STRUCTURAL BAMBOO DESIGN IN EAST AFRICA

by

EVAN T. MYERS

A REPORT

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Approved by:

Major Professor
Kimberly Waggle Kramer, P.E., S.E.

Abstract

This document addresses East Africa's need for safe, sustainable, and affordable housing and promotes use of bamboo as a structural material by providing adequate information and resources to evaluate the strength of bamboo. East African housing is a leading issue for the region because of the population growth, specifically in urban areas where housing resources and infrastructure cannot match the population growth. The solution may be bamboo housing as an alternative to urban slums. The bamboo species *Oxytenanthera abyssinica* is available throughout East Africa region and has been accepted and implemented in traditional housing throughout the region. This document references the resources provided by the International Code Council (ICC), International Organization for Standardizations (ISO), and International Network for Bamboo and Rattan (INBAR) for the use of bamboo as a structural material in buildings. This paper also discusses the mechanical strength of bamboo, and the structural behavior of bamboo in buildings. In addition, bamboo construction shows the tools, connections, and preservatives used in the field. The design example, using *Oxytenanthera abyssinica*, provides the traditional layout and materials for an Amhara house, and calculations show the practicality of bamboo in structural design. This document has led to recommendations for engineers and the bamboo industry, including the development of a codebook for bamboo design, promoting bamboo farms and plantations, creating a uniform connection, and increasing bamboo's service life. From research, bamboo is in need of further development before being considered a viable structural material to provide for commercial use but would suffice for the housing shortage in East Africa.

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List of Abbreviations

Bending .... B

Compression C

Density .... ρ

Effective Length Factor .... K

Length of Member .... ℓ

Radius of Gyration .... r

Shear V

Slenderness ($K\ell/r$) .... λ

Allowable Stress Design .... ASD

American Society for Testing and Materials .... ASTM

American Society of Civil Engineers .... ASCE

International Building Code .... IBC

International Code Council ICC

International Network for Bamboo and Rattan .... INBAR

International Organization for Standardizations .... ISO

Pascal .... Pa (N/m^2)

Peak Ground Acceleration .... PGA

United States Geological Survey .... USGS

Glossary

Bernoulli's Theorem (n.):	flat cross-sections remain flat
Buckling (n.):	instability in a slender column under axial loads
Culm (n.):	main portion of bamboo member
Drawing Details (n.):	an illustration used to describe construction components and assembly
Hectare (n.):	one thousand square meters
Joint (n.):	connection between two or more structural elements
Mega (prefix):	one million (10^6)
Node (n.):	region in bamboo culm where branches sprout and a diaphragm forms inside the culm
Ultimate Limit States (n.):	associated with collapse or other forms of structural failure, which may endanger the safety of people such as deformations
Serviceability Limit States (n.):	associated with states beyond which the specified service criteria such as deflections are no longer met
Service Life (n.):	length of time the building is used for its intended purpose

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I want to recognize Professor Kimberly Kramer for her guidance, inspiration, and care. For this, I owe Kimberly a great deal; she is the epitome of a great professor. Kimberly, thank you for your hard work and dedication to students and structural engineering.

Dedication

I dedicate this to my Lord and Savior, Jesus Christ, who has given me the strength to finish well. The verse below has continued to resound in my life.

> Whatever you do, work at it with all your heart, as working for the Lord, not for men, since you know that you will receive an inheritance from the Lord, as a reward. It is the Lord Christ you are serving. Colossians 3:23-24

I also dedicate this to my parents, Kevin and Cheryl Myers, who have continually supported my endeavors. I love you and it is an honor to be your son. As the Lord has allowed me to stand, you have allowed me to walk.

Chapter 1 - Introduction

This report addresses East Africa's need for safe, sustainable, and affordable housing and aims to increase awareness of bamboo as a structural material. East African housing is a regional issue because of the population growth, specifically in urban areas where housing resources and infrastructure cannot match the population growth. Bamboo housing may provide an alternative to urban slums, and the bamboo species *Oxytenanthera abyssinica* is available throughout East Africa and along with other species, has been accepted and implemented in traditional, rural housing throughout the region.

