we have good contact to him and as long as we have the permission from the Sub County and good construction plans it will not be a problem at all."*

In practice this means that the authorization process is to let the construction plans be approved by the district engineer's office. In general no construction or design changes are done by the office if there is no need of destroying environmental circumstances. This was confirmed orally. According to the District Engineer the responsibility for the construction itself is legally carried by the workshop that produces the construction. As the construction of the mast will not affect any buildings in the area and the plans should be adequate and clear there seems to be no worries about the permission. Even though this may seem to be insecure or vague in comparison to European countries these are the usual steps to be done to get a construction authorization. The district engineer finally advised to inform the UCC [Ugandan communication commission] as the tower construction is a communication Tower. However this aspect does not affect the construction plan at all, either. As a matter of fact the UCC is responsible to control whether transmission signals are sent with too much power or too far. For technical transmission details and equipment like this - BOSCO as communication project - is responsible and guarantees to have all necessary permissions. According to David Aliker it is honestly spoken like that:*"BOSCO is covered by the Archdiocese of Gulu. Basically we don't underlie the Communication Law, we are a catholic project. But we have contacted the UCC and work on it to make sure to avoid any problems."*

Norbert Demmelbauer, a technical employee for BBM Austria[10] , tightened the information above with his working experience in Uganda. Permissions *are* necessary. But technical issues concerning stability and security are secondary. Nobody usually cares about safety values concerning static calculations.

Aim of this diploma project is to provide construction plans which are understandable but nevertheless correct regarding authorization. In conclusion there should not be a problem to get the necessary permissions to set up a tower/mast for BOSCO. BOSCO will choose a suitable sub county. Next, they will inform and get the permission from the UCC.

4.1.2. Knowledge of architecture and structural engineering

Another fundamental question appeared already during the first study trip: Is the education of structural engineering and architecture in Uganda not sufficient to plan a technical advanced structure? Why is there nobody from Uganda itself with the required knowledge?

During the research study trips the following facts about tower constructions within the country have been found out: Most small water towers all over Uganda are built locally. They are of medium height, and overall medium load to support. But starting with a certain height and load, all of them are imported. It is the same situation concerning tower constructions.

Furthermore small antennas for radio transmission about the height of 8 to 10m can be found in each village. Requirements for those antennas are a long stick and probably some wires to jag it to the ground. However, when they get higher every single one is imported. The reason for this situation is not that workshops in Uganda do not have the option or technical capacity to build such constructions in terms of material or machines. It is the lack of constructional knowledge as the foreman of one of the workshops which were interviewed during the study trips said: *"We do all kinds of constructions. It's not a problem at all to work high in the air. But for a higher tower, as you were asking, we don't know how to do it. If we would get the experience once we could do it again!"*

In summary this means that workshops in northern Uganda just do not have the knowledge and experience to build these constructions themselves. How should they, if everything more technically advanced is imported from abroad? As said before the most fundamental question concerning this situation is why the required knowledge is not available in northern Uganda or Uganda in general. It seems that there are two key answers to this question which will be investigated further.

First of all it is important to have a closer look on education in Uganda. Summarizing Interviews done during the study trips con-

-10- http://www.miva.at/de/02BBM.shtml [accessed 2009 04 15] cerning education the following conclusion was reached: Education is unfortunately in many cases more a business than a necessary good for people. School fees have to be paid which are incredibly high (around 800.000 UGX per year per child for primary and secondary school) considering that a policeman (with a comparably higher income than the overall population) earns around 170.000 UGX per month. However, luckily the tendency to give children the opportunity to get education is rising and schools are crowded. Classes with more than 90 children which are taught by one teacher are the norm. Those who have the possibility to visit a school are somehow privileged; however, the quality and standard of teaching under such circumstances is of course questionable. For those who can afford attending high school or even university the quality improves slightly, nevertheless this example came across: A large NGO in Gulu wanted to recruit a new director's assistant. It turned out that the person who seemed to be most qualified – he had a finished master study in business - did not even know how to turn on a computer. This might seem an absurd situation and of course it must not be the case in general, but it is quite representable of the quality of education in Uganda. Therefore, the elite, who can afford it, tend to finish their higher studies in countries abroad.

Architecture and structural engineering in particular can be studied at Makerere University[11]. It is the only place in Uganda which offers this field of study (Gulu University[12], for example, does not offer any kind of engineering or architectural courses). Quality there can be assumed to be solid because it is a quite expensive and a respectable institution in Uganda. This leads to the second hypothesis why knowledge of architecture and structural engineering is widely unknown in Uganda: Already getting this kind of education is quite rare. Getting good education is even rarer, and spreading the knowledge of tower constructions (for example to workshops in rural areas) after gaining the necessary education simply does not happen.

Income in Uganda is low therefore it is common for higher educated people to work abroad, for an NGO or a governmental organizations as salaries are much higher. Those who get the opportunity of good education would like to get as much profit out of this chance as possible and the wages from working for a rural workshop, certainly cannot compete with large companies.

Summarizing there is first of all nearly no knowledge of these techniques due to the fact that, the probability to get good architecture and structural engineering education is rare. Secondly, if such knowledge exists, it remains at well situated organizations. Thirdly, a lot of this knowledge is transported abroad. And finally, the necessary structures are imported from abroad without bringing the knowledge and experience for the construction process to the country as well.

This thesis aims to achieve the opposite. To provide the knowledge on how a technical structure – in this case a tower/mast - can be produced locally. Furthermore to present different workshops the possibility to offer this service in the future instead of having to import towers from overseas.

-11- http://www.mak.ac.ug/ [accessed 2009 03 17]

-12- P.O. Box 166, Gulu; argulu_university@yahoo.com [accessed 2009 03 17]

4.1.3. Data research in Uganda

In order to design a construction at a certain place it is necessary to collect as much information about the local circumstances as possible. Without the necessary details it is impossible to make an efficient construction or structure for this particular spot. It is essential to investigate local circumstances ahead of the design process to ensure that the chosen construction fulfills every possible aspect regarding the local circumstances. It takes quite a lot of time to research these pieces in any country, but Uganda certainly poses a special challenge. There is nearly no central distribution and shops are not regulated which means that every store has their own conditions and prices. There is no organization to control quality or prices. Moreover, Uganda is an incredibly corrupt country[13]. Political and economical corruption is a big problem and reaches from small stores up to the government. Unfortunately my personal experience during the research study trips confirms this fact. With money, nearly everything can be arranged in Uganda.

For getting useful information it is necessary to arrange an appointment but usually it takes two or three meetings to actually get the needed information. Meeting people for the first time seems to have the only purpose of getting acquainted with each other. Birgit Klauser (an Austrian development worker, employed by the Ministry of Gender, Labour and Social Development in Uganda) told me: *"The first meetings are usually there to get an impression of the other person. As I know now, I don't even expect to get any details when I first meet a new client. It is only at the second one that we start talking seriously."* I can totally agree with this comment and all my appointments with anyone – even shopkeepers – ended up like this.

Being a white person –"muzungo" – certainly poses a further challenge as you do get a lot of attention. Locals are interested in you because it could be possible to make some profit out of you. Therefore you are often not taken as seriously as locals. Shopkeepers list higher prices for products until you meet them more frequently and you know the local prices. It is necessary to compare prices in different shops, and confront shopkeepers with your information. It is only after this step you are taken really serious.

A picture tells more than thousand words and photos are an important element throughout the research process. However, even this is not easy in Uganda. In order to take pictures of technical details it is usually necessary to ask the owner of the structure. To receive an impression I want to tell how I tried to take some pictures of the main UTL tower in Gulu: I went to the director of the local office and explained my appeal and expected it to be granted without a problem. However, I would have needed permission from the structural director in Kampala which could have only been given by going to his office in Kampala personally and writing a formal appeal. Only then I could go back there and take the photos. This is exemplary of how bureaucracy is working in Uganda, and probably it would have been necessary to pay a fine for these pictures on top of it all. For example, it is also forbidden by law to photograph the bridge over the Nile on Gulu road.

-13- http://en.wikipedia.org/wiki/Corruption_Perceptions_Index; http://report.globalintegrity.org/ [accessed 2009 04 27]

4.2. Relevant technical data

4.2.1. Load capacity of soil in Uganda / Gulu

During the research in Uganda it was not possible to obtain detailed information about the soil structure or to obtain data about the load capacity. However, it seems that there actually is no data of these facts in Uganda. Father Felix Opio (the former director of caritas Gulu) explained: *"On the building sites where I have been, the ground was all the time really strong. Most of the times it is clay, so you can estimate how strong the ground is."* Mostly the ground all over Uganda consists out of cohesive soils, like clay or silt. In general clay is used for brick production – page 54 [chapter 4.4.4.2] – even though it was not possible to get written information about the soil structure it was possible to have a closer look at soils all over the northern part of Uganda by myself. This investigation confirmed Father Felix's information of cohesive soils like clay in the northern part of Uganda.

The rainy season in Uganda, especially in Gulu, can be really heavy - page 31 [chapter 4.2.3]. Information from different development workers who have experience in constructions in Uganda give a good impression of what can be expected from the soil capacity in Uganda.

Stefan Hengst, a German development worker for the Jesuits in Gulu, explained: *"The soil has an excellent load capacity. As long as you make the foundation deep enough it should not cause any damage to a tower even during the rainy season. Look, for our 40ton and 12m high water tower we have constructed just 4 foundations with the size of 1,5m to 1,5m to 0,5m. Yes, we put them 1,5m deep into the ground, but the size is not too big."*

Norbert Demmelbauer once again confirmed the preliminary assessment. At most building sites the soil has been in excellent condition. Load capacity of soil can be assumed as one of the securest factors at the building process compared to material quality or work execution. Nevertheless it is important to avoid stagnant water during rain season by draining it.

In conclusion the soil seems to be in good condition, and does not ask for any special preparations concerning the foundations for the tower/mast. In addition the soil is quite resistant even during the rainy season. Nevertheless drainage around the foundations should be made to avoid stagnant water, which could reduce the capacity of soil. The other necessity is digging deep enough into the ground because strong layers of soil which will not be influenced by heavy rain are lying underneath.

4.2.2. Wind forces in Gulu

Winds can be very strong in Uganda. This is an important aspect as storm speed is the major influence in calculating the tower/mast for BOSCO.

On the other hand the constant or vertical loads on the tower/mast will be incredible weak. One antennas weights approximatly only 5kg. Including a technician who needs to climb up the mast from time to time in order to install other equipment the whole load can be estimated at about 200kg over all. Compared to wind speeds which can reach around 150km/h in Europe the load is not worth mentioning. For this reason, it is very important to obtain detailed data about wind forces and wind speeds. In order to obtain this information the Central Institute for Meteorology and Geodynamics in Austria has been contacted but unfortunately could not provide this kind of data. Finally the Commissioner Department of Meteorology in Uganda provided the following data.

In conclusion, it is the wind forces that will affect the tower dimension the most. As can be seen in the data sheet of the Commissioner Department of Meteorology wind speeds in Uganda can reach about 140km/h. To be secure the tower/mast should be calculated with maximum wind speed of 150km/h.

STATION NAME GULU MET. STATION **STATION NUMBER: 87320000**
LATITUDE - 02°45'N LONGITUDE - 32°20'E **ALTITUDE: 3622 feet / 1104 m**

MAX WIND SPEED

MONTH	mph	kmh
Jan	79,9	128,6
Feb	85,5	137,6
Mar	81,6	131,3
Apr	77,1	124,1
May	73,9	118,9
Jun	59,9	96,4
Jul	57,4	92,4
Aug	59,6	95,9
Sep	63,9	102,8
Oct	68,5	110,2
Nov	69,8	112,3
Dec	70,6	113,6
Year	70,6	113,7

chart 1 - Wind forces, Gulu

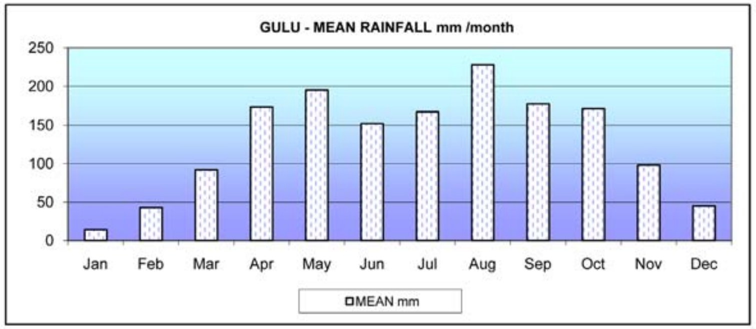
4.2.3. Rainfall

This data could be necessary to figure out the perfect time to start a building site. Even for the condition of the soil it is interesting - see page 29 [chapter 4.2.1].To overview strength and duration of rainfall in Gulu a detailed list compiled by the Commissioner Department of Meteorology in Kampala will follow.

Nevertheless, the building process should not be restrict by setting a timeline for the BOSCO tower/mast, because as mentioned on page 23 [chapter 3.5], it is the aim to be independent. If the construction plan will be as flexible and easy as desired it should not make a difference if it is raining or not.

STATION NAME GULU MET. STATION **STATION NUMBER: 87320002**
LATITUDE - 02°45'N LONGITUDE - 32°20'E ALTITUDE: 3622 feet / 1104 m

	RAINFALL			NUMBER DAYS OF RAIN		
MONTH	MEAN	HIGHEST	LOWEST	MAX 24 HOUR	RAIN	THUNDER
	mm	mm	mm	mm	>= 1mm	days
Jan	14	70	0	35,6	3	3
Feb	43	229	0	77,2	5	6
Mar	92	229	10	104,8	9	13
Apr	173	319	69	78,2	15	18
May	195	393	84	77	14	18
Jun	152	370	53	83,5	13	15
Jul	167	387	28	82,5	13	17
Aug	228	431	119	108,7	17	20
Sep	177	337	36	67,6	15	16
Oct	171	395	15	68,8	19	15
Nov	98	320	13	106,4	11	11
Dec	45	163	0	51,8	5	7
Year	1555	2144	869	108,7	139	159



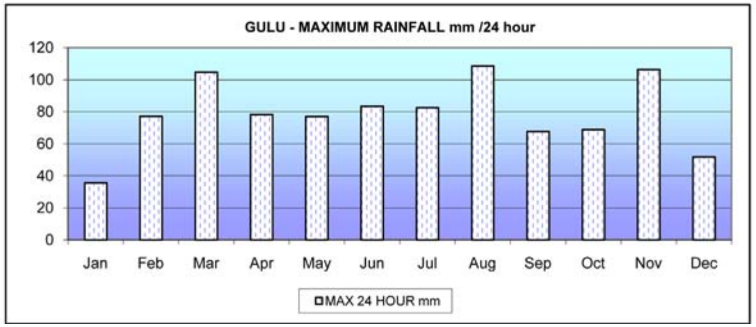


chart 2 - Rainfall, Gulu

4.3. Examples of Tower/mast constructions in Gulu

There are tower constructions all over Uganda. Sometimes two big towers are even standing within 10m from each other and look like towers all over the world, well-fabricated and typically colored in red and white.

Even the telephone poles look the same as in Europe or America. The question rises again if it is really necessary to produce a construction plan and guide for tower constructions for this region if there are so many already. The fact that you actually find as much towers as described makes it seem that there is the knowledge to build them. Quite the contrary is fact. Nearly all of these constructions have been built under the supervision of construction businesses from abroad. There are a few companies in Kampala - the capital of Uganda – which have the knowledge, experience and equipment to produce such structures but usually, most of the telecommunication towers in Uganda are prefabricated in Europe or America and shipped to Uganda. Given that all of the interviewed persons like shopkeepers and workshops confirmed this fact is has to be presumed that the know-how for the construction and maintenance of such towers remains in Europe or with these well situated companies. This means that the Ugandans get more and more dependent concerning this special field of work. Those described big radio towers are not of any interest for this thesis. They are planned and constructed abroad and then transported to their destination. The intention of this diploma project is just the opposite. It is not to transport a tower to Uganda but to transport the knowledge there to plan it.

BOSCO has been looking for a company which could build the necessary tower for the BOSCO project in Uganda. One company in Kampala did give an offer of around US$ 12.000 without even asking about the height. They told them that they could arrange it. In the end it turned out to be false- the company too wanted to order a readymade tower from abroad and set it up with their workers. The suggested price was just a blank number and probably would have doubled once

ill. 19 - common transmission towers in Uganda

ill. 20 - group of transmission towers in Uganda the order would have become more detailed. The sum of 12.000 US$ does not sound too expensive for a tower. But it is a high amount for Uganda. Considering the additional costs due to transport of workers as well as the probably prefabricated tower from Kampala (about 350 km away) or even further it has to be cheaper if everything would come from the local region.

Another reasonable question to ask would be why it is not possible to use an existing tower in Gulu to place the equipment used for the BOSCO project? This would certainly be possible for some locations but the rental price to fix such a small 5kg wireless LAN antenna to an existing tower is enormous. BOSCO asked UTL - Uganda Telecommunications - about renting a spot on their tower but the rent would have been US$ 2.800 per month. So after approximately one year a tower constructed by a company like the one which was asked in Kampala would be cheaper than renting a spot at an existing tower. This is also the reason why there are a lot of towers standing side by side: Renting a spot on an existing tower owned by someone else is more expensive in the long term than building a whole new one. The same goes for BOSCO; after a short time it will have been cheaper to build a tower and be the owner of it in addition. Furthermore, it opens the possibility to get an income by renting some spots for other equipment. Finally, it would not be possible to send the wireless signal to every desired location if BOSCO would rent a spot at an existing tower.

Therefore, the cheapest, most practical and most sustainable way for BOSCO is to build a tower themselves. The money for the building process would stay within the region. The material, as far as possible, will come from there as well. Most importantly, the local workshop which would participate in the building process would gain the knowledge of constructing such a tower. Moreover the workshop could have the possibility to construct something equal for another client in the future.

The aim of this thesis is to fulfill the specific requirements of BOSCO as well as to provide knowledge for workshops in Gulu.

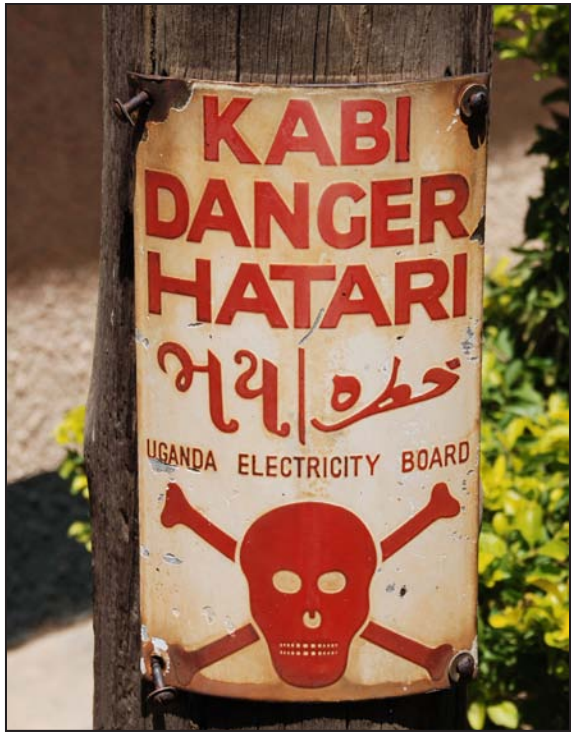
Some impressions and descriptions of tower/mast constructions around Gulu - mostly imported though - will follow.

4.3.1. Ugandan telephone / electrician poles

Basically, telephone poles have the same requirements as the tower / mast construction for BOSCO. Their purpose is to place the electric wires at a certain height – like BOSCO needs to place an antenna at a certain height. They do have the same construction principles all over the world. They even look the same: a wooden pole pushed into the earth – in Uganda usually without any foundation – and jagged with bundled iron wires to iron anchors / huge metal nails.

Most of them lost one of their anchors and are positioned in strange angels along the road. During the rainy season the ground sometimes becomes too soft to hold the poles and anchors. But the main reason for this is not the soft ground. At least 50 percent of the poles are just not pushed deep enough in the ground. Some of them even have not been pushed deeper than just 30 centimeters into the ground. The anchors did just have the length of about 20cm. So, the main reason that these constructions do not function properly is that the instructions for the foundation have not been carried out properly.

Another aspect which was investigated is where the material for these constructions came from. The poles are made out of a straight, around 7 - 8m long thick, timber pole



ill. 21- warning label on Ugandan telephone pole

ill. 22- Ugandan telephone pole

with a diameter of about 15 centimeter. During the research around Kampala and Gulu it turned out that these materials cannot be purchased in Uganda. It seems that they are imported from abroad, probably Congo, in high quantity and are not available for personal use. The same goes for the other technical equipment of these poles, e.g. the basic grounding.

Only their construction of tension cables is interesting for a mast construction for BOSCO. It seems to be possible and affordable to produce them yourself. They are made of thin iron wires drilled together roughly. It could be of use for the mast tower as well.

In conclusion, nearly all aspects of these poles are not functional for the desired construction way. The materials – especially the timber poles which would be of interest - are mostly imported and impossible to get anywhere in Uganda, never mind in Gulu. Even the way the construction was made is lacking. The self produced looking tension cables are however useful and seem to be a cheap and effective way to guy a mast.

ill. 23 - almost ruptured anchor connection

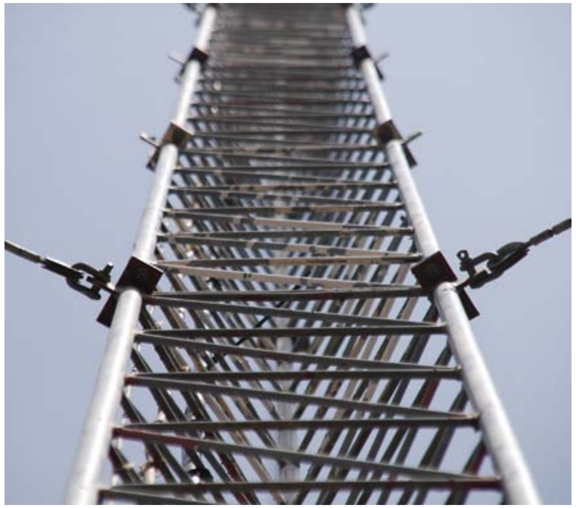
ill. 24 - tension cable - detail

ill. 25 - bundled tension cable - detail

4.3.2. Radio Maria tower – Gulu

This TV-tower is located in the centre of Gulu town. It is a huge and well constructed tower. As mentioned in the introduction of this chapter, those constructions are basically not interesting for this work in the way they were made actually - as they have been constructed and imported from abroad - but it serves well as an example of guyed masts in Uganda.

The construction principle is a framework which basically supports the pressure and 15 wires – fixed at different heights - which support the tension. The structure is triangular. The main pipes have a diameter of 50mm and a material thickness of 5mm. The framework in between is made out of 16mm steel sticks. The tower consists out of 14 segments with the height of 3m each. These parts have been bolted together on site. The framework can be imagined like stage elements. The whole construction has been galvanized to be resistant against corrosion which leads me into the conclusion that the whole construction has been prefabricated in another



ill. 26 - framework of the radio maria tower

ill. 27 - Foundations of the Radio Maria Tower

ill. 28 - Radio Maria Tower

ill. 29 - Radio Maria Tower

country as galvanized steel is expensive in Uganda. Furthermore, it has been welded and afterwards galvanized as a segment – which is not possible in Uganda at all. It is 42m high and the tension cables are fixed at 6 different foundation points around 20m away from the basement.

The foundations have been made at 6 different points. Three foundations in the diameter of about 11m from the basement are connected to the wires which support the lower segments of the tower. Three foundations are around 20m from the basement to support the upper parts of the tower.

It is possible to climb the whole construction by using the framework as a ladder.

An interesting aspect is that it has been decided that half of the tower will be pulled down. So, from my point of view, they will pull it down, remove the upper part and the jagged wires and set up the rest again. This is a great idea and could be used for the flexible BOSCO tower as well.

In many aspects this is a perfect example of how the BOSCO tower could be constructed. The technical solutions of this tower basically have to be transformed into cheap, affordable, self made reproduce-able details which can be carried out by the workshops in Gulu.

ill. 30 - welded joints of the Radio Maria Tower

ill. 31 - bolted module joint

ill. 32 - wire clamp

ill. 33 - concrete bloc foundation

4.3.3. Water tower CTC Gulu

Most of the small constructions which have to support a certain weight - like small water-towers around Uganda - are made out of steel and are welded. Different kinds and sizes of steel profiles are used. All types of frameworks with different angles and fascinating joint combinations are roughly welded together. They fulfill their purpose and furthermore they have been built locally, with the attitude to make it cheap and functional. I tried to investigate these cheap self-made towers / masts which have this certain unprofessional look as they are simply fulfilling their purpose. The example which will be described closer in the following paragraph is the water tower of the catechist center (CTC) in Gulu.

It is a construction at the average height of water towers in Uganda – around 8m. Buildings usually have just one floor or at maximum a second- therefore the water pressure is sufficient even with this height of those water towers.

The CTC has installed two water tanks with the quantity of $3m^3$ each which means that the tower has to support 6 tons. It is shielded quite well from wind forces because it is standing close to the main building but nevertheless has to support a serious weight. The base is 1,5m to 3m. The main poles are pipes with a diameter of about 10cm. All other stays are made out of different metal bars.

ill. 34 - example of a welded joint at the CTC water Tower

ill. 35 - CTC Water Tower

Detailed information about the water tower was gained from Fr. Joseph Okumu - the director of the CTC: No foundation has been used to fix the poles. They just have been pulled around one meter into the soil. But anyway, it is standing without any problems since 2004.

The way this tower has been constructed is of relevance for this thesis. In fact most of the joints have been welded in a rough way. Metal bars with different size and shape have been used. And still after taking a closer look at these welding joints they seem to be in really good condition – and as a matter of fact not a single one did get loose. Father Joseph explained that the tower has been set up by the workers of St. Joseph's garage close to the catechist center. This workshop will be described on page 61 [chapter 4.5.1.3]. Nevertheless, the construction design came from a person from abroad who has been a guest at the catechist center.

Another important aspect of this tower is the corrosion. Even though it has been standing for 4 years only, it is seriously corroded. The tower has not been treated with any kind of corrosion protection. Some of the sticks are made out of galvanized steel pipes, some out of bent steel bars. Material lying around at the workshop or the CTC obviously has been used for this tower.

In conclusion, for the desired BOSCO tower/mast it is essential to make the whole construction resistant against corrosion. Galvanized steel would be a good solution - if the tower will be made out of metal. But it still has to be calculated whether it is affordable and cheaper to buy galvanized steel or to paint the tower once in a while.

ill. 36 - examples of rough welded joints

ill. 37 - examples of welded joints

ill. 38 - Water Tower CTC

4.3.4. Water tower Pabo IDP camp

There are different examples of water towers in the camps around Gulu. Parts of these towers have been ordered abroad and set up by NGOs working in the camps. One example will be described in detail: This tower has been built by the ICRC – International Community Red Cross – and is standing at Pabo IDP camp. It was chosen to be outlined because of two interesting aspects.

The Tower supports three water tanks with the quantity of 30.000l on top of it. The height amounts 8m. Furthermore the water tower is free standing close to an IDP camp without any cover from trees. Small foundations have been used, as is the case with all constructions seen in Uganda. So the soil has to be in excellent condition. As mentioned on page 29 [chapter 4.2.1] load capacity of soil before.

Two aspects of this tower are of particular relevance to the investigation: First of all how it has been constructed and furthermore what happened to this tower over time. In fact there are a lot of bolts missing. One possible reason for this is that these bolts were lost on the way to the site. Materials are sometimes hard to get in Uganda. There is no store with a wide variety of bolts or other technical equipment in Gulu and therefore is it hard to find matching bolts. (For closer description investigate page 56 [chapter 4.4.5] technical accessories) It is necessary to work with the local possibilities and those are rather rare. Another possibility is that these screws have been stolen. Materials are rare and expensive. Especially close to IDP camps people are so poor, that they sometimes are forced to even steal bolts and other valuable things to provide their living. In this particular case the persons in charge decided to weld those joints where screws have been missing.

In conclusion there are two important aspects for the BOSCO tower which will be recapitulated. As technical accessories are mostly rare, it is absolutely necessary to use them in the most efficient way. Quantities of technical accessories have to be limited. A tower where 300 bolts are required would not be possible within the capability of Gulu. They

ill. 39 - Water tower IDP Camp Pabo

can be bought in Kampala, but it takes time to get them, and this contradicts the intention to make the tower locally constructible. It should have the potential to be built in Gulu, just within the capacity of this town. What is more, the aspect about the value of the material is interesting. How will it be possible to secure everything and therefore prevent parts being stolen?


ill. 40 - ladder to the top of the tower


ill. 42 - welded joints


ill. 41 - Foundation


ill. 43 - framework joint

4.3.5. Radio mast: Archbishops' residence

This will be a short description of a radio pole. It is located at the archbishop's residence in Gulu. Sister Kevin, who is responsible for the compound – provided all the information about the mast.

It is a slim, material saving construction of about 12m height and has been used recently to receive the signal from BOSCO. But as the network layout is changing it has been removed for some time.

The radio mast has been constructed by St. Joseph's garage in Gulu like the CTC water tower. No foundation was used. Two U-shaped metal bars have been pushed around 1,5m into the ground. These two bars have a height of 1m over ground. In between these two bars the main pole is fixed. This pole is constructed out of two galvanized steel pipes. The bottom one has a diameter of 76mm and the upper one of around 50mm. They are connected by pushing the thinner pipe into the bigger one and using 2 bolts to fix it. So it is even possible to adjust the height of the construction. Nevertheless, it does not make too much sense, because material use is the same for any height.

As it is a slim and light construction it is easy and possible to be set up and pulled down by just a few people. Yet, it is not possible to adjust the angle of the antenna when it is already fixed because it cannot be climbed. For the desired BOSCO tower it will be necessary to climb it in order to adjust the antenna to get the best signal.

ill. 44 - foundation of the mast

ill. 45 - Radio mast - archbishops residence

ill. 46 - detail of the mast- archbishops residence

4.4. Materials and technology

It does make a big difference in which region of Uganda you desire to construct a tower. From town to town material choice and prices are changing. Furthermore, even in a single town it can happen that the price of the same material in one shop can be completely different than in another shop. Any bigger town has hardware shops - some small stores where you can buy constructional timber or cement. In Gulu you can buy nearly any bolt but quantity is lacking. Each shop has a pile of screws or nails and it is up to you to find suitable ones. Different length and diameter, with or without a nut are up to the conditions of these shops.

Yet, it is possible all over Uganda to order any material or equipment you desire. These goods will be transported from Kampala. It is absolutely common to buy goods in Kampala and transport them to your place. Most workshops, even if they are small, order in certain periods a truckload of goods.

The aim for the BOSCO tower is to make the construction as cheap as possible. The consequence would be to buy most material in Kampala directly. Furthermore most of the workshops order material and equipment there. Nevertheless the intention for the construction plan is to make it produce-able with the capacities of rural areas. If possible local materials should be used and, most importantly, it has to be figured out how technical details can be produced without rare equipment or material.

The following chapters will describe material possibilities in Uganda, especially Gulu. Their production and quality will be explained. Furthermore the origin of the materials will be described. After all the possible use of those materials will be argued regarding a tower/ mast construction.

4.4.1. Constructional timber

Vegetation in Uganda covers a wide range of different trees. Over hundreds of different species have been documented. Nevertheless, there are regions in Uganda where it is hard to find any tree at all. Especially in some parts of northern Uganda nearly all trees have been cut down. Firewood is a necessary good in the daily life of Ugandan families. Wood coal and brick production is also popular but firewood is needed every day to cook their meals. Most timber is used to provide those basic needs. Therefore trees do not even get big enough so that beams and boards could be cut out of them.

Concerning possibilities of timber use in Gulu Ft. Joseph Okumu - who was born in northern Uganda and lives there for more than 50 years - explained: "*People need wood for their daily needs. And during this terrible war in the past 30 years even firewood had become expensive. How should there be a production of timber if the people need it for daily cooking?"* This surely may sound exaggerated but the essence is true. Constructional timber is not produced because it is needed elsewhere for daily needs. Furthermore, timber is not the kind of traditional construction material as in European countries. The traditional housing in Uganda is the round hut. It is a one room hut built out of clay. The roof is made out of bamboo and grass. *"Timber constructions don't have any tradition in Uganda. Timber is used for carpentering. But for constructions nearly nobody uses it."* Father Felix Opio explained. Every modern building nowadays is built out of bricks and concrete. Timber constructions are pretty rare.

Nevertheless, there are three kinds of timber for constructions available in Uganda and Gulu.

ill. 47 - traditional roundhuts in Uganda

4.4.1.1. Palm Trees

The locally most available types are beams made out of palm trees. It is cut into extremely rough beams with a size of around 10 to 10cm. They are produced in small family companies and are sold at intersections or close to the street.

Alfred Kilama, the technical assistant of BOSCO, clarifies: *"A lot of people in the countryside use these beams. They are cheap and are nearly completely resistant against insects. But don't use it for the tower. It will be too rough and broken soon."* The shop keeper explained: *"It is even stronger than other wood. See, there are all these wires, so it becomes really strong."* In fact it really is a heavy and quite strong looking material. The aspect that it exists out of a lot of tiny stings will cause for sure a high load capacity. They are used mostly for fencing.

Summarizing this material has some advantages. It has a high resistance against insects and a powerful internal structure. Even its local production is of interest for the BOSCO project. Nevertheless, the weight and roughness of the material is not suitable for any tower/mast construction. The lifespan is not too long either, as Alfred Kilama made clear. Furthermore, it would not be possible to calculate a tower/mast with it statically, because each beam has another size and structure.

ill. 48 - Palm tree structure

ill. 49 - Palm trees

4.4.1.2. Bamboo

Sold at spots close to the street, bamboo is the second local material which can be bought all over Uganda. It is used for roof constructions of round huts. The length of the sticks is about 5m with the average diameter of about 3cm and it is sold in bundles of about 5 to 7 pieces.

Bamboo is both lightweight and exceptionally durable. In China entire scaffolds up to the height of 200m have been constructed. Yet, Bamboo has to be treated to keep its high durability by hollowing out the core of each rod. In addition it has to be kept very dry; otherwise it will be easily infected by wood boring insects which destroy the internal structure fast.

In conclusion, this material would have excellent qualities for the BOSCO tower/ mast regarding some of the requirements. To hollow out the core of the rods would be possible but as the rainy season in northern Uganda covers nearly half of the year it would be impossible to protect it from water. It could be used for assistant scaffolding or any other short term construction needed for the tower/ mast construction. The construction would certainly last for one or two years, but the solution for BOSCO has to last a much longer period.

The situation in northern Uganda is stable right now, and people have started to move back to the countryside to their properties. But it will take years until the IDP camps can be abandoned entirely if this will ever happen. Therefore the BOSCO project still will be necessary to provide Internet in a couple of years. For that reason BOSCO needs a tower solution which is solid for many years. Many people grew up in these camps and lost their families and relatives. Basically, these camps are their homes. It will be a hard task for the government of Uganda to find a way out of this situation.

ill. 50/51 - Bamboo

4.4.1.3. Constructional timber – Hard and Softwood

If ever wood would be a possibility it seems that beams and boards out of constructional timber could be the only reasonable choice for a tower/mast construction. A small selection of about 3 to 5 dimension types can be bought in every town in Uganda. Available soft wood sorts are Pine and rare Cypress. Mahagony, Ubee, Zingo and Muvule are available hardwood types. Pinewood covers the majority followed by Mahagony. The other kinds cover just a small percentage.

Brother Michael, who manages S. Josephs Carpentry, provided a lot of important information. *"Most timber is used for furniture, as there is nearly no constructional use of it. The beams and boards are wavy. It's hard to find a beam without a serious crack. For furniture this isn't that problem as it is for constructions."* Nevertheless they produce small roof trusses. *"For a small roof truss timber is working. We support the cracks of the beams with metal strips, which work rather well. If the trusses get bigger, like about 6m wide, we use steel."* The question why the quality of timber beams is so poor, he answered: *"The main reason is that it is just cut badly. Most of it is cut by hand or with a chainsaw, which is actually forbidden because of the huge material loss. You can estimate how hard it is to cut a log into nice beams by hand."* It could be possible to get specific beams, although they would be of poor quality. *"They sell what they have to sell. And if you ask me, I don't have a clue where to get a specific beam."*

It is difficult to find out exactly from where timber is coming into Uganda. *"On one hand it is transported from far away, like Congo. The shops in Gulu and in other towns sell timber from there. As we are a well known, carpentry people come to us and offer their timber. It used to be cut somewhere in the country but quality is really low."* So obviously a lot of the timber is available in the stores but seems to be coming from abroad. *"Not all of it, but a lot for sure."* To confirm this information another shopkeeper who sells constructional timber in Kampala and offers a really wide range compared to other stores was interviewed. He confirmed that the timber is mostly im-

ill. 52/53 - Constructional timber

ported from Congo by train. The situation in Gulu and Fort Portal is similar. Timber sold there has been ordered in Kampala but was originally imported from Congo in Kampala.

During the second study trip it turned out that the situation has changed since the first study trip in July 2008. In fact another shop-keeper in Gulu explained in February 2009 that timber production has started recently. *"Before, we did buy the timber only from Kampala. I think it came by train from Congo. But now some of our timber is coming from the District of Oyam."* Obviously a production site in this district was founded and is now exporting from there recently. Unfortunately quality of these locally produced boards is even a bit worse compared to the boards and beams from Congo. Nevertheless, it is from inside the country and hopefully they will succeed to improve their quality.

In conclusion, timber constructions would theoretically be possible in Gulu. Recently it is even becoming a local produced material. In my opinion, though, it is not useable for the construction of the tower/mast because its quality is too poor right now. Brother Michael who has been a carpenter for more than 50 years reinforces: "*I would not use Ugandan timber for such a high construction. If quality would be as in Europe we could think about it. For furniture it is perfect as it has not to support loads, but for a loaded construction I wouldn't trust in it."* For assistant scaffolding Bamboo constructions could be of great use because of its medium price. Furthermore, varying unsafe quality would result in doubling up all dimensions to secure the load capacity of the tower in case timber would be used. Finally a construction out of constructional timber would be too heavy to make it as flexible as it should be to fulfill the goals of the BOSCO tower/mast.

ill. 54 - Timber detail

4.4.2. Iron – bars/ meshes/ sheets

The raw material is imported from other countries – especially India - entirely. The only manufacturer of metal products out of raw material in Uganda is Roofings Ltd.[14] in Kampala. All other metal products are imported from abroad. One of the biggest distributors of them is DOSHI Metal Corporation[15] from Mumbai/India. Every single steel-bar arrives in Kampala by train and is then distributed all over the country. Each village has a hardware shop and the selection decreases with the distance to Kampala. Yet, it would be possible at any hardware store to order a wide variety of steel bars, meshes and sheets. Each workshop investigated confirmed that they order their material in Kampala at Roofings Ltd. They seem to have the best conditions and the widest variety of metal products all over Uganda. Nevertheless, there are certain metal products which are available in most stores in Uganda and as said before the aim of this work – if the tower/mast will be out of metal – is to use locally available and locally fabricated materials.

Reinforcement cables to produce reinforced concrete are the most common metal pieces available. It can be bought at the strength of 8mm straight or 10mm drilled. Round bars with a diameter of 8mm up to 12mm usually for lightning protection is available as well. Length of both is 12m.

Steel bars are always 6m long. L-shaped, rectangular shaped and pipes dominate the selection. The variety and sizes change from shop to shop but it would be possible to order whatever is required. Pipes start with the diameter of 15mm up to 76mm maximum. L-profiles start with 20mm up to 60mm. Rectangular profiles start from 20mm up to 75mm. Thickness is between 1,2mm up to 6mm depending on the profiles. Steel strips are available too. They can be found in dimensions from 15mm wide and 1mm thickness up to 30mm wide and 3mm thickness. Starting on page 70 [chapter 4.6.2], the most common profiles will be listed with prices and dimensions. If metal would be used for the tower construction it would be reasonable to use the common ones.

ill. 55 - Shop variety of steel bars in Gulu

-14- http://www.roofings.co.ug/ [accessed 2009 03 12]

-15- http://doshimetal.com/default.html [accessed 2009 04 15]

Each shop also has a variety of meshes and wires. Thick meshes, used for reinforcement, are the thickest kind going down to mosquito-sized meshes. Thin 0.5mm thick wires are also available up to galvanized tension wires with a diameter of 3mm. Steel strips used for grounding with the measurements of 15mm to 0.3mm thickness are available too. The length of these wires and strips goes up to 100m. Both could be suitable to be used as tension wires.

Finally, iron sheets such as corrugated iron and straight iron with a thickness up to 6mm cover their full shop selection. These sheets have the size of about 3m to 1,5m.

An important aspect to bear in mind when using iron is corrosion. There are two possibilities in Uganda to secure constructions from corrosion.

The first one is to use galvanized steel. It is hard to find in Uganda and not a single store which was visited had them in stock but nevertheless it would be possible to order these profiles. The shopkeeper of Hardware Gulu clarifies: *“It’s not for sure corrosion resistant. It is supposed to be, but proper grounding and painting works as good and is even much cheaper.”* Available qualities are A, B and C. But 99% of all galvanized products are Quality B and C. They are marked with two different colors. B is marked blue and C is marked yellow. *”You have to pay attention at these color marks. Many shopkeepers grind of the yellow color and mark it as quality B.”* The shopkeeper continues. *“Material strength of galvanized products is around 1,3 to 1,5 times thicker than regular ones.”* This could be a huge advantage, but nevertheless the price is reasonable. A pipe with the same diameter of 76mm cost 230.000UGX galvanized compared to 120.000UGX regular. Although the galvanized pipe is around 1mm thicker it seems to be a very steep price.

The second possibility is to primer coat and paint the construction. Paint is available in every shop which sells iron bars. It will have to be calculated which possibility will be cheaper and more sustainable to secure the construction from corrosion.

ill. 56 - reinforcement steel

ill. 57 - steel meshes

In conclusion, metal seems to be the material which will fit best for the main pole of the tower construction. In summary the reasons why metal fulfills all the necessary requirements are:

- It is available all over Uganda. There are shops in every bigger village and even in the furthest areas there is the possibility to order a small selection of iron bars.

- The knowledge of welding and workmanship of metal exists everywhere in the country. Each small village has at least one workshop with a welder.

- In order to make the whole construction flexible in means of transportation and height – see page 23 [chapter 3.5.1] - it should be lightweight. Metal has, compared to its weight, the highest load capacity.

4.4.3. Concrete

To produce concrete it is necessary to mix cement with aggregates and water. So, even in rural areas it is possible to produce this material with medium effort. The only so to say technical material that is needed to produce concrete is cement. This is available all over Uganda and can be bought in almost every village. Furthermore it is produced in Uganda. There are two manufactures of cement in Uganda. Hima Cement which produces cement under the name "MULTIPURPOSE" is the market-leader. Bamburi Cement is called "SUPERSAFE". Both cements have the quality of PZ 275. Filled in 50kg paper bags it is quite easy to transport and it is common to put 2 bags on one bicycle or motorcycle. Prices of cement do not vary too much between different towns because it is produced in Uganda.

Aggregates can also be bought anywhere. Each village has at least the possibility to get sand and stones somewhere. Most towns have a variety of different aggregates. They call them river sand or grey sand and all of them fulfill their purpose. A usual method in rural areas to obtain sand or stones is to hire some workers who dig close to the building site and sift stones.

Water – the third component – is luckily not scarce in Uganda. Even if a lot of people are waiting with their "cherry cans" – empty oil cans – at water pumps the country does have enough water resources for all people. There are several lakes and rivers across the country.

The knowledge to produce different kinds of concrete structures is also widespread. The production process is however lacking some important steps like compression and curing. This lapse can be seen in surfaces which sometimes are quite rough. If reinforcement has been used at all it is not covered all the time. A construction worker explained this matter: *"We put in enough cement, and it will hold long enough. Concrete is so strong."* There is a true essence in this statement. In Uganda, they do not have problems with

ill. 58 - stones

ill. 59 - Concrete structure - detail

ill. 60 - Concrete structure - detail

freezing, which would cause a lot of problems in Europe if the surface would be as rough as here. Furthermore, it seems that there are no construction officers existing. Constructions are used until they really cannot be used anymore. Even if the concrete beam has a lot of cracks and is bending seriously it will not be secured or repaired.

Compared to other materials concrete structures in Uganda are expensive. As Norbert Demmelbauer explains: *"Compared to Austria one cubic meter of concrete costs in Uganda around 5 to 6 times as much."* Every ingredient will be transported separately to the building site. Stones and cement are rather expensive. In comparison to mass produced concrete in European countries the price difference is comprehensible.

Yet, the production of concrete structures is possible in Uganda. It would definitely take more education and preparation to build wide spanned ceilings for example but for basic use like foundations the quality is sufficient. Nevertheless work expenditure and prices for concrete structures are high.

4.4.4. Bricks

Bricks are one of the few entirely locally produced materials. Two kinds of bricks are locally available. Big and heavy concrete bricks or tiles and burned clay bricks.

4.4.4.1. Concrete bricks / tiles

In Gulu there is one shop specialized in producing concrete bricks. It is called James Concrete. Basically any kind of concrete work as well as bricks with any dimension can be produced there. James the owner of James Concrete: *"We produce them on our own, so we can make you any brick you want, as long as it is out of concrete."* A common brick in his shop has the size of 15 to 30cm and 20cm height. The quality of those bricks is excellent. Moreover the possibility to produce any individual dimension is of particular interest for the tower construction as bricks could be used as counterweights for the tower/mast construction.

ill. 61 - Concrete bricks/tiles

4.4.4.2. Clay Bricks

Clay is the by far most produced material all over Uganda. Even in the most remote areas of the country there are people who produce them. The production process is traditional and not complicated at all which makes is possible to find clay bricks everywhere. The soil all over Uganda has big amount of clay. Mixed with water, the soil becomes a homogenous paste which can be pressed in rough tiles of around 20 by 15 to 15cm.

The tiles are afterwards dried in the sun. These raw bricks are the most common building material in Uganda for the traditional round hut. In addition it is common to burn these raw bricks in order to make them harder and more resistant against rain. The procedure starts with stacking them on top of each other in a special way. Bottom openings and air-ducts inside the pile provide circulation. This is necessary because next the pile is covered with soil to seal it. The bottom openings are filled with firewood. Now, the heat can circulate through the whole stack and after about 24 hours of heating the process is finished. Finally, a stack of burned clay bricks is ready. As a matter of fact not all areas in this pile get the same amount of heat, so quality overall varies a lot.

Clay bricks are cheap (between 40 and 120UGX per piece). They are produced locally and represent the most common construction material for around 99% percent of all houses in Uganda.

ill. 62 - Producing clay bricks

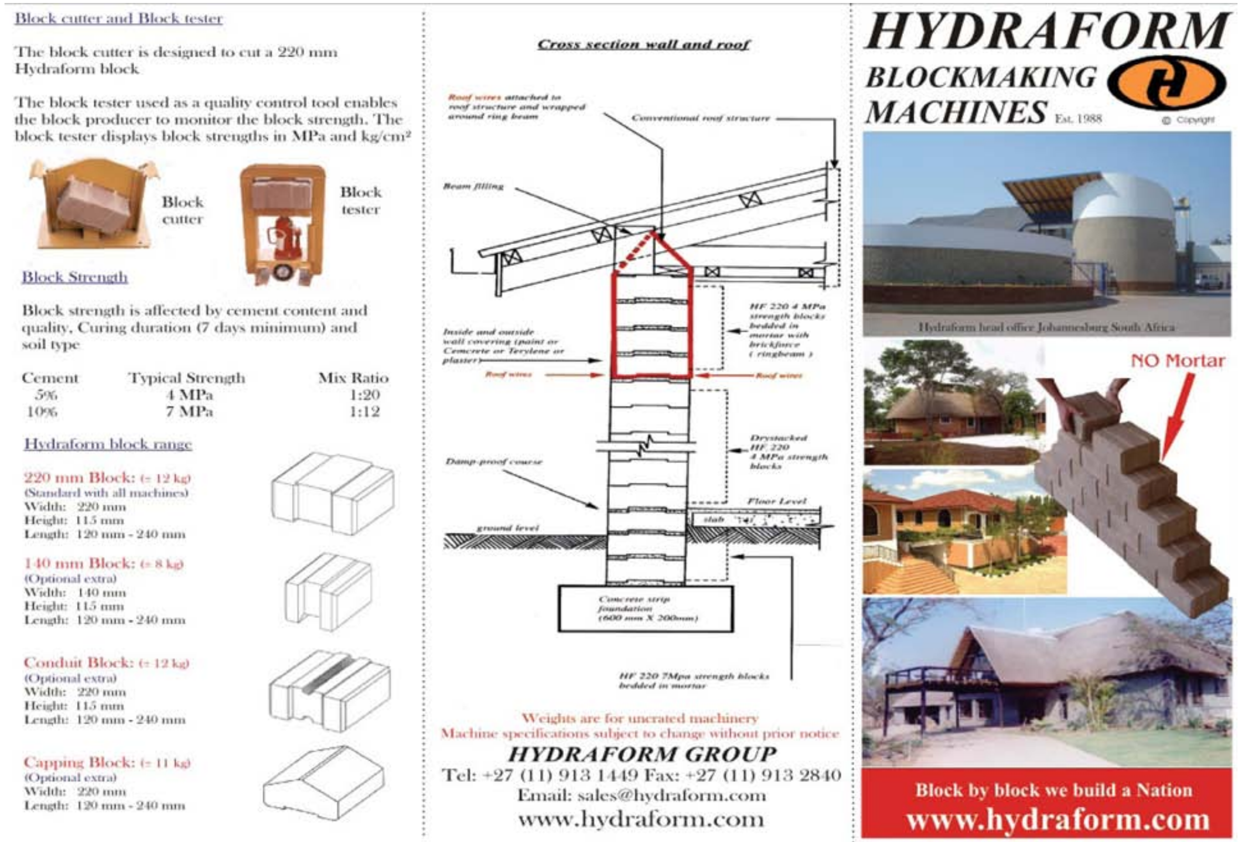
ill. 63 - Bottom openings of brick pile

ill. 64 - unburned clay bricks

4.4.4.3. Hydraform

Another method which is used to produce bricks is a system invented by the company Hydraform[16]. It is a specialized method which uses Hydraulic block machines to compress soil mixed with cement to produce interlocking dry stacked Soil Cement Blocks. These bocks do not require mortar as the shape of the blocks provide interlocking. It is a simple masonry system which can be taught by unskilled laborers. Nevertheless the costs for the hydraulic block pressing machines are rather high as well as the bricks are overall more expensive as traditional produced bricks as concrete is needed to provide stability for the blocks.

Bricks, either concrete, clay or soil are sustainable as they are produced within the local area. Yet, they cannot be used for a tower/mast construction. But they should not be discarded for the construction overall. Counterweights for foundations can be needed for any kind of tower/mast construction. Therefore these bricks could be of use.



ill. 65 - Hydraform product sheet

-16- http://www.hydraform.com/ [accessed 27 04 2009]

4.4.5. Technical accessories

By technical accessories all additional equipment which will be needed to construct a tower/mast is meant. Nails, screws, bolts, shackles, tendons or wire clamps are falling into this selection. They have to be mentioned particularly as they are rather hard to get anywhere. Shops have a medium variety of them. The more specialized an item gets, the less the variety gets. So the shops have around six kinds of screws or nails, four different bolt sizes and two tendon and clamp dimensions. Planning to use many accessories of the same kind would cause additional problems and should be avoided in advance. But finally it is possible to get up to100 matching pieces of the same kind in Gulu.

Norbert Demmelbauer tightened this investigation with his working experience. Nearly all necessary accessories are available all over the country. Quantity and variety is lacking in rural areas. And if not available in a town it is always possible to get any kind from Kampala.

The main problem he experienced was the quality of these parts. Any metal piece has to be assumed to be produced in China out of engineering steel – S235 (ST37). *"Quality of screws and nails is rather poor compared to European ones. Since recently it is possible to get other screws and nails in Kampala, but the prices for them are much higher than the Chinese version!"* Brother Michael from St. Josephs Carpentry explained and continued. *"Any screw or bolt can be ordered like any other material in Kampala. To work financially efficient it is most of the times necessary to do this. For a wooden screw I pay 500UGX in Gulu compared to 50UGX in Kampala."*

All kind of technical equipment can be ordered in Kampala and obviously this seems to be the most efficient way. Nevertheless there are some essential accessories unavailable in Uganda. Equipment for proper lightning protection cannot be found anywhere. A local made way, or importing this equipment has to be considered.

Overall a construction plan has to be figured out which does not need a wide variety or quantity of different accessories. Prices of more common accessories will be listed on page 75 [chapter 4.6.2].

ill. 66 - technical accessories at Gulu market

ill. 67 - typical market store

ill. 68 - selection of technical accessories

4.5. Labor Conditions – production and transport

4.5.1. Workshops

In general a local workshop in Uganda differs a lot from a European workshop. To get an idea of widespread working conditions workshops will be described more precisely. Most commonly, they have a size of around ten square meters. Inside this room they store their materials and tools. The actual working place is in front of the building mostly on the floor.

It is hard to find a workshop which provides metal and woodworks at the same time. Usually one workshop produce iron gates only, another one just fencing parts. Some furnish beds others produce chairs... in general every workshop produces just this very kind of product and nothing else. It is more or less a question of specialization. As they are very specialized, they just own the tools which are absolutely necessary for their specific trade. So, a shop which produces beds owns a saw, hammer, crowbar, plane and some clamps. Everything corresponds to basic standards and tools will be used literally until it is just not possible to use them anymore. Most welders at metal workshops are seriously broken. The insulation of the wire does not exist anymore. Every tool is twisted and it is visible that they have been fixed poorly very often.

The quality of your desired product depends most of the time on the amount you are willing to pay for it. As Fr. Felix from the catechist center in Gulu told me, you can decide how well the desired product is fabricated. *"If you have enough money you take the best quality- it will be working for years. If not it can happen that it will break after three months."*

However there are other kinds of workshops in Uganda as well. In general they are associated to Religious organizations and have a rather good infrastructure. Every village and town has at least one church. Since Christians started to proselytize the country, they set up workshops to maintain their infrastructure. Even though it was originally intended to maintain everything by missionary workers, they figured out, that it is necessary to have local staff as well. Nowa-

ill. 69 - common workshop condition in Uganda days, most of these religious workshops have a training system to teach local people and they aim to provide technical skills.

These religion based workshops are relatively well equipped compared to common local workshops. They own circle saws, different welders or bending machines. *"We get financially supported from our mother organization, for sure. But still we have to calculate every order precisely."* Brother Konrad explained the situation of one of the investigated workshops.

In the next chapter four workshops in Gulu and its surroundings will be described briefly. All of them are part of, or supported by, the Archdiocese of Gulu. It is possible to use the network of this religious organization as the Archibishop of Gulu is actually the legal project holder of BOSCO as well. All of them would be interested to construct the tower/mast for BOSCO and are willing to work under special conditions as they are interested in the opportunity to obtain additional knowledge throughout the project.

4.5.1.1. Lacor hospital workshop

This workshop is located in Lacor, a small village around 5km outside of Gulu town. It is the operation workshop of St. Mary's Hospital Lacor. *Better known simply as "Lacor Hospital" it is a non-profit charitable institution belonging to the Gulu Catholic Diocese, and has the mission of offering quality accessible health care to all, especially to the most disadvantaged people (children, women and people without economic resources)*[17].

Parts of the hospital and workshop were funded by Horizont 3000[18]. Through the introduction of Stephan Bock, consultant of BOSCO it was possible to get in touch with this workshop which usually is exclusively responsible to maintain the entire hospital complex. From brick laying to metal constructions everything would be possible with the equipment of this workshop. They own an excellent selection of different tools and the workers are quite experienced as they work on all different fields that need to be covered to maintain a hospital. To gain an impression of their tool selection it will be easier to have a look at the pictures taken on site. Head Technical Manager of the workshops is Brother Elio Croce.

The workshop would be interested to construct the tower/mast and gain the experience through the construction process. Yet, during my research and after some discussions with Stefan Bock and the Team of BOSCO– it was decided that Lacor hospital Workshop would finally not be shortlisted. On one hand they did not seem as enthusiastic as the other workshops. On the other hand this workshop is an operation workshop for the hospital. Usually they do not offer their services to any customers. So, if they would construct and set up the tower/mast for BOSCO, the chance that they reuse the gained knowledge again afterwards is close to zero.

As far as it is possible to choose a workshop, the aim is to provide the experience and knowledge to one, where the possibility exists that it will use this know-how at a later date again in a completely independent way.


ill. 70 - lathe


ill. 71 - metalworking equipment


ill. 72 - autogenic welder

-17- http://www.lhospital.org/eng/index.shtml [accessed 01 05 2009]
-18- http://www.horizont3000.at/ [accessed 01 05 2009]

4.5.1.2. St. Joseph's Carpentry - Brother Michael's workshop

This workshop[19] is situated in the neighborhood of the BOSCO headquarter and the Archbishops Residence of Gulu. As described in the introduction of the chapter, it is a missionary founded workshop of the Archdiocese of Gulu. The workshop has been set up around 1950 and since 1995 Brother Michael Dietrich, a German Comboni Missionary, is managing it.

This workshop is widely known all over the northern part of Uganda because of the excellent quality of their products. Some people call it the best carpentry in Uganda which is their main activity. However they are able to work with metal and bricks as well. They own several grinders and welders, probably the best selection of woodworking machines in Uganda and have a wide variety of working materials. *"We try to invest in new tools and maintain the old ones every year. Otherwise we cannot produce good quality and it is cheaper to maintain them than repairing them when they are broken!"* Once again it will be easier to get an idea about their tool selection by looking at the pictures.

Furthermore education is an important aspect within the St. Joseph's carpentry. *"All workers in this workshop have been trained here. They get their education by working on the furniture which we produce for schools or offices. They start with poorer works like painting and grinding and learn all skills until they are fully educated."* The education obtained there is excellent in comparison to other workshops furthermore the salary is rather high as well. *"For an eight hour working day we pay between six and ten thousand Uganda shilling. This is not too bad for Uganda, but our products are well priced as quality is good, so our workers get their share!"*

This workshop would have the capability and interest to construct the tower/mast for BOSCO. *"We can construct such a mast for sure. We have all necessary equipment and connections to get materials."*

ill. 73 - St. jospeh's carpentry


ill. 74 - yard of St. Jospeh's carpentry


ill. 75 - carpenters plane


ill. 76 - Welding set

-19- http://www.comboni.de/projekte/gulu/index.php [accessed 01 05 2009]

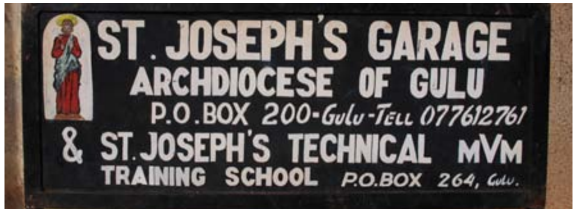
4.5.1.3. St. Joseph's garage

This workshop is also situated in the neighborhood of the BOSCO headquarter and the Archbishops Residence of Gulu. As the name of the workshop states, it is mainly a garage to repair and maintain vehicles. It has also been set up around 1950. Actually, it is the neighbor building of St. Josephs Carpentry. Still there is not a single connection between these two workshops which is quite visible after the first viewing.

St. Joseph's carpentry of Brother Michael which was described before is in a nice and tidy condition with well maintained and repaired tools. St. Josephs Garage in comparison follows more the Ugandan attitude as it is managed by Bob, a local villager. This should not sound condemning, but St. Josephs garage contrary to St. Joseph's carpentry has not renewed any tools over the past five to ten years. Some machines are in horrible condition, but they are still used. Bob told me: *"Our drilling machine and some other tools are in bad condition. But as long they work we use them."* It is certainly a matter of finances and the instable politic situation over the past years that in Uganda it is more common to use machines, vehicles etc. as long as they literally brake without any long- sighted Maintenance. However it is perhaps also the attitude to rely on help from abroad or NGOs which will renew machines in order to help simply because they are used to this kind of dependency.

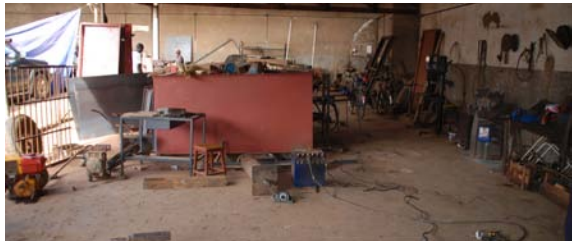
Main activity of St. Joseph's garage is maintaining and repairing vehicles for the staff of the Archdiocese. Besides, they have a small technical training school with around 20 students. The students get half theoretical education and half practical education on study projects. But they work on small metal constructions as well. *"It would be of great interest to learn something new. We know how to work with metal, have the fitting equipment and transport possibility as well."* Furthermore they own some welders and grinders and there is an abandoned looking room with fine mechanics equipment too.

The overall condition of St. Joseph's Garage is still above the average workshop in Uganda. But from these four examples, St. Joseph' Garage comes closest to the target possible workshop. After all even a simple Ugandan workshop (as decribed at the beginning of this chapter) should be able to construct the final prototype.



ill. 77 - St. Joseph's gargage

ill. 78 - working conditions



ill. 79 - Facilities of St. Joseph's garage

ill. 80 - Poorly maintained welder

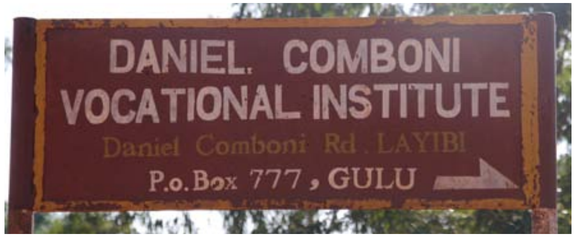
4.5.1.4. Daniel Comboni Vocational center

The Daniel Comboni Vocational Center[20] is a huge compound about 4km from Gulu. The Comboni Missionary Organization has around 3500 active members in more than 40 countries. Their idea of proselytization is a combination of pronouncement of the gospel, awareness of human rights and integrated human development in knowledge and crafts.

The Vocational Center in Gulu has been established around 1920 by Comboni missionaries. In 1995 it became a training center. Priests responsible for pastoral care and brothers who are technical trainers are living together. The training staff consists of missionaries of limited duration from all over the world and trainers from the local region. They are supported from the ministry of Uganda and their mother organization. *"Our training is based on offers from customers. Without this money we could not survive."* Brother Konrad Tremmel from Germany, Chief Manager since January 2009, explained. Before, he managed a workshop in Malavi for 12 years.

The Vocational Center tries to provide technical tutoring for the local population in order to give them the possibility to open their own workshop after finishing the education. The training consists of a theoretical part and practical training. *"We teach about 120 students right now. Our goal is to give them all necessary skills to work in a workshop or open one. But a lot of students quit their education, because they get an offer from an NGO. Nobody can compete financially against the salaries of NGO's. But they need workers just for a short period. After two or three years the organization quits the worker and they have unbelievable problems to find a job afterwards. Unfinished education and high salary expectations, because of their income at the NGO, are terrible conditions to find a new job."* Brother Konrad explained.

Within the Vocational Center a workshop with a nice selection of tools for different technical fields can be found. Practical training is possible in brick laying, metal works, carpentering and fine mechanics. Their equipment selection compared to the previous workshops – excluding St. Josephs Garage - is



ill. 81 - Entry of the Vocational center


ill. 82 - facilities


ill. 83 - Fine mechanics workshop

-20- http://www.comboni.org/index.php?Lingua=EN&; http://www.comboni.de/index.php [accessed 01 05 2009] equal, except for the fine mechanics workshop, which has an incredible wide range of different machines.

Their biggest difference to the other workshops is the attitude of Brother Konrad. He seemed to be especially interested in gaining experience in high rise constructions and he attitudes to train people in order to open up an independent business which corresponds to the aim of the thesis: Changing the dependence from multinational companies and trying to figure out a construction system which is locally produce-able. *"This is why I am interested. We would like to expand our works. We have absolutely no experience in high rise constructions and it would be great to get it."*

4.5.1.5. Workshop conclusion

The four workshops, which have been described, are in much better shape than the average workshop in Uganda. It should not appear, as if just the well equipped workshops are given the possibility to make this experience. They have been described because they are part of the BOSCO network. It would be a disadvantage for the construction process as well as finances if this excellent network and the resulting cost reduction would not be used. Furthermore, most of them are teaching facilities and they see the project as an opportunity to train new skills, which is most important for this thesis and BOSCO. In any case the most important aspect is that the entire construction plan can be carried out by any local workshop in Uganda as well. So the construction plan has to be simple enough to fulfill this goal.

In conclusion my suggestion about the best fitting workshop of these four examples would be the Daniel Comboni Vocational Center. Brother Konrad is more than interested to extend their field of work. It is a big teaching facility and has the highest probability to use the experience soon again. In the end, though, it will be up to BOSCO to decide which workshop they choose.

ill. 84 - bending machine - Vocational center

ill. 85 - further equipement - vocational center

4.5.1.6. Import of technical equipment – technical impulse?

Prototype constructions in general have great potential in different ways. The aim for this tower/mast project is to give local workshops the opportunity to get experience and knowledge in an additional field of work. My main approach for this thesis is to make use of the local circumstances and adjust the entire construction accordingly. Another approach would be to use this case study to introduce a new kind of tool or technical equipment to a local workshop. It is impossible to gauge these two aspects entirely but I would like to outline a few thoughts about it.

"The biggest difference between local workshops and our workshop is that we try to invest in equipment every year. We need modern tools to produce good quality. Without good quality we do not get enough orders and money and cannot invest in new tools." Brother Konrad from Daniel Comboni Vocational Center outlined. This is an important aspect concerning workshops in Uganda. As described before the usual mentality is that everything will be used until it is broken before it is repaired. Money is scarce. Nobody can invest it in advance. But this attitude leads into a fatal loop. As long as all tools are working they can work and earn money. However, when a tool breaks and needs to be repaired, money is needed to repair it. The workshop usually try to compensate the temporary loss of this tool by repairing it poorly on their own but the quality of the final products is worse in the end. As a result they do not receive as many orders as before and their profit gets less. Repairing the broken tool in such a situation is even more unlikely than before. As another tool breaks, the situation worsens and it becomes clear how the story will continue.

Therefore technological inputs are important. Someone brought the first welder to Uganda, and now it is one of the most common tools all over the country. It is now used widely for many different purposes. Workshops are familiar with it and know how to maintain it. But can this be the case with any kind of new tool or equipment?

It will be an interesting task during this thesis to figure out, if there are tools or equipments which have the ability to improve the construction of the BOSCO tower/mast and also have the capability to become an improvement for local workshops.

4.5.2. Means of transport

Transport of goods in Uganda is possible with all kinds of different vehicles. The range reaches from bicycles to motorcycles over mini-busses to pickups and trucks. To transport steel bars or cement bags bicycles can be used as well as trucks. Usually it is up to the customer to choose and organize the mean of transport of bought goods. Only big hardware stores own a truck.

There are two important aspects to bear in mind about transporting goods in Uganda. First of all it is possible to use trucks or pick-ups anywhere. However they are quite expensive compared to the material prices. Usually it is necessary to pay a certain amount for the truck and a salary for the driver per day and also the fuel used for the transport. Still it is an efficient and fast process. However arranging such a transport has to be planned and booked a long time in advance as trucks are rare.

Secondly it is a matter of supporting different social classes when choosing a way of transport. Bicycle riders for example need all their energy to transport a certain amount of goods. It would need the whole day to move the goods which would only take a few hours for the truck or pick-up. And, in comparison, the whole transport costs nearly the same because you need 10 bicyclists instead of one truck. Yet, this is a possibility which should not be left aside. Of course it is inefficient in terms of workforce and time-use. But it is possible to support 10 people for one day. They earn much more than they would usually do at one day. There is no company behind them and the whole amount of money would go directly to the driver and its family. So finally it is a question of efficiency and supporting of different people when choosing a certain way of transport.

It is certainly questionable if these arguments are feasible or if it would be better to support bigger companies in order to enable them to hire more employees. This way, those bicyclists might get the chance to work for salaries instead of having their own small insecure business never knowing if they get a well paid job tomorrow to feed their families. However my personal opinion is that it would be worth supporting those small structures as well.

ill. 86 - locomotion in Uganda

4.5.2.1. Human transport

Most people in Uganda cannot afford any kind of technical assistance to transport goods. They carry anything on the top of their head - from firewood to bags full of food or water canisters. Loads of up to 50kg and more are normal.

4.5.2.2. Bicycle – motorcycle (boda-boda)

The boda-boda[21] is an important part of Ugandan transportation. This kind of transport developed from the word Border-Border. Father Felix Opio told me the origin of this term. *"Around 1960 there was a dead zone of around one kilometer between the Kenyan and Ugandan Borders. No country was responsible for this area. There was no transport between the two border posts. So some people started a business with wooden carts to transport goods in-between. Afterwards, bicycles and motorbikes were used. And now all over Uganda any bicycle and motorbike which transports something is called boda-boda."*

bicycle

After human transportation the bicycle is the most common mean of transport for anything, anywhere. Bikes mostly are imported from China and India. It is possible to make some subdivisions between bicycle uses. Some of them transport people. Therefore footrests are installed as well as a padded seat at the back of the bike. Bicycle drivers offer their service for short distances. Others put a wooden construction above the handlebar and the seat. In this case bicycles are used to carry timber boards or metal bars or other bulky goods. The overall population uses the bike for means of transport. Strong strips out of used tubes are used to fix the load to the carrier. Most of the time they are so overloaded, that it is only possible to push the bike. It is a rather slow but certainly a cheap mode of transport.

ill. 87 - human transport

ill. 88 - human transport

ill. 89 - bicycles for transportation use

-21-http://en.wikipedia.org/wiki/Boda-boda [accessed 01 05 2009]

Motorcycle

This is the fastest transport all over Uganda. Motorcycles carry up to four people or three bags of cements as well. The drivers usually never own the bikes themselves. In general they are rented. Drivers are responsible for the condition and are allowed to adjust them in the way they would like to. Costs for this service depend on your trading ability, but for a distance of about 5km 3.000UGX is a reasonable price.

In order to rent a boda the driver has to pay around 10.000 to 12.000UGX per day to the actual owner of the motorcycle. Therefore they have to earn at least this amount in order to make a profit. Those motorcycles cost around 8.000.000UGX new and around 2.000.000UGX in used condition.

ill. 90 - bicyles for transport

ill. 92 - boda - boda

ill. 91 - bicycles for transport

ill. 93 - boda - boda

4.5.2.3. Minibus - Matatu

Minibuses are generally used as shared-taxis. The Ugandan name for this kind of transport is matatu[22]. They are small minivans usually made by Toyota Hiace. A matatu driver is allowed to carry 16 people but usually it is filled up with over 20 passengers and a lot of other goods. It is possible to transport any kind of goods with those small vans. In general matatus work as a kind of bus system with fixed destinations. It is actually the cheapest way to travel medium distances with so to say public transport because there is no other network for public transport. Like the motorcycle drivers matatu drivers rent the minibus from the owner and have to pay a certain amount per day. Average transportation of about 5km costs about 1.000UGX per person.

For this tower project transport with matatus is not suitable. There are other means of transport which are available and do not need as much preparation.

ill. 94 - matatus - old taxi park, kampala

-22- http://en.wikipedia.org/wiki/Matatu#Matatu_.28Kenya.29 [accessed 01 05 2009]

4.5.2.4. Pick-up / all terrain vehicle

All terrain vehicles are the common mean of transport for development workers or professionals from abroad. As street conditions are bad it is necessary to use these all terrain vehicles in rural areas. They can be rented in nearly any bigger town around Uganda. Prices, including a driver, range from 70.000UGX up to 130.000UGX per day depending on the model. Another way to calculate the price is around 500UGX per driven km. Most members of the BOSCO staff own such an all terrain vehicle. With their high dead weight of around 3.000kg and their cargo load of 1.000kg they could be used as transporting vehicle for the tower/mast parts. Most of these vehicles are equipped with a cable wrench. These wrenches have a maximum tensile force of 4.000kg. Therefore they could serve as lifting device in the erection process.

4.5.2.5. Truck

Heading along one of the major roads in Uganda involves getting in touch with trucks. Truck driver are aware that every other vehicle is smaller and less powerful than they are. Therefore it is up to you to move out of the way. The load capacity of a common truck ranges from 5 tons up to 30 tons. All kinds of goods are transported with trucks throughout the whole country and are mostly used for long distance transports. They literally transport anything. To get an idea I would like to illustrate an example: I was invited to attend a local wedding in the compound of the catechist center in Gulu. The bride's family, including all guests hired a 15ton truck in order to get from their village to the wedding. It was the cheapest and most effective way to commute. And, by the way, a very amusing picture when they arrived at the compound, crowded on the truck, but dancing, singing and celebrating this social event. *"Trucks are made to transport."* one of the guests explained honestly. I could only reply that he is absolutely right. So it is obvious that there are no restrictions about the use of vehicles.

Gulu is well equipped with truck transportation. Still few shops own their own truck but there is the possibility to rent one in Gulu. However it has to be ordered in advance, as everything takes time in Uganda.

Prices are around 200.000UGX per day including driver without petrol. A single carriage costs around 40.000UGX all inclusive.

ill. 95 - pick up

ill. 96 - off road vehicle

ill. 97 - truck

4.6. Economical aspects

Currency is Uganda Shilling (UGX). Exchange rate: 1Euro = 2700UGX (26.3.2009)

4.6.1. Salaries

It is not absolutely clear how much salary has to be paid to the workers for the required work effort. Different prices for different salaries have been gathered during the research. For constructing the tower/mast it is planned to use the network from the Archdiocese regarding workshops and workers. The whole process should function as a capacity building project. The workshops should get the possibility to learn how to construct the tower, with well arranged instructions. Moreover they should gain the possibility to widen their skills. Therefore BOSCO benefits of lower salaries and finally could erect the tower for nearly just the prices of the material. There should be benefits on both sides. In conclusion this mutual agreement would reduce the costs a lot. But it is more or less up to BOSCO how they can convince and discuss the salaries for the work.

Thus, different salaries will be listed briefly which have been investigated throughout interviews and inquiring at workshops or elsewhere. All these amounts are calculated for the local population. Development workers earn 10 to 20 times higher salaries in general. It should also be mentioned that if a worker is hired for a longer period it is also necessary to provide accommodation and food.

Driver salary (Caritas)
250.000 UGX per month
Technician (Caritas)
300.000 UGX per month
Office worker (Caritas)
250.000 UGX per month
Policeman
170.000 UGX per month
Mechanical worker (St. Josephs workshop)
200.000 UGX per month
Mechanical worker
60.000 UGX per month
Night guard
50.000 UGX per month

Food
50.000 UGX per month
Accommodation (low standard)
150.000 UGX per month

4.6.2. Cost of materials

It happens often that prices suggested to you as a “muzungo” – white person - are different from the actual price. Unfortunately a white person in Africa has to pay extra for whatever he wants to consume or purchase. Even in shops where everything is listed it can happen that shopkeepers try to tell you that the price on the sign is out of date. The safest way to get serious prices is to visit the shop more often. It is common, as mentioned on page 28 [chapter 4.1.3] data research, to have a few contacts until they trust you. In conclusion this means that both sides have to establish a certain relationship before you bargain with each other in order to obtain serious information.

It has to be mentioned either, that resulting from the war in northern Uganda the infrastructure around Gulu is in much poorer than the rest of the country. As a result less material selection and higher prices can be expected. Furthermore, as a result of the presence of many NGOs – there are around 100 in Gulu only – prices for work and materials became even more expensive. Shops, hotels, etc realized that NGOs could afford their services and products even if they are higher. Therefore, most workshops order their material and equipment in Kampala. Prices are cheaper than in Gulu, even including the transport of about 350km. Brother Michael from the St. Joseph’s workshop pictured it with a good example: “*If I would buy everything here in Gulu, it would cost me 25% to 30% more than if I buy it in Kampala. Small quantities for sure I buy in Gulu, and it would be possible to get nearly everything here as well, but they would as well just order it from Kampala, so it would not make a difference.”* Brother Konrad from Daniel Comboni Vocational Center in Gulu further underlined this argument: *”Some parts are 50% more expensive here in Gulu. If we are in need of something urgently we buy it in Gulu, but usually everything will be bought in Kampala.”*

A list of all kinds of different materials and equipment which might be of interest for the tower/mast design will follow. Furthermore comparisons between different towns in Uganda are provided. The list will contain materials which are available at most shops all over Uganda especially Gulu.

Metal Products

Unit	Thickness [mm]	width A [mm]	width B [mm]	length [m]	Price [UGX]	Notes
Gulu Hardware Store - 077612390						
angles - L shape	3	50	50	6	47000	
angles - L shape	3	60	60	6	42000	
angles - L shape	6	60	60	6	83000	
recangular hollow section	1,5	25	45	6	26000	
recangular hollow section	3	30	30	6	32000	
recangular hollow section	3	40	40	6	38000	
recangular hollow section	3	50	50	6	62000	
round hollow sections	1,2	20	20	6	18400	
round hollow sections	2,5	25	25	6	20000	
round hollow sections	2,5	32	32	6	33000	
round hollow sections	1,5	42	42	6	32000	
round hollow sections	3	42	42	6	55000	
round hollow sections	3	50	50	6	67000	
round hollow sections	2	76	76	6	75000	
round hollow sections	3	76	76	6	120000	
flat steel	1,5		25	6	12000	
flat steel	3		20	6	17000	
flat steel	3		40	6	26000	
flat steel	6		50	6	53000	
wire	2				3500/kg	25kg; galvanized
wire	3				6000/kg	25kg; galvanized
round bar	8			12	11500	
round bar	12			12	14500	
reinforcement steel	8			12	16000	circular
reinforcement steel	10			12	21000	whisked
iron plates	1	1220	2440		80000	
iron plates	3	1220	2440		200000	
iron plates	6	1220	2440		400000	
corrugated iron	0,2	875	762		62000	
reinforcement mesh	3		1830	18	215000	mesh size 200/50mm
chain link	1		1830	18	87000	mesh size 50/50mm

chart 3 - local available metal products and their prices in Gulu

Unit	Thickness [mm]	width A [mm]	width B [mm]	length [m]	Price [UGX]	Notes
Ngeye Hardware Enterprises Ltd - Plot 2/14 Kafumbe Mukasa Rd, P.o Box 72349 Kampala						
angles - L shape	3	50	50	6	38000	
angles - L shape	3	60	60	6	35000	
angles - L shape	6	60	60	6	78000	
recangular hollow section	1,5	25	45	6	22000	
recangular hollow section	3	30	30	6	25900	
recangular hollow section	3	40	40	6	30000	
recangular hollow section	3	50	50	6	55000	
round hollow sections	1,2	20	20	6	13000	
round hollow sections	2,5	25	25	6	15000	
round hollow sections	2,5	32	32	6	26000	
round hollow sections	1,5	42	42	6	26000	
round hollow sections	3	42	42	6	45000	
round hollow sections	3	50	50	6	62000	
round hollow sections	2	76	76	6	70000	
round hollow sections	3	76	76	6	105000	
flat steel	1,5		25	6	9000	
flat steel	3		20	6	12000	
flat steel	3		40	6	20000	25kg; galvanized
flat steel	6		50	6	47000	25kg; galvanized
wire	2				2800/kg	
wire	3				5500/kg	
round bar	8			12	9000	
round bar	12			12	12000	
reinforcement steel	8			12	13500	whisked
reinforcement steel	10			12	20000	circular
iron plates	1	1220	2440		73000	
iron plates	3	1220	2440		185000	
iron plates	6	1220	2440		380000	
corrugated iron	0,2	875	762		55000	
reinforcement mesh	3		1830	18	195000	mesh size 200/50mm
chain link	1		1830	18	82000	mesh size 50/50mm

chart 4 - prices of metal products in Kampala in comparison to Gulu

Unit	Thickness [mm]	width A [mm]	width B [mm]	length [m]	Price [UGX]	Notes
Rwenzori Hardware and Electronics - Fort Portal, salesman Malik Ali 0712517087						
angles - L shape	3	50	50	6	42000	
angles - L shape	3	60	60	6	37000	
angles - L shape	6	60	60	6	81000	
recangular hollow section	1,5	25	45	6	24000	
recangular hollow section	3	30	30	6	26000	
recangular hollow section	3	40	40	6	33000	
recangular hollow section	3	50	50	6	58000	
round hollow sections	1,2	20	20	6	14000	
round hollow sections	2,5	25	25	6	17000	
round hollow sections	2,5	32	32	6	30000	
round hollow sections	1,5	42	42	6	29000	
round hollow sections	3	42	42	6	50000	
round hollow sections	3	50	50	6	63000	
round hollow sections	2	76	76	6	72000	
round hollow sections	3	76	76	6	110000	
flat steel	1,5		25	6	10000	
flat steel	3		20	6	15000	
flat steel	3		40	6	22000	
flat steel	6		50	6	49000	
wire	2				3000/kg	25kg; galvanized
wire	3				5700/kg	25kg; galvanized
round bar	8			12	10500	
round bar	12			12	13500	
reinforcement steel	8			12	14000	circular
reinforcement steel	10			12	20000	whisked
iron plates	1	1220	2440		75000	
iron plates	3	1220	2440		200000	
iron plates	6	1220	2440		390000	mesh size 200/50mm
corrugated iron	0,2	875	762		60000	mesh size 50/50mm
reinforcement mesh	3		1830	18	203000	
chain link	1		1830	18	83000	

chart 5 - prices of metal products in Fort Portal in comparison to Gulu

TIMBER

mostly pine , per piece

dimensions [cm]	length [m]	price [UGX]
Timber Store Kabalagala - Kampala, P.o Box 26744; 041273080		
20 / 3	5	8500
15 / 5	5	8500
10 / 5	5	6500
10 / 7	5	8500
7 / 5	5	5500
30 / 3	5	16000
Trusts Management service Ltd. 0773023658 - Gulu		
20 / 3	5	20000
15 / 5	5	12000
10 / 5	5	9000
10 / 7	5	11500
7 / 5	5	7000
30 / 3	5	22000
Meyedo Supliers Gulu - 0772362480 - Gulu		
20 / 3	5	17000
15 / 5	5	10000
10 / 5	5	8000
10 / 7	5	9500
7 / 5	5	6500
30 / 3	5	18000
Palm trees		
~10 / 10	~5	2000
Bamboo		
~3 diameter	~5	300

chart 6 - prices of common timber dimensions
compared between different shops and towns

STONES - AGGREGATES - CEMENT - TECHNICAL EQUIPMENT

Type	Unit	Price [UGX]
kabalagala Lorry Park, Ggaba Road, P.o Box 52010, Salesman Henry - 0712-697442		
Cement multipurpose	50kg	24000
stones - different sizes		42500
aggregates - poorly graded gravel	1m³	30000
aggregates - sand from lake victoria	1m³	20000
aggregates - sand from the region	1m³	17500
Gulu Hardware Store - 077612390		
Cement multipurpose	50kg	28000
shop along Gulu road		
stones - different sizes	1m³	40000
aggregates - poorly graded gravel	1m³	35000
aggregates - sand from the region	1m³	25000
Ngeye Hardware Enterprises Ltd - Plot 2/14 Kafumbe Mukasa Rd, P.o Box 72349 Kampala		
Cement multipurpose	50kg	23000
Rwenzori Hardware and Electronics - Fort Portal, salesman Malik Ali 0712517087		
Cement multipurpose	50kg	25000
stones - different sizes	1m³	37000
aggregates - poorly graded gravel	1m³	20000
aggregates - sand from the region	1m³	15000
regional fabricated bricks		
burned clay brick	pcs	40 - 120
James Concrete Gulu		
concrete brick - 15/30/20cm	pcs	2000
equipment at Gulu market		
bolts - different sizes (4mm to 14mm wide; 20mm to 150mm length) inkl. Nu	pcs	500 - 1000
nails - different sizes (40mm to 150mm length)	pcs	10 - 200
tendon (300mm, diameter 12-14mm)	pcs	5000
wire clamps (for diamter of 6 to 12mm)	pcs	1500 - 2000
shackles (diameter 6 -12mm)	pcs	1500 - 2000
paint - primer coat	4l	20000
paint - final coating	4l	22000

chart 7 - price table of different goods in different regions in uganda

5. TECHNICAL BASE ELEMENTS OF TOWER/MAST CONSTRUCTIONS

The following chapter will give an overview of elements and technologies that are needed to construct a tower/mast. It will describe constructional aspects and their historical development. Basic static information and technical solutions will be shown in this chapter as well. Regarding the circumstances in Uganda this chapter analyzes different possibilities for the tower/mast construction there.

5.1. Tower / mast constructions

Basic possibilities and famous examples of tower/mast constructions will be explained in this chapter. Furthermore advantages and disadvantages of the different construction types will be analyzed concerning their possible use in Uganda.

First of all the term tower/mast has to be determined precisely: A tower/mast is a structure where the height is the multiple of the diameter of the building. They are vertical constructions which usually become thinner the higher they get.

5.1.1. Masonry constructions

Masonry constructions can be compared to hills and mountains. *When bulk granular materials are poured onto a horizontal surface, a conical pile will form. The internal angle between the surface of the pile and the horizontal surface is known as the angle of repose and is related to the density, surface area, and coefficient of friction of the material*[23]*.* In other words: If you use a material like a stone or brick and give this material a lot of friction on the surface area (this can be done in combination with some kind of glue) it should be possible to place this stones above each other to create a steep cone.

Historical approach

Historically masonry constructions have been the first way to construct towers. The Ziggurat[24] as well as the great pyramid in Giza[25] are two of the first examples of a high rise tower. A ziggurat was a temple tower in the ancient Mesopotamian valley and Iran. It has the form of a terraced pyramid of successively receding tiers. One well preserved example is the Great Ziggurat of Ur[26]. It was built approximately in the 21st century BC. It is built out of burned bricks up to the height of 30m. The great pyramid of Giza was been built around 2560 BC and is the oldest and largest of all existing pyramids. It has a height of 146,6m at the top. The pyramid remained the tallest man-made structure in the world for over 3,800 years, unsurpassed until the 160 meter tall spire of Lincoln Cathedral[27] was completed 1300.

But nevertheless the first actual tower construction regarding the definition of a tower was the Lighthouse of Alexandria[28] . With a height variously estimated at between 115 and 150 m it was among the tallest man-made structures on earth for many centuries. This tower has been built in the same way as other masonry constructions had been built before and after. As a matter of fact masonry constructions are massive piles of well arranged durable materials. The material – usually burned bricks or carved stone – is actually put above each other. The binding material

ill. 98 - angle of respnose

ill. 99 - Ziggurat- Air Ali Base- Iraq

ill. 100 - Kheops pyramid - Giza

-23- http://en.wikipedia.org/wiki/Angle_of_repose [accessed 01 05 2009]
-24- http://www.mesopotamia.co.uk/ziggurats/home_set.html [accessed 01 05 2009]
-25- http://www.gizapyramid.com/ [accessed 01 05 2009]
-26- http://www.crystalinks.com/ziggurat.html [accessed 20 04 2009]
-27- http://en.wikipedia.org/wiki/Lincoln_Cathedral [accessed 20 04 2009]
-28- http://www.unmuseum.org/pharos.htm [accessed 20 04 2009]

– usually cement, clay or lime – agglutinates those bricks or stones together creating a sustainable construction.

Reinforced concrete in fact is made out of poured stones and binding material. It facilitates more durable and higher tower constructions. Moreover the excellent load capacity and the flexibility of concrete (it can be poured in any shape) is the reason why it is often used for chimneys (for instance INCO superstack[29]) and TV towers (for example TV tower Stuttgart[30]). High structures out of reinforced concrete are relatively expensive but their high degree of mechanical rigidity, concerning strong winds, explains why it is the favorite choice for these towers. Furthermore some of the tallest freestanding structures of the world have been built out of reinforced concrete. The next chapter covers mast constructions. Static aspects of masts will be described in detail. Slim high rise towers out of concrete actually do have similar static aspects and therefore they would belong to the following chapter 5.1.2. Masts - page 79 - as well.

ill. 101 - Lincoln Cathedral

ill. 102 - Lighthouse of Alexandria

ill. 103/104 - INCO superstack / TV Tower Stuttgart

-29- http://en.wikipedia.org/wiki/Inco_Superstack [accessed 01 05 2009]

-30- http://www.fernsehturmstuttgart.com/ [accessed 01 05 2009]

5.1.2. Masts

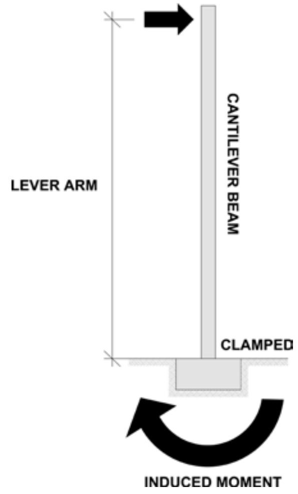
A mast is a rigid vertical standing construction out of different materials. Areas of application are flag poles or street lamps. Moreover masts are used in the ship building industry in order to fix sails.

Statically a mast is a cantilever beam. In fact a mast has to be clamped. Forces – to be precise moments - accruing at the bottom of the mast are usually high. The lever arm or accruing loads – for example wind loads - is the full height of the mast. Therefore the mast has to resist these high moments and has to be flexural rigid. To provide enough rigidity, several different methods with material mixes are possible. Usually circular cross sections – because of their high rigidity – such as pipes are used for mast constructions.

The foundation actually has to resist all accruing loads - reaction forces and moments - from the mast to avoid falling over. Therefore the foundation has to be huge in comparison to the size of the mast.

Examples

Nearly all street lamps or flagpoles are masts made out of steel or aluminum round hollow sections with a concrete foundation. An impressive example is the Raghadan Flagpole[31] in Amman, Jordan. With its 126,8m height it is one of the highest freestanding flagpoles on the earth.



ill.105 - Statical description of a mast

ill. 106 - Raghadan Flagpol - Amman, Jordan

-31- http://en.wikipedia.org/wiki/Raghadan_Flagpole [accessed 2009 04 15]

5.1.3. Lattice towers

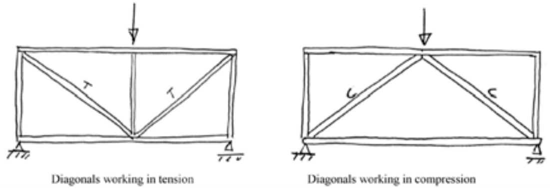
Lattice towers are freestanding steel, iron or timber framework construction. A framework is a construction out of several truss elements which are connected at their ends. With this principle only pressure or tensile forces (normal forces – parallel to the axis of the truss) accrue in these truss elements.

Characteristic of trusses

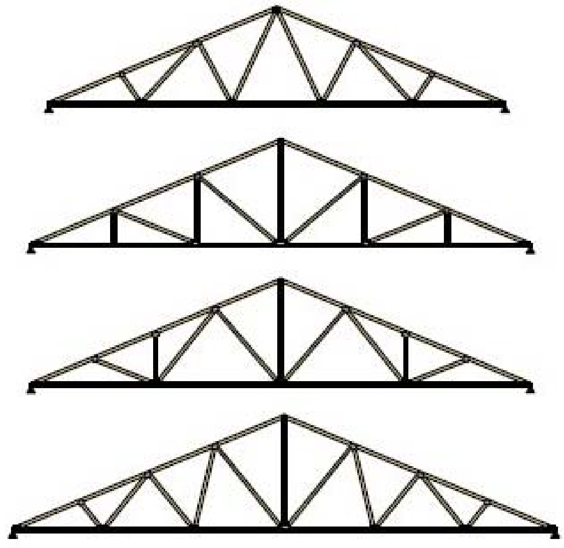
In architecture and structural engineering, a truss is a structure comprising one or more triangular units constructed with straight slender members whose ends are connected at joints referred to as nodes. External forces and reactions to those forces are considered to act only at the nodes and result in forces in the members which are either tensile or compressive forces[32].

A truss is composed of triangles because of the structural stability of that shape and design. A triangle is the simplest geometric figure that will not change shape when the lengths of the sides are fixed[33]. In comparison, both the angles and the lengths of a square must be fixed for it to retain its shape. The simplest form of a truss is one single triangle. This type of truss is seen in a framed roof consisting of rafters and a ceiling joist[34]. Because of the stability of this shape and the methods of analysis used to calculate the forces within it, a truss composed entirely of triangles is known as a simple truss[35].