This report investigates bamboo manuals and technical information, mechanical properties, and behavior to determine and promote bamboo feasibility as a structural material. Manuals for bamboo include the International Code Council's (ICC) *Acceptance Criteria* and International Organization for Standardizations (ISO) 22156, which provide information on testing, equations, and general considerations for the use of bamboo as a structural material. Empirical design provides an introduction to basic guidelines and equations for preliminary guidance in design of bamboo structures. Bamboo's mechanical properties show quantitative strength and qualitative behavior of the material, in general and for the species *Oxytenanthera abyssinica*, used for the design example in this report. For bamboo, P-δ effects and seismic activity have an impact on the structural design and are discussed in order to develop an understanding of bamboo structural behavior and performance. Thus, technical information, mechanical properties, and behavior indicate bamboo's ability as a structural material to adequately support a building.

Bamboo construction, the bamboo design example, and recommendations develop bamboo's feasibility for structural design and construction. Bamboo requires an understanding of its physical make-up and construction in order to safely design a structure. The bamboo design example reveals difficulties and capabilities of bamboo structural design. The aforementioned items are used to evaluate bamboo's feasibility as a structural material.

Chapter 2 - East Africa and Bamboo

This chapter discusses the need for housing in East Africa and the availability and acceptance of bamboo in that region. This section also explains the goal of this document, to promote bamboo as a structural material. East Africa's need for housing continues to rise because of an exploding population and little means to provide housing. The availability and acceptance of bamboo in East Africa is discussed in order to determine the feasibility of structural bamboo design.

Need for Housing in East Africa

International Network for Bamboo and Rattan (INBAR) has developed several documents that address the housing problem in East Africa. Housing issues in East Africa are a result of the population explosion, unaffordable housing, and inability of the housing supply to (Kibwage, Frith, and Paudel, 2011). Shyam Paudel, author of several INBAR documents, has determined slums are an issue due to the current rate of urbanization and the population growth rate (Paudel, 2011). These slums are dangerous for the people living in the area because of overcrowding, inadequate care, and underdevelopment. Ethiopia is the model country in East Africa for the current housing crisis where approximately 85% of the urban population lives in unsatisfactory conditions. These poor living conditions need addressed or will worsen as the expected rate of population growth and urbanization increase in Ethiopia (Kibwage et al., 2011). The issue with housing in East Africa requires a solution; bamboo could provide a safe, sustainable, and cost-effective option as a structural material for housing. East Africa must decrease the housing deficit and provide housing that promotes care and cleanliness.

Availability and Acceptance

A region's availability and acceptance of a material dictates usage in that region. Availability is the measure of how easily accessible the commodity is in the region; acceptance, in this case, is the willingness to use the material. An available and accepted resource can minimize transportation costs that otherwise negate benefits of an alternative material over other local materials. Availability and acceptance of bamboo must be identified in order to determine the feasibility of bamboo as a structural material in East Africa.

As previously determined by researchers, three percent of the world's bamboo grows in Africa (van der Lugt, Dobbelsteen, & Janssen, 2006; Adams, 1997). Bamboo grows in the highlands and lowlands of the East African region, and the country of Ethiopia has 850,000 hectares of the lowland bamboo species *Oxytenanthera abyssinica*. A hectare is one thousand square meters and equal to 2.47 acres. Therefore, Ethiopia has a resource of *Oxytenanthera abyssinica* that would cover 10% of the state of Kansas (*Kansas*, 2010). *Oxytenanthera abyssinica* is available throughout eastern and western Africa, in a variety of environments (United Nations Industrial Development Organization [UNIDO],2009). *Oxytenanthera abyssinica* thrives in East Africa from Ethiopia to Malawi, Zambia, and Zimbabwe (UNIDO, 2009).

Although bamboo is widely available in East Africa, overuse has become an issue in the regional bamboo industry for several years. Overuse of bamboo has caused the establishment of organizations, such as the East African Bamboo Project (EABP) and INBAR, in the region in order to facilitate growth in the bamboo population after years of depletion (Ababa, 2012). Availability of bamboo will continue with programs and farms to encourage its growth in East Africa.

The acceptance of bamboo as a structural material in East Africa is evident through its use in indigenous and low-income housing. Bamboo housing in East Africa is not engineered, but highly refined due to the tradition of building with bamboo in the region (Kibwage et al., 2011). Thus, the acceptance of bamboo in the East African culture has been established through tradition but has not infiltrated the middle and upper-class because of the negative connotation towards bamboo, known as the "poor man's" material. The ability to integrate engineering and traditional practices will beneficially remove the cultural stigma towards bamboo and allow for the design of safe, affordable, and sustainable bamboo structures in East Africa.