Constructions out of frameworks can support much heavier loads in relation to their weight compared to masonry constructions. Inside the structure of masonry constructions there are a lot of areas which do not have any supporting quality to the overall construction. Forces impacting on a tower construction actually conduct to the basement the shortest way. Frameworks actually use this fact and try to direct them most efficiently to the basement. Therefore Rods of frameworks are arranged in this specific short way to direct external forces to the basement. Areas in between those rods can be left empty because they are not necessary. Therefore frameworks are material saving and cost efficient in comparison to masonry constructions.



ill. 107 - types of truss systems



ill. 108 - basic truss configurations

-32-http://en.wikipedia.org/wiki/Truss [accessed 2009 04 15]

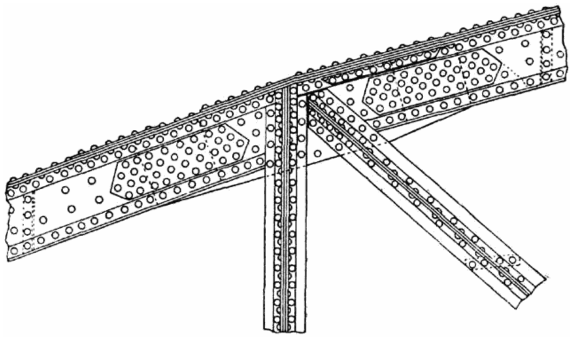
-33-Ricker, Nathan Clifford (1912) [1912]. A Treat on Design and Construction of Roofs. New York: J. Wiley & Sons. pp. 12. Retrieved on 2008-08-15.

-34-Maginnis, Owen Bernard (1903). Roof Framing Made Easy (2nd edition ed.). New York: The Industrial Publication Company. pp. 9. Retrieved on 2008-08-16.

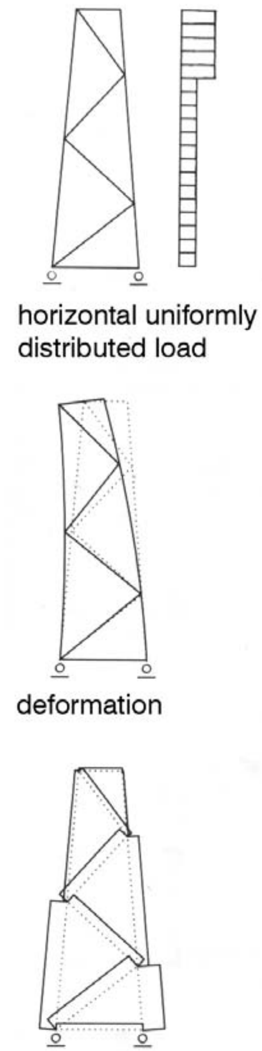
-35-Hibbeler, Russell Charles (1983) [1974]. Engineering Mechanics-Statics (3rd edition ed.). New York: Macmillan Publishing Co., Inc.. pp. 199–224. ISBN 0-02-354310-8.

A lot of different methods have been invented to calculate the appearing forces inside frameworks. Describing the entire calculation process would go beyond the scope of this thesis. The intention of this specific chapter is rather to give an overview of possible methods to construct a tower/mast.

Joints of these frameworks have to support most loads. Forces act along the axis of rods. When these rods meet at joints different forces have to be supported. Therefore the implementation of these joints is most important. Different joining techniques will be described starting on page 102 [chapter 5.3].



ill. 109 - truss joint



ill. 110 - tower framework

Historical examples

The probably oldest and most visible implementations of frameworks regarding constructional aspects are timber framed houses[36]. Since the beginning of the 12th century these houses have been built around the European continent. They consist out of a wooden framework – a skeleton structure – which basically opposes the loads. Materials like bricks, clay or plaster are used to fill up the spaces between the frameworks. Filling materials are necessary to stiffen the entire construction, but basically these frameworks would have the possibility to stand tall by themselves.

One of the most recognizable lattice constructions of the world is the Eiffel tower[37]. *It is an iron tower built on the Champ de Mars beside the Seine River in Paris. Named after its designer, engineer Gustave Eiffel, the Eiffel Tower is the tallest building in Paris*[38]. It has a height of 324 meters (including antenna) and has been erected between 1887 and 1889 for the World Fair, the century celebration of the French Revolution.

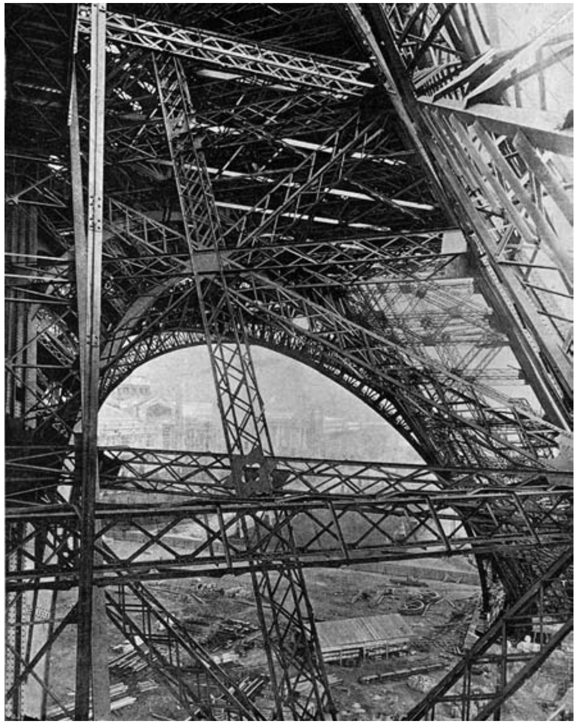
ill. 111 - timber framed house

ill.112 - Eiffel Tower

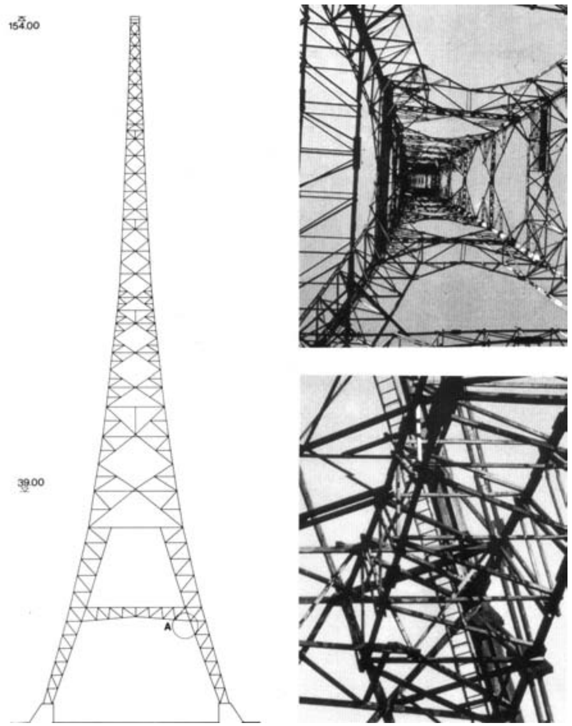
-36- http://www.fachwerkhaus.de/ [accessed 2009 04 15]
-37- http://www.eiffelturm.org/Eiffel_tower/eiffel_tower.html [accessed 2009 04 15]
-38- http://en.wikipedia.org/wiki/Eiffel_Tower [accessed 2009 04 15]

The weight of the metal structure is about 7.300 tons, including all non-metal parts around 10.100 tons. 18.038 pieces have been connected with 2.5 millions rivets. The Eiffel Tower has been a demonstration of the technical possibilities of this age and was actually the first building that outreaches the heights of middle-aged towers by far and more remarkable in terms of structural lightness. The average soil pressure is about 4kg per square centimeter[39] , which is the same as a person sitting on a chair. The design of the Eiffel tower is strongly affected by the forces inside the framework. In particular wind pressure has an impact on the tower. This force increases closer to the ground. Therefore the structure widens at the base. The Eiffel tower has been influencing many following transmission towers around the globe.

But not only lattice towers made out of steel should be mentioned. An incredible example made out of timber is the transmission tower in Ismaning. This was a 165m high freestanding tower, constructed in 1932. It has been detonated 1983 because of danger of calapse.



ill. 113 - Eiffel Tower



ill. 114 - transmission tower Ismaning

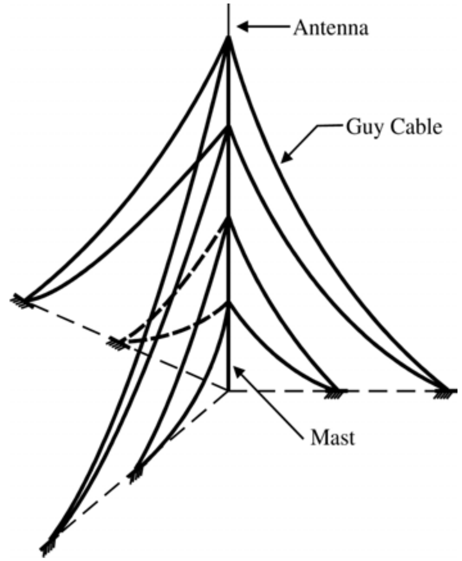
-39- Werner Müller, Gunther Vogel : dtv - Atlas Baukunst II. Baugeschichte von der Romanik bis zur Gegenwart 11. Auflage April 2000 - deutscher Taschenbuch Verlag GmbH & Co. KG München, - ISBN 3-423-03021-6; page 555

5.1.4. Guyed masts

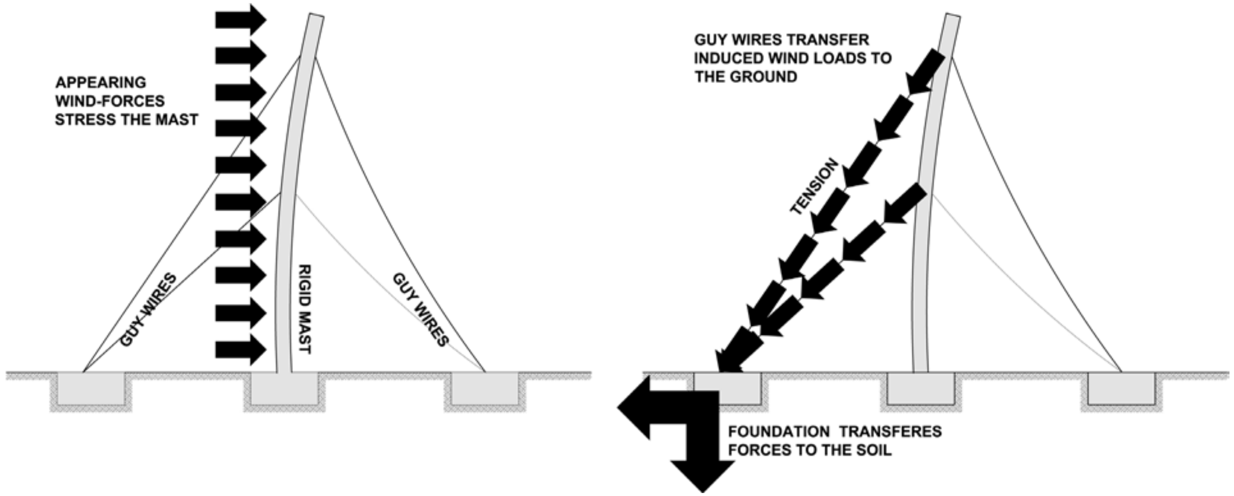
Guyed masts have a complex structural behavior because of the interaction of mast and guys and are significantly different from conventional structures. Basically guyed masts are three dimensional frameworks with the difference that some parts – guy wires – can transfer only tensile forces. With this principle moments are mostly avoided and turned into normal forces.

A guyed mast usually comprises a slender lattice steel mast that is typically pinned at its base and guyed cables anchored at ground level. The mast typically has three or four legs, made from solid members, galvanized steel angles or tubes, connected by horizontal and diagonal components, (web members), assembled in different configurations, which serve to transfer wind induced forces to the foundation.

The pretensioned guyed cables supply lateral supports to the mast at several levels along the mast height as a means of reducing vibration and increasing the stiffness of the structure; as well, guy cables contribute to internal damping, apply axial prestressing forces to the mast, and help transfer wind loads from the mast to the ground[40].



ill. 115 - scheme of a guyed mast

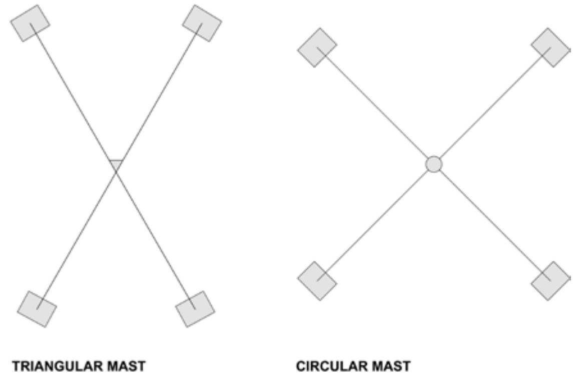


ill. 116 - force reaction diagramm

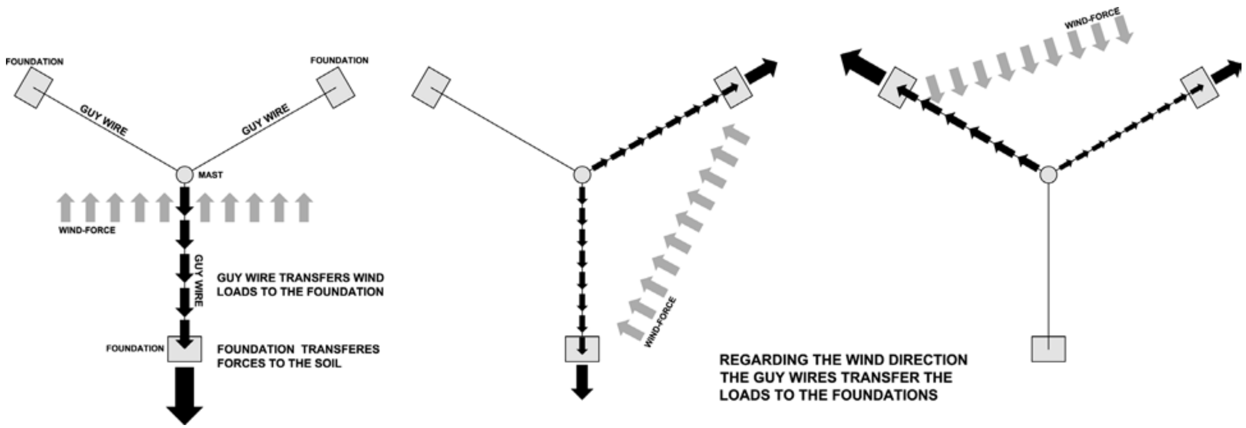
-40- Zhu, Ningli; 2007 “Wind Tunnel Test for Guyed Mast Dynamic Characteristics under Wind Loads”; page 3; http://library2.usask.ca/theses/available/etd-11302007-161327/ [accessed 02 04 2009)]

Simplified the mast of a guyed mast construction can be statically imagined as it is divided into beams at each connection of the guy wires. Actually it is a simple beam, mounted at both ends. Therefore the lever arm which is most decisive for accruing moments is incredibly reduced. In addition the mast has to be flexural rigid. Therefore they are mostly constructed as lattice constructions additionally. As explained on page 80 [chapter 5.1.3] it is an efficient way to optimize a structure regarding material use and therefore self weight. Nevertheless it is possible to fabricate a solid guyed mast out of a single pole as well.

Guy wires provide stability and increase the stiffness of the mast. Mostly wind induced forces create pressure on the surface of the mast - guy wires resist these forces and decrease deflection. The wires on the lee side do not support in this case. They provide stability if the direction of the wind force is changing. Angle between the wires and the mast should be close to 45 degree, as this is the angle which creates as less normal forces in the wires as possible. A minimum of 3 anchors – arranged in 120 degree angles - are necessary to stabilize this mast to cover any possible wind direction. Most of these masts are triangular shaped which provides the possibility to fix each guy wire at one corner. Other guyed setups are possible with 4 different anchors. The fourth wire is fixed in matter of redundancy. The tower will still not tumble down if any of these wires ruptures.



ill. 117 - four point anchor



ill. 118 - top view of force reactions regarding wind direction

Foundations for these mast types have to be planned carefully. As it is not necessary to clamp the mast no moment will be transferred to the foundations. Mast foundations have to support mostly pressure. Self weight, payload of the mast and pre-stressing forces of the guy wire are the main loads lasting on it. All other foundations, usually called anchors, have to support only tensile forces resulting from the guy wires tensile forces.

Some guyed masts exceed more than 600m in height. Therefore they belong to the tallest structures on the globe. They tend to be the cheapest method to construct high elevated structures. *They have relatively light self weights, and they are slender, with typical face width to height ratios ranging from 1/80 to 1/180*[41].

The downside of a guyed mast is that they require an extended surface area. Diminution of the ground usage can be provided by redirecting the guy wires. Horizontal stays attached to the mast serve as redirecting points. With this method it is possible to retain nearly the same angles between mast and wire – same normal forces in the wires - without a lot of ground usage. These horizontal redirection stays have to resist pressure forces generated by the redirection of the guy wires. With this method a vertical framework attached on the mast is created. It is an optimized structure as the vertical stays of these frameworks have to support only tensile forces and the horizontal stays only pressure.

Examples

The tallest example of a TV transmitting mast is the KVLY-TV mast in North Dakota[42], United States. It is listed because it becomes quite visible, that this constructional principle is the most slender way for high elevated structures. From 1963 to 1974 and again since 1991 it is the tallest man-made structure[43] with a height of 629m. It is a triangular lattice tower guyed by 27 wires fixed to nine different anchors. The entire construction did cost around 500.000US$ and it took 33 working days with an 11 man crew to erect it. It is an extremely slender construction with a width to height ratio around 1/250. Nevertheless this tower "covers" the incredible area of 0.64km^2.[44]

ill. 119 - KVLY-TV mast, North Dakota

-41- Zhu, Ningli; 2007 "Wind Tunnel Test for Guyed Mast Dynamic Characteristics under Wind Loads"; page 3; http://library2.usask.ca/theses/available/etd-11302007-161327/ [accessed 02 04 2009)]

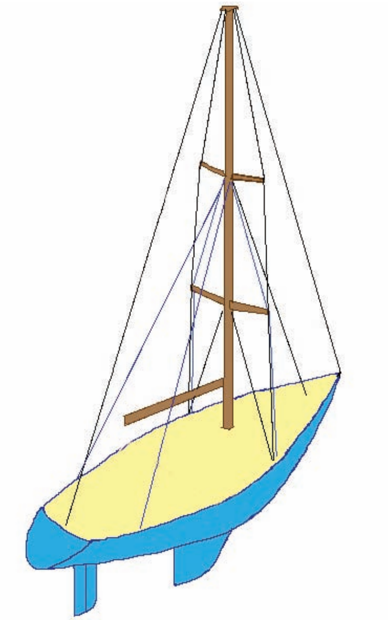
-42- http://en.wikipedia.org/wiki/KVLY-TV_mast
http://skyscraperpage.com/ cities/?buildingID=471; [both accessed 02 04 2009]

-43- Excluding the Burj Dubai which is still in construction, but will not be reconsidered until its completion. (status 04 2009)

-44- http://www.valleynewslive.tv/info/info_tower.html [accessed 02 04 2009]

Sailboats use a redirecting guy system. Masts have to be lightweight but still support heavy forces. Ground surface of boats is limited. Sails attached to these masts provide the movements of the boats therefore the forces are intense. Guy wires attached to the end of the mast and redirected with guy stays to the limits of the deck provide stability.

ill. 120 - anchor of the KVLY-TV mast, North Dakota



ill. 121 - sailboat mast

ill. 122 - KVLY-TV mast, North Dakota, Detail

5.1.5. Mixed tower/mast designs

There are a few borderline designs of tower/mast constructions.

5.1.5.1. Hybrid construction

These are constructions which combine a freestanding tower with a guyed mast. The lower part is freestanding and independent. It is built out of massive concrete or as a framework out of steel. The upper part uses a guyed construction which is mounted on top.

There are three reasons why this kind of construction is used sometimes.

Concrete and framework towers offer a lot of space inside their construction which is usually used for office, technical or observation space. Regarding material use and therefore costs it is inefficient to construct high towers out of concrete or as freestanding frameworks just to place some antennas. Therefore the base serves as necessary space and the guyed mast is chosen to provide a cheap and efficient way to lift the antennas up high.

Hybrid constructions do consider different types of antennas. Long distance radio link antennas are transmitting their signal with narrow beam widths. They have a low tolerance regarding deflection of the structure on which they are mounted. Additionally they do not have to be mounted in high altitude. As they are directed to a specific point, their necessary height has to consider surrounding vegetation and elevation between sending and receiving antenna only. Therefore these antennas are mounted on the lower part of these hybrid constructions. In addition concrete or steel frameworks have high rigidity and are not affected by high winds or other environmental impacts. UKW- or TV-antennas in contrast have their best range the higher they are mounted. They send their signal radial. Therefore they are not as dependent on a rigid structure as radio antennas. For that reason they can be mounted on the guyed mast.

Finally this construction method is used when an existing tower needs to be extended in height. As long as the existing concrete or framework tower has enough supporting quality, it is possible to mount a guyed mast on top. In conclusion Hybrid constructions are a cheap and efficient method to upgrade an existing tower.

ill. 123 - Hybrid tower Jauerling

5.1.5.2. Tensegrity [45]

"The word 'tensegrity' is an invention: a contraction of 'tensional integrity.' Tensegrity describes a structural-relationship principle in which structural shape is guaranteed by the finitely closed, comprehensively continuous, tensional behaviors of the system and not by the discontinuous and exclusively local compressional member behaviors. Tensegrity provides the ability to yield increasingly without ultimately breaking or coming asunder"[46]

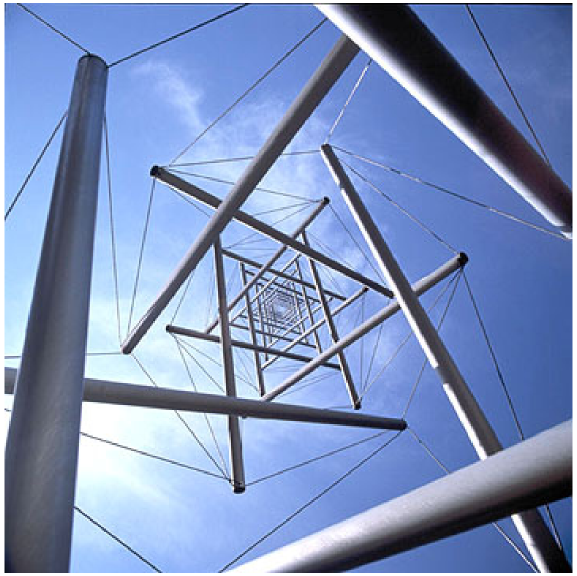
Tensegrity is a portmanteau of tensional integrity. It refers to the integrity of structures as being based in a synergy between balanced tension and compression components. The term "tensegrity" was first explored by the artist Kenneth Snelson to produce sculptures such as his 18 meter high Needle Tower in 1968.

Tensegrity is the exhibited strength that results *"when push and pull have a win-win relationship with each other".* Tension is continuous and compression discontinuous, such that continuous pull is balanced by equivalently discontinuous pushing forces.

The system contains out of rigid elements, poles, sticks or similar, which receive the compression and tension elements, pre stressed ropes, wires or similar. It is important that the rigid elements do not have any contact to each other. The only connections are the tension elements. A popular example for this kind of system is the spoke wheel. The hub and spokes receive the tension and the rim the compressive stress.

[47]The practical use of the tensegrity system is limited. It has a complex force process and is hard to calculate without new software. It requires a lot of joints which have to be technical advanced. It can be completely prefabricated but its assembly is technical advanced as well.

ill. 124 - spoke wheel



ill. 125 - Kenneth Snelson - Needle Tower

-45- http://en.wikipedia.org/wiki/Tensegrity [accessed 02 04 2009]
http://www.kennethsnelson.net/ [accessed 02 04 2009]

-46- Richard Buckminster Fuller (exerpt from Synergetics, p. 372.)

-47- Valentín Gómez Jáuregui; Tensegrity Structures and their Application to Architecture, http:// www.alumnos.unican.es/uc1279/table_of_contents.htm [accessed 02 04 2009]

The fact that these structures vibrate readily means that they are transferring loads very rapidly so the loads cannot become local. This is useful in terms of absorbing shocks and seismic vibrations. Tensegrity structures would be desirable in areas where earthquakes are a problem.

The practical use concerning deflection, which is important regarding a tower construction and their ability to transmit signals in a certain defined direction, is rather good.

Last but not least there is another disadvantage: The construction system as an entity is quite fragile. If one element of the whole construction fails the whole tower would collapse immediately without any warning.

In summary tensegrity would be applicable for small constructions which should have the ability of prefabrication and lightweight. These two aspects would be required for the BOSCO tower as well, but in areas with basic technical equipment and low tech materials tensegrity is not appropriate.

ill. 126 - Kenneth Snelson - Needle Tower

5.1.6. Lightning protection

Transmission Tower/masts are highly vulnerable to lightning because of their exposed position and the fact that they are mostly electrically conducting.

A lightning protection system is a system designed to protect a structure from damage due to lightning strikes by intercepting such strikes and safely passing their extremely high voltage currents to "ground"[48].

It has to be divided between lightning protection and surge protection.

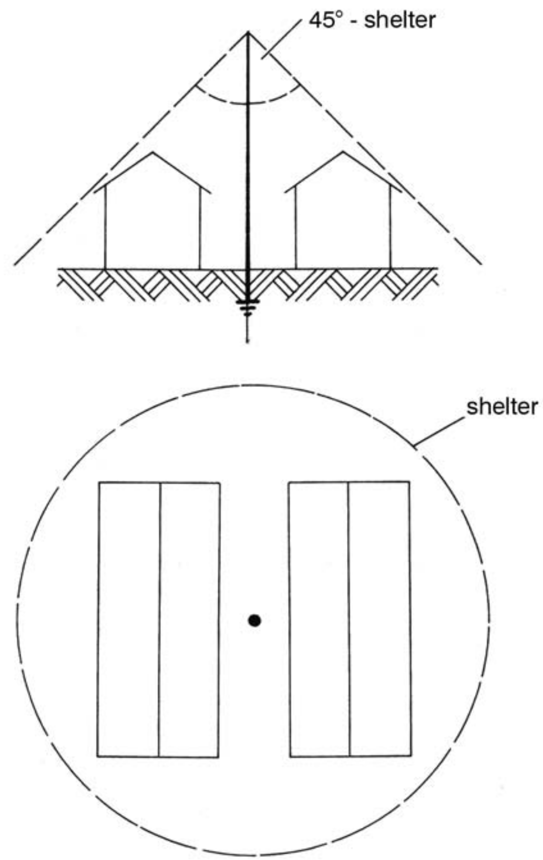
Lightning protection

The term lightning protection covers all means to "catch" and conduct the lightning stroke to the grounding.

In order to intercept the lightning an air terminal is necessary. This is a metallic structure which is on top of the protected building or lateral of it. This structure - usually a metallic round bar - provides shelter in a 45° cone below. All buildings and structures inside this shelter cone are protected from lightning.

In order to lead the lightning to the grounding a lightning arrestor is necessary. Therefore round bars have to be attached to lead it from the air terminal to the grounding.

The grounding is necessary to lead the lightning into the ground. Therefore it must have enough contact with conducting soil. Different methods to provide enough contact are possible. Circular grounding or single grounding is the mostly used.



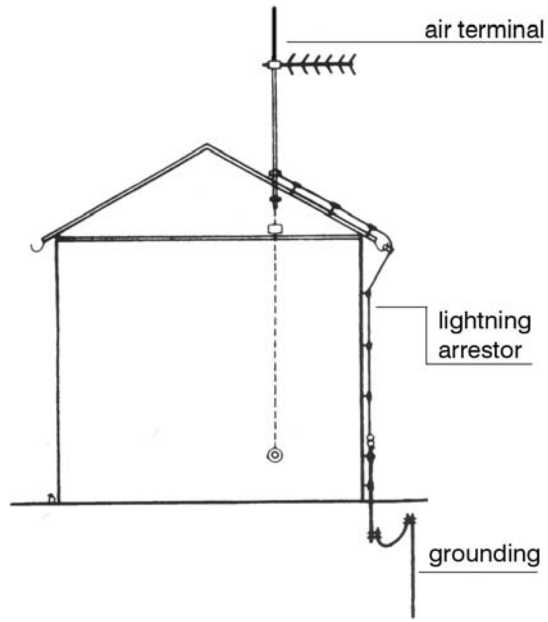
ill. 127 - lightning shelter

-46- http://en.wikipedia.org/wiki/Lightning_protection_system [accessed 02 04 2009]

Surge protection

The lightning which has been conducted to the grounding through the lightning arrestor creates a strong electrical and magnetically force field. The antenna equipment has to be protected from this force field in order to avoid damage. Different technical solutions are available on the market, but basically the equipment has to be indirectly connected with the lightning protection. This indirectly connection can be done by special connectors and leads the electric and magnetic force field away from the equipment to the ground. Concerning the installed equipment the surge protection has to be adjusted.

It has to be mentioned that overall lightning protection is a technical expensive task field. Special connectors and high quality metals have to be used. The company DEHN[49] provides excellent information for all protection parts.



ill. 128 - lightning protection system

-49- http://www.dehn.de/ [accessed 2009 04 15]

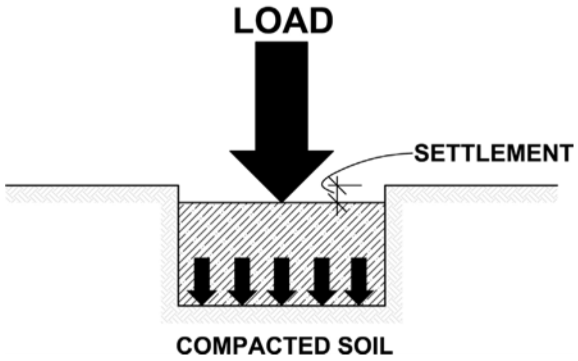
5.2. Foundation

The foundation is the structure which transfers loads like pressure or tension or moments to the ground. The foundation must assure that deformation of the structure above is reduced to a minimum. The possibility of deformation is dependent on the capacity of the soil and the type of the foundation.

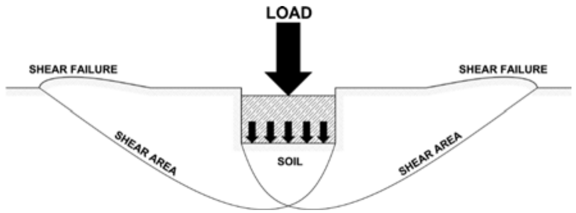
The capacity of soil has two important aspects. First of all there is the load capacity which is the capacity of soil to resist forces. If loads are transferred to the ground, the soil has to resist these forces by deforming as less as possible. The second one is the soil bearing capacity. This is the capacity of soil to support the loads applied to the ground. It is the maximum average contact pressure between the foundation and the soil which should not produce shear failure in the soil.

Most of the time foundations consist of several smaller parts. Each part must have the same settlement. Otherwise the structure – especially a tower – can bend on the side where the settlement is different and the whole structure can collapse.

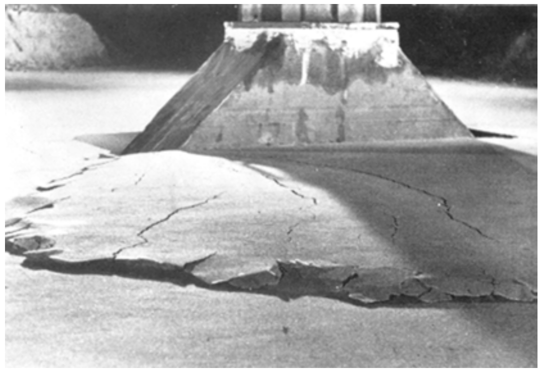
Summarizing foundations have to be strong enough to support load of the structures above and the soil must be able to take the loads within acceptable deformation.



ill. 129 - foundation



ill. 130 - shear failure - schematic illustration



ill. 131 - shear failure

5.2.1. Typology of foundations

Shallow foundations

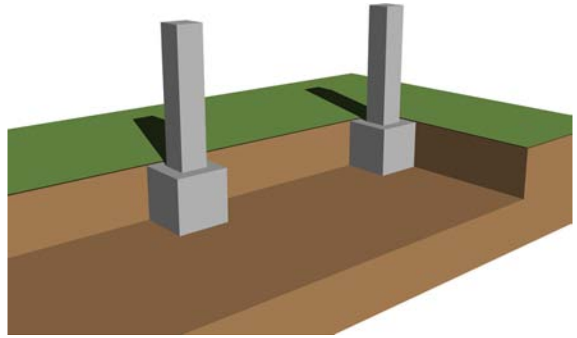
Most foundations used at building constructions are shallow foundations. In this case the load is transferred directly to the ground below the structure. This provides the advantage that it is not necessary to dig deep into the ground. This type is usually embedded approximately a meter into soil. The requirement to use this type of foundation depends on the structure of the soil. It must have an adequate load capacity – like described in the introduction of this chapter above. Otherwise it is necessary to use deep foundations which will be described in the next paragraph.

A common type for shallow foundation are spread footing which consists of strips or pads of concrete (or other materials) and transfer the weight from above to the soil. The positions of those pads or strips depend on the forces of the construction above. Another common type is the slab-on-grade foundation where the weight of the building is transferred to the soil through a concrete slab placed at the surface.

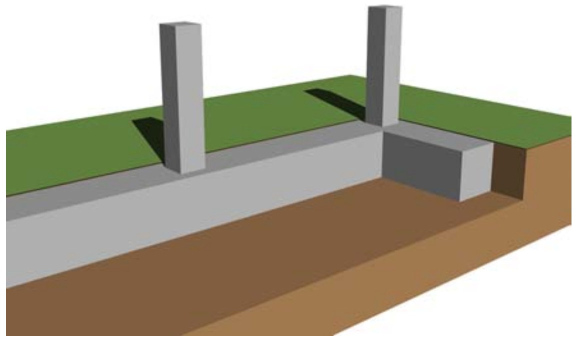
Deep foundations

If the soil beneath the construction is too weak, to support the structure's load, it is necessary to use deep foundations. They transfer the load through an upper weak layer of soil to a stronger deeper layer of soil. This can be done by digging deep holes to reach the stronger soil layer and filling these holes with material like stones or concrete which are able to take the loads.

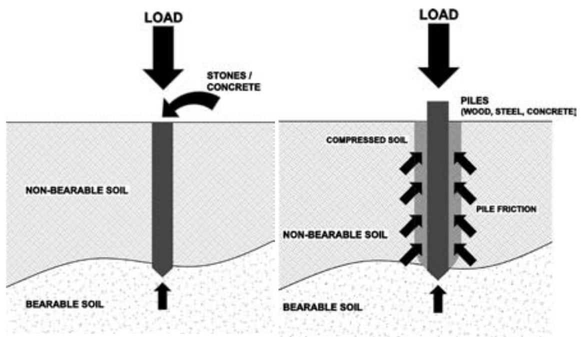
Another method is to push piles into the soil to reach the stronger deeper layers of soil. This has two advantages. It is not necessary to dig holes and the soil around the piles gets compressed which makes the soil more bearable. The friction of the pile increases the load capacity. Historically the piles were wood, later steel, reinforced concrete, and pre-tensioned concrete.



ill. 132 - pad foundation



ill. 133 - strip foundation



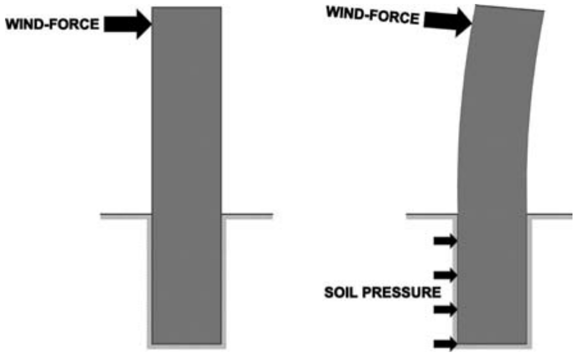
ill. 134 - deep foundations

5.2.2. Foundation aspects for tower/mast constructions

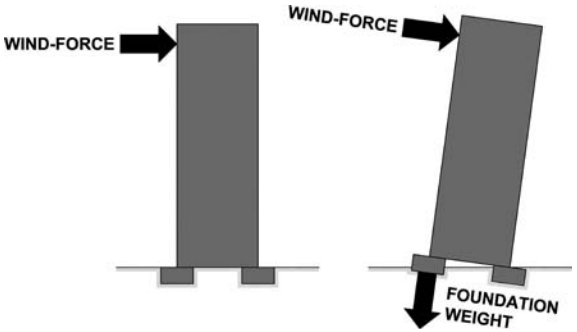
Usually tower/mast constructions do not have a lot of weight compared to their measurements. Their surface is rather wide in comparison to their base area. For that reason the foundation of such constructions has to be planned in a different way. The foundation for towers/masts has to work with the aspect to hold the building to the ground and preserve them of bending and as a result tumbling down. Wind-forces, which generate high tension on the wind claimed sides, will try to pull the foundations including the tower out of the soil. Possibilities to prevent this are based on heaviness of the foundation or the soil around.

The first possibility is to dig the foundation deep into the ground. It can be imagined like pushing a stick into the ground. If the construction would like to bend the masses of soil pressing against the sides of the foundation will hold against the force of the wind-pressure at the top. Statically it works like a clamping. The foundation has no possibility to move in any direction. It is an easy and understandable way to fix a building but the effort for a high building like a tower is enormous in relation to its effect. The depth of this foundation depends on the structure of the soil. Material use and construction effort is high because the foundation itself has to work statically as an entity. It can be imagined like a tower in the ground which works as an antithesis to the tower above.

The second, and in my opinion more practical, possibility is to make the foundation heavy enough to withstand these tension forces. There are several ways to provide the foundation with enough weight. Stones or



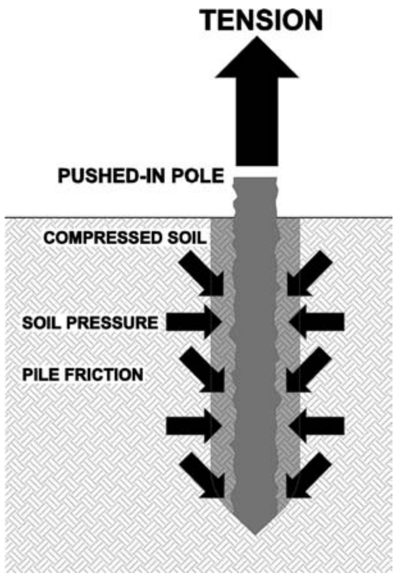
ill. 135 - clamping



ill. 136 - counterweight

concrete blocks, held together with wires or meshes can be used as well as scrap metal pieces. The advantage of this construction method is that it is not necessary to dig deep into the ground. Also the material use is relatively small. It has to be calculated how much force the wind is producing to pull the foundation out of the ground. The foundation weight can be adjusted to resist this force.

The third possibility is to use the pressure of the soil beneath the construction. If a pole gets hammered into the ground, the soil which gets displaced by the pole gets condensed and is pressing on the surface of this pole. Additional all the soil around this pole is pressing against it as well. The combination of these two aspects results in a high resistance against pulling out this pole. This pressure is called shear-force. This force is highly dependent on soil structures and even more on the surface of the pole. The smoother the pole is, the easier it can be pulled out, the opposite with a rougher pole. No earthworks are required for this method.



ill. 137 - friction

5.2.3. Soil consistency[50]

As described in the chapter before tower/mast foundations have to handle with tension rather than with pressure. The foundation has to transfer the tension into the soil. Each soil type has another internal structure therefore there are differences concerning tension and pressure capacities. Literature divides soils in more than 20 types, each with varying capacities. In this work this classification is simplified and all soil types are reduced down to three regarding their quality of binding.

Cohesive soils

Cohesive soils, such as clay[51] or silt, in general consist out of particles smaller than 0.05mm. They are dense and plastically. Their particles are able to bind a lot of water. Therefore their behavior and load capacity depend a lot on their water content. The quality to support tension forces are not as dependent as their pressure load-ability regarding water content. For foundation aspects it should be considered to drain water around the foundation. Otherwise the soil gets affected by moisture and loses a lot of it qualities. If these measures are kept in mind, these soil types can handle forces in an excellent way.

Non cohesive soils

Non cohesive soils are soils like sand and gravel. They consist out of particles with the size beginning by 0.063 mm up to more than 10 mm. These soils consist out of a stable grain structure and are not dependent on water content. Therefore they provide excellent pressure and tension support as long as these particles are compacted. Foundations in non cohesive soils have much higher pressure loads than in cohesive soils. Their tension support is equal to cohesive soils.

Rock

Un-weathered rock is a solid and load able structure. Nevertheless preparations for foundations can be intense. Heavy machinery or dynamite has to be used to prepare this type of soil. Rocky ground is an excellent bedrock for foundations which have to support pressure forces. But tension forces cannot be directed into this soil type without a lot of preparations. Ground nails cannot be pushed into it either; Moreover holes for counterweights cannot be excavated in this soil without breaking the rocks.

ill. 138 - clay

ill. 139 - different kinds of gravel

-50- http://de.wikipedia.org/wiki/Baugrund [accessed 02 04 2009]

-51- http://en.wikipedia.org/wiki/Clay [accessed 02 04 2009]

5.2.4. Foundation method – ground screws

Ground screw systems have interesting advantages, which would fit well as foundation type for the BOSCO tower/mast. They will be explained exemplary by showing two manufacturer and their systems.

KRINNER ground screws[51]

The Ground Screws are installed, using a number of different screwing aids and machines. Perfectly perpendicular and at the exact point in a matter of minutes. This new screw - in foundation system is not only suitable for natural ground, but also for dense and even tarred surfaces. Applications are countless, from securing garden umbrellas, windy dryers and fences; to carports, flag poles and traffic signs. Solar panel systems, advertising boards and even outdoor buildings for events and expositions are quickly and easily erected and removed.

The KRINNER Ground Screw System is extremely environmentally friendly and economical. The Ground Screws are statically tested and have been approved by the German Federal Road & Transport Authorities for the erection of all types of traffic & directional signs.

Advantages

Cost & Time Saving

No Digging – No Concreting

For Natural Ground

The Surrounding Area Remains Unspoiled

No Waiting Time, Immediately Usable

Durable & Long Lasting

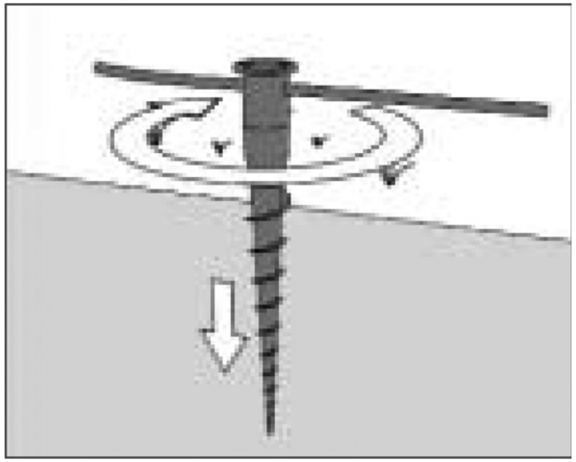
Environmentally Friendly, Surface Remains Un - Sealed

Easy to Dismantle & Relocate

Statically Tested - Storm Proof

For Masts up to 12 m

ill. 140 - application of a ground screw



ill. 141 - schematic erection detail of ground screw

-51- http://www1.krinner.de/schraubfundamente.html [accessed 20 04 2009]

Load Capacity for Screws with the Length of 1000mm

Load	half hard ground / clay	sandy, semi dense ground
Push (kN)	**48**	**128**
Pull (kN)	**21**	**24**
Horiz. Load (kN)	**13.5**	**6**

The test results shown have been obtained in the ground conditions as stated. For specific projects and for more accurate results the relevant ground will have to be tested.

Technical Details KSF FPK 140 x 1000

Side View (mm)

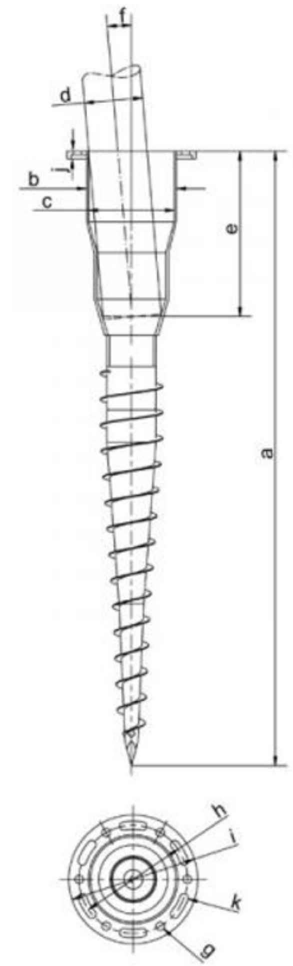
a Tube length:	**1000**
b Outer Ø:	**139.7**
c Inner Ø:	**132.5**

Adjustment Ø (d)
Determines depth (e) and adjustment area (f)

d Adjustment Ø:	**75-80-90**
e Depth:	**330-322-306**
f Adjustment:	**5.5°-5.0°-4.5°**
j Flange:	**12**

Top View (mm)

g Durchmesser Lochbohrung:	**6 x Ø 13**
h Throat Ø:	**167**
i Flange outer Ø:	**199**
k Elong. hole:	**6 x Ø 13 - sleufgaten 20°**



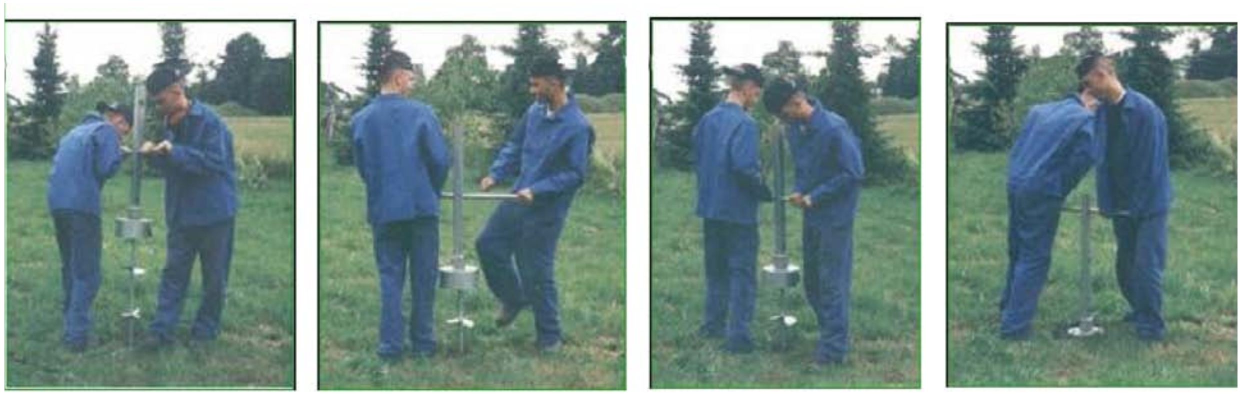
ill. 142 - technical data of Krinner ground screws

KESEAS – ground screw system

Keseas[53] is a similar ground screw system. Different types of lengths with high tension and pressure loads are available. They have two different screw principles: One for non cohesive soil and one for cohesive. Both of them have similar advantages as the KRINNER system.

The most interesting aspect of this specific system, regarding BOSCO's tower/mast, is the design simplicity of the screws.

ill. 143 - KESEAS ground screw



ill. 144 - Erection process

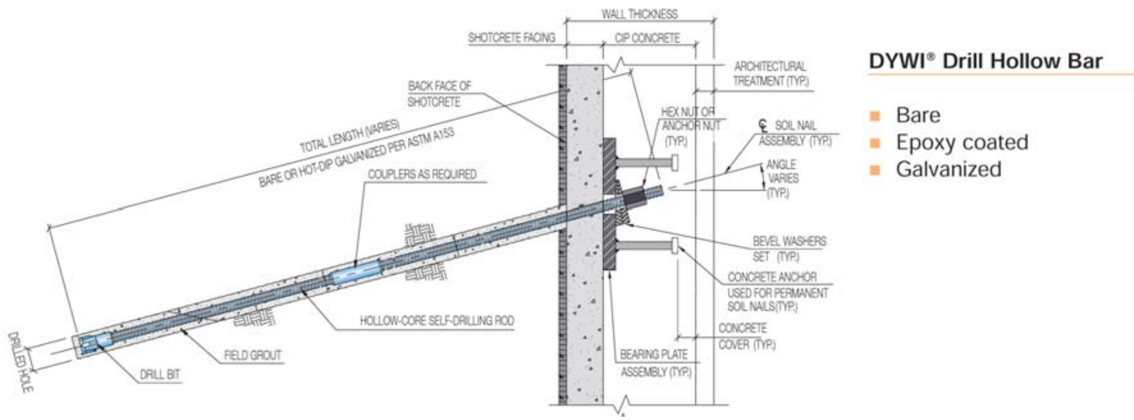
-53- http://www.keseas.de/index.htm [accessed 20 04 2009]

5.2.5. Foundation Method – soil nails

The technique of soil nailing began to evolve in the early 1970's. Major research programs in Germany in the mid to late 70's and in France in the late 80's advanced this method of construction. It has been successfully utilized worldwide for excavation support and slope stabilization and its use continues to grow rapidly[54]. Basically it is a system to secure the soil of slopes. The soil nails system from *DYWIDAG systems international (DSI)*[55] should serve as an example to understand the technique. These soil nails need a lot of technical equipment. They are drilled into the soil and grouted with concrete. They require bearing plates and a concrete wall to stabilize a slope. It is absolutely clear, that this system has another field of application and is technically too advanced for BOSCO's tower/mast. But why is this topic added to the thesis?

Tower/mast foundations as mentioned before generally have to support tension forces. For example the anchors of guyed masts - page 84 [chapter 5.1.4] - have to support tensile forces only. Therefore soil nails are of great interest for this work. These soil nails have to resist strong tensile forces. They can resist the tension because the weight of soil which is lasting on them avoids that they are pulled out of the slope. Transferring this fact to foundations for a tower/mast construction, the soil nail has to resist the tensile force that appears because wind induced forces are directed through the wires to the foundation.

This chapter about soil nails should serve as an impression of the possible functioning of self made soil nails. Multiple iron bars pulled into the ground could serve as foundations to support tensile forces.



ill. 145 - technical data of DYWIDAG soil nail

-54- http://www.dsiamerica.com/products/geotechnic/dywidag-soil-nails/history-and-general-notes.html [accessed 02 04 2009]

-55- http://www.dsiamerica.com/ [accessed 02 04 2009]

5.3. Materials and their fastening-methods

Material possibilities and fastening methods for foundations of tower/mast constructions will be described in this chapter. Furthermore the subchapters explain fastening methods of the different materials.

5.3.1. Timber[56]

In constructional aspects timber is the only renewable material source. In general it is available in the region and therefore an economic material choice. The internal structure can be imagined like a lot of straws side by side. Therefore it makes a big difference which kind of force it should support (tension or pressure) and how it is exposed to the force. Handled in an appropriate way timber has good load capacities compared to its medium weight of around 500 to 800kg/m³. The durability of the material is depending on the exposure of external conditions. There are examples of timber structures which have been constructed more than thousand years ago and still exist today.

Concerning foundations this material was used historically for piles as a method to reach the deeper stronger layers of soil.

Many tower constructions have been built out of timber. Fading into oblivion in the second half of the 20th century when steel and concrete dominated the market, it became widely used again during the past 20 years for any kind of architectural construction.

-56- One of the most useful resources for timber in general and timber constructions is the "'Timber Construction Manual" – see reference in the bibliography.

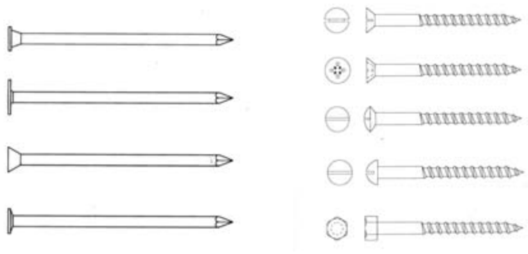
5.3.1.1. Engineered connections

Nails and wood screws

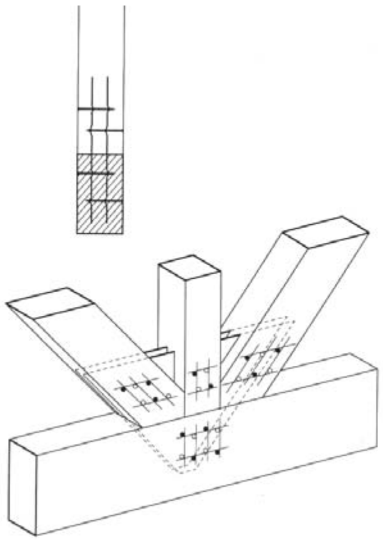
With these types of screws all kinds of timber beams and boards can be connected. By driving or screwing them in- the material around the nail/screw gets compressed. The bigger the pressure on the surface of the nail/screw and the rougher it is, the bigger is its resistance against pulling out. Therefore screws have a much higher resistance. The load capacity against shear force depends on the sturdiness of the nails/screws as well as the sturdiness of the connected parts. If the force gets to high, the nail can break or will be pulled out and bend.

Metal sheets can be used in combination with nails/screws and provide high load capacities. It is possible to arrange them as inlets in sawed slots or perforated metal plates on the surface of the joint. Inlets can be stamped if they are thinner than 2mm.

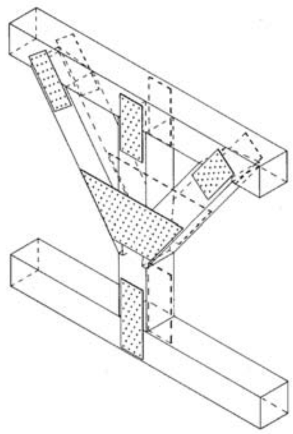
Another combination method is the use of stamped nail-sheets. These are 1 to 2mm thick metal sheets where the punching out is used as nails. They get pressed on the timber surface. Because of the number of this so to speak nails they have a high load capacity and their use would reduce the labor costs incredibly.



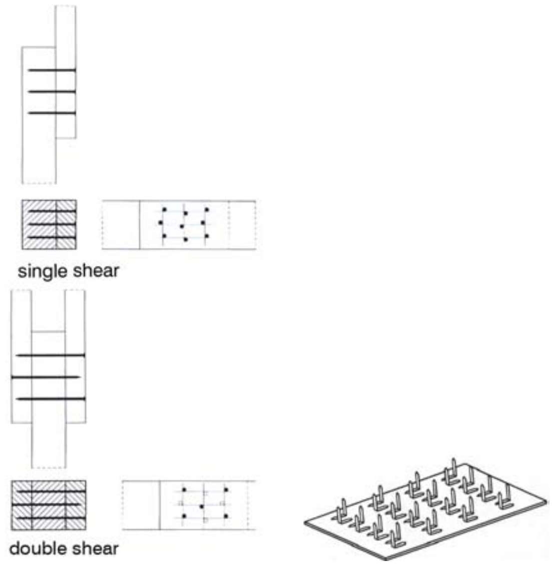
ill. 146 - nails and wood screws



ill. 147 - sawed in metal inlets



ill. 148 - perforated metal plates



ill. 149/150 - nailed joint / stamped nail sheet

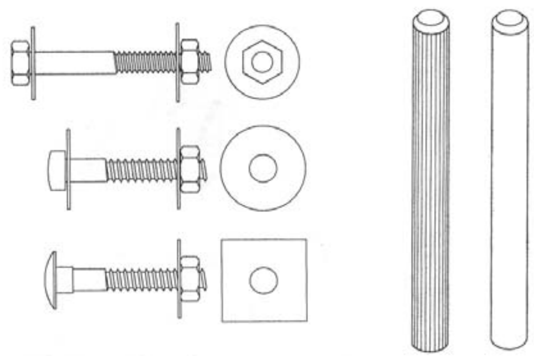
Pegs

Pegs are joining means which are driven into pre-drilled holes of the construction. Shear resistance, based on the principle of nails and screws, and tensile force depends on the used type. There are three different peg types available. Stick-pegs, press-in pegs and bolts. They can be used independently or in combination with steel fasteners. Profile reduction, as a matter of pre-drilling, has to be considered.

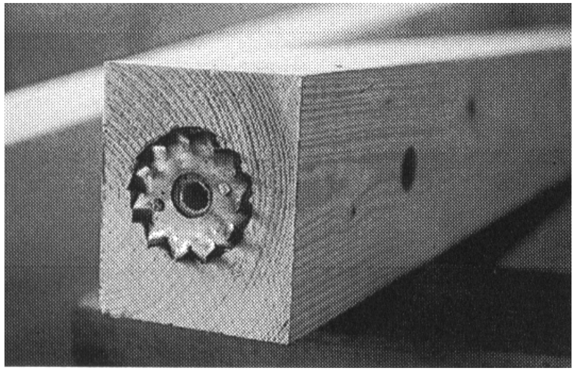
Glue

This connection type is mostly used for glue laminated timber. It is a method to create beams or boards with big dimensions out of smaller timber parts. Glue is a very rigid connection type, because the entire connecting surface is glued together instead of some connection points. Using only glue connections at constructional joints is not applicable, because they do not have any ductility, which is important for joints.

To produce load bearing glue connections there are special requirements to be taken into account. Certified workshops have to use specialized staff and glues, as well as a certain climate (around 20°C and 65% air humidity) is necessary.



ill. 151 - bolts and pegs



ill. 152 - press in peg

ill. 153 - gluelam

5.3.1.2. Handcrafted connections

Handcrafted wood connections without reliance on external materials have been utilized through the centuries for manifold purposes. In the modern wood constructional engineering they were almost plenarily displaced by connections using steel fasteners[57].

Different connection types have been developed over centuries. Especially in Japan handcrafted wood connections have an unbelievable variety.

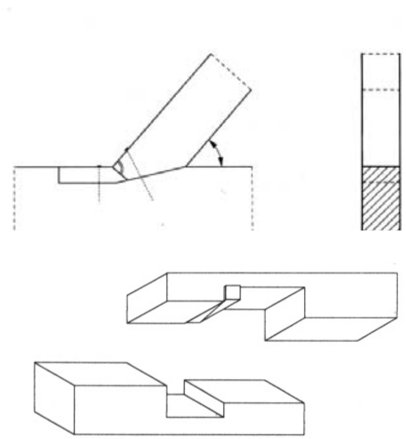
Force transmission mostly takes place through contact edges. The disadvantage of these connections is the weakening of the profile which can be compensated with special means. The most practical types are the batch composition, scarf joints and contact edges.

5.3.1.3. special connections

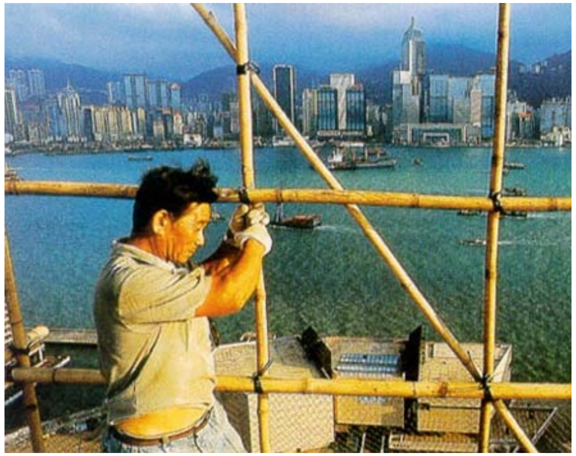
Tied - Bamboo

Scaffolding in Asia is mostly done with Bamboo. These assisting structures reach heights of 200 meters and are entirely tied together.

Materials used in this case are traditional barks from bamboo, rattan and liana and ropes made out of them. Nowadays most of these scaffold constructions use cable fixers. Complex knots have been developed to provide stability.



ill. 154 - handcrafted connections



ill. 155 - scaffolding with bamboo

ill. 156 - tied bamboo joint

5.3.2. Metals – Steel and Iron

Metals are by far the most used basic materials for any kind of technical use. The reason for this fact is their availability all over the world, which makes them rather cheap. Iron and steel cover most implementations, although steel is mostly used in architecture or civil engineering. It has excellent load capacities and a weight of around 7800kg/m³. Therefore structures out of steel can be designed much thinner than structures out of other materials.

However once metal gets moistened a chemical reaction starts which slowly destroys the structure. This reaction is called corrosion. Therefore metal structures have to be treated. Possible methods to secure metals from corrosion is using different alloys (galvanization is the most popular) or covering it with paint once in a while.

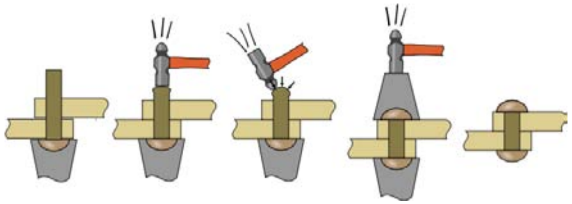
Concerning foundations metal can be used for piles in order to reach the deeper stronger layers of soil. In addition ground screws or ground nails are made out of it. Any other use for foundations would be a waste of material. An exception would be the use of scrap metal because of his high weight - in this case it could be used as a counterweight for foundation parts.

However for tower constructions themselves metal is a widely used material. L/T shaped or hollow sections out of metal have high load capacities. Therefore metal is widly used in tower constructions.

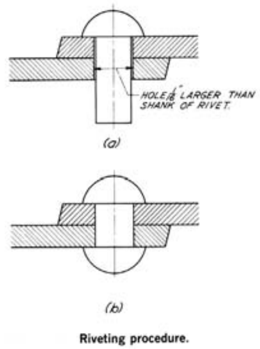
5.3.2.1. Rivets

A rivet is a permanent mechanical fastener. Before it is installed it consists of a smooth cylindrical shaft with a head on one end. The end opposite the head is called the buck-tail. On installation the rivet is placed in a pre-drilled hole. Then the tail is "upset" (i.e. deformed) so that it expands to about 1.5 times the original shaft diameter and holds the rivet in place.

Because there is effectively a head on each end of an installed rivet it can support tension loads (loads parallel to the axis of the shaft); however, it is much more capable of support-



ill. 157 - rivet deformation



ill. 158 - rivet

ill. 159 - rivets example

ing shear loads (loads perpendicular to the axis of the shaft). Bolts and screws are better suited for tension applications[58]*.*

Many different types are available on the market. Concerning constructional aspects the solid rivet is utilized the most. Tail deformation of a rivet can be done by hammering or with a rivet gun – a pneumatically powered gun.

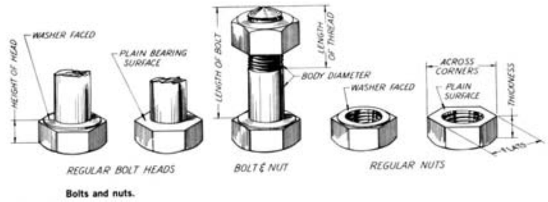
It has been the common fastening method for structural steel structures at the turn from the 19th to the 20th century. The forth railway bridge[59] or the Eiffel tower are two famous examples.

5.3.2.2. Bolted connections

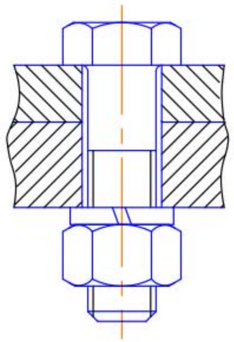
A bolt is an externally threaded fastener designed for insertion through holes in assembled parts, and is normally intended to be tightened or released by torquing a nut[60]*.*

There are two main types of bolted joint designs. In one method the bolt is tightened to a calculated clamp load, usually by applying a measured torque load. The joint will be designed such that the clamp load is never overcome by the forces acting on the joint (and therefore the joined parts see no relative motion). The other type of bolted joint does not have a designed clamp load but relies on the shear strength of the bolt shaft[61]*.*

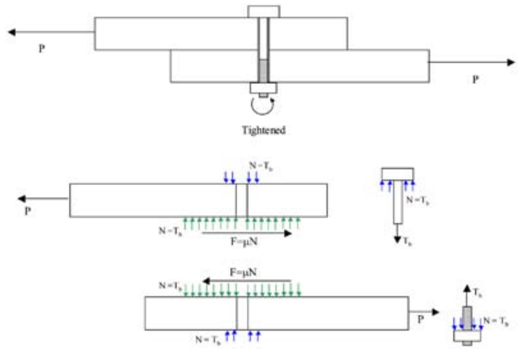
When a bolt is tightened the captured parts are compressed. External forces will act on the parts which have been compressed. The bolt does not see the full amplitude of the load and furthermore will not become lose.To set such a bolt at engineering joints the pre-torque has to be set accurately regarding external forces and thread strength. This is usually done with a torque wrench.



ill. 160 - bolts and nuts



ill. 161 - bolt



ill. 162 - statics of a bolted connection

-58- http://en.wikipedia.org/wiki/Rivet [accessed 02 04 2009]

-59- http://www.forthbridges.org.uk/railbridgemain.htm [accessed 02 04 2009]

-60- Jones (2000). Machinery's Handbook 26th edition. p. 1492.

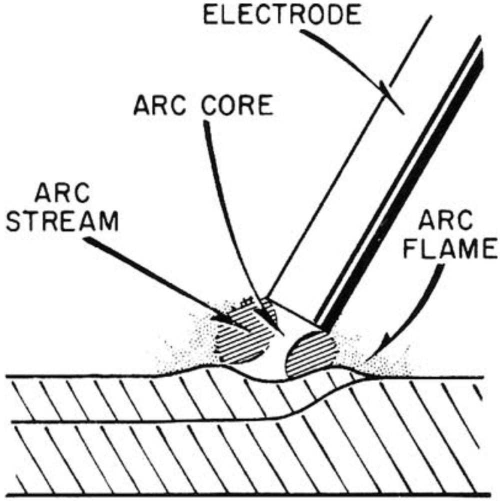
-61- http://en.wikipedia.org/wiki/Bolted_joint. [accessed 02 04 2009]

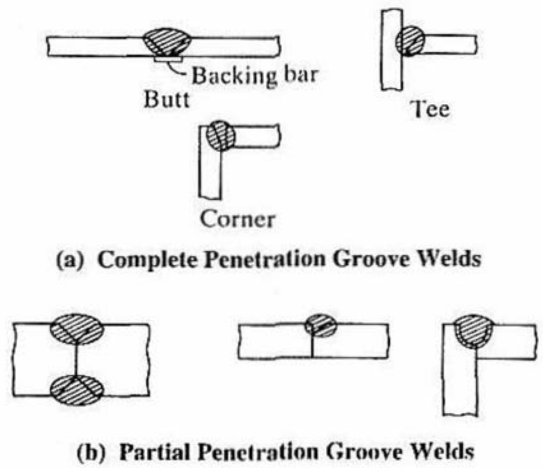
5.3.2.3. Welded connections

Structural welding is a process by which the parts that are to be connected are heated and fused, with supplementary molten metal at the joints. A relatively small depth of material will become molten, and upon cooling, the structural steel and weld metal will act as one continuous part where they are joined[62].

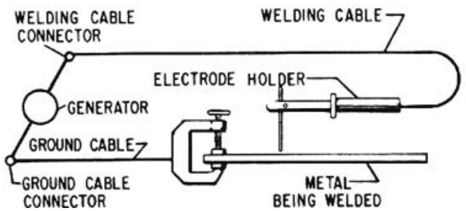
Many different energy sources can be used for welding, including a gas flame, an electric arc, a laser, an electron beam, friction, and ultrasound. While often an industrial process, welding can be done in many different environments, including open air, under water and in outer space[63]. Nevertheless the most common welding method is electric arc welding. *The additional metal is disposed from a special electrode, which is part of the electric circuit that includes the connected parts*[64].

The most common types of welding are the fillet weld and the groove weld. Fillet welds are placed in the corner of the intersection of two plates. Groove welds are made in a gap or groove between two beveled parts.

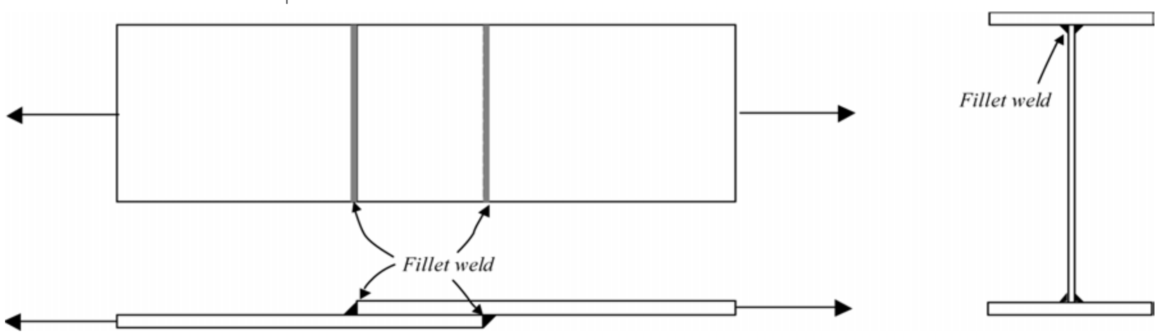




ill. 164 - groove welds



ill. 163 - electro weld description



ill. 165 - fillet weld

-62- A. - CE 405: design of steel structures - chapter 6.welded connections; http://www.egr.msu.edu/classes/ce405/harichan/chap5.pdf (accessed 2009 04 17)

-63- http://en.wikipedia.org/wiki/Welding

-64- Varna A. - CE 405: design of steel structures - chapter 6.welded connections; http://www.egr.msu.edu/classes/ce405/harichan/chap5.pdf (accessed 2009 04 17)

5.3.2.4. "Direct fastening" – powder actuated tools

This fastening method is used in construction or manufacturing works by using a so called nail gun to join materials such as steel. These nail guns rely on a controlled explosion similar to the process that discharges a firearm. This explosion transfers a certain velocity – which can be adjusted with different cartridges – to the fastener. The velocity drives the fastener into the material. Therefore powder-actuated fasteners have to be out of higher quality as the material and are usually nails made out of hardened steel. The nail drives out the material and gets combined with it entirely. It cannot get loosen afterwards without serious force input.

They have a muzzle safety interlock to avoid discharge in an unsafe manner. If this muzzle is not pressed against a surface with sufficient force it will not be possible to fire it. Nevertheless they should be treated with the same respect as loaded guns.

Manufacturer of these powder actuated nail guns including high quality nails and explosion cartridges are little. Ramset[65] and HILTI[66] offer a wide variety of uses.

For each different use the proper cartridge and nail type has to be chosen. Otherwise many failures can happen with this fastening method.

ill. 166 - nail gun

ill. 167 - nails and cartridges of nail guns

ill. 168 - fastener

-65- http://www.ramset.com.au/public/article/show.asp?articleid=1008&menuItemID=92&toplvlID=6&menuNo=2 [accessed 2009 04 17]

-66- http://www.us.hilti.com/holus/modules/prcat/prca_navigation.jsp?OID=-17120 [accessed 2009 04 17]

5.3.3. Stones / bricks

Stones

Quarried stones have been used historically for masonry constructions. As technical solutions have advanced it became highly inefficient to use this material for high rise constructions. Nevertheless stones can be used as basements for towers. They have a lot of weight – between 1800 to 2500 kg/m^3 - and an excellent load capacity. It is possible to get them in every region around the world and they are rather cheap. Furthermore they are needed as aggregates for mixing concrete.

Bricks

A brick is a block of ceramic material used in masonry construction, usually laid using mortar[67].

Most common base material for brick production is clay. Further materials are soft slate, calcium silicate or concrete. The raw material can be processed as soft mud, dry pressed or extruded. Bricks can be used air dried or burned which gives them a high resistance against moisture and insect attacks. Market disposes a wide variety of different dimensions and shapes.

5.3.3.1. Mortar

Mortar is a homogenous paste which is used to bind bricks and stones together and fill the gaps between them. It is a mixture of a binding agent, water and fine granular aggregates. Lime or cements are the most used binding agents. After setting hard the mortar creates a hard and durable structure together with the bricks.

5.3.3.2. Meshes

Another possibility to create cohesion between several smaller rocks is to bundle them up. Lattice vessels out of meshes and wires can be used. The cohesion is highly dependent on the quality and density of the mesh. Density and therefore weight of this vessel is dependent on the used stones. To avoid empty inclusions a mixture of different sizes have to be used. Counterweights and foundations can be constructed with this simple method.

ill. 169 - bricked wall

ill. 170 - lattice vessel

ill. 171 - filled lattice vessel

-67- http://en.wikipedia.org/wiki/Brick [accessed 02 04 2009]

5.3.4. Concrete

Concrete is a construction material composed of cement (commonly Portland cement) as well as other cementitious materials such as fly ash and slag cement, aggregate (generally a coarse aggregate such as gravel, limestone, or granite, plus a fine aggregate such as sand), water, and chemical admixtures[68]*.*

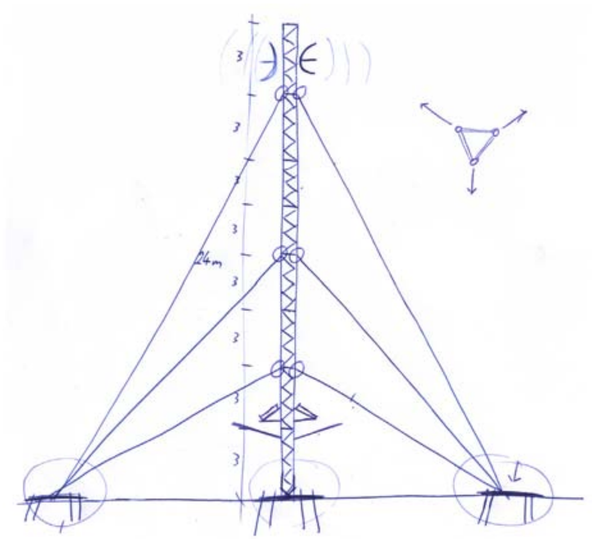
Concrete is a highly durable and an on sight produced material. It is moldable and allows any type of geometrical design.

Basically it is the common material for most foundations. It has a high load capacity for pressure forces and can be used as anchor against tension because of its weight of 2000 to 2800 kg/m^3. For tower/mast constructions it has been often used for industrial chimneys and TV towers because of its high rigidity - page 78 [chapter 5.1.1] Nevertheless it is a rather expensive choice of material for a tower construction compared to other constructional possibilities.

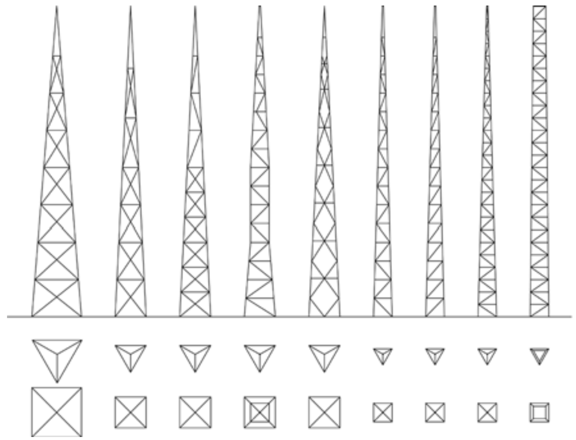
-68- http://en.wikipedia.org/wiki/Concrete [accessed 2009 04 17]

PART 3 – DEVELOPMENT OF PROTOTYPES


ill. 172 - realized guyed mast



ill. 173 - sketch


ill. 174 - lattice tower possibilites

6. Project Requirements for the BOSCO tower/mast

All requirements for the tower/mast will be gathered in this chapter in order to give a complete outline of all aspects which have to be taken into account for the construction.

6.1. Design aspects

The tower/mast construction needs to meet certain pre-requisites as explained on page 23 [chapter 3.5 Extension of the system].

- BOSCO needs a system which is height flexible. The tower/mast should have the possibility to fulfill the required heights for any site around Gulu. As researched on site and concluded by the technical consultant of BOSCO - Stefan Bock from Horizont 3000 – a maximum height of 25m is sufficient.

- BOSCO is using radio link antennas. These antennas have a narrow band width. To provide maximum transmission quality, limited deformation of the tower is highly necessary. For the current antennas as well as for advanced antennas the deflection on top of the tower/mast should be less than 150mm.

- BOSCO should be able to choose any site. This includes the option to be flexible regarding changes of the network layout. If one site cannot be used anymore – for various reasons – or becomes inefficient, the structure should be moveable and serve the BOSCO project somewhere else instead of being abandoned.

- A cheap and efficient construction is necessary. Therefore it should be made with materials which can be bought in hardware stores in Uganda.

- Easy instructions and low-tech details to be carried out by any workshop in Gulu are required. Aim of this project is to provide a technical tower/mast prototype. Through this project the workshops are offered the possibility to extend their field of work.

- For reasons of maintenance and directional adjustment of the antenna, it is required that a person can climb the tower securely.

This work will try to provide BOSCO a modular tower/mast prototype. Different heights between 10 up to 25m should be possible. The aim is to design a tower/mast which can be set up and pulled down in a fast and efficient way. This provides the possibility to change the height and, if possible, the site of the tower/mast. All these aspects have to be combined and offer the possibility to be technically fulfilled within the local conditions and carried out by local workshops.

Furthermore, it is most important to make this work accessible to the workshops of Gulu. Therefore, instructions need to be understandable and clear. The workshops should have the opportunity to extend their field of work. Throughout the acquired knowledge of the tower construction they should profit from the project as well. Brother Konrad from Daniel Comboni Vocational Center: *“To get the knowledge and experience of setting up such a structure is why this workshop would like to co-operate. It cannot be that everything a bit more technical gets imported.”*

6.2. Load assumption

Radio towers/masts usually do not have to carry many loads. Antennas mounted on top of them, are small and lightweight. However, additional equipment needed and the fact that a technician has to climb it once or twice a year has to be taken into account as well. Finally the force causing most stress to the tower/mast will be generated by wind pressure. All appearing weights and forces will be listed in the following chapter.

6.2.1. Technical equipment

The maximum antenna configuration on the tower will be calculated. This includes the installation of 4 antennas and power management.

Antennas

As the BOSCO project tries to develop fast, they are using different antennas. Antennas from the initial phase are still in use, but newer generations of antennas are already in place and will be used more frequently in the future. Datasheets of antennas can be investigated in the appendix. The weights of these antennas range from 0.4kg to 4kg.

Antenna Hyperlink 3,62kg
0,60m² mesh surface > estimated 0,20m²

Antenna Nano Station 0,40kg
0,02m² enclosed surface

Antenna Power Station 3,99kg
0,15m² enclosed surface

Again, the wind pressure lasting on the surface of the antennas will cause more stress to the tower/mast as their weight itself. Therefore, the surface of these antennas is listed to calculate the wind pressure.

Power management

The entire BOSCO system is planned with low power consuming equipment, including the use of solar panels if the power grid is not accessible. The tower/mast will be standing in a rural area. Therefore, electric power will not be available. Solar panels and the required battery backup will also need to be installed on the tower. All of this equipment can be mounted on the lower part of the tower. (see datasheets in the appendix).

Battery Backup Solar Block 12V 135
46,00kg

Solar Panel Lorentz LA75-12S
7,40kg

Charge ControllerPhocos CML-V2
0,50kg (estimated)

Switch D-Link 1008D
0,30kg

Additional Cables
10,00kg (estimated)

6.2.2. Dynamic wind pressure

As researched through the Commissioners department of Meteorology the maximum wind speed in Gulu is 137,6km/h - page 30 [chapter 4.2.2]. To secure the calculations a slightly higher value should be taken into account. Static calculations in Europe are conducted with a value of 150km/h. Therefore, the calculations will be done with the common European dynamic pressure values listed in chart 8.

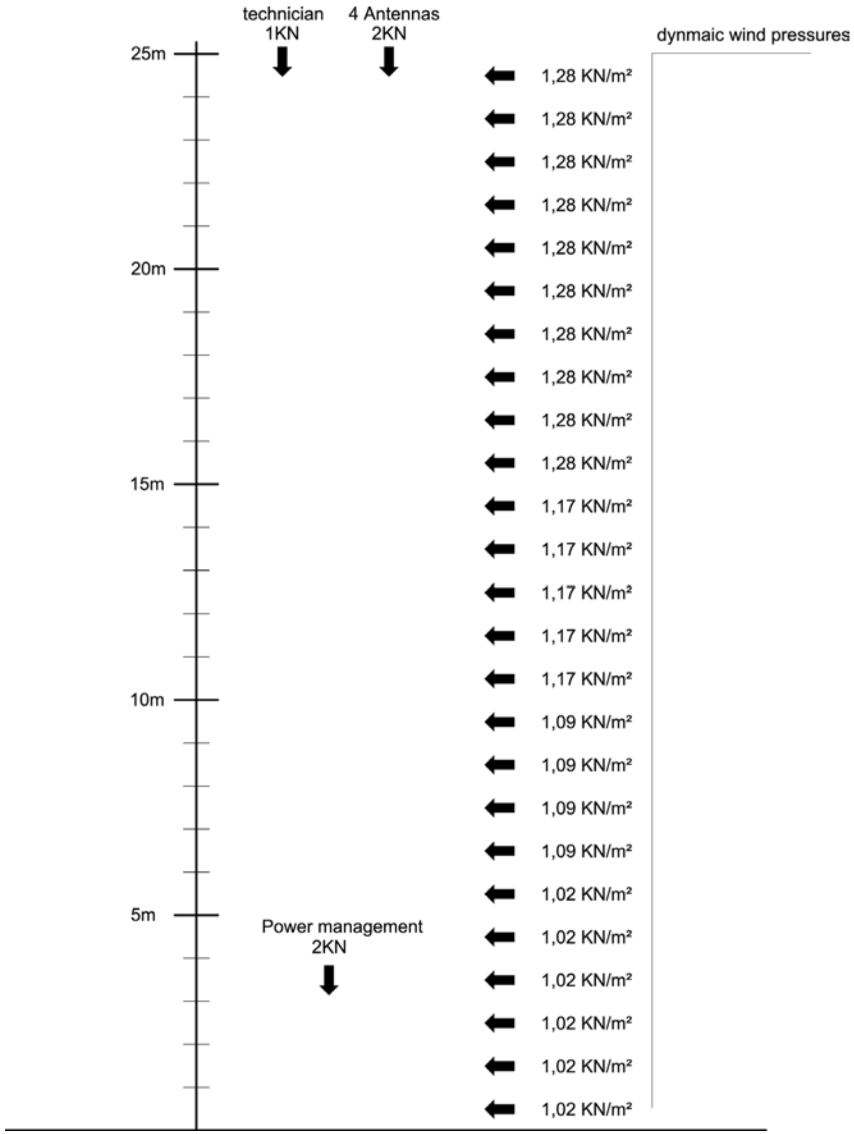
As these values are dependent on the surface area (kN/m²) the tower should as slender as possible.

The chart considers different shapes of the ground. The environment of the mast tower/mast will change as it is designed to be relocated. Therefore the values with the highest dynamic wind pressure will be taken into account.

Grundwert (in km/h)		90			100			110			120			130			140			150		
Geländeform		I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
Höhe über Boden (in m)	150	0,59	0,58	0,57	0,74	0,71	0,70	0,89	0,86	0,85	1,05	1,03	1,00	1,24	1,21	1,18	1,44	1,40	1,37	1,65	1,61	1,57
	100	0,56	0,54	0,51	0,70	0,66	0,63	0,84	0,80	0,76	1,00	0,95	0,90	1,18	1,12	1,06	1,37	1,30	1,23	1,57	1,49	1,41
	75	0,54	0,51	0,47	0,67	0,62	0,58	0,81	0,76	0,70	0,96	0,90	0,83	1,13	1,06	0,97	1,32	1,23	1,13	1,51	1,41	1,30
	50	0,51	0,47	0,41	0,64	0,57	0,51	0,76	0,69	0,61	0,91	0,82	0,72	1,07	0,97	0,85	1,24	1,12	0,99	1,43	1,29	1,13
	25	0,46	0,39	0,31	0,57	0,48	0,38	0,68	0,58	0,46	0,82	0,69	0,55	0,96	0,82	0,64	1,12	0,95	0,75	1,28	1,09	0,86
	15	0,42	0,34	0,24	0,52	0,42	0,29	0,63	0,50	0,35	0,75	0,60	0,42	0,88	0,70	0,49	1,02	0,82	0,57	1,17	0,94	0,65
	10	0,39	0,30	0,18	0,48	0,36	0,22	0,58	0,44	0,27	0,69	0,52	0,31	0,82	0,62	0,37	0,95	0,71	0,43	1,09	0,82	0,49
	6	0,36	0,27	0,15	0,45	0,33	0,19	0,54	0,40	0,23	0,64	0,47	0,26	0,77	0,56	0,31	0,89	0,65	0,37	1,02	0,75	0,42

chart 8 - dynamic wind pressure chart in KN/m² in consideration of wind speed, elevation and shape of the ground

In summary, following loads have to be considered for the static calculation. They cover the highest possible configuration that can last on the tower simultaneously.



ill. 175 - final load assumption in consideration of their height impact

7. Structural comparison of tower/mast possibilites

As shown starting on page 76 [chapter 5 – base elements] there are several possibilities to construct a tower/mast. Concerning material choice and construction principles different types would be feasible.

A static software programm, provided by DLUBAL[69], has been used to calculate accruing forces and deformations of different tower/mast possibilites in order to compare them.

7.1. Towers / masts

Regarding the project requirements - listed on page 113 [chapter 6] - possible tower systems will be statically compared in this chapter to finally choose the most efficient and sustainable option for BOSCO and the region.

The design of the tower will be influenced by the chosen construction material. This decision needs to be made during the first stages of this project and has to be well thought out. Material choice is based on two aspects:

The material for the tower/mast should be available in the specific area of Gulu and its surroundings. Above all it is necessary that local workshops can work with the material.

As described in previous chapters, there are actually only three materials which are entirely produced within the region of Gulu: bamboo, beams made out of palm trees and clay bricks. Considering that the aim of this thesis is to use local materials this would mean to construct a tower/mast of the required height out of bamboo, palm trees or clay bricks. Even if this would be possible these materials would not fulfill all requirements of the desired tower/mast. However, the objective of this diploma thesis still is to reduce dependency. Nevertheless, it is necessary to plan technically advanced in order to compete with international companies on the one hand and on the other hand meet the requirements of BOSCO. Metal and timber are imported, yet, they can be considered local materials, because they are easy to obtain anywhere. These two kinds of materials would also fulfill the stated aspects above. Iron, nevertheless, has an important advantage compared to timber. Quality of iron is assured – at least to a certain degree - compared to wavy timber beams with cracks and holes. More importantly even, there are workshops all over the country which are capable to weld. This is exactly why metal is my favor-

-69- http://www.dlubal.de/ [accessed 2009 04 23] ite choice. It is easily available everywhere, as well as timber, but with the big advantage that it is much more common in Uganda to work with metal than timber.

The tower/mast should fulfill the requirements of being transportable and easy to be set up and pulled down which commands a lightweight construction.

In conclusion, a lattice construction or guyed mast will probably be required to achieve these characteristics. Furthermore is it necessary to use a material with a high load capacity. As outlined before, iron and timber would be the materials of choice. Yet again, iron has a small advantage. Compared to its weight, iron has much more load capacity than timber. Therefore, it facilitates the option to transport the whole construction.

In conclusion, my choice for the main material of the tower/mast is metal for the reasons mentioned above.

7.1.1. Masonry tower

Although metal has been chosen as construction material of the tower/mast some aspects of masonry constructions should be analyzed in consideration of the specific circumstances in Uganda, especially Gulu. Bricks are fairly cheap and a traditionaly locally produced construction material in Uganda. It would be highly sustainable to use bricks. Unfortunately a tower made out of bricks would not cover any of the prerequisites of BOSCO besides the aspect of a sustainability.

Although a single brick is cheap, it would need thousands or millions for a 25m tower. Mortar to bind the bricks is also quite expensive as cement is needed. The foundation of such a heavy construction would have to be massive either, so the material costs would rise. The building process would take months and assistant scaffolding would be necessary. Finally, the tower could not be moved to another site or changed concerning height without destroying it. In addition no prefabrication is possible. Nonetheless, masonry is a reasonable construction method for a tower if the space inside the construction is needed for further use. As transmission towers just need a certain height and no extra room for technical equipment masonry has mostly disadvantages for these specific towers/masts.

There are much more economic and sustainable ways to reach all of BOSCOs requirements.

7.1.2. Mast

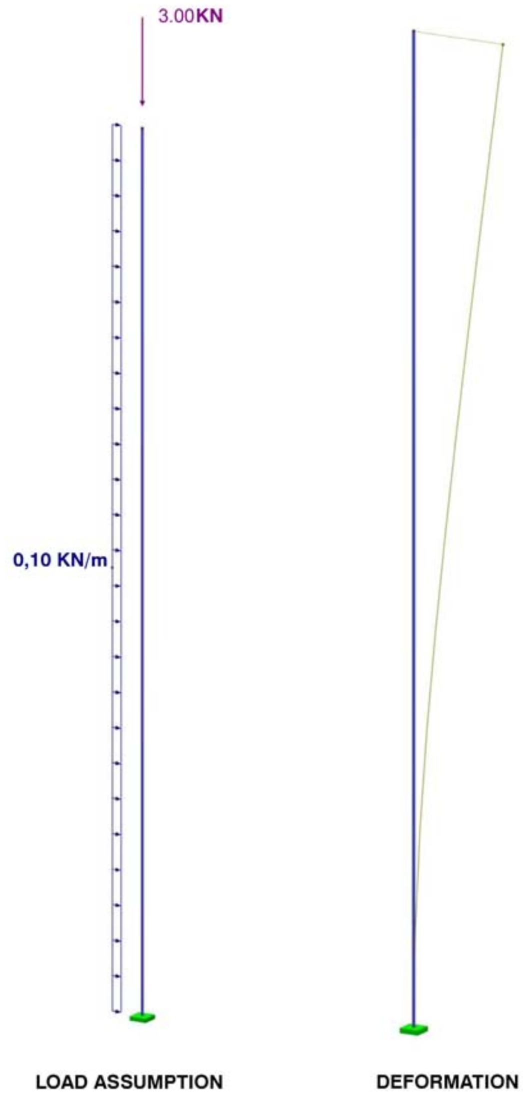
In this subchapter a simple mast construction will be analyzed regarding accruing forces. A mast construction – as described on page 79 [chapter 5.1.2] – is dependent on two aspects: the rigidity of the mast and the size of the foundation. The output of a static calculation with a simplified load assumption of the BOSCO project will be shown. Concerning material, the biggest available steel profile in Uganda has been chosen to calculate the mast: A steel pipe with 76mm diameter and 3mm material thickness.

The most considerable aspect of this example is the moment of 31,25KNm. It is created through the huge cantilever arm of 25m. The moment affects both the cross section of the mast and the foundations.

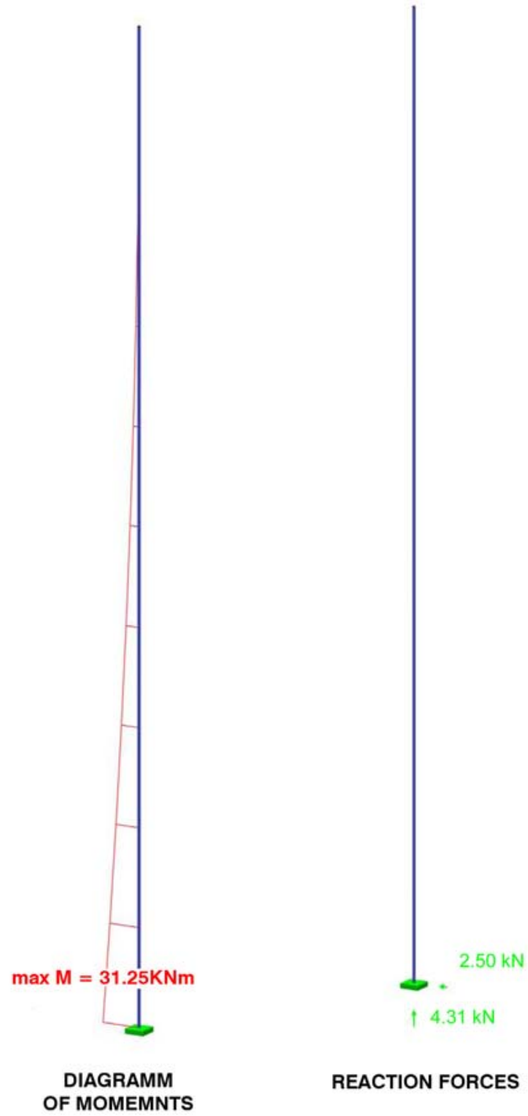
After calculating it became clear that the mast would not be able to withstand the forces and would buckle. As BOSCO is using radio link antennas, the deflection needs to be limited. Grouping of profiles or lattice constructions in order to stiffen the mast would avaoid buckling. Thus, the surface of the mast would rise which would affect a much higher wind force. As the length of the mast is rather high, the moment would rise exponentially. Material expense would increase enormously in order to resist the moment, avoid buckling and to finally reach a certain limited deflection.

To adjust the foundation size the reaction forces will not be authoritative. Compared to this example they would rise slowly as the mast would gain material and weight to reduce deflection. But the moment affects the foundation more than reaction forces. It would require huge earth works and big foundations to cover this moment.