Chapter 3 - Bamboo as a Structural Material

In this section, design provisions, mechanical properties, and bamboo behavior are discussed in order to develop the feasibility of bamboo as a structural material. These topics provide a brief overview of structural bamboo design. Bamboo is used in a variety of applications for structural purposes, ranging from indigenous housing to commercial buildings. A summary of the design provisions is included, providing guidance for structural engineers guidance while working with bamboo. Bamboo's mechanical properties discussed are based on testing of a variety of species and specifically, the species *Oxytenanthera abyssinica*. In addition, general failure modes of bamboo are discussed, and bamboo structural behavior is analyzed to determine bamboo performance during extreme load cases.

Design Provisions

Technical documents describe the benefits, uses, and equations for structural materials. A structural codebook for bamboo does not exist, but the first manual for bamboo design was published in 2000 with the ICC's technical document titled *Acceptance Criteria for Structural Bamboo*, and the second in 2001 with the ISO's document *Bamboo Structural Design (ISO 22156)*. The ICC's document defines codes and references to use during structural bamboo design and procedures for testing. The ISO document, referred to as ISO 22156, was created to centralize the suggestions of researchers. ISO 22156 is not an international standard, but a step in the recognition of bamboo by other agencies as a structural material and creation of a codebook for design. ISO 22156 has suggestions for design and drawing details to provide adequate guidance essential for proper bamboo structural design. ISO 22156 is summarized to increase understanding of requirements for designing bamboo structures.

Traditional knowledge can provide adequate design of bamboo structures, but structural engineering occurs when the engineer verifies the loads on a building and executes a safe, affordable, and sustainable design. Generally, a material has a codebook governing the structural design, which has information regarding equations, detail guidelines, and construction practices. Bamboo has a manual of guidelines, ISO 22156, and empirical design criteria to accommodate quality design practice but requires the development of a codebook to become a relevant structural material.

Acceptance Criteria

The ICC document *Acceptance Criteria for Structural Bamboo* provides codes and references to use while designing bamboo structures, including the International Building Code (IBC), INBAR, and several American Society for Testing and Materials (ASTM) documents. The document primarily discusses bamboo testing and how to accurately perform tests. The ICC document also provides equations to determine allowable stresses considering factors in design such as the Load Duration and Adjustment Factors and Safety Factor in Allowable Stress Design (ASD) (International Code Council [ICC], 2012). These equations were not used in the design example because they are less conservative than the INBAR equations.

ISO 22156

ISO 22156 is based on limit state design and bamboo structural performance. It includes requirements for mechanical resistance, serviceability, and durability of structures (International Organization for Standardization [ISO], 2001). The ISO document does not develop specific requirements for bamboo structural design but introduces generalities to promote safe and quality design.

A bamboo structure must serve the intended purpose of the building with regard to service life, cost, and durability. Damage incurred by events such as explosions, impacts, extreme weather, or consequences of human error must be proportional to the event and not greater. Potential damage from the aforementioned events must be mitigated by one of the following strategies in the structural design:

- Decreasing the likelihood of hazards.
- Providing a form with a high degree of resistance to hazards.
- Transferring forces when accidental removal of an element occurs.
- Retaining continuity.

Bamboo construction concepts are based on calculations, knowledge from previous generations, and reports. General calculations are discussed in the empirical design section and further calculations are shown in **Appendix A**. ISO 22156 defines standard requirements as, "Experience from previous generations, well preserved in a local tradition, and carefully transmitted to people living today. This expertise can be considered as an informal, non-codified 'standard.'" Design and construction practices must be generally known, accepted, and viewed as wisdom by the local authority. ISO 22156 defines applicable cases as those in which, "The community shall be characterized by an undisturbed social structure, with a well-recognized social pattern." These practices are not valid after the community migrates, unless applied in comparable conditions.

Disaster reports of quantitative magnitude that analyze successful bamboo structures with full details and information may be applied to similar instances in the future. ISO 22156 requires the disaster report receive recognition from engineers with experience in bamboo structural design and the international technical community in order to verify the report's accuracy and reliability.