A mast is a construction method which uses as little bottom space as possible which is an advantage concerning ground usage. Still they usually are not applied for radio link antennas. Towers for radio antennas require as less deformation as possible in order to transmit signals properly. A simple mast has relatively high deformations on top of it. In or-



ill. 176 - load assumption and deformation output der to avoid deformation at the top a material expensive stiff version has to be found. Additionally a huge foundation would be necessary. Therefore a mast is inefficient for a radio tower. Other construction principles provide better opportunities for BOSCO. A combination with guy wires which will be examined on page 124 [chapter 7.1.4] could be an option.

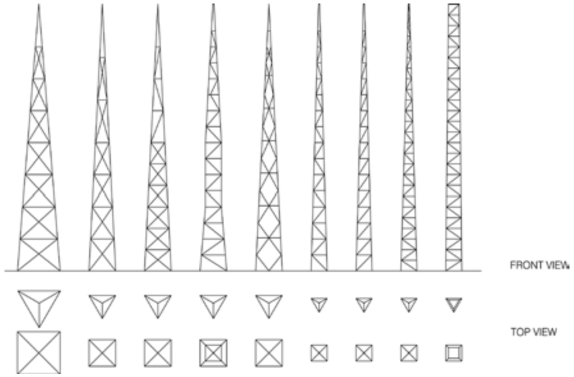


ill. 177 - diagramm of moments and reaction forces

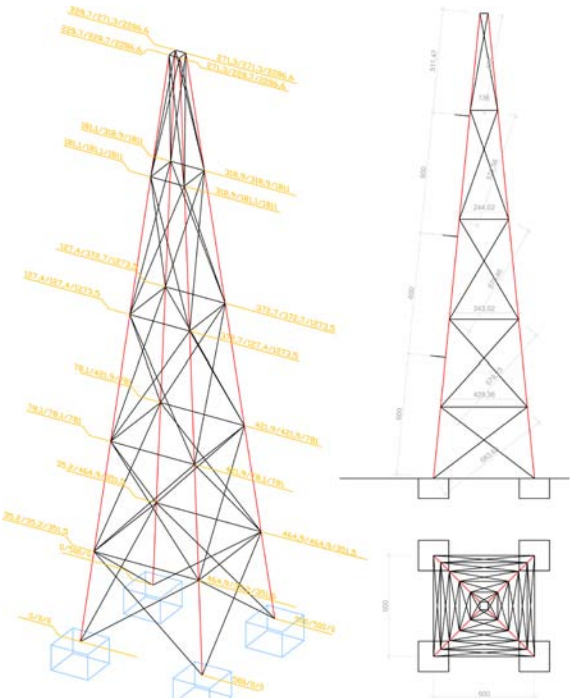
7.1.3. Lattice tower

Different configurations of truss elements and shapes would be possible. Considering the costs material has to be used most efficiently. As described on page 49 [chapter 4.4.2], material lengths of metal profiles are always 6m. The following lattice tower has been adjusted to use material lengths close to 6m as often as possible to avoid wastage. It has a square cross section which would provide the possibility to use L-shaped or rectangular hollow sections for the truss. Nevertheless the same round hollow section with 76mm diameter and 3mm thickness has been chosen for the calculation as it has to be comparable to the other construction possibilities like the mast on page 119 [chapter 7.1.2].

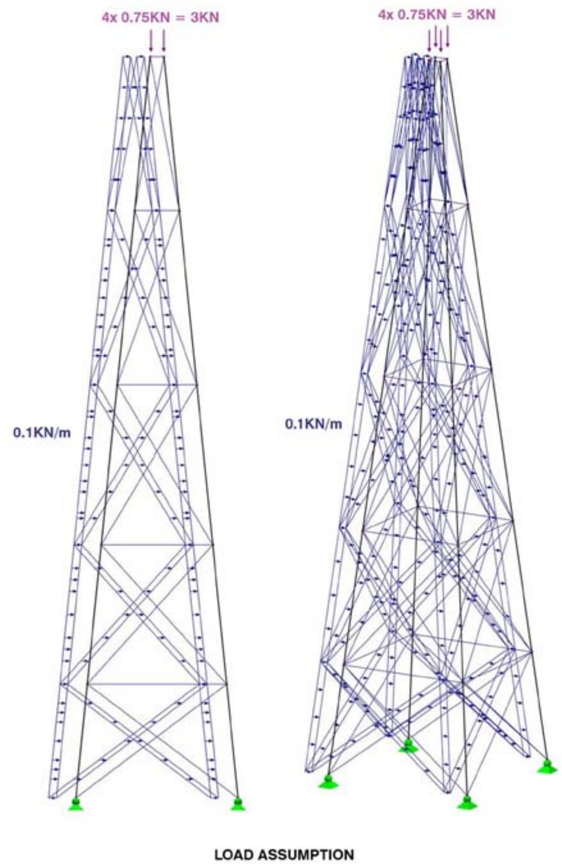
The following static calculation estimates the stress in a lattice tower in order to compare it with other construction principles.



ill. 178 - possible lattice tower configurations



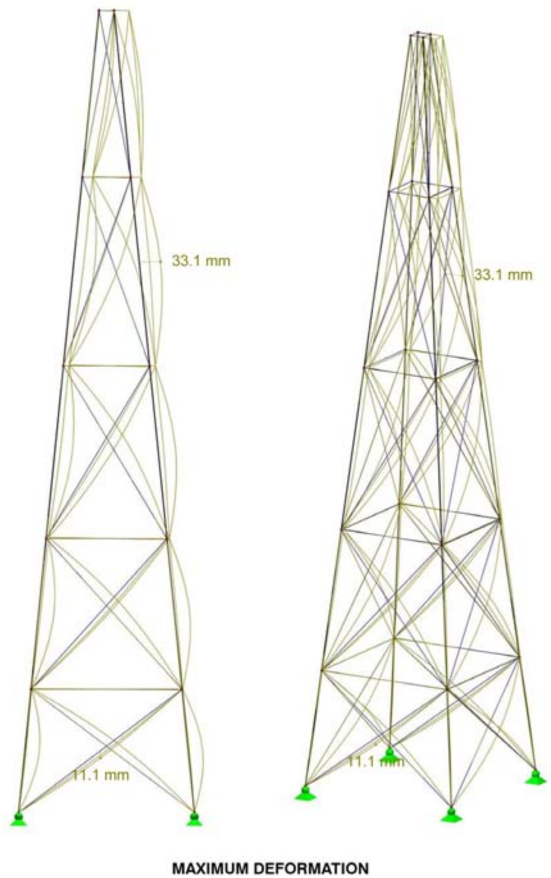
ill. 179 - lattice tower design



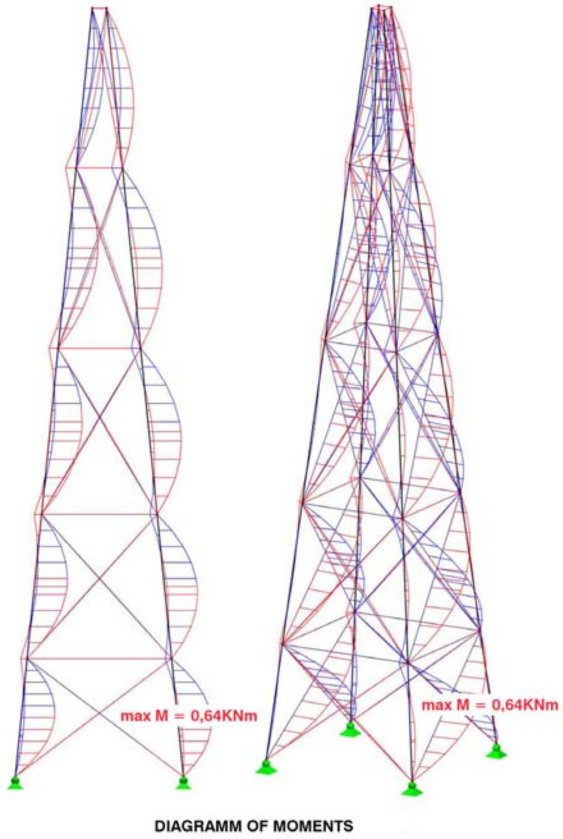
ill. 180 - load assumption

The deformation of the tower is low as the framework stiffens the tower. But the most important advantage of frameworks is the almost entire reduction of moments. As described on page 80 [chapter 5.1.3], no moments accrue in frameworks. Thereforce lattice constructions are often used. This fact provides the advantage that truss elements have to handle mostly tensile or compression forces instead of moments which they can resist much better. Actually just small moments accrue in the trusses because of wind induced forces. The maximum accruing moment in this example is 0,64KNm overall and will not affect the dimensions of the trusses.

The trusses have to resist normal forces and therefore avoid buckling. So, these truss elements have to be controlled and adjusted concerning their actual forces in combination with their buckling length. The maximum normal force of this example is 41,06KN. Thicker cross sections - which are fairly limited in Uganda - or groupings of profiles could be methods to avoid buckling. After adjusting the trusses regarding buckling it still would need less material as a mast. The rigid construc-



ill. 181 - deformation output



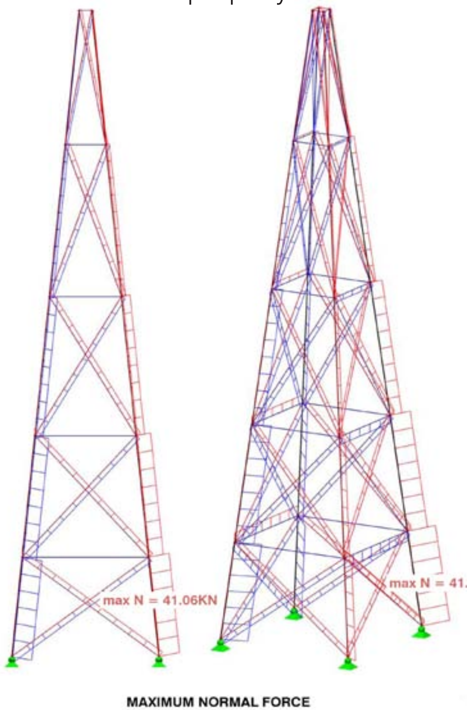
ill. 182 - diagramm of moments

tion of the lattice tower would provide limited deflection for the radio link antennas. Bottom usage is higher as for masts, but as this tower should be set up in a rural area the bottom area is not an important design aspect.

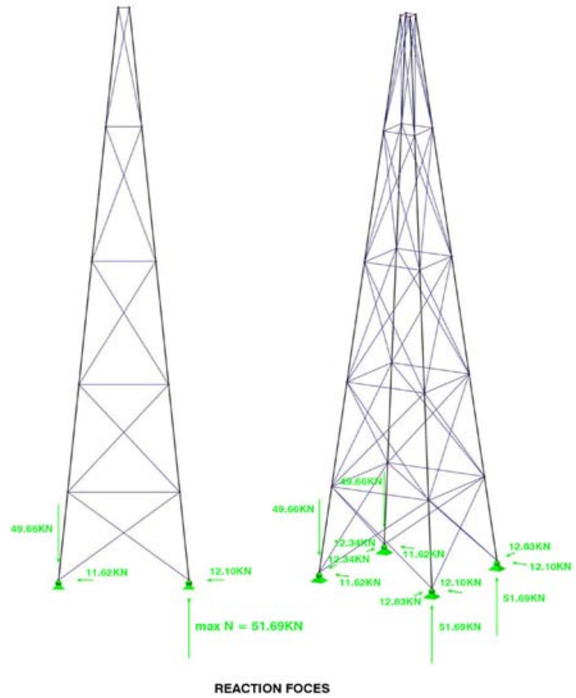
Reaction forces in the foundations of the lattice tower are higher compared to the mast example. As the mast is not as rigid as the lattice tower it would have to be adjusted to be sufficiently rigid. In this case the reaction forces become almost equal to the lattice construction. These reaction forces are dependent on the base area of the lattice tower. The wider the distance of the legs would be, the less the reaction forces would get. Overall, the highest reaction force of this example is 51,66KN (~5200kg). This could be covered with two cubic meters of concrete (~5600kg) at each leg for example.

Framework towers have the capability to be self supporting. Their bottom usage is relatively less. Therefore, a lattice tower is chosen in rather dense areas. As the BOSCO tower will be standing in a rural area bottom usage will not be of great concern.

In conclusion, a lattice tower could be a good choice for BOSCO. It has a good balance of material usage and height. Height flexibility could be possible by adjusting the framework to several segments. With detachable fasteners it would be possible to move this tower but with high labor effort. But still other construction methods have to be examined in order to find a more effective way whereby all requirements can be executed properly.



ill. 183 - normal forces

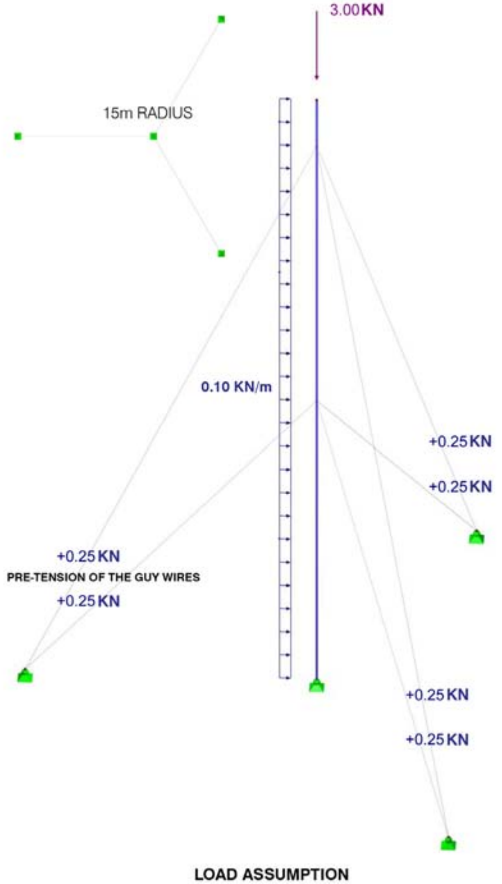


ill. 184 - reaction forces

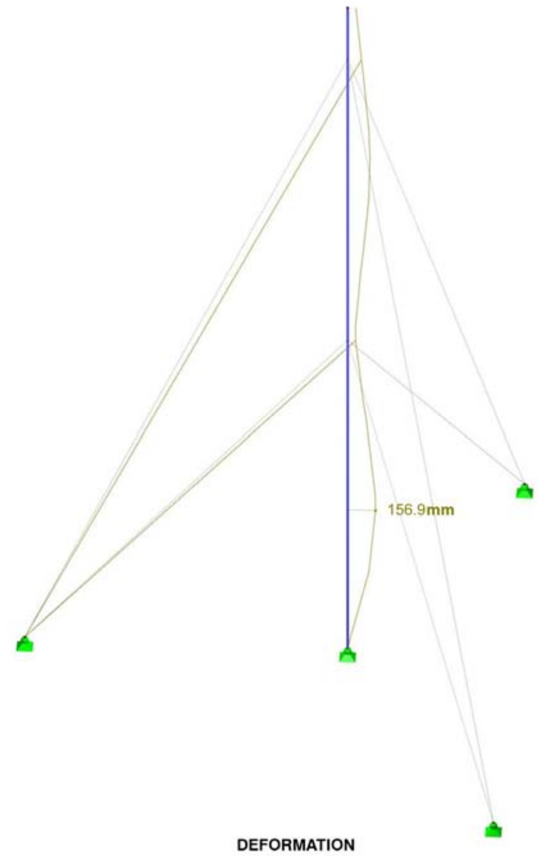
7.1.4. Guyed mast

A guyed mast will be compared concerning the appearing stresses with the previous possibilities - page 119 [chapter7.1.3 - mast] and page 121 [chapter7.1.4 - lattice tower]. Therefore, the same load assumption will be applied. The mast material is once again a steel pipe with 76mm diameter and 3mm thickness. Six guy wires out of 5mm thick steel cables which are anchored radial in the distance of 15m at three anchors have been chosen. Concerning the load assumption there is one difference: the guy wires have to be pre-stressed. It is a low normal force of around 0,25KN (25kg) but it provides stability as explained on page 84 [chapter 5.1.4].

By investigating the deformation output, it is obvious that these guy wires provide lateral support. Although the guyed mast has the same cross section as the mast example page 119 [chapter 7.1.3] it is not bending a lot. Wind induced forces create this deflection and can be covered with a more rigid cross section of the mast.



ill. 185 - load assumption

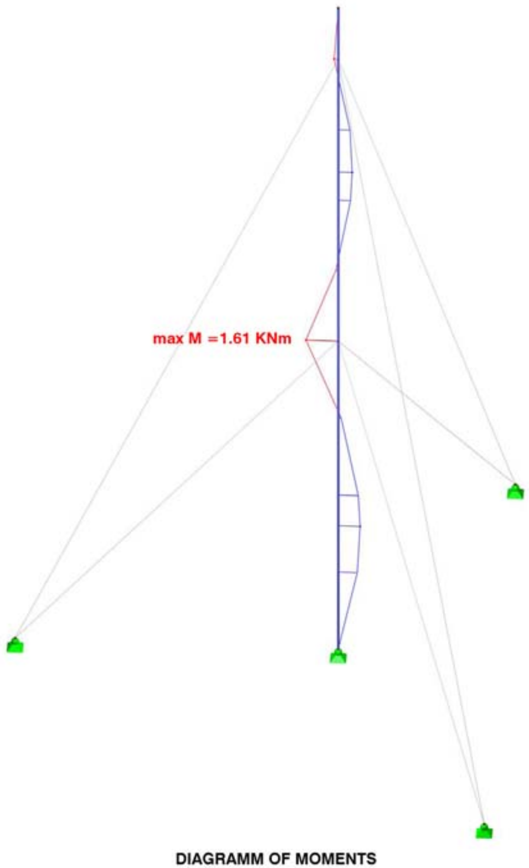


ill. 186 - deformation output

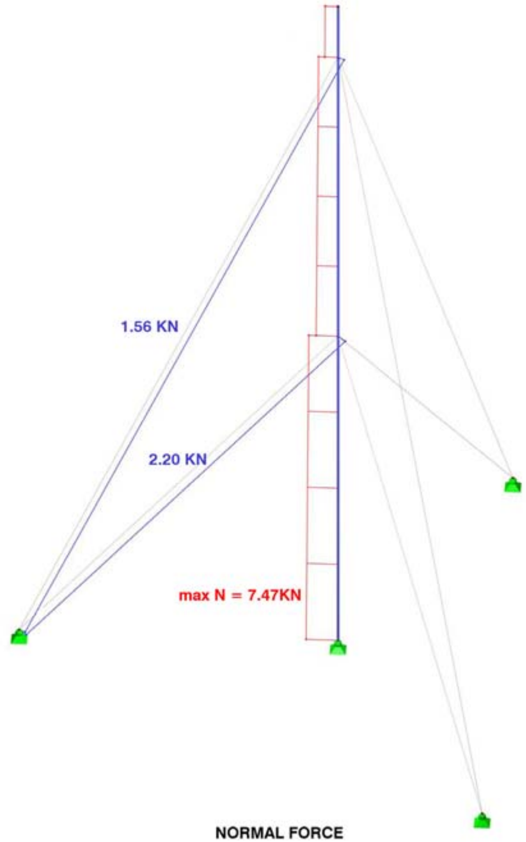
Even more important is the fact that guyed mast reduces moments. As described on page 84 [chapter 5.1.4], guyed masts turn most moments into normal forces. Moreover, is it possible that these wind induced moments accruing on the mast can be modified by adjusting the height distance of the guy attachments. With less guy wires along the mast the moment would increase, the opposite would be the case with more wires.

Guy wires take all tensile forces and the mast has to resist the compression forces only. In comparison to previous construction methods, the overall accruing forces are much smaller. With 7.47KN (747kg) compression of the mast and a maximum tensile force of 2.20KN (220kg) the forces are less than 20% of a lattice tower. By maximum tensile force a wind direction is meant which affect only one guy wire and therefore produces maximum stress to the affected tension member set.

Reaction forces are small as well. There are several reasons for this: One aspect is the lightness of the entire construction. But the more reasonable explanation is the distance



ill. 187 - diagramm of moments

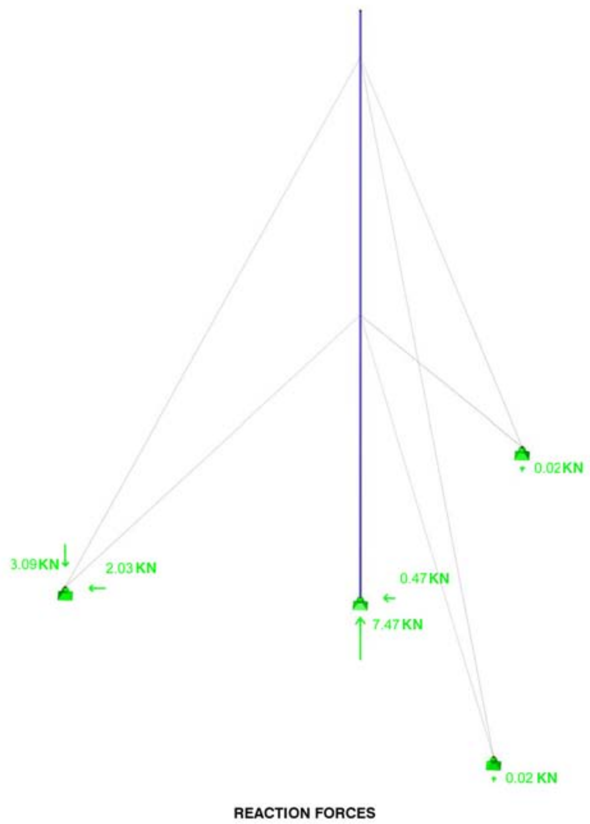


ill. 188 - normal forces

of the anchors to the base. This distance which affects the angle between guy wires and mast is responsible for the accruing tensile forces and reaction forces. Ensuring a balance of ground usage and reaction forces / tensile forces is vital. The ground usage is probably the downside of this example. With a ground usage of around 700 square meters a guyed mast needs several times more ground than other tower/ mast types.

The requirement to move the entire tower can be provided with this construction system as it is the lightest construction in terms of weight. A guyed mast consists out of slender parts which can be divided into several pieces which could provide prefabrication.

Finally, a guyed mast is a optimized structure to reach a high elevated point. It has a better balance between material effort and height than other tower systems. For BOSCO a guyed mast could a reasonable option.



ill. 189 - reaction forces

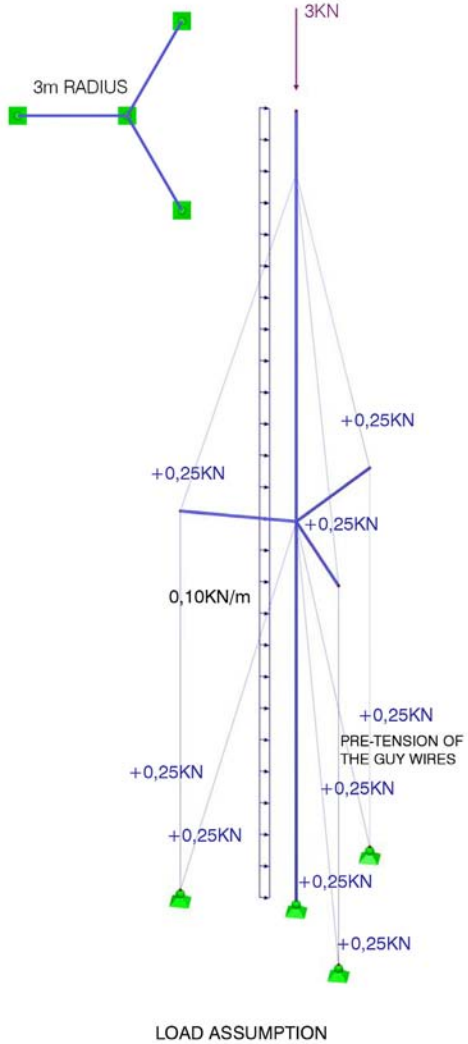
7.1.5. Sailboat mast - guyed mast variation

In this sub-chapter a variation of a guyed mast will be compared. Sailboats use these masts frequently. As mentioned on page 84 [chapter 5.1.4] it is possible to redirect the guy wires. Ground usage can be reduced with this method.

Like in the previous example six guy wires are aligned at the mast. The first difference is that the anchor distance is highly reduced. 3m radial distance has been chosen. However the second and more important difference is the redirection of the upper guy wire. A horizontal stay mounted on the alignment point of the bottom guy wire provides this possibility. Same load assumption and materials – 76/3mm steel pipe as mast and horizontal redirection stays and 5mm steel wires as guy wires – have been chosen to provide comparability.

Deformation of this sailboat mast is even smaller than of a simple guyed mast. Reduction of wire length creates less deflection. Basically this example would provide the acceptable deformation for BOSCO. But the mast would require a thicker cross section as it could not avoid buckling. Accruing moments in this variation are not authoritative too. They are nearly similar to the guyed mast example and could be reduced with more guy attachments.

The values which have changed in comparison to the guyed mast are the normal forces. The maximum normal force (compression) in the mast – 13.21KN – has nearly doubled. Tensile forces inside the wires are higher too. The force in the upper redirected wire did not increase a lot, but the normal force in the bottom wire did. 8.23 KN is the maximum tensile force. It is accruing because of the low angle between the wire and the mast. Nevertheless is it possible to reduce these forces by increasing the distance of the guy anchors and increasing the guy alignment points on the mast.

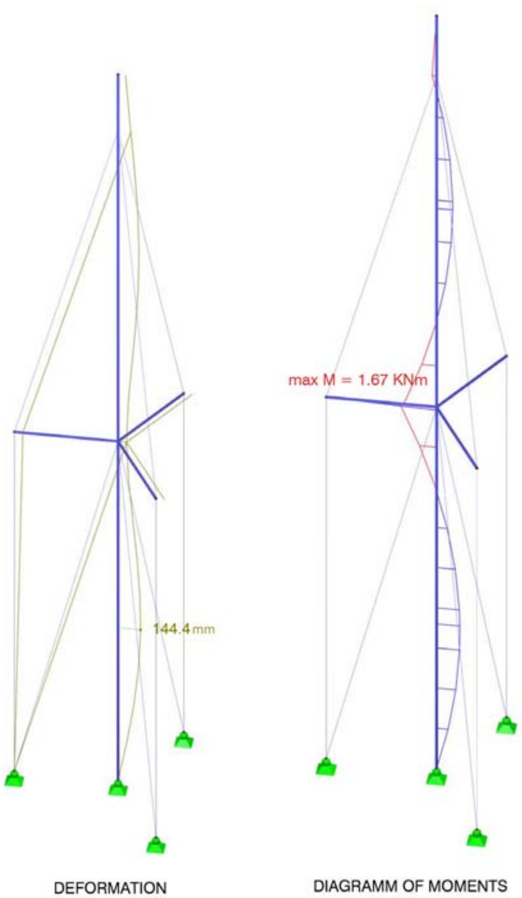


ill. 190 - load assumption

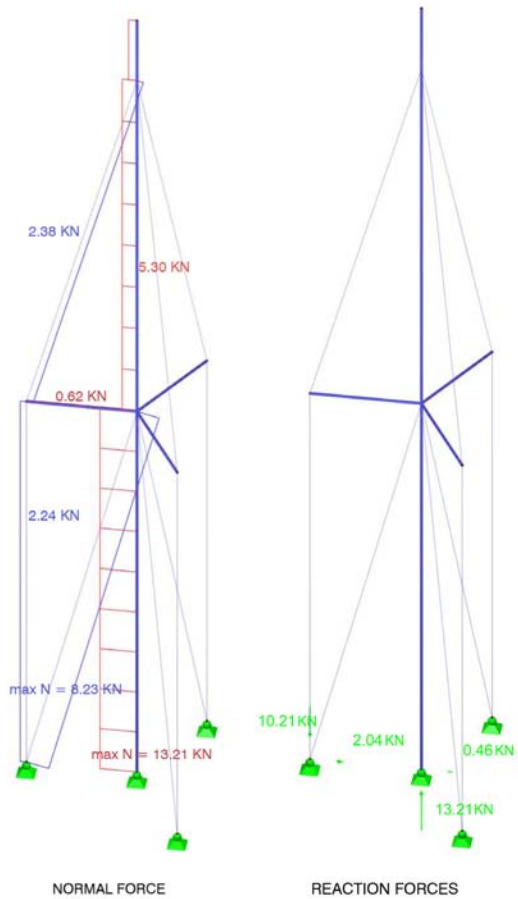
Reaction forces in comparison did rise as well. Once again the distance of the anchors – therefore the angle between guy wires and mast – is responsible for higher reaction forces. By increasing the distance it will be possible to reduce these forces.

In conclusion the sailboat mast provides mostly the same advantages as the guyed mast. Normal forces and reaction forces are higher in comparison. To resist these forces it is either possible to use thicker cross sections or the guy system has to be adjusted. Adjustment of the guy system would be to plan more guy alignments and more distance between mast and anchors. As the guy wires of the sailboat mast do not have to be as long as at those of a guyed mast material use would be reduced. Through the reduction of material costs could be economized.

The most important aspect of this variation is that the ground usage can be reduced to less than 5% in comparison to the normal guyed mast. The guyed mast example needs 700 square meters in comparison to only 30 square meters for the sailboat mast with merely higher forces.



ill. 191 - deforamtion and diagramm of moments



ill. 192 - normal and reaction forces

7.1.6. Choice of the most efficient tower/mast system for BOSCO

The construction which was finally chosen is a sailboat mast. Through the comparison it turned out to be most efficient in terms of accruing forces and fulfilling the requirements of BOSCO.

Reasons for this decision are listed below.

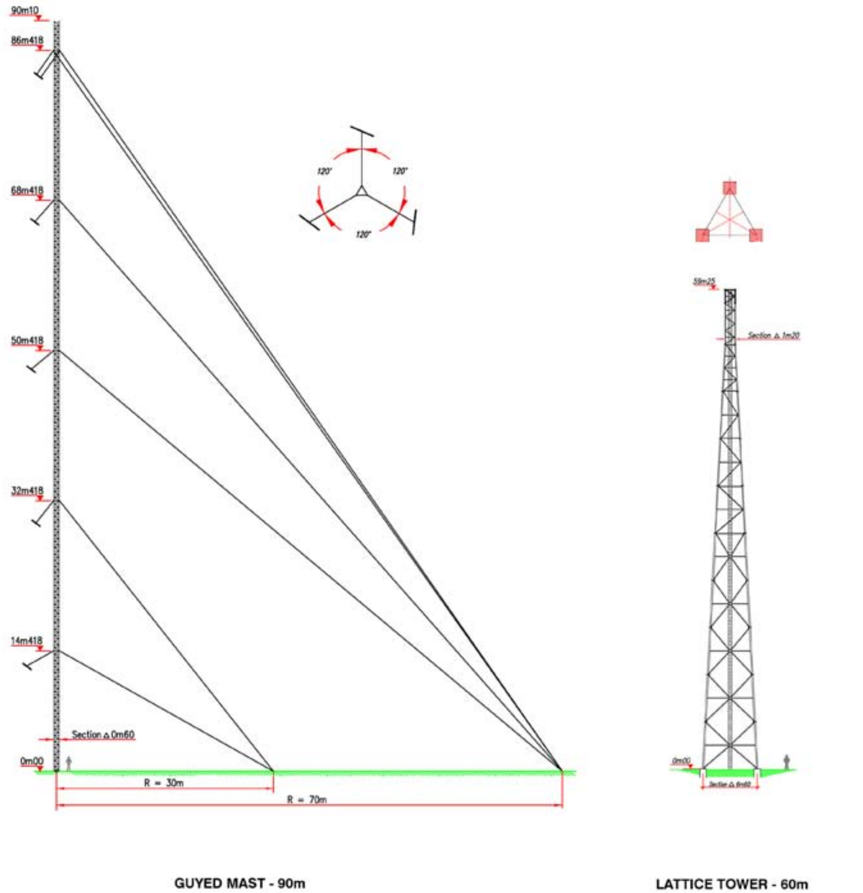
- Guyed mast systems in general are statically most effective to reach high elevated points.
- A sailboat mast is a material efficient structure. Technical implementation is more complex than other methods but overall costs will be equal.
- Through a sailboat guy system the ground usage can be limited to a reasonable value. A guyed mast in contrast to the sailboat variation would be statically more effective, but would need more than 20 times more ground.
- Transportability and prefabrication of the entire construction is possible. First of all, the mast including the guy system is lightweight. The slender mast and the guy system can be divided into parts. What is more, the prefabrication provides a higher implementation quality as conditions in workshops are better than on site.

Designing a technical complex construction prototype which can be executed even in rural areas can be a big challenge, but this is exactly one of the intentions of this work.

To outline the material and cost efficiency of a guyed mast in comparison to a lattice tower cost estimates of an international company will be instanced.

A 90m guyed mast will be compared with a 60m high lattice tower. Although they have a huge height difference it is clearly visible which tower is more efficient.

Although the guyed mast is 50% higher than the lattice tower it is lighter, cheaper and it uses less material.



ill. 193 - comparison of industrialized guyed mast with a lattice tower

GUYED MAST - 90m	LATTICE TOWER - 60m	
4090 kg	9790 kg	WEIGHT (without foundation)
28m³	31m³	FOUNDATION VOLUME (concrete)
26m³	123m³	EXCEVATION VOLUME
23 230 €	30 990 €	PRICE

chart 9 - comparison data

7.2. Foundations

Different foundation methods will be shortly investigated in this chapter. The requirements for the foundations should cover the design aspects from page 113 [chapter 6.1].

7.2.1. Concrete foundation

Concrete foundations are most common to construct a foundation for any structure. Concrete is moldable, can be produced on site even in the most rural areas, and does not need too many different components. All ingredients would be available in Uganda.

As concrete is a fairly heavy material it would be rather simple to resist the forces of the guyed mast. Yet, one requirement of BOSCO is to make the entire construction, transportable which includes the foundations. As only human force is available to lift parts of the tower, it would be rather difficult to separate the foundations into lift-able pieces.

Another option would be to abandon this concrete foundation every time BOSCO is moving. But as this is unsustainable and inefficient it cannot be examined. Furthermore, concrete is rather expensive in Uganda.

7.2.2. Meshed baskets

As described on page 110 [chapter 5.3.3.2] - meshes would be another method to create heavy blocks out of stones. Like concrete foundations they would have enough weight to support the mast.

Advantage of it is that the lattice vessels could be used at different sites. Removing the stones and filling the vessels at the new spot would be possible in terms of labor effort and costs.

It would be necessary to figure out the required dimension of such a vessel to provide enough weight with loose poured stones. More importantly though, would be to figure out a system how the tensile forces of the wires and the compression of the mast would be transferred into this vessel.

In summary meshed baskets would also cover the requirements of BOSCO.

ill. 194 - lattice vessel

7.2.3. Ground screws

Ground screws – page 98 [chapter 5.2.4] – are a technical foundation system in contrary to meshed baskets. Nevertheless, they seem to be a perfect foundation system in order to provide transportability. Once fabricated, they are easy to dismantle and relocate but still durable and long lasting. It is time saving as it is not necessary to do any digging or concreting. Load capacities of industrial fabricated ground screws are more than sufficient enough to support a guyed mast.

7.2.4. Choice of the most efficient foundation method for BOSCO

Finally, ground screws are the most effective system for BOSCO.

The straightforward procedure of dismantling and relocating is the main reason for this decision. Moreover it is the most sustainable solution. Once constructed and fairly regularly maintained, they could be used for several years without any additional costs.

In this specfic case a ground screw, which has the capability to be produced locally, will be figured out. It would certainly be possible to import some of these ground screws, but this would contradict the goal of this thesis to design a prototype which can be executed in Uganda.

Once again, the technical complexity of this system will be a great challenge. Yet, using a technical advanced system and figuring out a construction prototype which can be executed in rural areas is one of the intentions of this work.

ill. 195 - KESEAS ground screw

Weight: ca. 12,5kg

Length: 120cm

Material: Steel St. 37 K2

Vertical Tension Capacity: ~2000kg

Horizontal Tension Capacity: ~ 2000kg

Vertical Pressure Capacity: ~ 3000kg

8. Realized project – 10m guyed mast

A small guyed mast has been constructed locally around November 2008 in Gulu. Purpose of this construction was to investigate the area around Gulu in order to figure out the best site to erect the tower/mast in means of transmission quality of the signal.

There have been two basic requirements in terms of construction design for this mast: First of all it has to be set up fast and easy secondly the mast should be adjustable to the local conditions. Considering the collected data the most efficient and practical solution has been a guyed mast.

The main purpose of the mast was temporary use in order to adjust an antenna and to test sites around Gulu in terms of their transmission ability. As it was planned for temporary use exclusively, the only forces which affect the mast are the antennas. Including their additional equipment a weight of about 15kg was estimated. Wind forces and additional weights – like a person who has to reach the top for maintaining or adjusting the equipment – has not been considered. Therefore it was actually possible to reduce the static demands of the entire construction basically down to support the self weight of the mast. With these ideal requirements it was possible to construct a slim and lightweight construction.

Surprisingly the mast had the capability to reconnect most of the camps. Therefore this mast did bridge the entire network for months when the formerly used radio mast could not be used any longer.

ill. 196 - building set

ill. 197 - guyed mast in use

8.1. Technical implementation

A steel pipe with a diameter of 50mm has been used for the mast. The material thickness was 3mm. To make it transportable the pole has been divided into pieces of 2m length. In order to connect these segments a simple connection method has been chosen: On top of each pipe a small piece of a 42mm pipe has been welded. Through these adjustments it was possible to stick the pipes on top of each other. To secure them from sliding apart, bolts has been screwed through the area of intersection.

A square metal sheet with the thickness of 3mm has been used as basement below the main pole. The basement was necessary to spread the weight of the pole. Otherwise the slim and long pole would have pushed himself into the soil because of his self weight and the pretension of the guys. The second necessity for this metal sheet was the possibility to fix the base at a certain position. It was fixed with big iron nails which were pushed into the soil through holes in the metal sheet. The steel pipes have been connected with the metal sheet in the same way as the pole segments have been connected among each other: A 42mm pipe piece has been welded properly on the metal sheet.

To stabilize the mast the guy wires are extremely important. They provide the stability of the whole system. Three anchors have been chosen to stabilize the system. They have been arranged in 120 degree radius around the main pole to cover all directions. Six medium sized plastic strings used as tension wires and around 30cm long metal nails as ground nails have been used. These wires have been fixed to the pole in the height of 8m and 5m to avoid bending of the main pole. Mounts have been welded on the ground nails to provide the possibility to tense the plastic strings as good as possible.

ill. 198 - segment connection - detail

The technical work effort for this construction was low. Metal works have been carried out by St. Joseph's garage - page 61 [chapter 4.5.1.3]. In summary the work demands for the workshop included welding as well as cutting the poles and drilling holes. All together the construction of the mast has been executed in one afternoon. The quality of the welding was sufficient as the implementation of the connections have been explained and instructed in advance.

Overall the tower costs around 200.000 UGX.

ill. 199 - guy connection, basement, anchors

8.2. Erection process

The poles of the mast have been connected in a horizontal position at first. Afterwards the entire mast has been lifted by using the guy wires. For the first tries to erect the mast several persons have been needed, as it was unclear how the construction would react or how strong the tension of the wires will be. It took a rather long time to tilt the mast. However after getting some experience it was possible to erect it with four to five persons only in around 5 to 10 minutes.

One person's task was to fix the base of the mast at the prospected defined place. Otherwise the mast would have shifted along the ground. Two persons where pulling at the tension wires to lift up the pole slowly. They have been supported by one or two person who pushed the pole from the opposite side upwards.

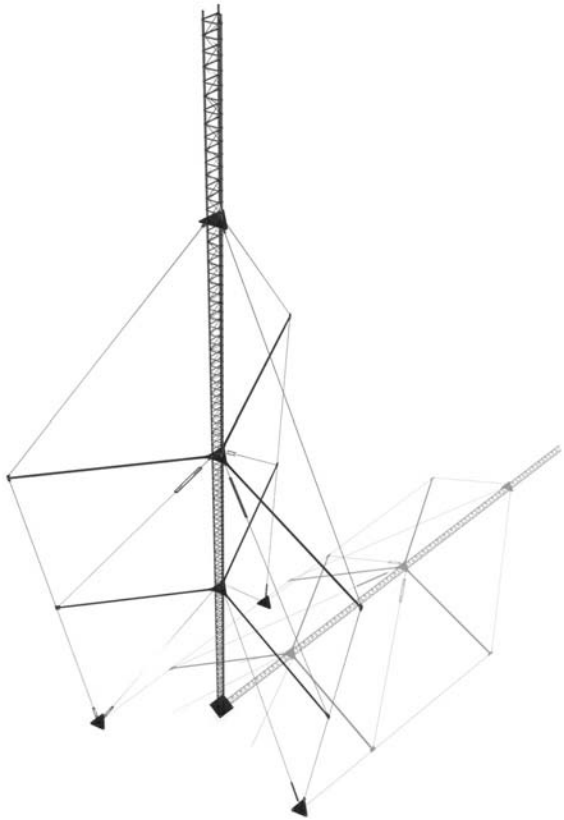
ill. 200 - erection process

8.3. Conclusions and experiences for the case study

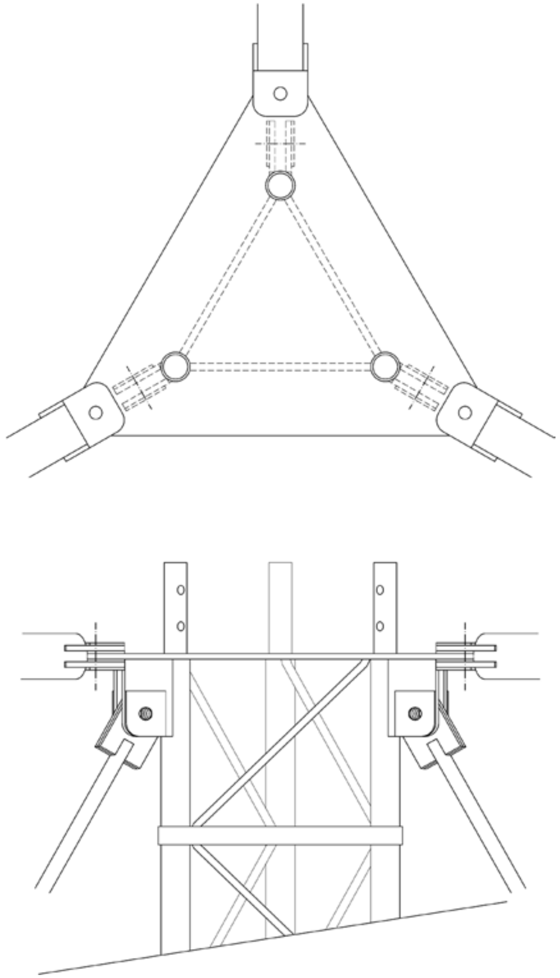
This construction did fulfill its purpose much better than expected. Intended to work temporary it has been used to bridge the network situation of the entire BOSCO network for months. Nearly all camps have been reconnected through this mast. Although the transmission quality did reach just 25% of their maximum, because of the low height, it kept the system running. Moreover it did resist strong wind forces during the beginning of the rain season in March. At this time another way to bridge the situation has been investigated, and the tower has been turned down. Nevertheless it is still necessary for the extension of the BOSCO system to construct a main tower/mast with the height of around 25m to reach camps located farer away.

The prefabrication of the pole at St. Joseph's Garage did give a good impression about welding quality and working quality overall. If the importance of certain welds is explained, qualities of local produced metal works fulfill their purpose. The erecting process as it is fast and simple could be adjusted to the 25 m mast in a similar way.

PART 4 – SAILBOAT MAST PROTOTYPE



ill. 201 - image of the prototype



ill. 202 - technical drawing

ill. 203 - mast model picture

9. Case study – sailboat mast prototype

In this chapter the final proposition for the BOSCO tower/mast will be outlined in detail. The following tower construction principle, as well as foundation methods and material have been chosen considering the outcome of the analysis starting on page 117 [chapter 7 - structural comparison of tower/mast construction possibilities].

The first chapter will provide an overview of the prototype. Schematic description and model studies of essential joints and parts of the mast will follow. Furthermore instructions for the erection process as well as the static verification of essential cross sections of the construction will round out this prototype study.

Finally the necessary technical plans of this prototype in detailed scale and the detailed assembling process of the single modules can be found in the appendix.

9.1. Project Description

Considering the necessary requirements – outlined in detail on page 113 [chapter 6] the final proposition for BOSCO is a sailboat-mast. The advantage of this choice is the proportionally small ground usage. The sailboat guy system needs less ground usage in comparison to a simple guy system but provides the same stability. A relatively small ground usage is of great interest for BOSCO as it is not sure yet at which location the mast will be set up in the end. Moreover the sailboat construction requires only 100m tension members in comparison to 600m guy wires in case of a simple guy system. Therefore it was possible to reduce material costs.

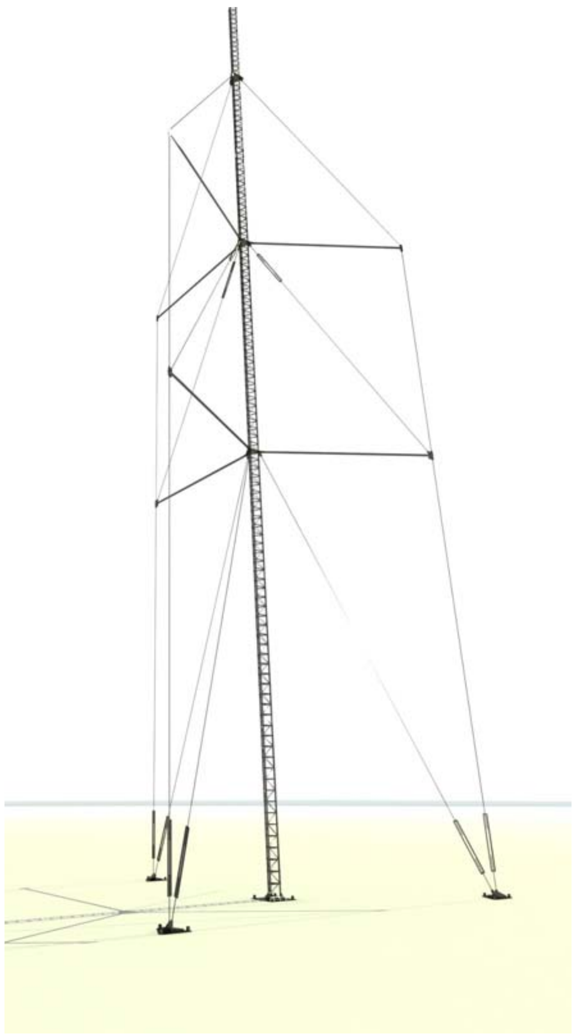
The finally developed prototype provides the required transportability through a construction of modules which can be detached from one another. Every single module has been dimensioned precisely in order to provide the possibility that it can be carried with human force.

The maximum height of the mast is 24m. It consists out of a lattice mast, which can be divided into eight segments/modules - each 3m in height. So the mast can be set up in different heights, starting from 9m up to 24m in case all of the eight segments are used.

The guy system consists out of six 4m long guy stays and 15 tension members. The tension members represent the longest parts of the system with 9,9m. Nevertheless their weight is less, so except of their length it is no expenditure to transport them.

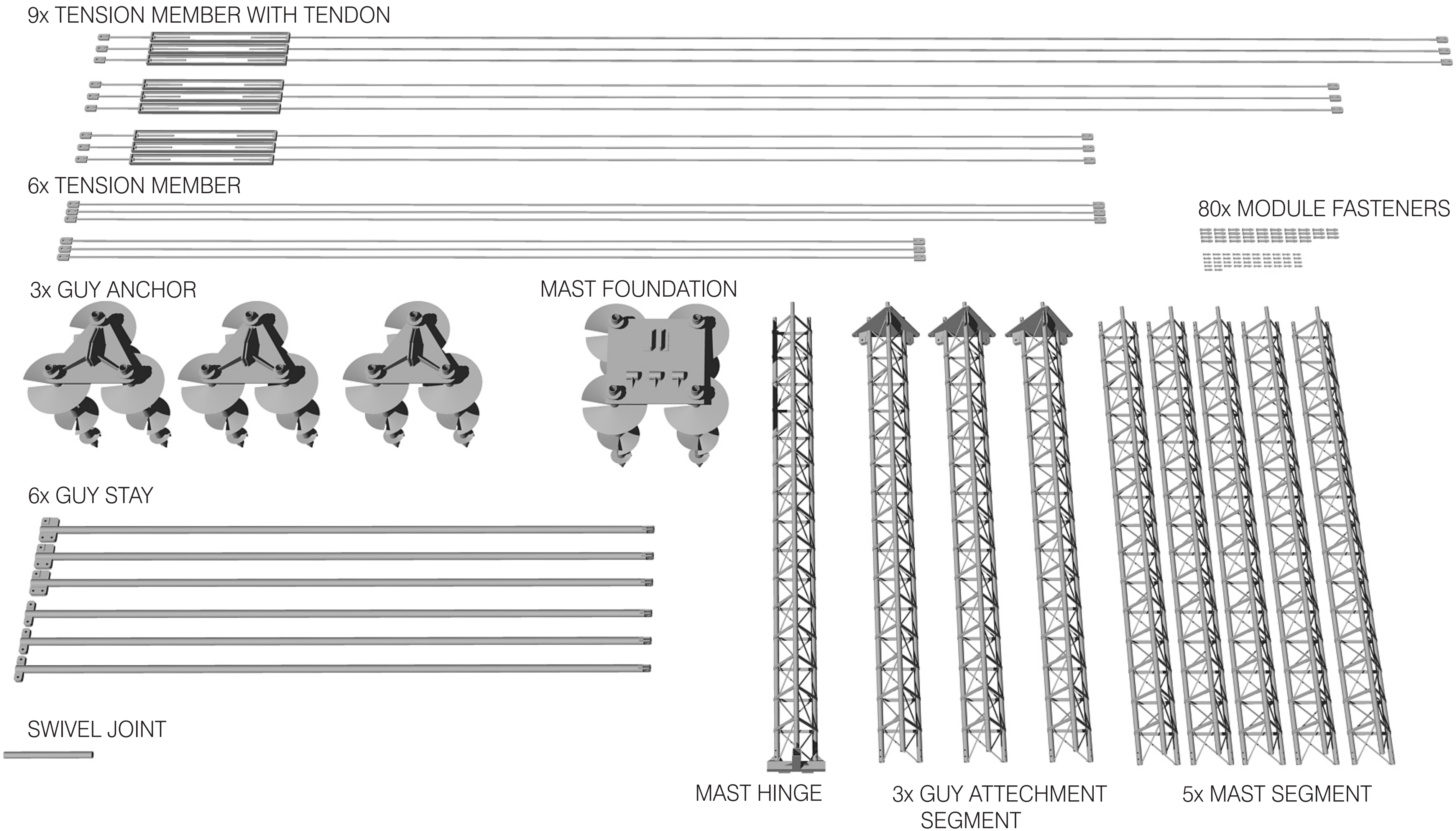
Foundations of the prototype are divided into mast foundation and anchor foundations. Both use the same principle. Ground screws have to be pre-assembled in advance. The entire segment of the foundation simply has to be set in position and the screws have to be turned into the ground which can easily be done by two persons.

Finally only 80 bolts are required all together to connect the component parts. The other joints within one module are welded.

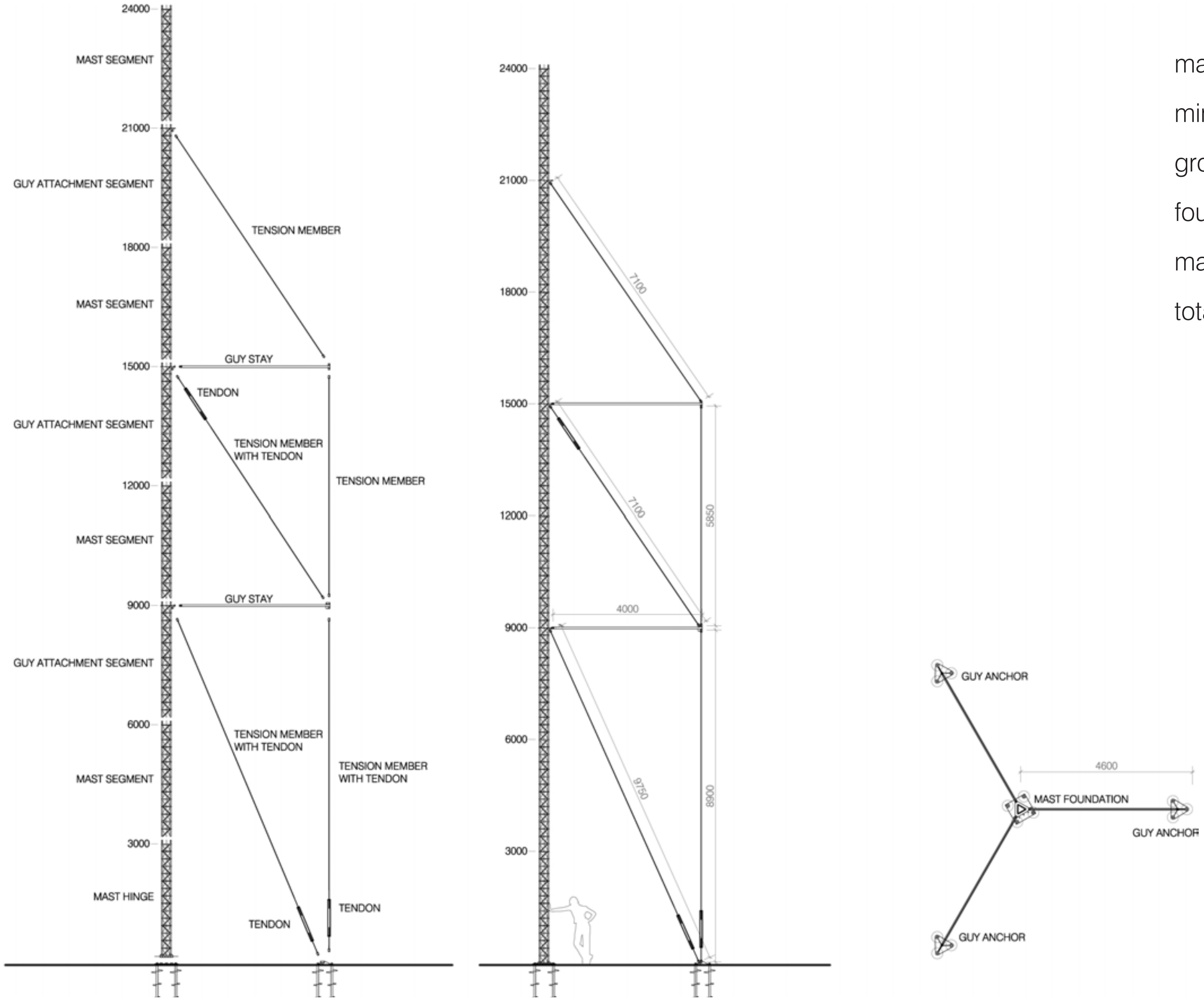


ill. 204 - visual output

BUILDING SET



ill. 205 - building set of the prototype



ill. 206 - exploded view, assembled view, top view

MAST SPECIFICATION

maximum height:	24 m
minimum height:	9 m
ground usage:	66 m^2
foundation weight:	185 kg
mast + guy system weight:	430 kg
total weight:	615 kg

9.2. Diagrammatic Design / Component Parts

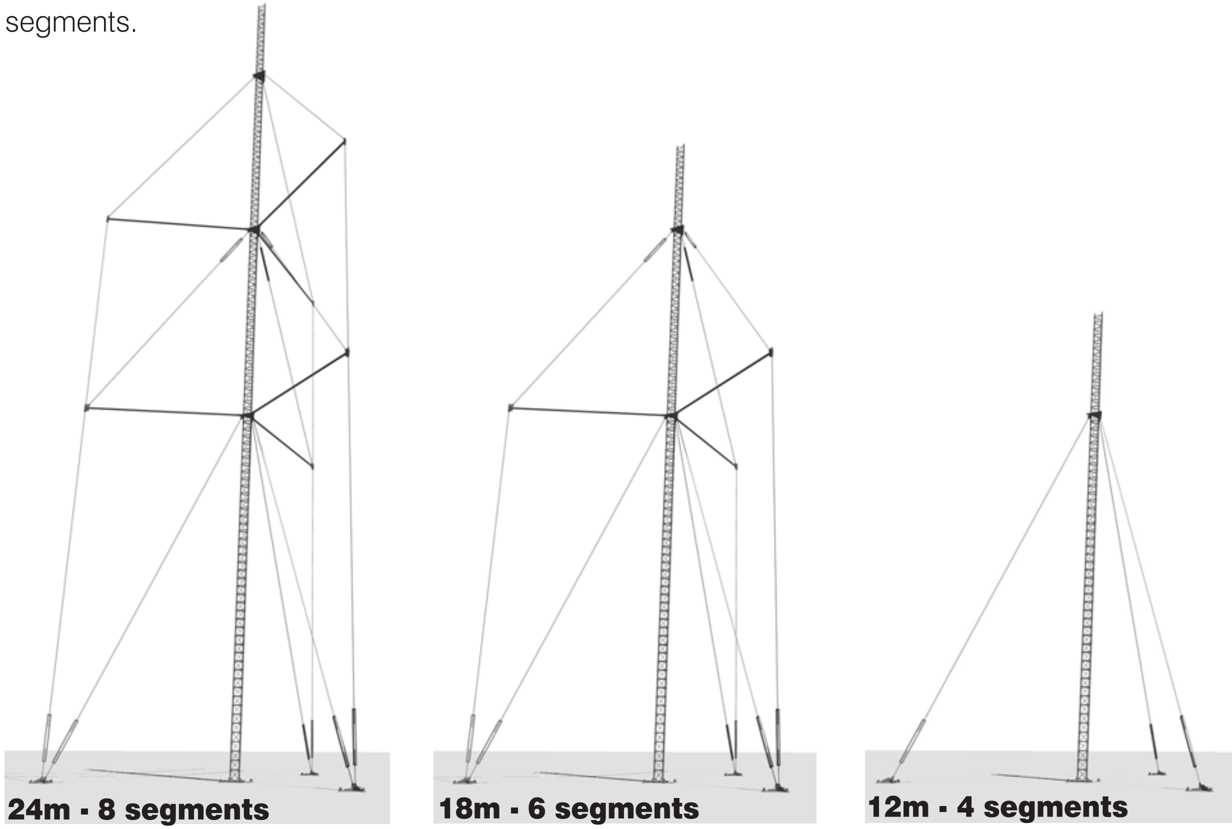
Description of the component parts and dimensions are determined in this chapter. Verification of their load capacity has been calculated and will follow on page 166 [chapter 9.5].

9.2.1. Mast Segments

9.2.1.1. Modular system – Mast height

In order to provide transportability the mast has been divided into segments. Finally a single segment has been designed with 3m in height. It has been taken into account that a lot of small segments would result in many joints. Big segments, longer than 3m would be inconvenient to transport. Finally 3 meter segments avoid wastage – as metal bars in Uganda are sold in lengths of 6m usually - see page 49 and 70 - [chapter 4.4.2. and 4.6.1]. In summary segments of 3m in height provide the best balance of weight and joint expenditure.

BOSCO requires a height flexible construction. Through the modular system it is possible to set up any multiple heights of 3m starting from 9m. The maximum configuration of this mast is 24m and will consist out of 8 segments.



ill. 207 - different height possibilities

9.2.1.2. Lattice configuration – cross section / face width

As outlined before a lattice framework provides the lightest construction in relation to its load capacity. Moreover a light construction meets the demands of transportability.

Furthermore a truss with a triangular cross section is the lightest way of implementing a stiff mast. The triangular prototype uses as less legs and stays as possible. The weight of the mast is therefore less than it would be in case of choosing a square prototype. Furthermore a 3 point and 4 point configuration would be possible with a triangular cross section. See page 85 [chapter 5.1.4]

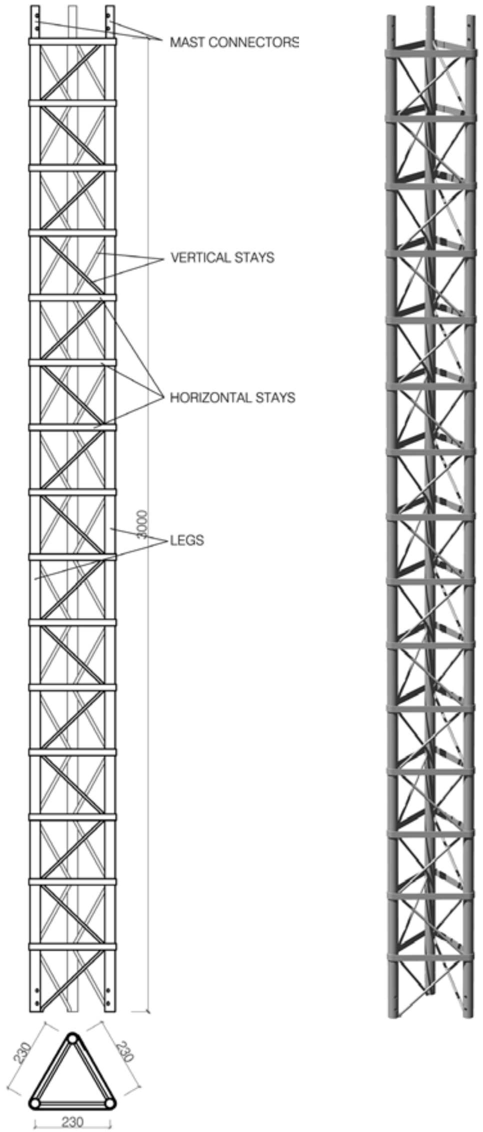
Face width of the mast

As described on page 86 [chapter 5.1.4], typical face widths to height ratios are ranging from 1/80 to 1/180. Considering this ratio the face width of the prototype would result between 30cm and 13cm for a 24m mast. For safety reasons the value closer to 1/80 should be taken into account. For design reasons a face width between 20cm to 30cm has been envisaged. Another reason for a face width of 20 to 30cm was the fact that a person has to use the truss for climbing.

Finally the axial distance of the legs of the mast is 230mm.

Legs and Stays

Usually the highest normal forces will accrue at the legs of the lattice truss. Therefore buckling of the legs has to be avoided Design and arrangement of the stays will affect the buckling lengths. Short buckling lengths of the legs have been envisaged. The truss has been executed by 90 degree bent diagonal stays out of 8mm round bar and vertical metal strips (20/3mm) wrapped around the mast in the height distance of 20cm in order to reduce the buckling length of the legs. The vertical metal strips can be used as a ladder at the same time.



ill. 208 - mast segment

In order to provide a bending pattern for the stays, a simple construction has been developed which can be produced easily. Considerations such as less material use have been taken into account when developing the bending pattern. A rigid and sufficiently stiff construction has been found.

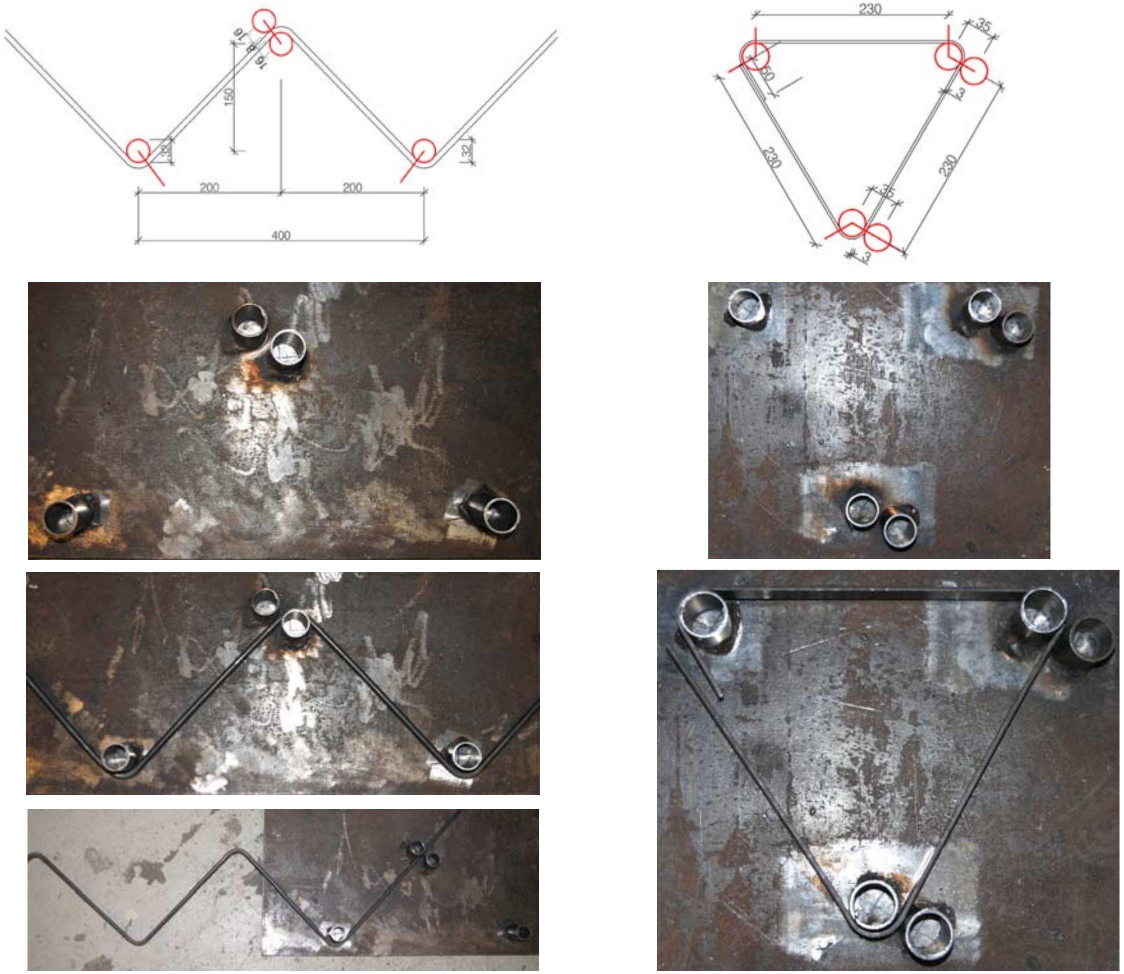
DIMENSIONS

- Legs: round hollow section - 32mm diameter 2,5mm thickness
- Diagonal stays: round bars – 8mm diameter
- Horizontal stays: flat steel - 20/3mm

This configuration provides a rigid truss which is looking rather complex but can be executed with minimum effort. This has been tested by producing a 1:1 prototype model.

BENDING PATTERN MAST STAYS

Oddments of 32/3mm round hollow sections have to be welded on even metal plate.



ill. 209 - bending pattern for horizontal and vertical stays and pictures of 1:1 model prototype

COMPONENT PARTS

ill. 210 - building set

ASSEMBLING

ill. 211 - assembling procedure

1. use horizontal stays to define distance of the legs

2. use 15mm thick spacer to determine exact position of the diagonal stays

3. weld diagonal stays

4. repeat this procedure on all sides

ill. 212 - mast segment without and with horizontal stays

MAST PROTOTYPE

ill. 213 - pictures of finished mast prototype

DETAILS

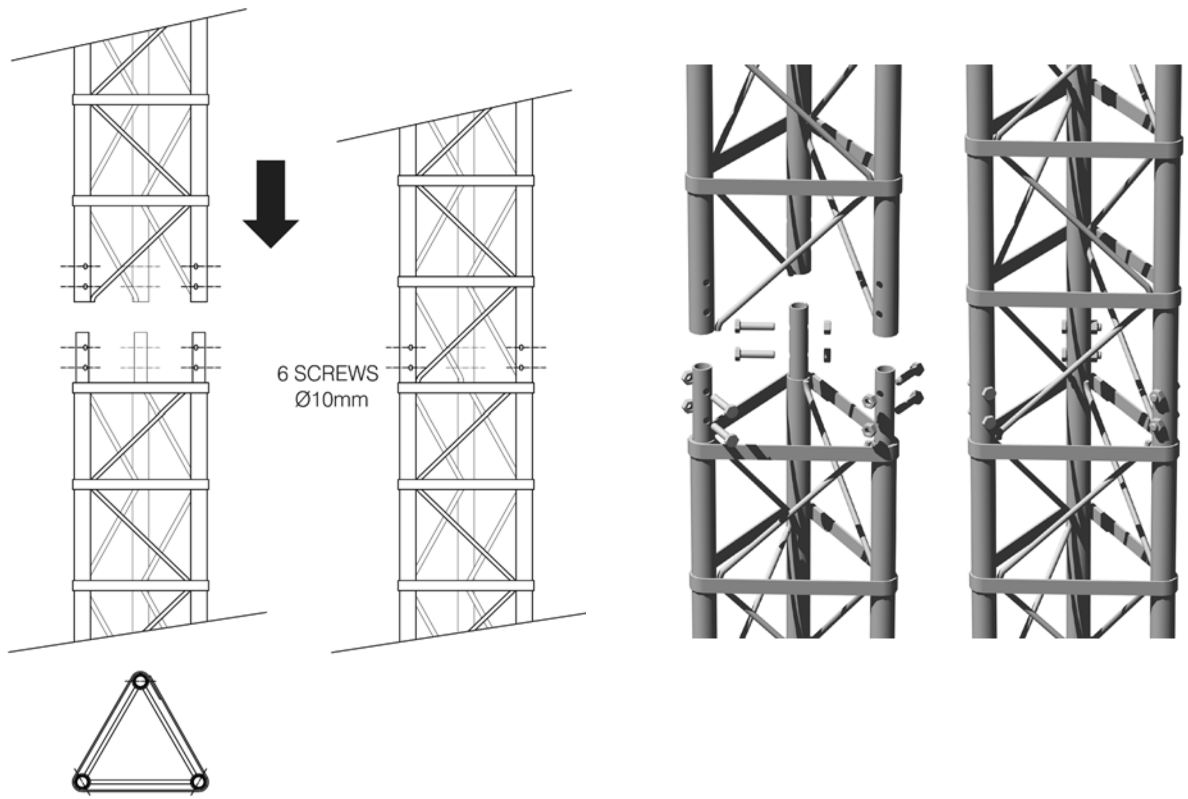
ill. 214 - prototype model details

9.2.1.3. Connection points

The connections between the modules of the sailboat mast have to be detachable in order to provide transportability.

Mast connection

Connection of the mast segments among each other will be executed by plugging them together. Thinner round hollow sections are welded on top of each segment. Two screws at each leg (diameter 10mm) are used to secure this joint. This method had been executed at the mast prototype - page 134 [chapter 8.1] and emerged as an excellent solution.

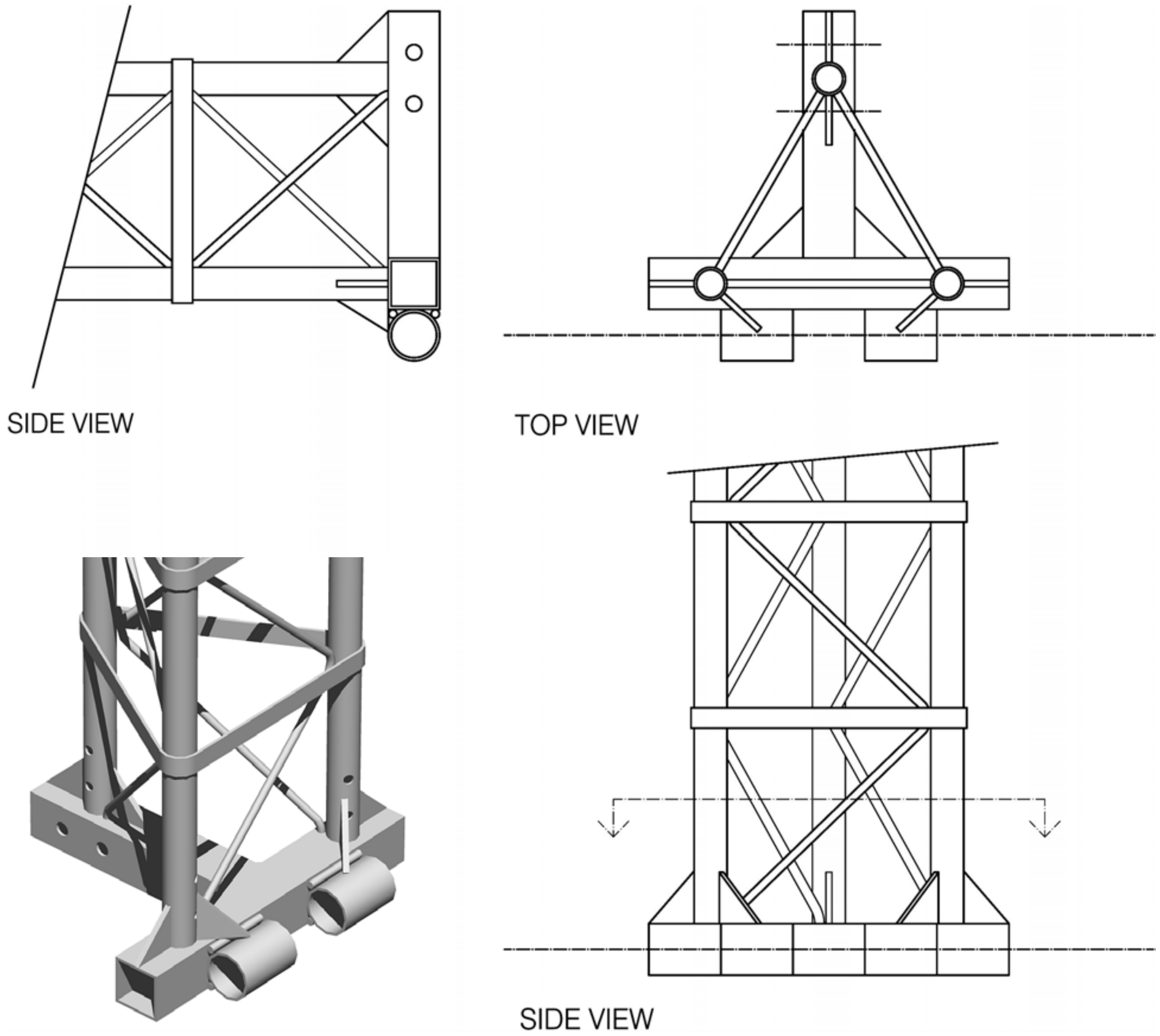


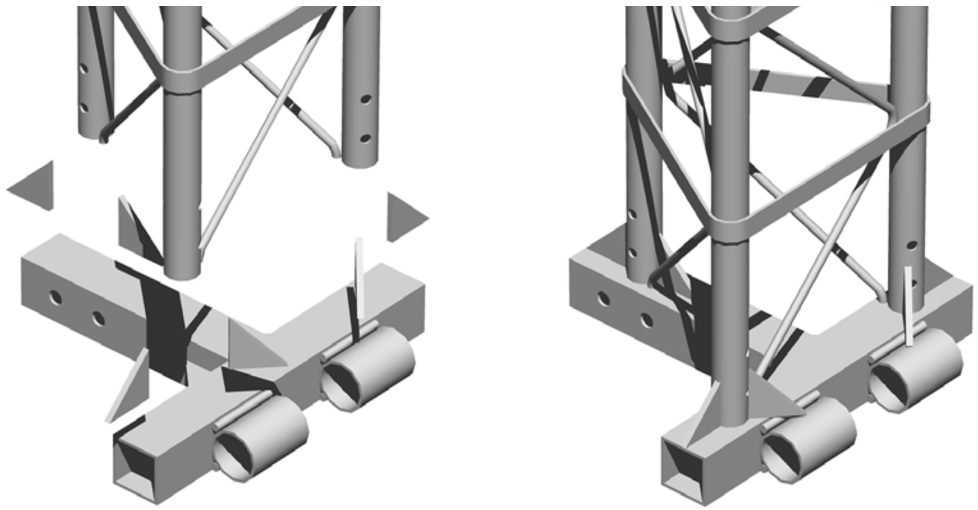
ill. 215 - mast connection

Mast Hinge

The mast will be erected by tilting it vertically - see page 162 [chapter 9.3 - erection process]. In order to provide the possibility of tilting the mast to an upright position a hinge which connects the bottom mast segment and the mast foundation has been developed.

This element will be prefabricated and later on welded on the bottom of one mast segment. Triangular steel plates will reinforce this joint.



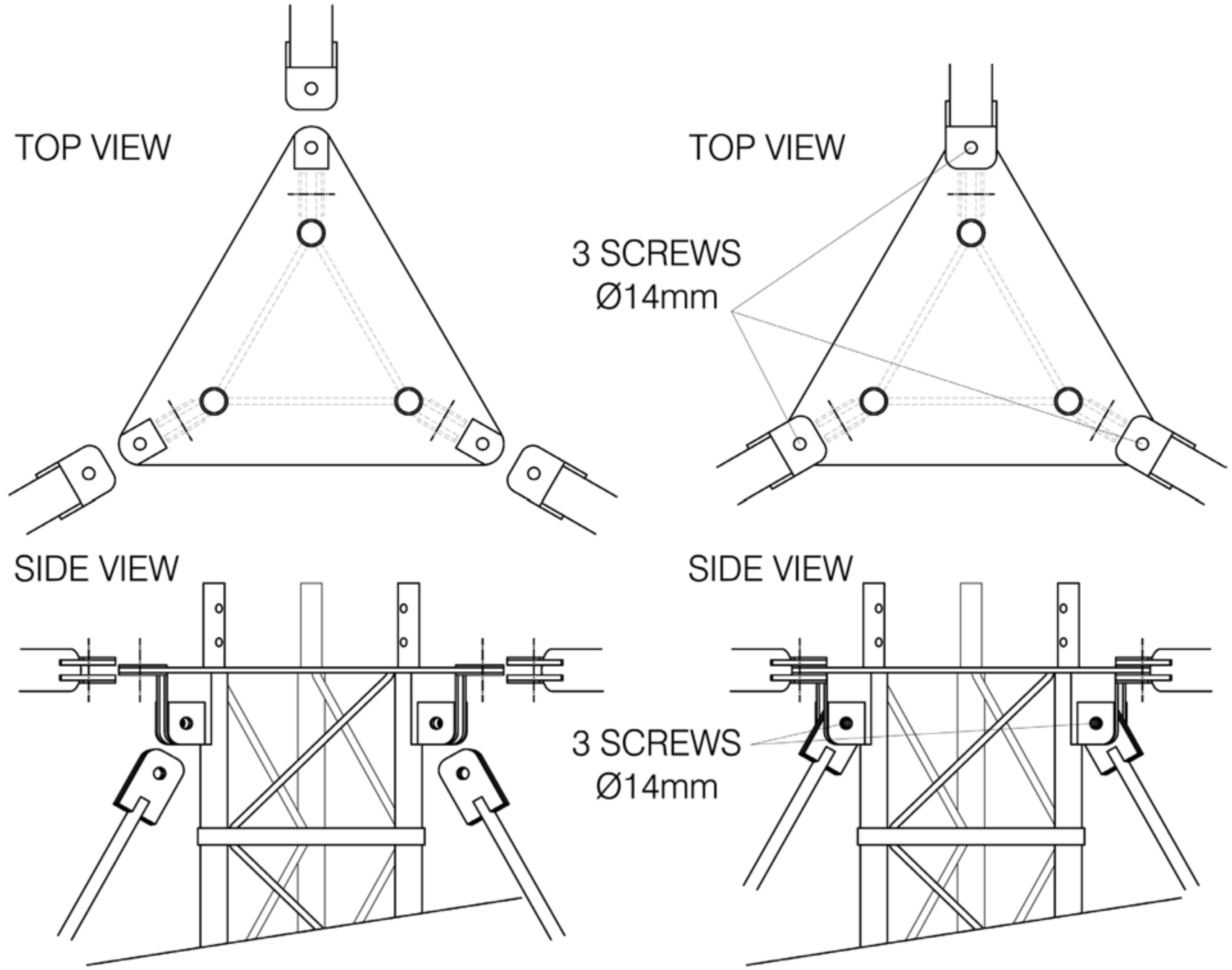


ill. 216 - mast hinge

Guy attachment segment

At three positions along the mast the guy system is connected with it. At these intersections the guy stays and the tension members will be connected with the mast. The guy stay are connected hinged. At the same time two mast segments are connected at these specific intersection. A technically simple connection system has been developed to meet the demands of this complex intersection.

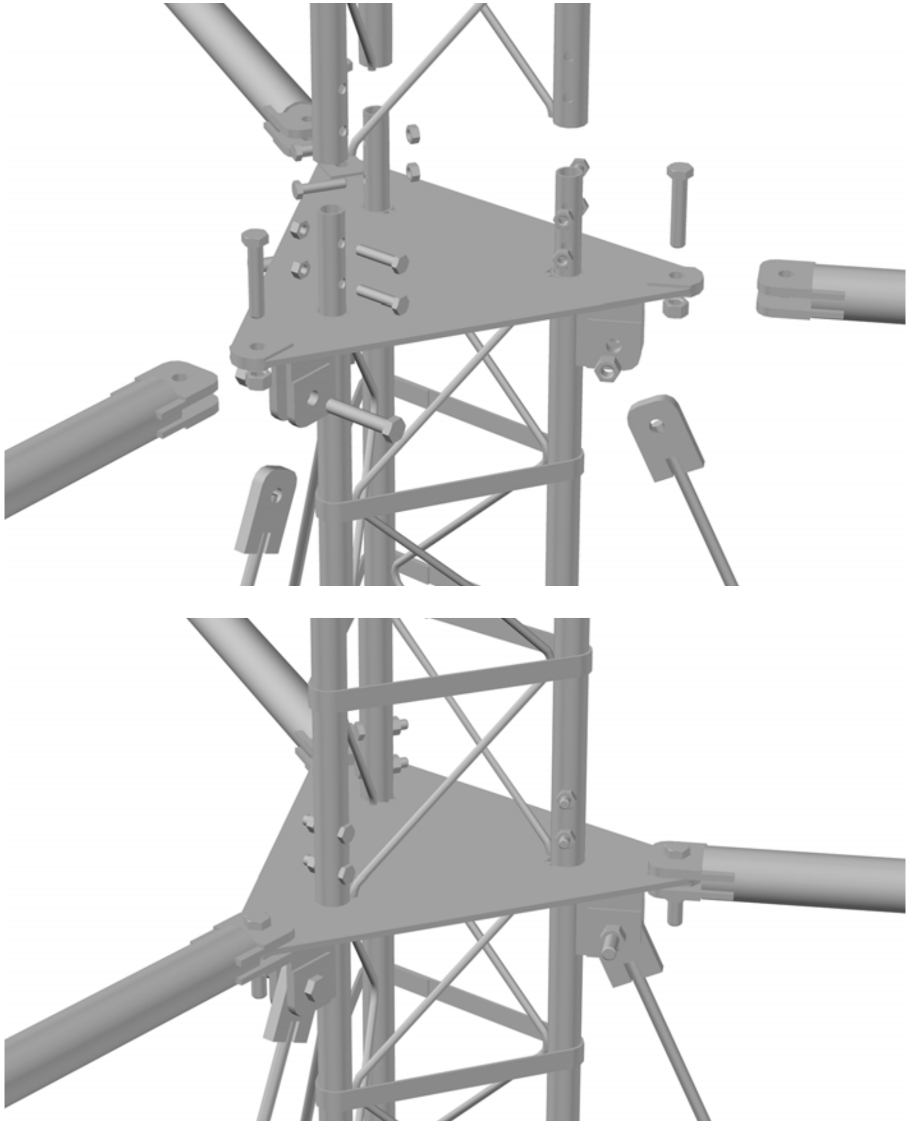
The guy stays will transfer pressure forces induced from the guy system into this joint. The horizontal stays of the mast at this position would not have the capability to resist them and would buckle. Therefore a triangular metal plate on top of these mast segments has been chosen to resist these forces and to connect the guy stays.



ill. 217 - guy attachment

To provide least stress to a construction it is most efficient to direct the induced forces to the centre of the cross section. The tension member connection has been designed to provide this. Therefore the joint of the tension member is placed beneath the metal plate in the exact position to direct these forces to the intersection of the guy stay and the mast legs. Technically this connection is executed with two metal plates welded on the mast leg.

The holes of the bolted connections have been reinforced with 3mm thick metal plates.



ill. 218 - guy attachment

9.2.2. Guy system

9.2.2.1. Tension members

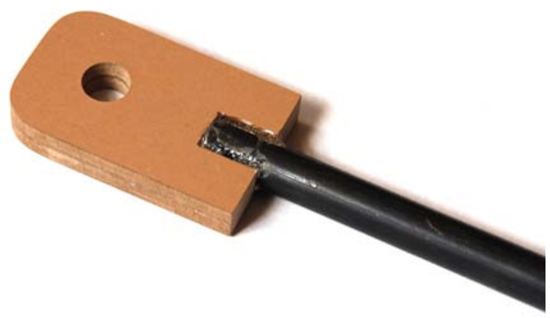
Tension members are responsible for the dimension of the guy system. The sailboat mast solution facilitates to take all tension forces into account and still be able to use locally available materials.

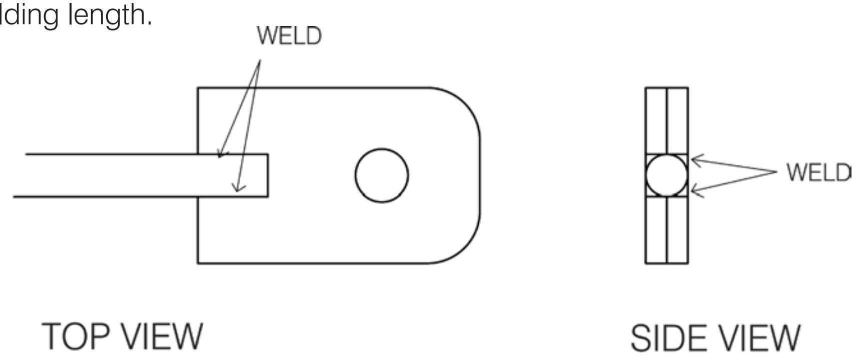
In Uganda, especially Gulu the selection of cross sections and lengths of steel bars which could be potentially used as tension members is limited. Nearly all profiles are sold with the length of 6m. It would be possible to construct the tension member out of these short cross sections, but it would be necessary to connect them in order to provide enough length for a efficient guy system.

The only exceptions are reinforcement steel and round bars. They are sold with 12m length. The one with the thickest cross section is a 12mm round bar. As these 12m round bars avoid an additional connection those steel bars have been finally chosen as tension members.

Steel has a tensile capacity of 14.5KN/cm². Therefore the maximum forces which the available round bar can support is 16.4KN (1640kg). The adjustment and length of the guy stay – which are mostly responsible for the forces in the tension members - have been adjusted frequently to remain below this value.

At each connection point of a tension member either with a guy stay or with the anchor at the bottom segment specific connection parts have been designed. These connection parts are made out of steel plates and are slit in order to provide enough welding length.





ill. 219 - tension member connection

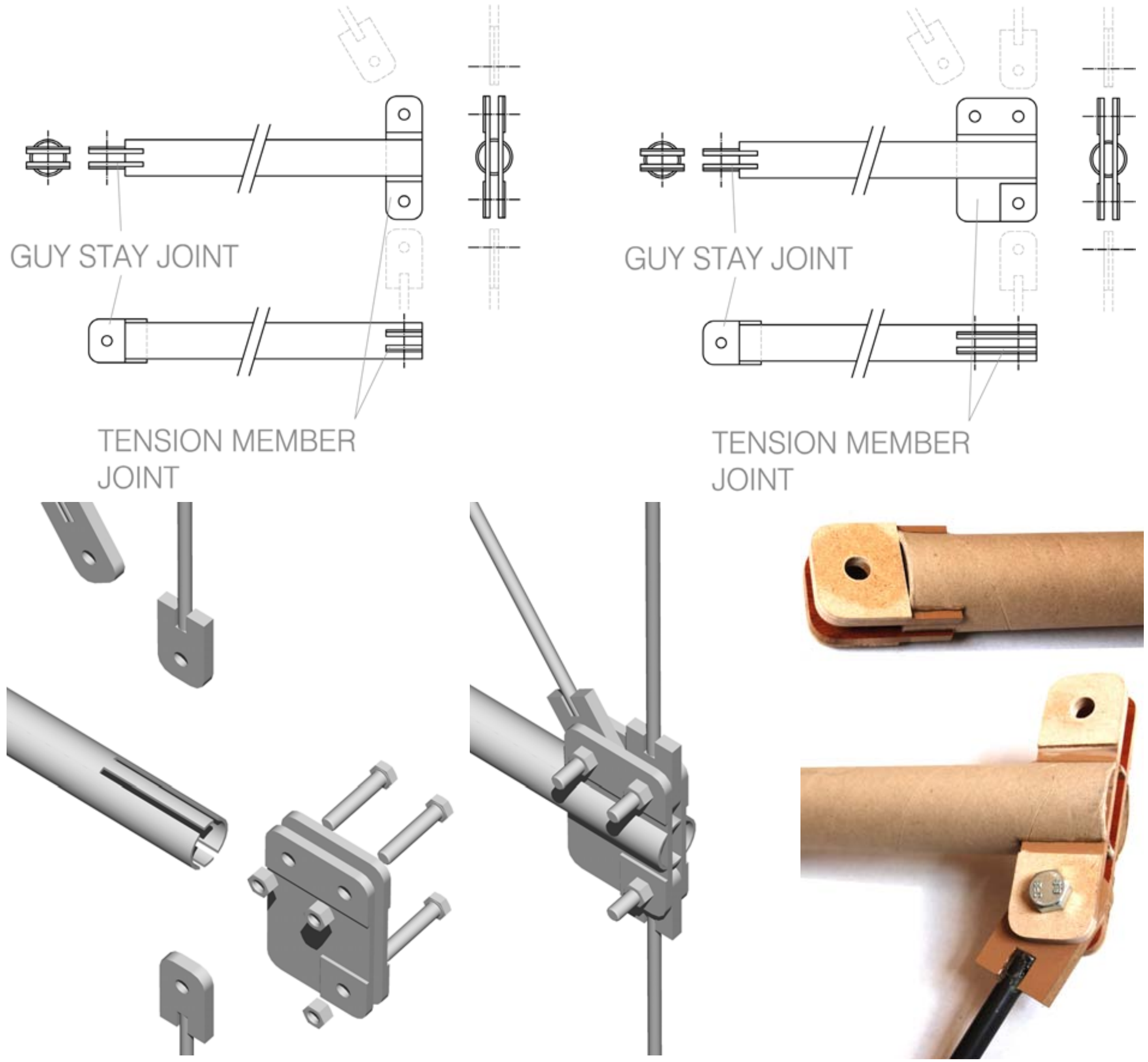
9.2.2.2. Guy stays

The guy stays have been adjusted in dependence of the tension members. Other factors for their dimensions have been other accruing forces and the deflection.

Guy stays basically have to resist the normal forces induced by the guy system. Buckling has to be considered in the statically verification as well as the deflection of this wide spanned beam.

Resulting from the static calculation 4m long guy stays provide a good balance of accruing forces and dimensions. A round hollow section with 50mm diameter and 3mm thickness will be used for the guy stays. Connection parts between guy stays and tension members as well as the mast will be slit to provide enough weld length.

Once again the holes of the bolted connections had been reinforced with 3mm thick metal plates.