Design requirements include checking all limit states and load cases. An accurate design model must be created to perform calculations, and the limit states and load cases must comply with national standards. For design purposes, bamboo culms are tapered, hollow tubes with differing thickness and minimal eccentricity. In bamboo design, the structural engineer should treat joints or supports as hinges, use conventional structural analysis, use Bernoulli's theorem, and use Euler's buckling.

Air-dried bamboo must be used for construction with the structure designed and detailed in such a way as to keep the bamboo dry and allow wet bamboo to dry. This measure protects bamboo from deteriorating and developing structural inadequacies in-situ. The construction process shall be monitored to verify assumptions made during the design phase and validate the design as sufficient. All bamboo projects must meet these requirements with adequate specifications, detailing, production, construction, and compliance with ISO 22156 (ISO, 2001).

This description of ISO 22156 refers to key points for design and construction of structural bamboo. The document is purely descriptive, not prescriptive in the guidelines and does not provide values or equations for the design process.

Empirical Design

Several empirical design criteria and guidelines for bamboo structures have been developed in order to use bamboo in structural design. The empirical design criteria for bamboo strength require the density of the species analyzed (Janssen, 2000). The equations below pertain to air-dried bamboo in compression (C), bending (B), shear (V), modulus of elasticity (E), slenderness (λ), and deflection (δ). These equations relate to the density (ρ in kg/m^3) and safety factor (Ω) for allowable stresses ($MPa=N/mm^2$). These equations are used when the mechanical properties are unknown.

$C=0.094\rho$	(1)	$C_{ALLOWABLE}=0.094\rho/\Omega$	(2)
$B=0.14\rho$	(3)	$B_{ALLOWABLE}=0.14\rho/\Omega$	(4)
$V=0.021\rho$	(5)	$V_{ALLOWABLE}=0.021\rho/\Omega$	(6)
$E=24\rho$	(7)	$\lambda=K\ell/r \leq 50$	(8)
$\delta_{max}=\ell/300$	(9)		

The determined compression, bending, and shear stresses are the primary stresses a bamboo member experiences in application. Tension stresses must also be considered in design; thus, an equation is necessary to determine allowable tension stresses for structural bamboo design. The modulus of elasticity, slenderness, and deflection also contribute to the structural design and can be attributed to the limit states involved.

Allowable stresses are the calculated stresses divided by the safety factor. Research by Dr. Jules Janssen's indicates that the safety factor varies based upon testing quality and load-cases in order to account for the variance in bamboo culm diameter, thickness, degradation, and eccentricity (Janssen, 2000). The safety factor provides a conservative design approach for structural bamboo applications, and the equation presented by Dr. Janssen directly mirrors the ICC's allowable stress equation but has more conservative coefficients. The deflection guideline defined by Janssen in *The Fundamentals of Bamboo* is $\delta_{max}=\ell/300$, consequently preventing the designed members from experiencing extreme deformation and bending and allowing for continued serviceability of bamboo structures and their components (Janssen, 2000).

The empirical design criteria provide a baseline for structural engineers to begin designing bamboo structures. These calculations allow engineers to produce a proposal before conducting formal testing on the specified bamboo species. The empirical design criteria do not replace or neglect the significance of quantitative mechanical properties determined from testing because without these properties, the engineer cannot accurately design a structure. However, these empirical design criteria provide further documentation of design parameters and equations. Again, the next step for the bamboo industry is to provide a codebook or reference manual for structural design.

Mechanical Properties

Mechanical properties of bamboo vary depending on the analyzed species, therefore this section considers bamboo's mechanical properties, specifically *Oxytenanthera abyssinica's* mechanical properties. Properties required for structural design and applications include tension, compression, bending, shear, and the modulus of elasticity. These mechanical properties provide the framework for bamboo's implementation in structural design. Mechanical properties, general properties, and failures are discussed in order to more fully understand bamboo behavior.

Oxytenanthera abyssinica has a density of 778 kg/m^3, a height ranging from five to fifteen meters, a diameter of three to ten centimeters, and intermodal lengths of fifteen to forty centimeters (Didier, Ngapgue, Mpessa, & Tatietse, 2012; Inada & Hall, 2008). *Oxytenanthera abyssinica* is defined as a solid bamboo with a completely solid base and nearly solid above the base (Kitil Farm, UNIDO, 2009). Since mechanical properties are dependent on the cross-sectional area of the culm, the average diameter and wall thickness are required for design and will be discussed for the design example. *Oxytenanthera abyssinica* test results provide quantitative data for the mechanical properties. From Inada and Hall's technical document, the mechanical properties for *Oxytenanthera abyssinica* were determined at 47% moisture content, which is high for structural applications (Inada & Hall, 2008). Additional test results were used from Markos Alitos' research on *Oxytenanthera abyssinica*; thus, the most conservative value was taken for each mechanical property.

Tension

Tension forces are experienced in a variety of structural members, beams, truss-members, and others. All species of bamboo have high tensile strength, but bamboo has an advantage over other structural materials because of its dual strength in tension and compression (Trujillo, 2009). Thus, structural bamboo design must utilize the tensile strength of bamboo. The general tensile strength range is 35-230 MPa, and O*xytenanthera abyssinica*'s tensile strength is 127 MPa (Arce-Villalobos, 1993; Bhalla, 2008; Janssen, 2000; Kassa, 2009; Yu, Chung, & Chan, 2003; Alito, 2005).

Many parameters affect the tensile strength, including node placement, age, and moisture content. Based on Arce-Villalobos' research, tensile strength at the nodes is 80% of the tensile strength at the internodes (Arce-Villalobos, 1993). Peak tensile strength occurs from age three to four of the culm (Arce-Villalobos, 1993). The moisture content of the bamboo culm can dramatically impact the tensile strength of the bamboo, decreasing it by half in extreme cases (Yu & Chung, 2002). A brittle failure occurs in bamboo under tension, affecting design because engineers prefer members and systems to fail in a ductile manner (Arce-Villalobos, 1993).

Compression

The compressive strength of bamboo allows structural engineers to design columns, truss-members, and other compression members in bamboo structures. The general compressive strength parallel to bamboo's grain ranges from 27-176 MPa, with a majority of species' testing around 60 MPa (Arce-Villalobos, 1993; Bhalla, 2008; Sharma, 2011; Yu, Chung, & Chan, 2003). The compression strength of *Oxytenanthera abyssinica* is 40 MPa (Alito, 2005). Bamboo compressive strength increases with age, while nodes and moisture content do not affect compressive strength (Arce-Villalobos, 1993). Although *Oxytenanthera abyssinica* has a lower compressive strength, P-δ effects generally govern the structural design of bamboo compression members.

Failure modes for compression are splitting and end bearing. **Figure 3.1** shows splitting in a test specimen (Yu & Chung, 2002). Splitting is the primary failure mode for bamboo in a majority of load cases. In Chung and Yu's testing of the species *Bambusa pervariabilis* and *Phyllostachys pubescens*, most specimen's failed in end bearing resulting in crushing. This plays a key role in connection design, as discussed in **Chapter 4**.

Figure 3.1 Compression Failure Modes

(Reproduced from K.F. Chung and W.K. Yu's *Mechanical properties of structural bamboo for bamboo scaffoldings*)

Splitting occurs in bamboo because of tangential stresses induced by the circular shape of the bamboo culm (Arce-Villalobos, 1993). These stresses govern a majority of failures in bamboo, especially in compression members because bamboo is weak in perpendicular compression and tension (Trujillo, 2009). When maximum tangential stress is reached within the culm fibers, longitudinal splitting of the culm occurs. Maximum tangential strength is determined by bamboo's tangential modulus of elasticity, which is approximately one-eighth of the longitudinal modulus; for O*xytenanthera abyssinica* the tangential strength is 1827 MPa (Arce-Villalobos, 1993; Didier et al., 2012).

Arce-Villalobos found a majority axial stresses in bamboo culms are distributed to the outermost rings due to axial stiffness increasing from the inside to outside of the culm, as shown in **Detail A** of **Figure 3.2**. The distribution of axial stresses creates radial bending moments in the culm, as the outermost layers are in compression and the innermost layers are in tension as shown in **Detail B** of **Figure 3.2**. Compression on the outermost rings will force the culm to expand to the failure as shown in **Detail C** of **Figure 3.2**; when longitudinal cracking commences. Cracking may occur around the ring of the culm because of movement and interaction of the outermost and innermost rings (Arce-Villalobos, 1993). Yet, O*xytenanthera abyssinica* is less susceptible to these stress concentrations because of its solid form, assuming minimal eccentricity (UNIDO, 2009).