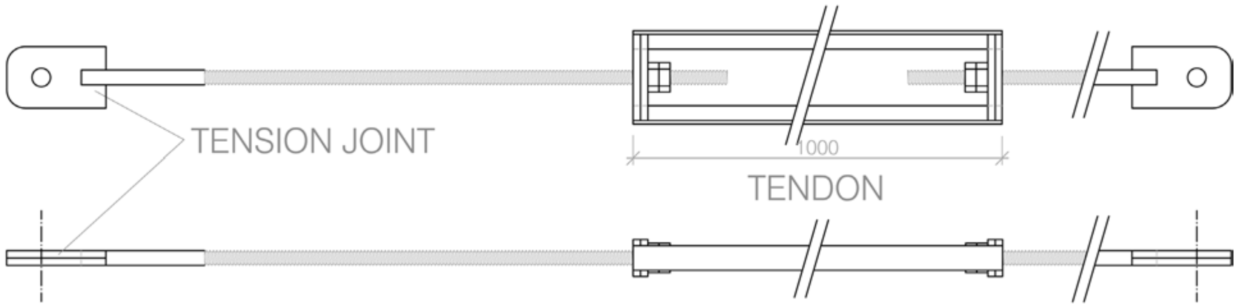
ill. 220 - guy stays

9.2.2.3. Tendon

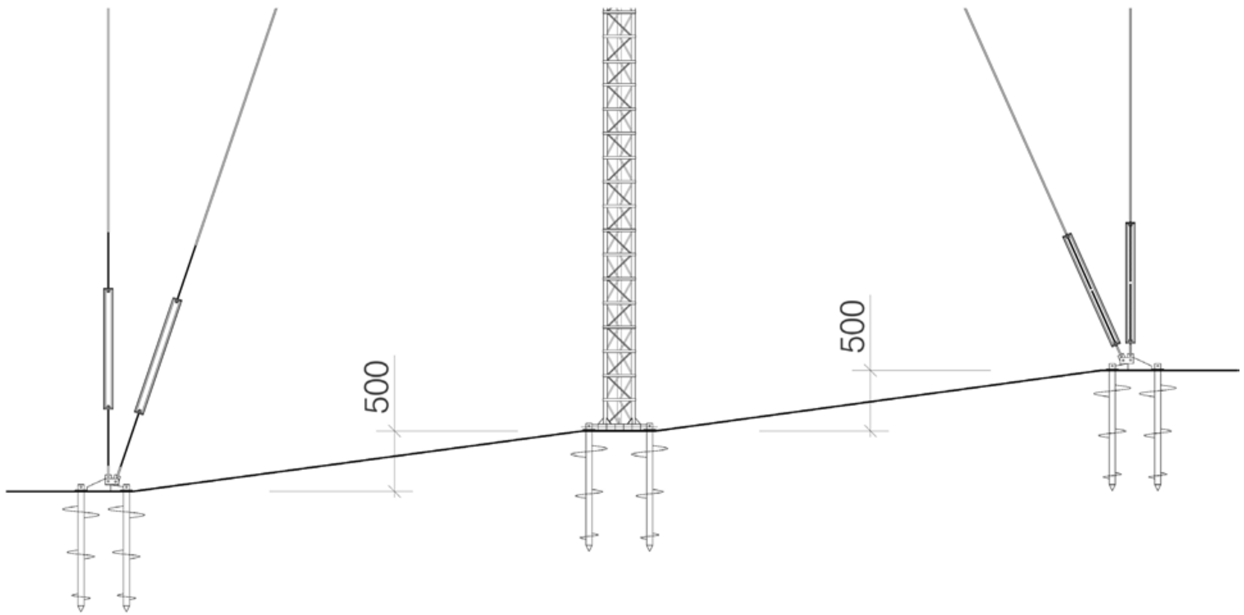
Tendons are needed to create the required pre-tension of the guy system. Three of the five tension members on one side need to be equipped with tendons, the other two will be tightened automatically through the others.

In order to tighten these three tension members a 1m long tendon has been designed. Steel plates, round bars and strip metal as reinforcement has been used to design the tendon. The round bar of the tension member is divided at the intersection with the tendon. By creating a 50cm long thread and 2 nuts on both sides of the round bar it is possible to tighten the tension member with the nuts. The tendon serves as link.

Moreover it is possible to adjust the length of these tension members by using the tendon. So topographical height differences between mast foundation and anchors with a maximum of 50cm can be adapted through the bottom tendons.



ill. 221 - tension member with tendon



ill. 222 - possible topographical height differences

9.2.3. Joints and fastening method

Technical accessories like bolts are rather rare in the region of Gulu and certainly difficult to find in big amounts all over Uganda except Kampala. Considering the investigation on site welding is the most common joining technique. For these reasons welding has been chosen as connection method in all of the connection points except the connection of the intersections of the modules. Implementation quality of the welded joints would be much lower if the welding would have to be done on site. First of all the welders would have to be transported to the construction site secondly the implementation would have to be done while climbing on the mast. Quality of welding if it is executed in the workshops themselves is much higher as on site. Therefore the mast can be completely prefabricated in the workshops in advance. Besides that the prefabrication of the mast is an advantage in terms of transportability and the erection process. Since the single modules can be prefabricated and afterwards be physically carried at once by a single person transport is easy and flexible. The only joints which have to be executed with detachable fasteners are located at intersections between the modules of this tower system. For these joints bolts have been chosen.

Overall the exact number of only 80 bolts is required for the entire construction.

- Mast connection: 42 bolts diameter 10mm length >45mm
- Guy system: 36 bolts diameter 14mm length > 45mm
- Mast hinge: 2 bolts diameter 14mm length > 80mm

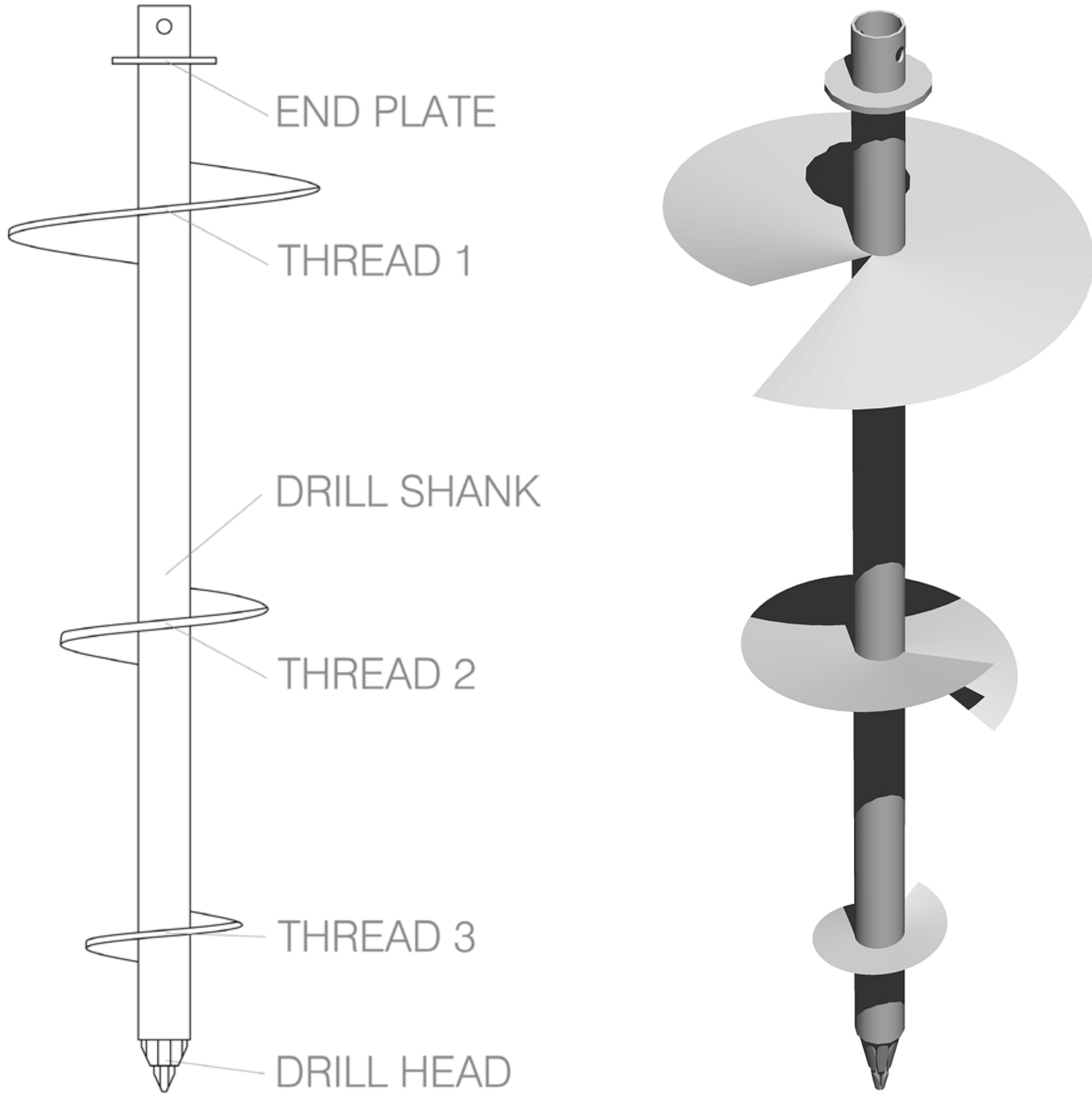
9.2.4. Foundation system

The finally chosen foundation system is based on ground screws. A ground screw prototype which can be produced by a local workshop in Uganda has been developed. The design of the ground screws was inspired by the ground screw system KESEAS - page 100 [chapter 5.2.4].

Resisting forces of industrialized ground screws with same dimensions are around 20KN (2000kg) vertical and horizontal tension and 30KN (3000kg) pressure. As the designed ground screw prototype has a different configuration it would be necessary to test it in roder to verify its load capacity.

For this proposition the resisting forces of a single self made ground screw has been presumed with 10KN (1000kg) only in order to avoid a lack of safety. Multiple ground screws, already preassembled with metal plates will be used at the foundation points.

The surface close to the foundation has to be leveled, as it is most important that the foundations are set in place horizontally.

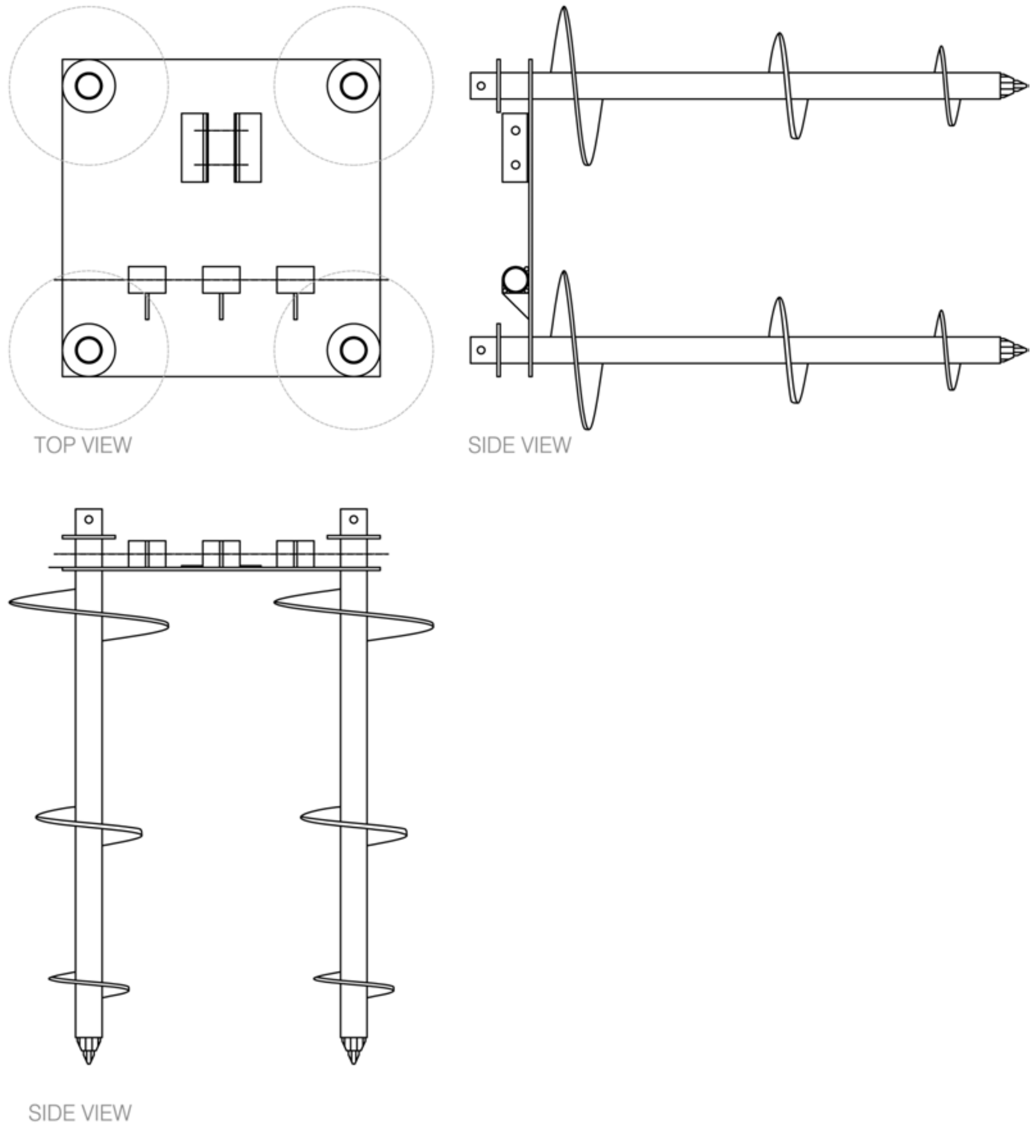


ill. 223 - ground screw

9.2.4.1. Mast foundation

The mast foundation has to resist vertical pressure forces mostly. During the erection process - the mast will be tilted vertically – also horizontal pressure will accrue.

A mast foundation unit has been designed which is preassembled and provides a fast and convenient foundation process. Technically this unit consists out of four preassembled ground screws and the base plate.

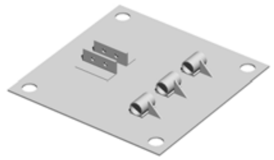


ill. 224 - mast foundation

The base plate provides the connection with the mast segments. A swivel joint has been developed. It consists out of round hollow sections welded on the base plate and the mast hinge. They get connected by pulling through a round hollow section with less diameter. Cantilever angles provide the attachment of mast and base plate once the mast is fully erected.

The ground screws are connected rotatable with the base plate in order to turn them into the soil. Therefore four holes at the corners of the base plate are provided. The top of a ground screws will be put through one of these holes. Afterwards end plates have to be welded on top of the ground screws. Through these end plates the ground screws are force-fit and inseparably connected with the base plate but still rotatable which is necessary to turn them into the soil.

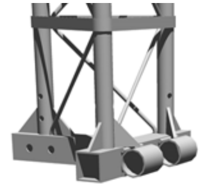
Once the unit will be positioned on site the ground screws will be continuously turned into the soil - this is all which is necessary to implement the foundation.

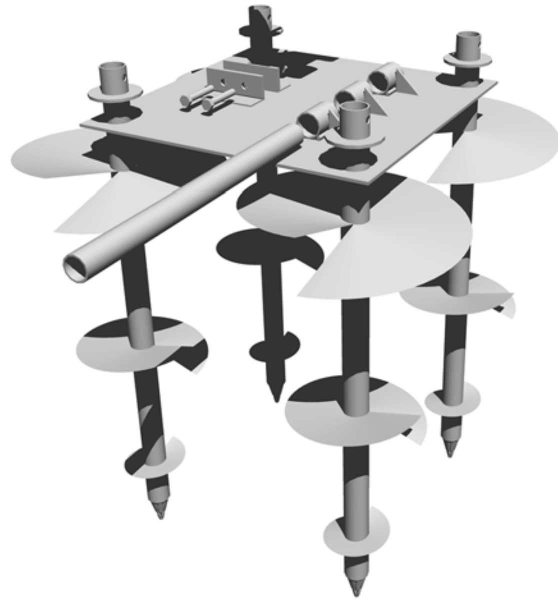


1. preassembled base plate

2. ground screws put through holes

3. end plates welded on top of gournd screws





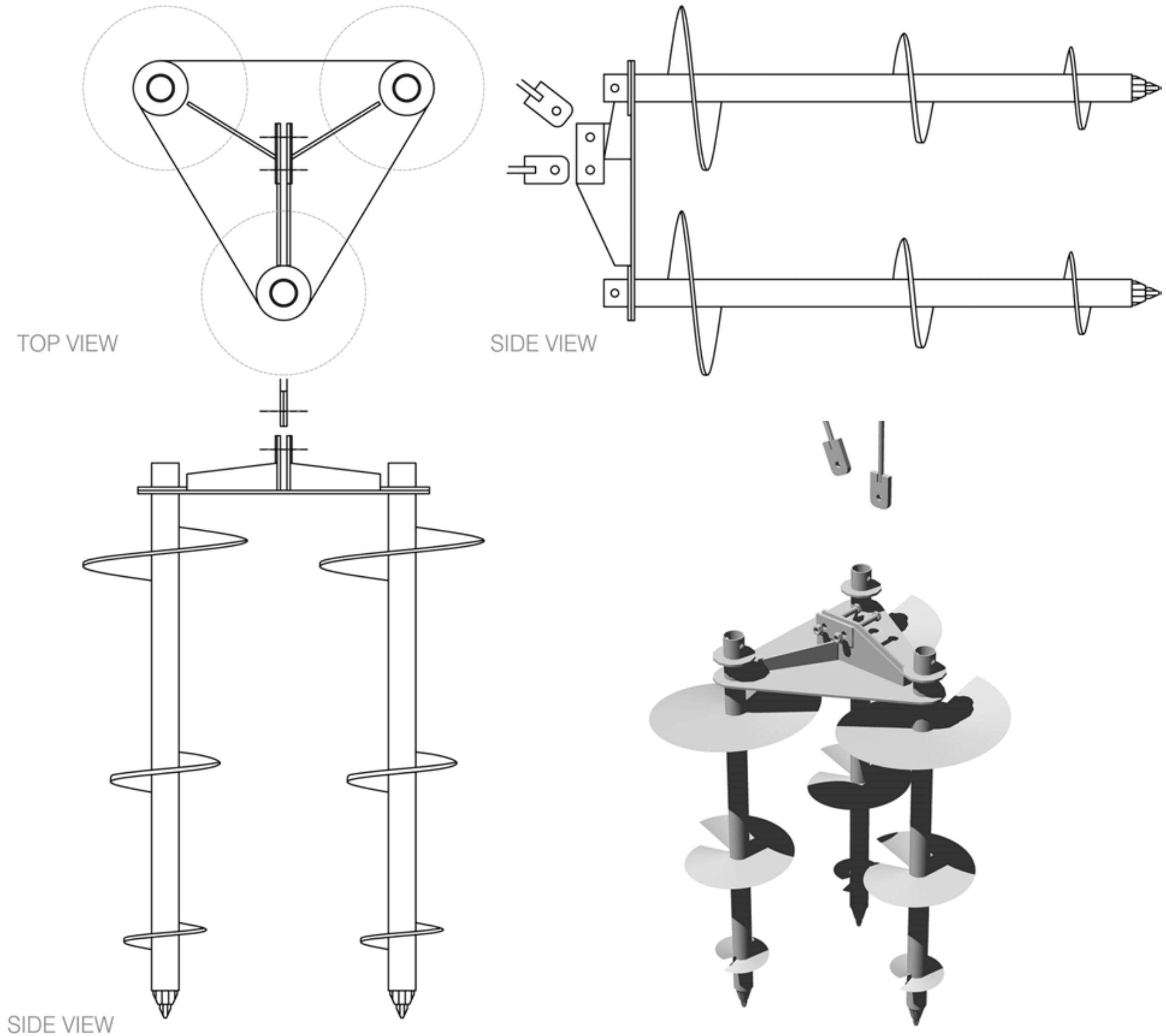
ill. 224 - mast foundation assembling

9.2.4.2. Guy Anchors

The foundations of the tension members have to resist tensile forces only. Again multiple screws have been used for each anchor. In this case three ground screws are connected by a triangular metal sheet. Tension member connection parts are welded on top of the metal sheet including bracing plates to avoid buckling of the metal plate.

The assembling of the triangular metal plate with the ground screws will be realized in the same way as the base foundation. The screws will be put through holes of the steel plate and finally fixed by welding end plates onto them. Through this method they are still rotatable in order to turn them into the soil.

In order to implement the guy anchors properly, it is important to set them exactly at the specified position. The position is defined thourgh the horizontal angle between the guy stays which needs to be 120 degrees exactly. Otherwise torsional moments will accrue and stress the mast construction.



ill. 225 - guy anchor

9.2.5. Additional Aspects

Implementation quality

Material and implementation quality of works such as welding are influencing the safety of the prototype. In Terms of material quality no significant losses in comparison to European steel have to be presumed. In terms of execution of welding etc. the quality depends highly on the working conditions. As mentioned before quality of welding differs a lot whether it is implemented on site or in the workshops in advance. Therefore is it important that the entire construction has the capability to be prefabricated in workshops. In this case the implementation quality rises enormously and can be presumed sufficient in terms of safety.

The experience gained with the realization of the 10m guyed mast (see chapter 8) gives a good impression of the welding quality. Overall the quality can be assumed as sufficient especially if the welded connections have been explained frequently in addition.

Lightning Protection

Lightning protection is an expensive task field. In order to find an affordable and sustainable solution to this project a specialized technician in the field of lightning protection has to design and verify a system. Investigation of possible local solutions would go beyond the scope of this work.

Considerations for a possible system could be finding a solution which uses the ground screws as groundings.

Corrosion

To prevent the mast from corrosion it is recommended to primer coat and paint the construction. This is the common and cheapest method in Uganda to prevent steel from corrosion. Additional car lute should be used at the joints to fill up each pore and smooth the welds.

Otherwise galvanized steel would prevent metal constructions from corrosion. However galvanized steel is rather expensive in Uganda. Besides that quality of galvanization is poor. So even by using this material corrosion would not be prevented. As the construction is flexible it will be easily possible to check the material once in a while – for example at each erection - if it is necessary to renew the paint at certain positions. Overall paint should provide corrosion resistance for several years if executed properly.

Ground screws are penetrated by humidity much more than the mast as they are located in the soil. After all they are exposed to corrosion the most. Paint cannot be used to prevent them from corrosion as the paint would be striped while turning them into the ground. Therefore galvanized steel is exeptionally recommended for the production of the ground screws.

Security Aspects

In order to prevent problems regarding bureaucracy etc. BOSCO prefers to set up the mast a property of one of their supporters. In addition this option allows to set up the mast without any fencing to secure the expensive equipment mounted on the mast. Still at the final location BOSCO has to decide definitely if a fence or theft security system is necessary. However it will not be possible to remove any parts of the mast construction because most of them are welded and the few bolts will be stressed and hard to loosen.

There are two propositions to prevent vandalism or theft of equipment. First would be a triangular fence around the anchor points made out of poles and meshes. Another is to secure the equipment with chains and locks on the mast. Finally BOSCO has to decide how to secure the mast.

9.3. Erection process

A system has been figured out to erect the mast under consideration of the conditions in Uganda. Two methods are possible.

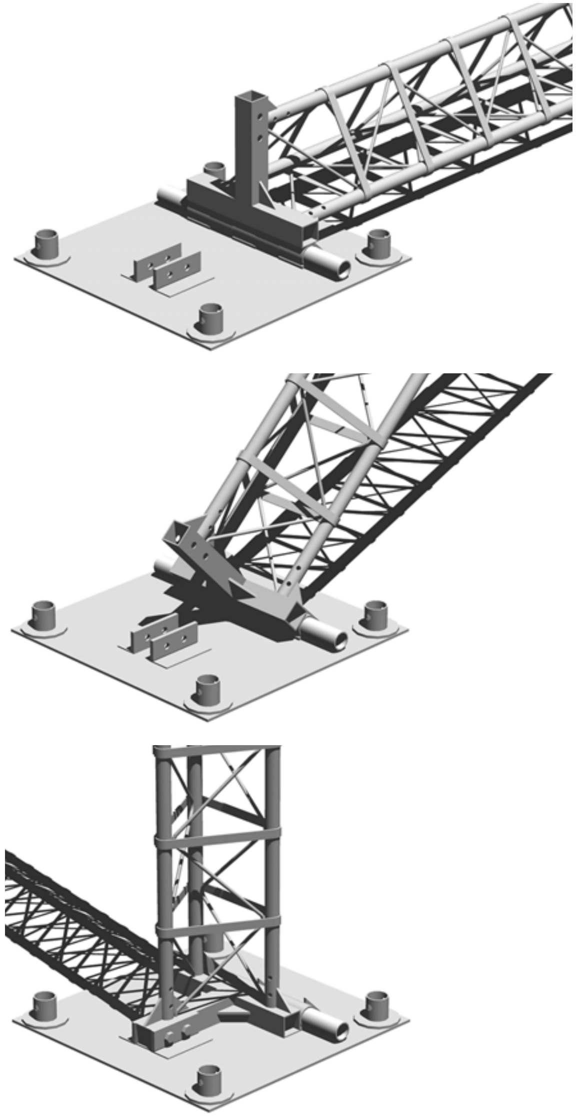
- Piece by piece vertically assembled
- Horizontally assembling and radial tilting

The second option was chosen. Technical equipment for the erection process is rare. No vertical lifting devices such as cranes are available in this rural area. Erecting the mast piece by piece would cause danger for the workers as they would have to climb up high on the mast. Besides that it would demand a lot of time and physical effort by the workers.

As described on page 69 [chapter 4.5.2.4] a lot of all terrain vehicles are used in Uganda. The weight of these vehicles amounts ~3000kg. Together with their cable wrench (tensile force 4000kg) those pick-ups provide the possibility to tilt the mast. In addition the guy system of the sailboat mast has the potential to be used as lifting device for the erection process. As the guy system is supporting the mast when induced wind forces last on it, it is resisting the tension forces during the erection as well.

The bottom of the mast has been designed with a hinge that provides tilting the entire mast. Once vertical erected the tension members will be connected with the anchors and the mast will be cantilevered with the mast foundation.

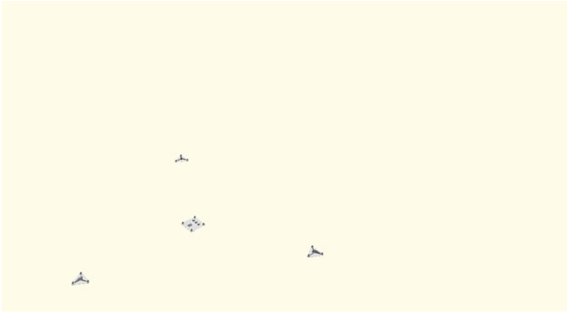
The entire guy system can be mounted on the mast in horizontal position. The guy stays are connected hinged with the mast. The tension members are assembled at all possible joints wheres the rest of the tension members will be connected frequently during erection. At the beginning of the erection process the entire preassembled mast lies on the ground. The hinge at the foundation allows only one direction in which the mast can lie on the ground. By pulling the bottom vertical tension member at the opposite side of the hinge the entire tower will slowly tilt into vertical position. The other two tension members will be used



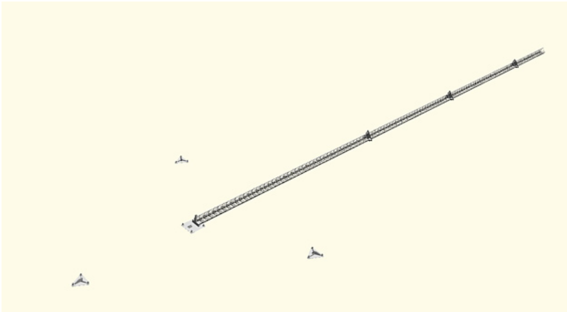
ill. 226 - mast hinge during erection process to provide lateral support during tilting. The wrench of the vehicle provides the possibility to lift the whole construction by pulling it.

In order to reduce the stress to the mast at the beginning of the erection it is necessary to support this procedure with human force. The persons who assembled the mast should help to lift the mast at the beginning of tilting and later on by giving it lateral support with the guy system.

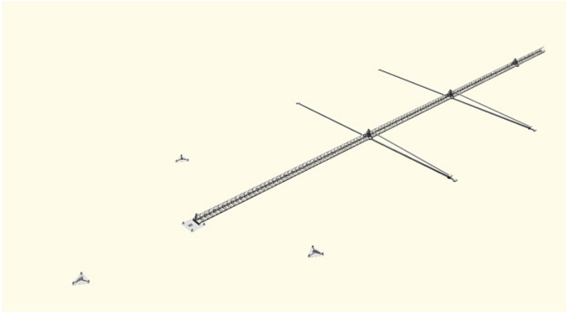
SCHEMATIC ERECTION PROCESS



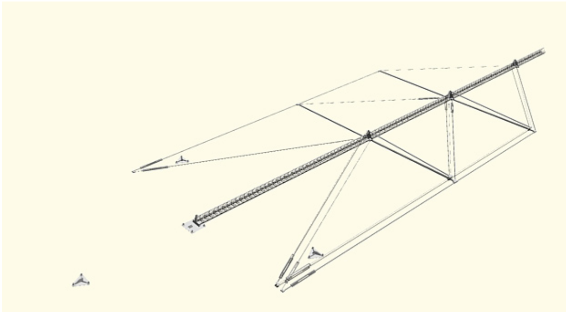
1. place anchors and mast foundation and fix them



2. assemble mast segments

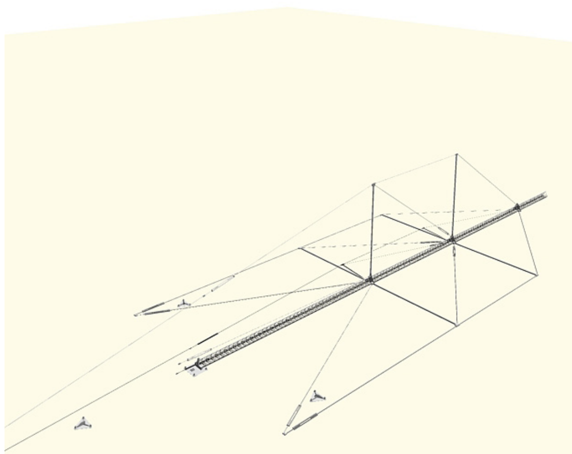


3. mount guy stays



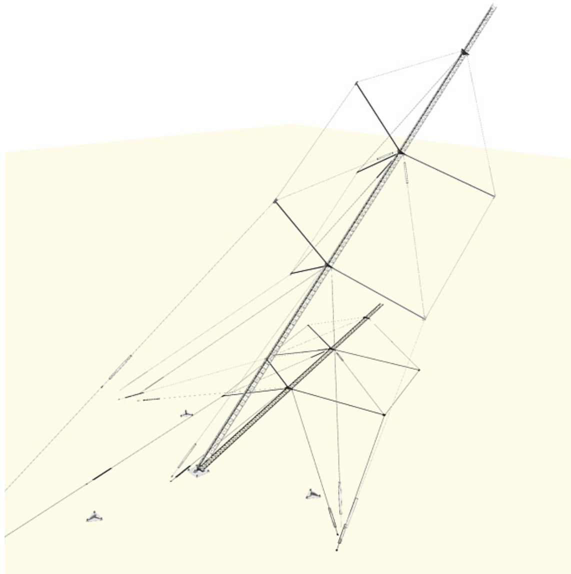
4. connect tension members with guy stays

ill. 227 - schematic erection process



5. tilt central guy stays into vertical position and fix associated tension members with the mast

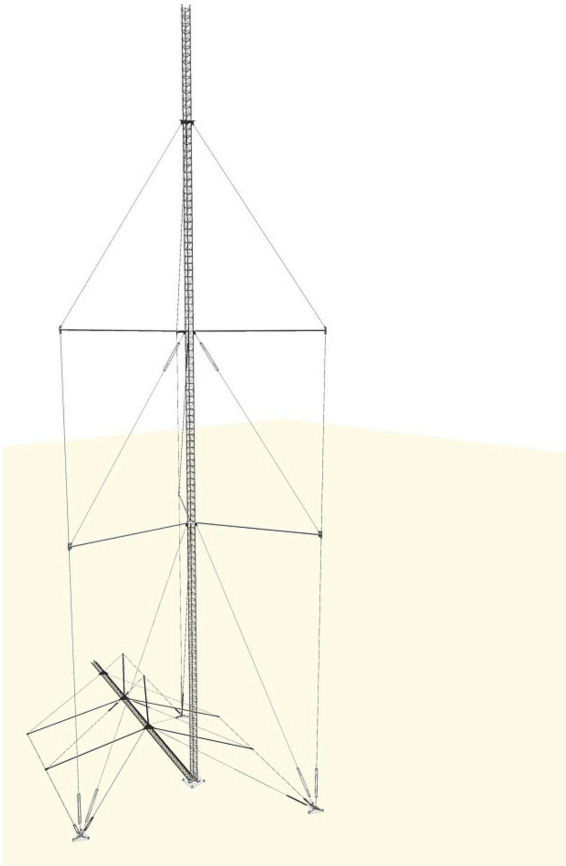
   simultaneously start to pull slowly with the cable wrench from the off road vehicle at the bottom tension member



6. support the mast during the start of the tilting procedure with human force

   fix tension members with the mast frequently during erection process

   use bottom tension members to provide lateral support

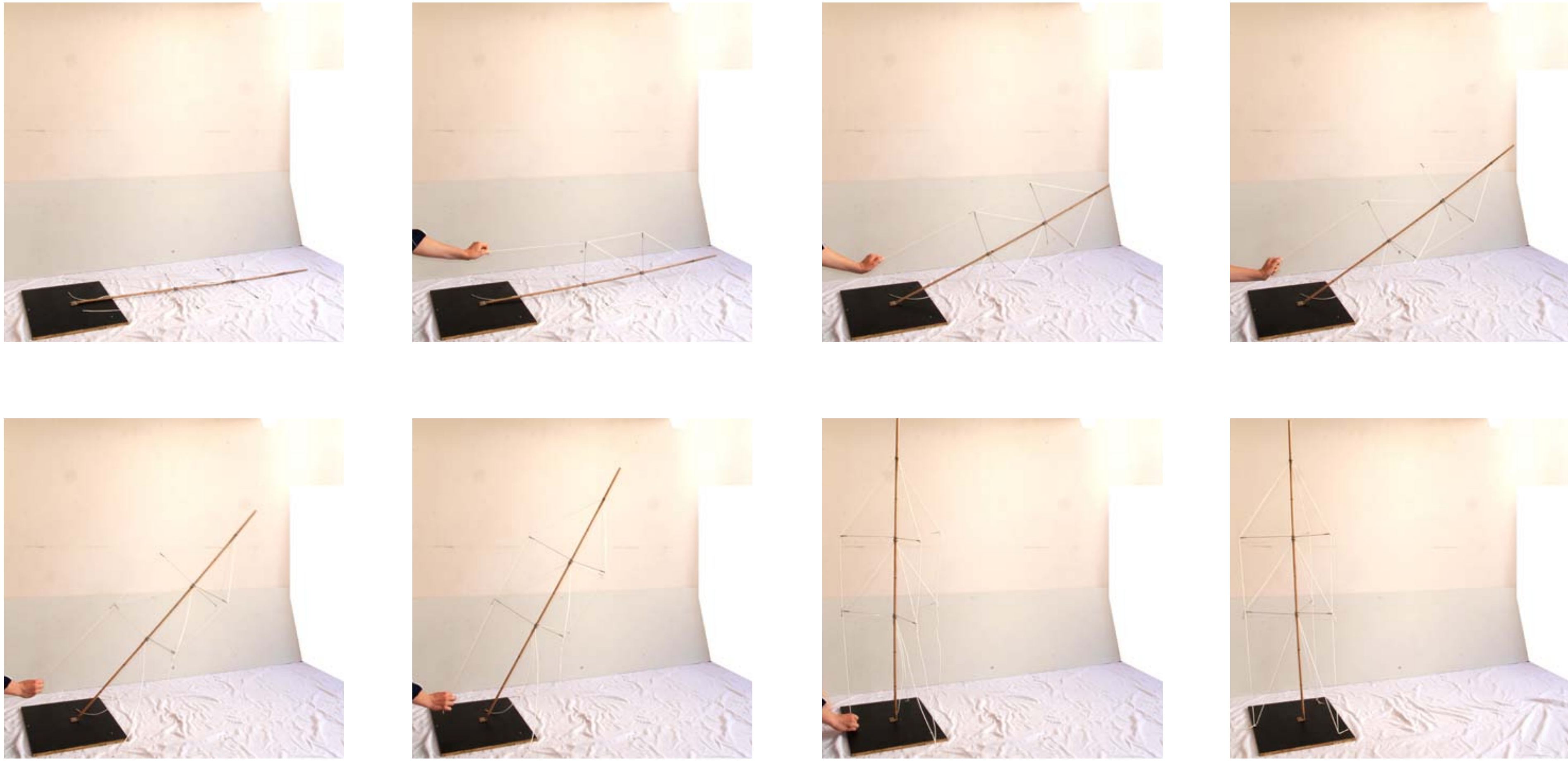


7. connect tension members with anchors once this is possible

   fix mast hinge with base foundation

ill. 228 - schematic erection process

MODEL STUDY OF ERECTION



ill. 229 - model study of erection

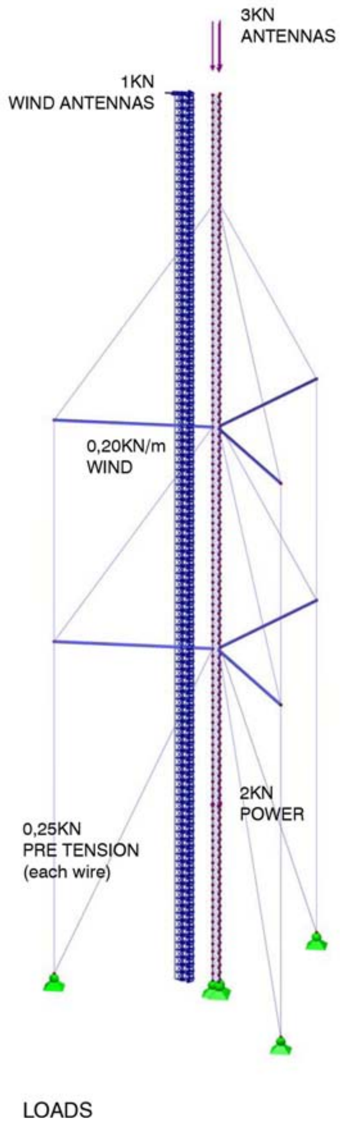
9.4. Static calculation – Verification of the design

The aim of this static calculation has been to estimate the feasibility of this prototype. Essential joints and cross sections have been selected to be calculated statically to prove if they are sufficient to resist the accruing loads. It has been executed in consideration of the Austrian calculation regulation ÖNorm. Nevertheless is it important to point out, that this calculation does not replace a full static calculation. More detailed verifications in association with a structural engineer of further joints or welds need to be executed.

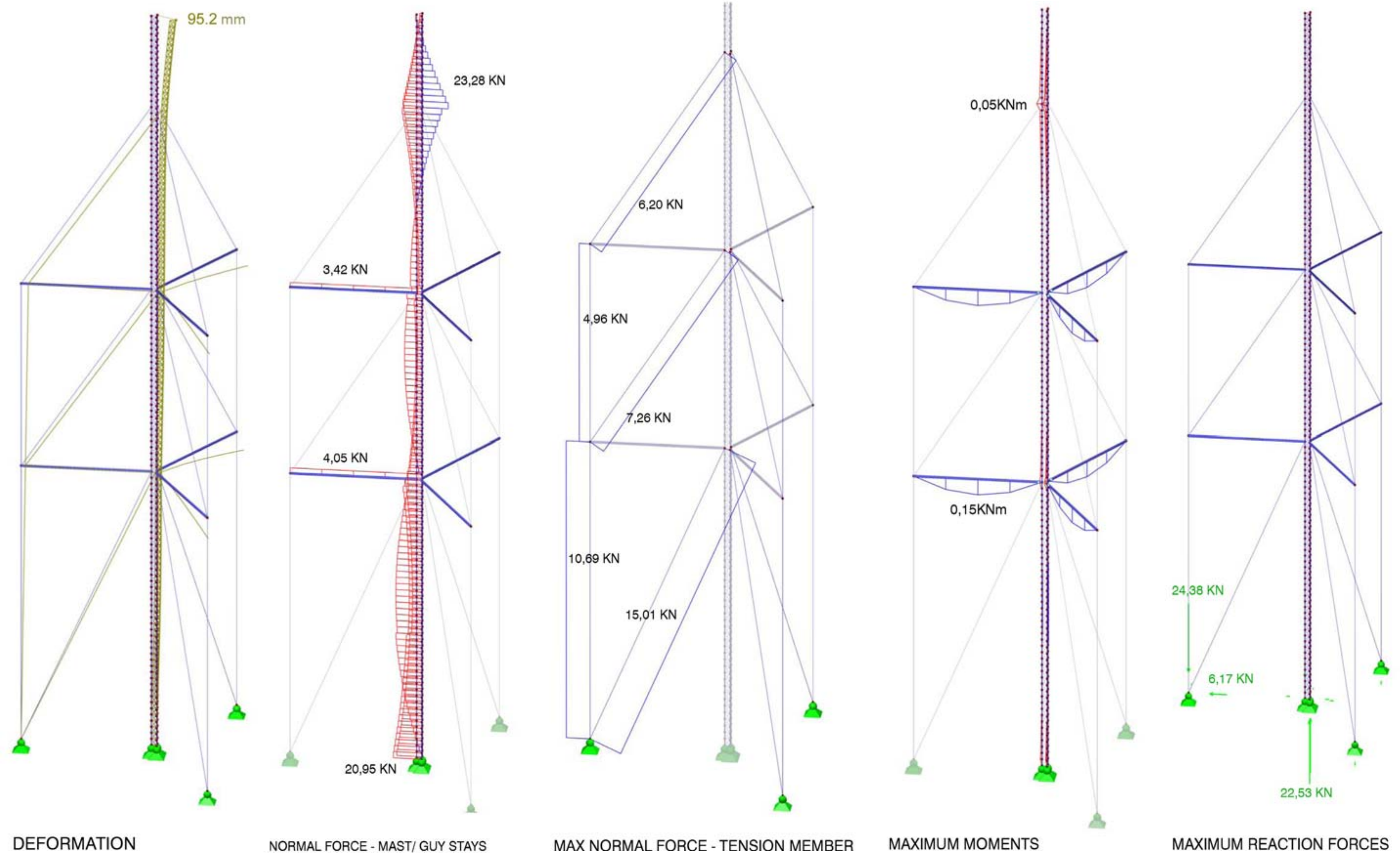
The static software program, provided from DLUBAL, has been used to generate the forces accruing in the construction and the maximum deformation. The aim of this chapter is to check if the chosen profiles are sufficiently stiff while use and during erection process. Moreover a deformation margin of the construction of 150mm has been determined - page 113 [chapter 6.1] - which must not be exceeded in order to meet the requirements of BOSCO.

Load assumption has been determined in detail. Surface of the lattice construction has been taken into account as the wind loads are dependent on the penetrated surface area. If the wind is directly affecting only one tension member set the maximum force occurs. This situation has been taken into account while calculating.

The final construction provides the required limited deformation of 150mm. With a maximum deformation of 95,2mm at the top of the mast it is highly rigid and provides transmission of the signal even during maximum stress.



ill. 230 - load assumption



ill. 231 - output of the static software prgramm - deformation / normal force / moment / reaction force

9.2.5. Full load

Necessary verifications of some high stressed cross sections and intersections of the mast will follow. All calculations have been executed with the formulas from Bautabellen - Robert Krapfenbauer/ Ernst Sträussler[70].

Buckling verification of the mast leg

Round Hollow Section 32/2,5mm

cross sectional area	$A = 2{,}32cm^2$
radius of gyration	iy = 10,5mm
Max. normal force	N = 23,28KN
buckling length	$s_k = 200mm$
slenderness ratio	λ
valid buckling stress	σ_k

$$\lambda = \frac{sk}{iy} = \frac{200}{10{,}5} = 19{,}04$$

with this value the valid buckling stress, listed in the chart on page 367 can be selected

$\sigma_k = 14{,}5\ KN/cm^2$

verification

$$\frac{N}{A} <= \sigma_k$$

$$\frac{23{,}28}{2{,}32} = 10{,}03KN/cm^2 < 14{,}5KN/cm^2$$

Tensile stress verification of the tension members

round bar 12mm diameter

Max. normal force N = 15,01KN
cross sectional area $A = 1{,}14cm^2$
valid tensile stress of steel (ST37)
$\sigma_{valid} = 14{,}5KN/cm^2$

maximum tensile stress of the tension member

$\sigma_{valid} \times A = 14{,}5 \times 1{,}14 = 16{,}53KN$

verification

$$\frac{N}{A} <= \sigma_{valid}$$

$$\frac{15{,}01}{1{,}14} = 13{,}15KN/cm^2 < 14{,}50\ KN/cm^2$$

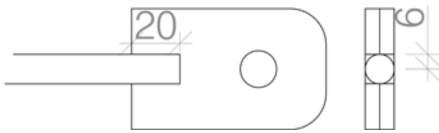
Weld verification of the tension meber

round bar 12mm diameter
steel plate 12mm

Max. normal force N = 15,01KN

page 383 - load capacity of welds per cm length - results in σ_{valid} = 1,45KN/cm per millimeter weld thickness

weld length l = 2cm
weld thickness d= 6mm



verification

$\sigma_{valid} \times d \times l >= \max N$

$1{,}45 \times 6 \times 2 = 17{,}40\ KN > 15{,}01KN$

-70- Krapfenbauer / Sträussler - Bautabellen, 2002, Verlag Jugend & Volk, ISBN 3 - 224 - 14585 - 4

Foundation verification

A single industrial ground screw from KES-EAS which served as a template has folllow-ing load capacity

vertical tensile capacity:	~20KN
horizontal tensile capacity:	~20KN
vertical pressure capacity:	~30KN

It would be necessary to test the designed ground screws which will be used at this prototype mast. But for this verification the load capacities of the developed ground screw will be assumed at 50% of the load capacity of the industrial template.

anchor verification

maximum reaction forces anchors

tensile stress vertical	N_V = 24,38KN
tensile stress horizontal	N_H = 6,17KN

3 ground screws will be used at each anchor therefore the maximum load capacity of one anchor is...

vertical tensile capacity:	~30KN
horizontal tensile capacity:	~30KN

verification

24,38KN < 30KN

6,17KN < 30KN

mast foundation verification

maximum reaction forces mast foundation

pressure vertical N_V = 22,35KN

4 ground screws will be used

vertical pressure capacity: ~60KN

verification

22,35KN < 60KN

Shear of / bearing stress verification of bolt and connection of the tension members

Bolt diameter 14mm (M14)

maximum stress	N = 15.01KN
hole wall	t = 9mm

Chart on page 387 results in following valid capacities for this screw and hole wall

bolt	29,50 KN
hole wall	27,75 KN

verification

15,01 KN < 29,50 KN

15,01 KN < 27,75 KN

Buckling verification of the Guy stays

Round Hollow Section 50/3mm

cross sectional area	A = 4,52cm²
radius of gyration	iy = 17mm
moment of resistance	W_y = 5,13cm³
Max. normal force	N = 4,05KN
moment	M = 0,15KNm
buckling length	s_k = 4000mm
slenderness ratio	λ
valid buckling stress	σ_k

$$\lambda = \frac{sk}{iy} = \frac{4000}{17} = 235$$

with this value the valid buckling stress, listed in the chart on page 367 can be selected

σ_k = 1,6 KN/cm²

verification

$$\frac{N}{A} + 0,9 \times \frac{M}{w} <= \sigma_k$$

$$\frac{4,05}{4,52} + 0,9 \times \frac{0,15}{5,13} = 0,92\,KN/cm^2 < 1,6\,KN/cm^2$$

9.4.2. Erection process

A simple comparison of occuring forces during use and erection will serve as a estimation of the stresses. The weight of the single modules of the entire sailboat mast has been calculated starting on page 171 [chapter 9.6]. The parts which have to be tilted are the mast including the guy system.