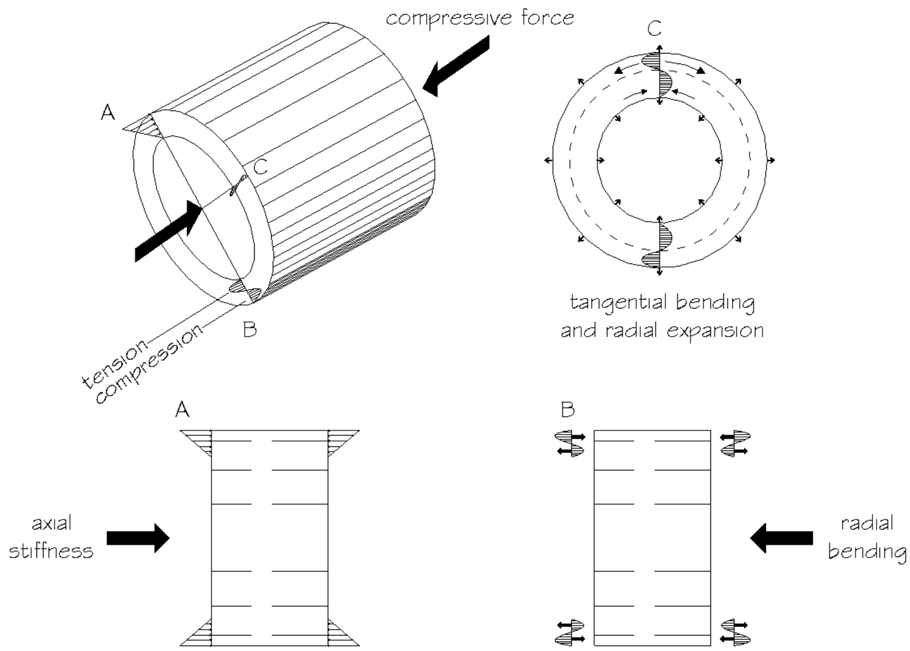


Figure 3.2 Governing Failure Mode

(Reproduced based upon figure in Arce-Villalobos' *Fundamentals of the Design of Bamboo Structures)*

Bending & Shear

Bamboo bending strength is critical to determine member size and span length. Bending strength of a bamboo member can be determined by the span. Shear governs for short members, and pure bending governs for long members, generally depending on load intensity, strength of the species, and span. Bending strength can be compromised because of stresses producing strain, which have a critical value of $1.1x10^{-3}$ for bamboo. The average tested bending strength of bamboo is 62 MPa (Janssen, 2000). The modulus of rupture indicates the ultimate strength of the a bamboo culm in bending, and *Oxytenanthera abyssinica's* modulus of rupture is 82 MPa and shear strength is 11 MPa (Inada & Hall, 2008; Ahmad, 2000; Sharma, 2011).

Bamboo failure modes for bending are local crushing and splitting (Yu & Chung, 2002; Janssen, 2000). For Chung and Yu's research, local crushing was a failure mode because the researchers carried out a single-point load bending test at the mid-point, instead of a three or four point bending test. Although the worst-case scenario, a single-point load will not occur often in application unless prescribed by the engineer. The typical failure mode for bending is splitting with the culm separating into four quarters, similar to **Figure 3.1** (Janssen, 2000).

Modulus of Elasticity

The modulus of elasticity of bamboo is significant because it indicates bamboo's flexibility and behavior. The modulus of elasticity helps predict the culm's change in length based on axial loading in tension or compression, and the modulus of elasticity is used to determine member deflection. The modulus of elasticity for tested bamboo species ranges from 2113-22000 MPa (Sharma, 2011; Yu, Chung, & Chan, 2003). INBAR conducted a study which found that the modulus of elasticity for air-dried bamboo can be estimated as twenty-four times the bamboo density, $E=24\rho$ (Janssen, 2000). Therefore, *Oxytenanthera abyssinica*'s modulus of elasticity could be taken as 18672 MPa ($\rho=778$ kg/m^3), but the tested modulus of elasticity for *Oxytenanthera abyssinica* is 14617 MPa (Didier et al., 2012). Thus, structural engineers should use the latter value in design because the value is determined from testing and more conservative. 14617 MPa for the modulus of elasticity indicates *Oxytenanthera abyssinica* has a high resistance to deflection compared to other bamboo species yet provides flexibility (Ahmad, 2000).