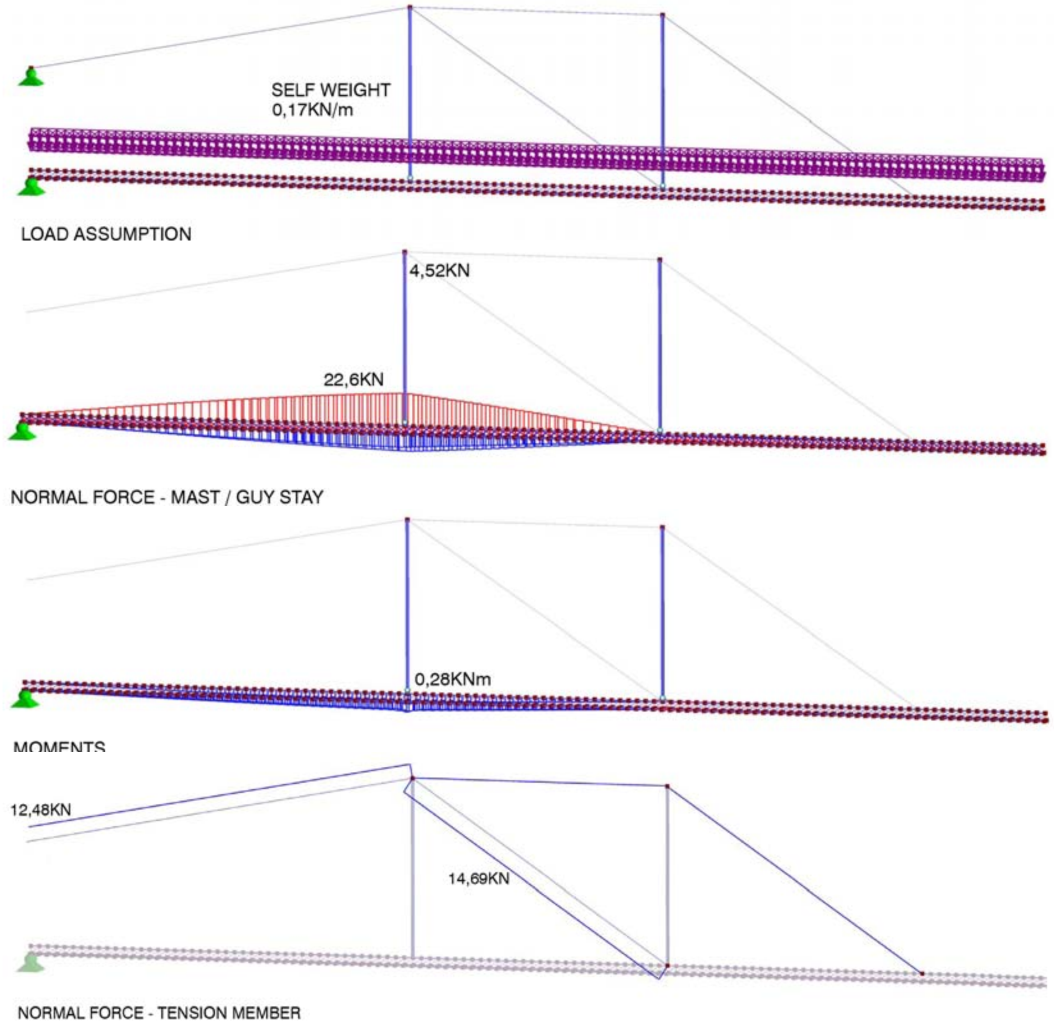
Weight of mast + Guy system:	430kg
Height of the construction	24m

This results in a self weight of 17kg/m

The load assumption for the erection process is 0,17kN/m.

The accruing wind forces on legs and stays during use are 0,20KN/m. They are already higher than the loads during errection. The construction will be stressed most at the beginning of the erection. Therefore is it required to support the mast with human force at the beginning.

The calculation output shows that the stresses accruing in the mast are less than the stresses during use. Therefore the cross sections are sufficient.



ill. 232 - static output at beginn of the erection process

9.5. Technical plans - implementation

Detailed full scale plans from the parts of the construction and from the assembling process can be investigated in the appendix.

List of plans

Mast Outline M= 1:50

Detail plans M= 1:5

1 - guy anchors
2 - mast foundation
3 - mast hinge
4 - mast hinge
5 - guy attechment segment
6 - tension member guy stay

Assembling plans M= 1:10

A1 - ground screw
A2 - guy anchor
A3 - base plate
A4 - mast foundation
A5 - mast segment
A6 - mast segment
A7 - mast hinge
A8 - guy attechment segment
A9 - guy stay 1+2
A10 - tension members

9.6. Weight and costs calculation

Aim of this thesis was to provide a tower system which fits exactly the needs of BOSCO. As outlined on page 113 [chapter 6.1] the construction plan has to be cheap and efficient. During the material research and the planning of the construction it always has been taken into account to choose a cost efficient solution. A workshop will be chosen which will work under special conditions as they can expand their work field. Therefore labor costs cannot be calculated. Transport costs can also be dropped in the calculation: Transportation of the raw material to the workshop will be done by the shop or by the workshop itself. Transport of the entire sailboat mast will be possible by one of the off road vehicles from BOSCO.

Finally a detailed chart of the material use of the single modules will be listed. First of all the weight of these modules resulting in a total weight has been calulated. Secondly the material costs have been estimated.

Ground Screw 13x

piece	type	length [mm]	dim. A[mm]	dim. B[mm]	weight/m	weight/piece	quantity	weight [kg]
drill shank	round hollow section 50/3 mm	1000			3,48	3,48	1	3,48
thread 1	metal plate 6mm		300	300		4,24	1	4,24
thread 2	metal plate 6mm		200	200		1,88	1	1,88
thread 3	metal plate 6mm		150	150		1,06	1	1,06
drill head	round bar 12mm	50			0,84	0,04	8	0,33
drill head	round bar 8mm	50			0,39	0,02	4	0,08
end plate	metal plate 6mm		100	100		0,47	1	0,47
							Sum	11,55

anchor plate

piece	type	length [mm]	dim. A[mm]	dim. B[mm]	weight/m	weight/piece	quantity	weight [kg]
anchor plate	steel plate 6mm		550	475		12,30	1	12,30
guy connector	steel plate 6mm		260	100		1,22	2	2,45
bracing plate	steel plate 6mm		190	50		0,45	2	0,89
reinforcement	steel plate 3mm		110	50		0,13	2	0,26
							Sum	15,91

base plate

piece	type	length [mm]	dim. A[mm]	dim. B[mm]	weight/m	weight/piece	quantity	weight [kg]
base plate	steel plate 6mm		600	600		16,96	1	16,96
cant. Angles	angle bar 50/50/3	130			2,72	0,35	2	0,71
swivel joint	round hollow section 50/3 mm	70			3,48	0,24	3	0,73
reinforcement	steel plate 6mm		50	50		0,06	3	0,18
reinforcement	steel plate 3mm		130	45		0,14	2	0,28
weld inset	round bar 8mm	70			0,39	0,03	6	0,16
							Sum	19,01

mast hinge

piece	type	length [mm]	dim. A[mm]	dim. B[mm]	weight/m	weight/piece	quantity	weight [kg]
frame	rectangular hollow section 50/50/3	240			4,37	1,05	1	1,05
frame	rectangular hollow section 50/50/4	350			4,37	1,53	1	1,53
swivel joint	round hollow section 50/3 mm	70			3,48	0,24	2	0,49
reinforcement	steel plate 6mm		50	50		0,06	8	0,47
weld inset	round bar 8mm	70			0,39	0,03	4	0,11
swivel joint	round hollow section 50/3 mm	550			3,48	1,91	1	1,91
							Sum	5,56

chart 10 - detailed calculation of the prototypes weight

Roundings of metal plates, drilled holes have not been considered in this chart. Adding welds and paint for corrosion will result in an overall equal weight.

Foundation weight:	185kg
Mast + guy system weight:	430kg
Total weight:	615kg

mast segment 8x								
piece	type	length [mm]	dim. A[mm]	dim. B[mm]	weight/m	weight/piece	quantity	weight [kg]
leg	round hollow section 32/2,5mm	3000			1,82	5,46	3	16,38
diagonal stay	round bar 8mm	3720			0,39	1,45	3	4,34
horizontal stay	strip metal 20/3mm	810			0,43	0,35	15	5,25
mast connectors	round hollow section 25/2mm	150			1,13	0,17	3	0,51
							Sum	26,48

guy attachment 3x								
piece	type	length [mm]	dim. A[mm]	dim. B[mm]	weight/m	weight/piece	quantity	weight [kg]
connection plate	steel plate 6mm		400	455		4,29	1	4,29
tension member joint	steel plate 6mm		55	85		0,11	3	0,33
reinforcement	steel plate 3mm		40	50		0,02	6	0,14
reinforcement	steel plate 3mm		50	50		0,03	6	0,18
							Sum	4,93

guy stays 3x								
piece	type	length [mm]	dim. A[mm]	dim. B[mm]	weight/m	weight/piece	quantity	weight [kg]
guy stays	round hollow section 50/3 mm	4000			3,48	13,92	2	27,84
tension member joint	steel plate 6mm		170	50		0,40	2	0,80
tension member joint	steel plate 6mm		170	110		0,88	2	1,76
guy stay joint	steel plate 6mm		60	80		0,23	4	0,90
reinforcement	steel plate 3mm		50	110		0,13	4	0,52
reinforcement	steel plate 3mm		50	50		0,06	2	0,12
reinforcement	steel plate 3mm		60	50		0,07	4	0,28
							Sum	32,23

tension members 3x								
piece	type	length [mm]	dim. A[mm]	dim. B[mm]	weight/m	weight/piece	quantity	weight [kg]
tension member	round bar 12mm	7030			0,84	5,87	1	5,87
	round bar 12mm	5780			0,84	4,83	1	4,83
	round bar 12mm	7030			0,84	5,87	1	5,87
	round bar 12mm	8830			0,84	7,37	1	7,37
	round bar 12mm	9680			0,84	8,08	1	8,08
tension joint	steel plate 6mm		80	50		0,19	20	3,77
tendon plate			70	30		0,10	12	1,19
tendon bar		1000			0,84	0,84	6	5,01
reinforcement	strip metal 20/3mm	1000			0,43	0,43	6	2,59
							Sum	33,88

foundation			
type	kg	quantity	weight [kg]
ground screw	11,55	13	150,09
anchor plate	15,91	1	15,91
base plate	19,01	1	19,01
			185,01

mast + guy system			
type	kg	quantity	weight [kg]
mast hinge	5,56	1	5,56
mast segment	26,48	8	211,83
guy attachment	4,93	3	14,80
guy stays	32,23	3	96,68
tension members	33,88	3	101,65
			430,51

total weight	615,52

chart 11 - detailed calculation of the prototypes weight

The weight calculation served as a basis for the following cost calculation. Material use has been conflated to finally calculate how many pieces of the individual goods are required. Local prices from the Hardware Shop in Gulu - listed on page 72 [chapter 4.6.2] - have been used for the calculation.

Finally the material cost of this prototype is 3.000.000 UGX which represents an equivalent of around 1.200 Euro.

type	required length [m]	unit length [m]	required units	order	price / unit	price [UGX]
round hollow section 50/3 mm	37,90	6,00	6,32	7	67000	469000
round hollow section 32/2,5mm	72,00	6,00	12,00	12	33000	396000
round hollow section 25/2m	3,60	6,00	0,60	1	20000	20000
round bar 12mm	138,25	12,00	11,52	15	14500	217500
round bar 8mm	92,58	12,00	7,72	10	11500	115000
strip metal 20/3	37,44	6,00	6,24	10	17000	170000
rectangular hollow section 50/50/3	0,59	6,00	0,10	1	62000	62000
angle bar 50/50 /3	0,26	6,00	0,04	1	47000	47000
					Sum	1496500

type	required dimension [m²]	unit dimension [m²]	required units	order	price / unit	price [UGX]
steel plate 6mm	3,96	2,98	1,33	2	400000	800000
steel plate 3mm	0,22	2,98	0,07	1	200000	200000
					Sum	1000000

type			required units		price / unit	price [UGX]
bolt + nut diameter 14mm			38,00		1000	38000
bolt + nut diameter 10mm			42,00		1000	42000
primar coat 4l			10,00		20000	200000
paint 4l			10,00		22000	220000
					Sum	500000

total price	2996500

chart 12 - calculation of material costs

9.7. Conclusion / Evaluation

The final result of this prototypical study is the design of a mast construction taking all of BOSCOs requirements into account. It is a lightweight construction combining factors like transportability and height flexibility.

The overall objective has been achieved: The construction has been fully adapted to the specific requirements of Uganda. Only materials and cross sections which can be bought and processed in the specific region have been used. Moreover, a simple method enables the erection even in rural areas.

The following is a brief description of the key notes of the sailboat mast.

After extensive research and planning, a slender lattice steel mast was proposed. The prototype consists of round hollow sections for the legs, round bars and strip metal for the stays. The mast is divided into several segments - 3 meters each - to facilitate flexible height configurations. Heights between 9 meters out of three mast segments up to 24 meters out of eight mast segments are possible. For maintenance purposes, a technician can easily climb the construction by using the horizontal stays of the mast segment.

A sailboat guy system was developed to stiffen the mast. It consists of 15 tension members and 6 guy stays. Through this system, the ground usage has been reduced to a medium level compared to other guyed masts. Overall an area of 66 square meters is required for this prototype. Five tension members on each side are necessary to stabilize the mast. Additionally, three tension members at each side are equipped with a tendon to create the necessary pre-tension of the guy system. Furthermore, these tendons provide the possibility to adapt topographical height differences between mast and guy anchors.

Foundations have been designed by using ground screws. The straightforward procedure of dismantling and relocating is the main reason for this decision. A mast foundation unit has been designed to tilt the mast vertically. The mast foundation, as well as the guy anchors for the guy system, uses multiple ground screws to resist the accruing reaction forces. By using the ground screws, the overall weight of the construction has been minimized. Consequently, transportability is ensured. Through developing a hinge connection, an easy erection procedure has been invented.

The single modules of this prototype are lightweight in order to guarantee transportability. All elements can be carried by a single person. The by far heaviest unit is the mast foundation unit with a weight of 60kg. The entire prototype weighs 615kg: 430kg for mast and guy system and 185kg for the foundation system.

The entire construction can be pre-fabricated in workshops which raises the implementation quality to a high value. Most joints are welded as this is the most common processing method in Uganda. After all, exactly 80 bolts are needed to assemble the modules of this prototype.

The erection procedure is to tilt the mast vertically with the cable wrench of a common off-road vehicle. Firstly, the mast foundation and guy anchors are turned into the ground. Secondly, the mast and the guy system are horizontally assembled. Finally, the cable wrench is connected with one tension member and pulls the mast slowly into vertical position.

It is, however, necessary to examine the construction carefully before implementation. Technical details like welds and specific joints of the construction have to be verified and, if necessary, adjusted in association with a structural engineer. Furthermore, it will be indispensable to supervise the construction, assembling and erection process of the first prototype to check if the suggested methods and joints are sufficient in order to provide an easily applicable mast system.

The aim to provide this information to workshops in Uganda will be the next step of this work. In association with the workshops it will be examined and evaluated if the construction process is executable even without the instruction of a technical supervisor.

In conclusion, this system is not only suitable for rural areas like Uganda or other less developed countries. It could be applied in almost any country around the world. Without wanting to be overweening, I assume that this mast system has the possibility to compete with other technically advanced transmission towers.

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B. register of illustrations and charts

ILLUSTRATIONS

CHARTS

C. Appendix

BOSCO Uganda Brochure

Datasheets of technical equipment

Hyperlink Technologies - Antenna HG2424G
UBiQiTi Networks - Antenna Nano Station2
UBiQiTi Networks - Antenna Power Station PS2-17D
Hoppece - Solar Block 12V 135
Lorentz - Solar Panel LA75-12S
Phocos - Charge Controller CML-V2
D-Link - Switch 1008D

List of plans

Mast Outline M= 1:50

Detail plans M= 1:5
- 1 - guy anchors
- 2 - mast foundation
- 3 - mast hinge
- 4 - mast hinge
- 5 - guy attachment segment
- 6 - tension member guy stay

Assembling plans M= 1:10
- A1 - ground screw
- A2 - guy anchor
- A3 - base plate
- A4 - mast foundation
- A5 - mast segment
- A6 - mast segment
- A7 - mast hinge
- A8 - guy attachment segment
- A9 - guy stay 1+2
- A10 - tension members

BOSCO

UGANDA

BATTERY OPERATED SYSTEMS FOR COMMUNITY OUTREACH

Northern Uganda Conflict

Northern Uganda has been trapped in an armed conflict between the LRA (Lords Resistance Army) and the Ugandan Government troops over the past 20 years. The war has displaced almost 2 million people into squalid Internally Displaced Person (IDP) camps, causing massive social unrest and dependency on charity and aid for basic life necessities. This has led to a profound isolation of the displaced Acholi people as movement and communication between the IDP camps and the outside world was heavily restricted.

A peace agreement is on the horizon and a cease fire has held for more than two years, giving hope for permanent peace to the Acholi people for the first time in 20 years. Yet, the conflict has left its impact, destroying the social, cultural, and economic fabric of the vibrant Acholi people of northern Uganda. BOSCO-Uganda believes that access to communications services in rural areas can reduce the isolation of communities and improve service delivery in the fields of health, education, agriculture using innovative Web 2.0 social collaboration tools.

Vision of BOSCO

To provide Communication and Information Technology to foster social and economic development and peace building in rural communities of northern Uganda using a collaborative, web-based approach. BOSCO-Uganda provides access to the Internet and VoIP telephony connecting users to the world wide web and to an internal (Intranet) network, using low-power PCs and long-range WiFi connectivity to build a network that requires no access to the electrical grid. Moving beyond the provision of technical solutions, BOSCO will concentrate on both proven and emerging directions for ICT usage, including a Web 2.0 collaborative approach to cooperation with health centers, human rights groups, e-agriculture, and many others.

History of BOSCO

In April 2007 BOSCO was launched as a solar powered, long-range wireless computer network covering 9 locations including IDP camps in Gulu and Amuru districts of northern Uganda. Low power PCs and VoIP phones were installed in schools, health centers and parish offices, bringing Internet and Intranet connectivity to remote areas.

Project information ▸ Mail: Stefan.bock@horizont3000.org
Web: www.bosco-uganda.org
www.bosco-uganda.wikispaces.com

BOSCO

UGANDA

BATTERY OPERATED SYSTEMS FOR COMMUNITY OUTREACH

BOSCO Programming and Future Expansion

BOSCO is currently pursuing collaborative Web 2.0 ICT training in all network locations. We **work with experienced partners to identify key change agents**, who in turn **form user groups** and craft a constitution to guide their efforts. Collaborating from the start with local and international partners, these user groups **document their local stories, articulate local needs, and propose local solutions**, all this done in the public eye using **simple collaboration tools** (Wikispace.com, Skype, the Google suite). As they draw others into these collaborative efforts, they begin to organize their assistance to newer users, **turning traditional ICT training on its head, collaborating first**, which is IC2.0T (Information, Communication and **Collaboration** Technology, or **IC2T**) training.

Documenting their local stories (digital ethnography) **as the first steps toward creating a collaborative environment** restores proper attention to war-scourged cultural elements, enables greater cultural sensitivity from remote partners, and safeguards against the loss of cultural diversity, particularly when taking place under the watchful guidance of stable and experienced local shepherding (see: www.bosco-uganda.wikispaces.com). Pilot efforts in 7 camps are succeeding; nothing but funding keeps us from spreading this approach throughout the North of Uganda.

Low Power, Solar, and Wireless Technical Solution

BOSCO-Uganda is using technologies, especially designed for rural areas without access to the electrical grid:

- Low Power components and PCs operating on 12V DC, powered by solar panels
- Directional Wireless antennas mounted on water towers or roofs to transmit WiFi over distances of 30-50 km throughout northern Uganda
- Free and Open Source Software (FOSS) is used to avoid expensive licensing issues and simple, user-friendly operating system which is invulnerable to viruses

Project information ▸ Mail: Stefan.bock@horizont3000.org
Web: www.bosco-uganda.org
www.bosco-uganda.wikispaces.com

HyperLink Technologies — Innovative Solutions For Wireless Communications

2.4 GHz 24 dBi High Performance Die Cast Reflector Grid Wireless LAN Antenna - Model: HG2424G

Applications and Features

Applications:

- 2.4 GHz ISM Band
- IEEE 802.11b, 802.11g Wireless LAN
- IEEE 802.11n (Pre-N, Draft-N, MIMO) Applications
- WiFi Systems
- Long-range Directional Applications
- Point to Point Systems
- Point to Multi-point Systems
- Wireless Bridges
- Backhaul Applications
- Wireless Video Systems

Features:

RoHS Compliant

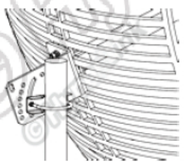
- Superior performance
- Die Cast aluminum construction
- UV stable light gray powder coat finish
- All weather operation
- 8° beam-width
- 12 inch coax lead
- Easy to assemble
- RoHS Compliant

Description

Superior Performance

The HyperGain® HG2424G High-Performance Reflector Grid Wi-Fi Antenna provides 24 dBi gain with an 8 degree beam-width for long-range highly directional applications. Applications include point to point systems, point to multi-point and wireless bridges in the 2.4GHz ISM band as well as IEEE 802.11b, 802.11g and 802.11n wireless LAN systems. It can be installed for either vertical or horizontal polarization.

Rugged and Weatherproof



This 24dB grid antenna's construction features a rust-proof die cast aluminum reflector grid for superior strength and light weight. This antenna's 2-piece reflector grid is simple to assemble and significantly reduces shipping costs. The grid surface is UV powder coated for durability and aesthetics. The open-frame grid design minimizes wind loading.

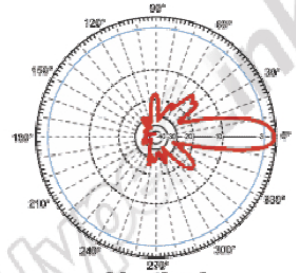
The HG2424G antenna is supplied with a 60 degree tilt and swivel mast mount kit. This allows installation at various degrees of incline for easy alignment. It can be adjusted up or down from 0° to 60°.

HyperLink Technologies, INC.
e-mail: sales@hyperlinktech.com • tel: 561-995-2256 • fax: 561-995-2432
web: www.hyperlinktech.com • 1201 Clint Moore Road • Boca Raton FL 33487

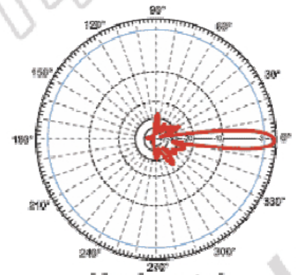
HyperLink Technologies — Innovative Solutions For Wireless Communications

Specifications

Frequency	2400-2500 MHz
Gain	24 dBi
-3 dBi Beam Width	8 degrees
Cross Polarization Rejection	26 dBi
Front to Back Ratio	24 dB
Sidelobe	-20dB Max
Impedance	50 Ohm
Max. Input Power	50 Watts
VSWR	< 1.5:1 avg.
Weight	8 lbs. (3.62 kg)
Grid Dimensions	39.5 in (100 cm) x 23.5 in (60 cm)
Mounting	1.25 - 2 in. (31.8 - 50.8 mm) dia. mast
Elevation Angle	0 to +10 degrees
RoHS Compliant	Yes
Operating Temperature	-40° C to to 85° C (-40° F to 185° F)
Lightning Protection	DC Short



Vertical



Horizontal

Wind Loading Data

Wind Speed (MPH)	Loading (2.1 sq. ft.)
100	80.5 lb.
140	125.5 lb.

Guaranteed Quality

This product is backed by Hyperlink's Limited Warranty

HyperLink Technologies, INC.
e-mail: sales@hyperlinktech.com • tel: 561-995-2256 • fax: 561-995-2432
web: www.hyperlinktech.com • 1201 Clint Moore Road • Boca Raton FL 33487

UBIQUITI NETWORKS

NanoStation2

Datasheet

GLOBAL WISP ROI INITIATIVE

SYSTEM INFORMATION	
Processor Specs	Atheros AR2315 SOC, MIPS 4KC, 180MHz
Memory Information	16MB SDRAM, 4MB Flash
Networking Interface	1 X 10/100 BASE-TX (Cat. 5, RJ-45) Ethernet Interface

REGULATORY / COMPLIANCE INFORMATION	
Wireless Approvals	FCC Part 15.247, IC RS210, CE
RoHS Compliance	YES

RADIO OPERATING FREQUENCY 2412-2462 MHz

TX SPECIFICATIONS

	DataRate	TX Power	Tolerance
802.11b	1Mbps	26 dBm	+/-1dB
	2Mbps	26 dBm	+/-1dB
	5.5Mbps	26 dBm	+/-1dB
	11Mbps	26 dBm	+/-1dB
802.11g OFDM	6Mbps	26 dBm	+/-1dB
	9Mbps	26 dBm	+/-1dB
	12Mbps	26 dBm	+/-1dB
	18Mbps	26 dBm	+/-1dB
	24Mbps	26 dBm	+/-1dB
	36Mbps	24 dBm	+/-1dB
	48Mbps	23 dBm	+/-1dB
	54Mbps	22 dBm	+/-1dB

RX SPECIFICATIONS

	DataRate	Sensitivity	Tolerance
802.11b	1Mbps	-97 dBm	+/-1dB
	2Mbps	-96 dBm	+/-1dB
	5.5Mbps	-95 dBm	+/-1dB
	11Mbps	-92 dBm	+/-1dB
802.11g OFDM	6Mbps	-94 dBm	+/-1dB
	9Mbps	-93 dBm	+/-1dB
	12Mbps	-91 dBm	+/-1dB
	18Mbps	-90 dBm	+/-1dB
	24Mbps	-86 dBm	+/-1dB
	36Mbps	-83 dBm	+/-1dB
	48Mbps	-77 dBm	+/-1dB
	54Mbps	-74 dBm	+/-1dB

RANGE PERFORMANCE	
Outdoor (BaseStation Antenna Dependent):	Over 15km

FOR 2312-2732 MHz Extended Frequency applications, please contact support@ubnt.com

INTEGRATED ADAPTIVE ANTENNA POLARITY + EXTERNAL ANTENNA SUPPORT (4 OPTIONS TOTAL)

Gain	10dBi (2400-2500MHz)	External Connector	SMA
Polarization	Multi-Polarized	3dB Beamwidth Elevation	30 degrees
Polarization Selection	Software Controlled	3dB Beamwidth Azimuth	60 degrees

Azimuth

Elevation

PHYSICAL / ELECTRICAL / ENVIRONMENTAL	
Enclosure Size	26.4 cm x 8 cm x 3cm
Weight	0.4kg
Enclosure Characteristics	Outdoor UV Stabalized Plastic
Mounting Kit	Pole Mounting Kit included
Max Power Consumption	4 Watts
Power Supply	12V, 1A (12 Watts). Supply and injector included
Power Method	Passive Power over Ethernet (pairs 4,5+; 7,8 return)
Operating Temperature	-20C to +70C
Operating Humidity	5 to 95% Condensing
Shock and Vibration	ETSI300-019-1.4

SOFTWARE

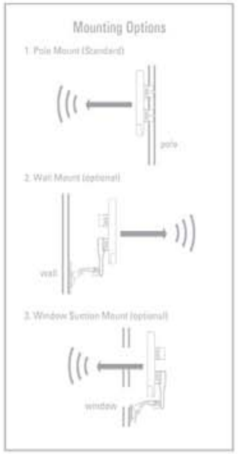
AirOS™

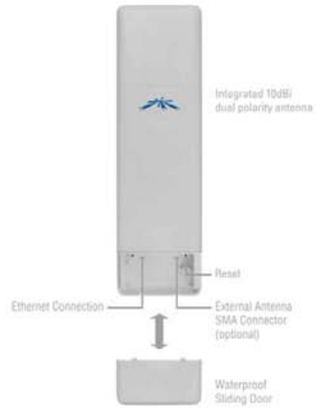
by Ubiquiti Networks

visit www.ubnt.com/airos

UBIQUITI NETWORKS

www.ubnt.com





UBIQUITI NETWORKS

www.ubnt.com

UBIQUITI NETWORKS
www.ubnt.com

Power Station 2
Datasheet

SYSTEM INFORMATION	
Processor Specs	Atheros AR2316 SOC, MIPS 4KC, 180MHz
Memory Information	16MB SDRAM, 4MB Flash
Networking Interface	2 X 10/100 BASE-TX (Cat. 5, RJ-45) Ethernet Interface

REGULATORY / COMPLIANCE INFORMATION	
Wireless Approvals	FCC Part 15.247, IC RS210
RoHS Compliance	YES

RADIO OPERATING FREQUENCY 2412-2462 MHz

TX SPECIFICATIONS				RX SPECIFICATIONS			
	DataRate	TX Power	Tolerance		DataRate	Sensitivity	Tolerance
802.11b	1Mbps	26 dBm	+/-1dB	802.11b	1Mbps	-97 dBm	+/-1dB
	2Mbps	26 dBm	+/-1dB		2Mbps	-96 dBm	+/-1dB
	5.5Mbps	26 dBm	+/-1dB		5.5Mbps	-95 dBm	+/-1dB
	11Mbps	26 dBm	+/-1dB		11Mbps	-92 dBm	+/-1dB
802.11g OFDM	6Mbps	26 dBm	+/-1dB	802.11g OFDM	6Mbps	-94 dBm	+/-1dB
	9Mbps	26 dBm	+/-1dB		9Mbps	-93 dBm	+/-1dB
	12Mbps	26 dBm	+/-1dB		12Mbps	-91 dBm	+/-1dB
	18Mbps	26 dBm	+/-1dB		18Mbps	-90 dBm	+/-1dB
	24Mbps	26 dBm	+/-1dB		24Mbps	-86 dBm	+/-1dB
	36Mbps	24 dBm	+/-1dB		36Mbps	-83 dBm	+/-1dB
	48Mbps	23 dBm	+/-1dB		48Mbps	-77 dBm	+/-1dB
	54Mbps	22 dBm	+/-1dB		54Mbps	-74 dBm	+/-1dB

ADJUSTABLE CHANNEL SIZE SUPPORT			
5MHz	10MHz	20MHz	40MHz

RANGE PERFORMANCE	
Outdoor (BaseStation Antenna Dependent):	Over 50km

PHYSICAL / ELECTRICAL / ENVIRONMENTAL	
Enclosure Size	18 in. length x 13 in. height x 2in. Width
Weight	8.8 lbs
Enclosure Characteristics	Outdoor UV Stabalized Plastic (Antenna) and die cast metal (system)
Mounting Kit	Pole / Wall Mounting Kit included
Max Power Consumption	6.5 Watts
Power Supply	12V, 1A (12 Watts). Supply and injector included
Power Method	Passive Power over Ethernet (pairs 4,5+; 7,8 return)
Operating Temperature	-40C to 85C (System PCB optimized for hi-temp)
Operating Humidity	5 to 95% Condensing
Shock and Vibration	ETSI300-019-1.4

SOFTWARE (www.ubnt.com/airos)

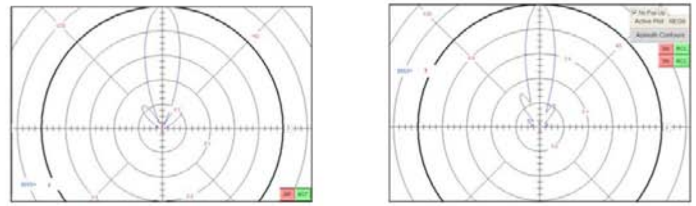
AirOS™ by Ubiquiti Networks

UBIQUITI NETWORKS
www.ubnt.com

MODEL NUMBERS

PS2-17D
Integrated 17dBi Dual Polarity Panel Antenna

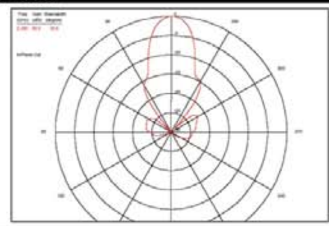
Antenna Information			
Gain	17dBi (2412-2462MHz)	3dB Beamwidth	18 Degrees
Polarization	Vertical And Horizontal	Surival Wind	185km/hr
Front to Back Ratio	30dB+	VSWR	1.4:1



Vpol — Hpol

PS2-18V
Integrated 18dBi Vertical Polarity Panel Antenna

Antenna Information	
Gain	18dBi (2400-2500MHz)
Polarization	Vertical
Front to Back Ratio	30dB+
3dB Beamwidth	20 Degrees
Surival Wind	185km/hr
VSWR	1.4:1
Impedance	50 ohm



PS2-EXT
(2) N-Type External Connectors for External Sector/Omni/Dish Applications

solar.bloc

Sealed lead-acid battery

Product features customer benefits

- Ideal storage for renewable energy (solar, wind etc.)
  = **reduced CO_2-emission**
- Electrolyte fixed in glass mat
  = **reduced maintenance (no water refilling)**
  = **horizontal operation (option)**
- Optimised grid electrode
  = **long life in cyclic operation**
  = **efficient take-up of charging current**
- Robust, reinforced PP
  = **resistant to environmental factors**
- Integral handles
  = **easy to handle**

Main applications:

Solar applications

HOPPECKE
POWER FROM INNOVATION

HOPPECKE
POWER FROM INNOVATION

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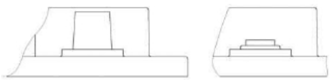
Type overview

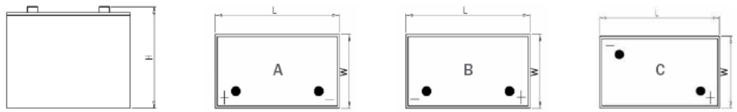
Capacities, dimensions and weights

Type	C_{100} 20 °C Ah	C_{48} 20 °C Ah	C_{24} 20 °C Ah	C_{10} 20 °C Ah	Length L mm	Width W mm	Height H mm	Weight kg	Connection	Handle	Terminal layout
solar.bloc 12 V 58	58.3	54.0	53.3	50.0	247	175	190	19	A-Terminal	yes	B
solar.bloc 12 V 70	70.0	64.8	64.0	60.0	278	175	190	23	A-Terminal	yes	B
solar.bloc 12 V 80	81.7	75.6	74.6	70.0	315	175	190	24	A-Terminal	yes	B
solar.bloc 12 V 90	93.3	86.4	85.3	80.0	353	175	190	28	A-Terminal	yes	B
solar.bloc 12 V 105	105.0	97.2	95.9	90.0	344	177	230	38	F-M8	no	A
solar.bloc 12 V 135	134.2	124.2	122.6	115.0	344	170	275	46	F-M8	no	A
solar.bloc 12 V 150	151.7	140.4	138.6	130.0	498	177	230	55	F-M8	no	A
solar.bloc 6 V 200	198.3	183.6	181.2	170.0	242	170	275	32	F-M8	no	C

Connection and torque



Terminal layout



Life expectancy: up to 15 years
Suitable for cycling: up to 600 cycles, 80% DOD

HOPPECKE
POWER FROM INNOVATION

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Bontkirchener Straße 1 · D-59929 Brilon-Hoppecke
Phone: + 49 (0) 29 63 61-0 Email: info@hoppecke.com
Fax: + 49 (0) 29 63 61-2 70 Internet: www.hoppecke.com

LORENTZ GERMANY

LA75-12S

High-efficiency PV Module

Technology

The LORENTZ LA-Series of PV modules offer a conversion efficiency of 17-20% due to the unique back-contact technology.

Our monocrystalline silicon solar cells yield a higher voltage per cell. Therefore 32 cells are sufficient to provide the same voltage as traditional 36-cell modules. As a result, LORENTZ modules are lighter and smaller.

In combination with an extremely low voltage-temperature coefficient, this guarantees a superior battery charging performance, even at high operating temperatures.

Exceptional low-light performance and broad spectral response further enhance energy delivery in all weather conditions, year round.

Applications

- water pumping
- water purification systems
- remote village lighting
- solar home systems
- street and camp lights
- traffic signals
- medical facilities in remote areas
- microwave/radio repeater stations
- battery charging

Features

- aerospace style cell interconnects with in-plane strain relief
- advanced EVA encapsulation system with multi-layer backsheet for long-term package durability
- bypass diodes to minimize the power drop caused by shade
- high reliability

Warranty

- Warranty: 2 years
- Performance guarantee:
  10 years (90% power output)
  20 years (80% power output)

  Details according to warranty issued by LORENTZ

Standards

LA75-12S meets the requirements for IEC and CE.

Specifications

Electrical Data

Peak power	Pmax	[Wp]	75
Tolerance		[%]	+15 / -5
Max. power current	Imp	[A]	4.6
Max. power voltage	Vmp	[V]	16.5
Short circuit current	Isc	[A]	5.4
Open circuit voltage	Voc	[V]	21.0
Efficiency of cells		[%]	17.0
Temperature co-efficient for Pmax		[%/°C]	-0.38
Temperature co-efficient for Voc		[mV/°C]	-60.8
Temperature co-efficient for Isc		[mA/°C]	3.0
Max. system voltage		[V]	600

All technical data at standard test condition:
AM = 1.5, E = 1,000W/m², cell temperature: 25 °C

Cells

Number of cells per module	32*
Cell technology	monocrystalline
Cell shape	rectangular

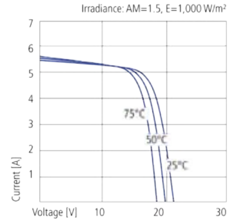
* Due to the back-contact cell technology only 32 cells are required to yield the same Vmp voltage as traditional SI products with 36 cells.

LA75-12S

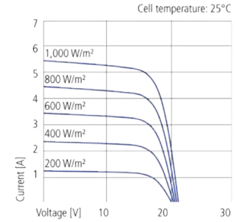
High-efficiency PV Module

LORENTZ GERMANY

Electrical Performance

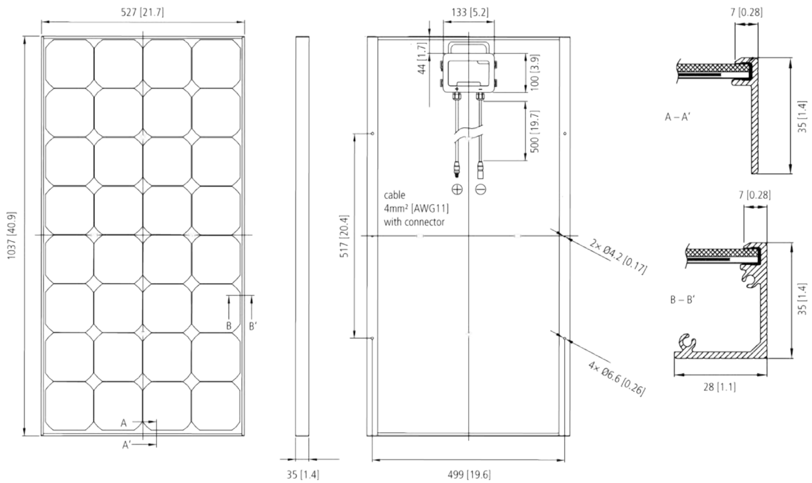


Current-voltage characteristics of PV module LORENTZ LA75-12S at various cell temperatures.



Current-voltage characteristics of PV module LORENTZ LA75-12S at various irradiation levels.

Physical Specifications mm [in]



Weight	[kg]	7.4
Dimension	[mm]	527 × 1037 × 35
Cable		approx. 1 m / 40 in, 4 mm² / AWG 12
Connectors		ZJRH Cixi Renhe 05-1

Datasheet_CML_ENG

Final Version

CML05, CML08, CML10, CML15, CML20

Solar Charge Controllers

- Battery State-of-Charge display with 3 LEDs
- Acoustic load disconnect pre-warning
- PWM-regulation (series type)
- Boost,Equalize and Float charging, also for VRLA
- Automatic 12/24 Volt detection
- Integrated temperature compensation
- Large terminals (up to 16mm² wire size)
- SOC and voltage controlled LVD
- Fully electronically protected

The CML series is a sophisticated solar charge controller family for low cost applications. The electronic circuit is equipped with a microcontroller that provides high-efficiency charging technology together with a number of outstanding status display, warning and safety functions.
The temperature-compensated three-stage PWM charging method (boost-equalization-float) is now adjustable to sealed and vented lead-acid batteries. The new version also allows an either SOC or voltage controlled low voltage disconnect function.
The battery status is clearly indicated by three LEDs.
As the first controller on the market in this price range it comes with an acoustic low voltage load disconnect pre-warning feature.

TYPE	CML05	CML08	CML10	CML15	CML20
Max. module current	5A	8A	10A	15A	20A
Max. load current	5A	8A	10A	15A	20A
System voltage	12/24V				
Self power consumption	<4mA				
Dimensions(WxHxD)	80x100x32mm				
Type of protection	IP22				

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Phocos USA
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D-Link®

10/100Mbps Unmanaged Switch

DES-1008D

DES-1008D switch provides 8 auto-sensing 10/100Mbps ports in a palm-sized box. The switch allows mix and match of Ethernet and Fast Ethernet in full- and half-duplex modes.

8-Port 10/100Mbps Switch for SOHO

The DES-1008D is an unmanaged 10/100Mbps switch designed to enhance small workgroup performance while providing a high level of flexibility. Powerful yet easy to use, this device allows users to simply plug any port to either a 10Mbps or 100Mbps network to multiply bandwidths, boost response time and satisfy heavy load demands.

8 Auto-sensing 10/100Mbps Ports

The switch comes with 8 10/100Mbps ports, allowing a small workgroup to flexibly connect to Ethernet ad Fast Ethernet and integrate. These intelligent ports detect the network speed and auto-negotiate between 100BASE-TX and 10BASE-T, as well as between full- and half-duplex.

Flow Control for Secure Transmission

All ports support 802.3x flow control. This function minimizes dropped packets by sending out collision signals when the port's receiving buffer is full. Flow control is available in the full-duplex mode.

Auto-negotiation of MDI/MDIX Cross Over

All ports support auto-negotiation of MDI/MDIX cross over. This eliminates the need for cross over cables or uplink ports. Any port can simply plug to a server, a hub or a switch, using the usual straight-through twisted-pair cable.

SOHO Plug-and-Play

With 8 plug-and-play ports, the switch is a perfect choice for the small workgroup to upgrade performance in a client/server environment. The ports can be connected to servers in full-duplex, or hubs in half-duplex.

Desktop Power

With low-cost connection per-port, the switch can also be set up for direct connection from the PCs. This relieves data bottleneck by giving each workstation a dedicated bandwidth on the network.

Key Features

- *8 10/100Mbps ports*
- *Per-port auto MDI/MDIX*
- *All ports support full/half-duplex, network speed auto-negotiation*
- *Per-port 802.3x flow control for protection against data loss*
- *Auto-learning of network configuration*
- *Secure store-and-forward switching scheme*
- *Auto-correction of reverse twisted-pair polarity*
- *Compact size*

DES-1008D

Technical Specifications

10/100Mbps Unmanaged Switch

General

Standards
- IEEE 802.3 10BASE-T Ethernet
- IEEE 802.3u 100BASE-TX Fast Ethernet
- ANSI/IEEE 802.3 NWay auto-negotiation
- IEEE 802.3x Flow Control

Protocol
CSMA/CD

Data Transfer Rates
- Ethernet:
  10Mbps (half-duplex)
  20Mbps (full-duplex)
- Fast Ethernet:
  100Mbps (half-duplex)
  200Mbps (full-duplex)

Topology
Star

Network Cables
- 10BASE-T:
  UTP Cat. 3, 4, 5 (100 m)
  EIA/TIA-568 STP (100 m)
- 100BASE-TX:
  UTP Cat. 5 (100 m)
  EIA/TIA-5681 STP (100 m)

Number of Ports
10/100Mbps port x 8

Twisted-pair Rx Reverse Polarity
Auto-correction

LED Report
Per device:
- Power
Per port:
100Mbps Link/Activity, 10Mbps Link/Activity

Performance

Transmission Method
Store-and-forward

MAC Address Table
1K entries per device

MAC Address Learning
Automatic update

Buffer Memory
64KBytes per device

Packet Filtering Rates
- 10BASE-T: 14,880 pps per port (half-duplex)
- 100BASE-TX: 148,800 pps per port (half-duplex)

Packet Forwarding Rates
- 10BASE-T: 14,880 pps per port (half-duplex)
- 100BASE-TX: 148,800 pps per port (half-duplex)

Physical & Environmental

Power Input
- AC 9V/1A
- DC 7.5V/1A
- Switching 5V/1.2A

* Different Switch versions are packed with different power adapter

Power Consumption
2 watts

Operating Temperature
0°~50°C

Storage Temperature
-10°~70°C

Operating Humidity
10% ~ 90%

Storage Humidity
5% ~ 90%

Dimensions (W x D x H)
192 x 118 x 32 mm (7.5 x 4.5 x 1.2 inches)

Weight
301 grams

Emission (EMI)
- FCC Class B
- ICES-003 Class B
- CE Class B
- C-Tick Class B
- VCCI Class B

MTBF
116,186 hours

Safty
CUL
CSA International

* Different Switch versions come with different safety standards

ACN 052 202 838

D-Link Worldwide Offices

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Finland	TEL: 358-10 309 8840	FAX: 358-10 309 8841	South Africa	TEL: 27-12-665-2165	FAX: 27-12-665-2186
Italy	TEL: 39-02-2900-0676	FAX: 39-02-2900-1723	Russia	TEL: 7-495-744-0099	FAX: 7-495-744-0099
Spain	TEL: 34 93 409 0770	FAX: 34 93 491 0795	Japan	TEL: 81-3-5781-0963	FAX: 81-3-5781-0965
Portugal	TEL: 351 21 8688493		Korea	TEL: 82-2-890-5491	FAX: 82-2-890-549
Greece	TEL: 30 210 9914 512	FAX: 30 210 9916902	China	TEL: 86-10-58635800	FAX: 86-10-58635799
Czech Republic	TEL: 420 224 247 500		Taiwan	TEL: 886-2-6600-0123	FAX: 886-2-6600-3939
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