General Properties and Failures

General properties and failures of bamboo in design include the inherent variation of culms and buckling. Culm variation contributes to the difficulty of designing bamboo structures and obtaining accurate quantitative data. Bamboo is weak because of variation in the cross-section, which can substantially impact the bending and axial stiffness of the culm (Arce-Villalobos, 1993). Buckling occurs in bamboo culms because of bamboo culm's slenderness and curvature (Yu et al., 2003). Both qualities are avoidable through quality control and design checks throughout the design and construction process.

Behavior

Bamboo behavior depends on mechanical properties discussed in the previous section. P-δ effects and seismic behavior provide insight into the mechanical properties and performance of bamboo. These two behaviors can initiate complete failures of a structure if not accounted for in the design process. Thus, behavior of bamboo through P-δ effects and seismic events are paramount to understanding and safely designing bamboo structures.

P-δ Effects

P-δ effects are secondary forces induced by initial eccentricity of a structural member and increase with increased axial loading. These secondary forces create additional bending stresses within the structural member experiencing the effects, thus creating instabilities leading to failure. Member slenderness contributes to P-δ effects because slenderness correlates with the member's ability to resist P-δ effects. The approach for resisting P-δ effects differs based on the structural material used by the engineer because mechanical properties influence material behavior during P-δ effects (Kramer, 2011).

P-δ effects create bending stresses and can negate the compressive strength of bamboo (Arce-Villalobos, 1993). P-δ effects occur in bamboo because of initial eccentricity of the culm, and P-δ effects can detrimentally impact the integrity of bamboo structural members because of bamboo's flexibility. Bamboo has a tendency to buckle during P-δ effects due to the slenderness of the culms. Thus, bamboo member's maximum slenderness ratio is 50 or less ($\lambda \leq 50$) to avoid significant P-δ effects. Nodes within the culms weaken the structural integrity of the member in bending, but decrease the effect of buckling (Arce-Villalobos, 1993). Since creep is negligible in bamboo, initial P-δ effects of a member are not magnified (Janssen, 2000). Bamboo's flexibility and strength combination make initial deflection critical in design, but proper bracing design and details can decrease the impact of P-δ effects.

Buckling, due to P-δ effects, is a significant consideration in structural bamboo design. The Euler buckling equation can be used for structural bamboo, which is similar to the Euler buckling equation for materials such as steel and wood. (Janssen, 2000). Arce-Villalobos determined the following assumptions to be adequate for buckling analysis of bamboo (Arce-Villalobos, 1993):

1. The cross-section of the culm is a circular ring with a constant diameter and wall thickness.
2. The modulus of elasticity in the x-direction along the element is constant.
3. The angular modulus of elasticity is constant.
4. Deformations in bamboo are small.
5. Material is perfectly elastic.

These assumptions provide a basis for determining the stability of bamboo structural members and simplify the culm's complexity, and these assumptions are appropriate with the use of conservative design values.

Seismic

Seismic performance of structures in East Africa warrants consideration because of the high degree of seismic activity in the region. **Figure 3.3** shows East African seismic activity and the intensity of this activity ranging from minimal to destructive, based on the Modified Mercalli Scale (*The Modified Mercalli Intensity Scale*). This section explains two seismic measuring systems and then briefly two seismic events in which bamboo structures performed in a pristine manner. The attributes contributing to bamboo's success during seismic events are listed in order to encourage the consideration of bamboo as a structural material.

The Modified Mercalli Scale shown in **Figure 3.3** is defined as a scale measuring magnitude of seismic events in relation to event effects. For example, few people at rest feel a Degree II seismic event, but during a Degree VIII seismic event, ordinarily designed structures experience extensive damage and seismically designed structures experience slight damage or partially collapse, in addition to overturning of heavy furniture (*The Modified Mercalli Intensity Scale*). Degree VIII governs for East Africa and was considered in the design example because as engineers, we must design for the worst-case scenario for the location.

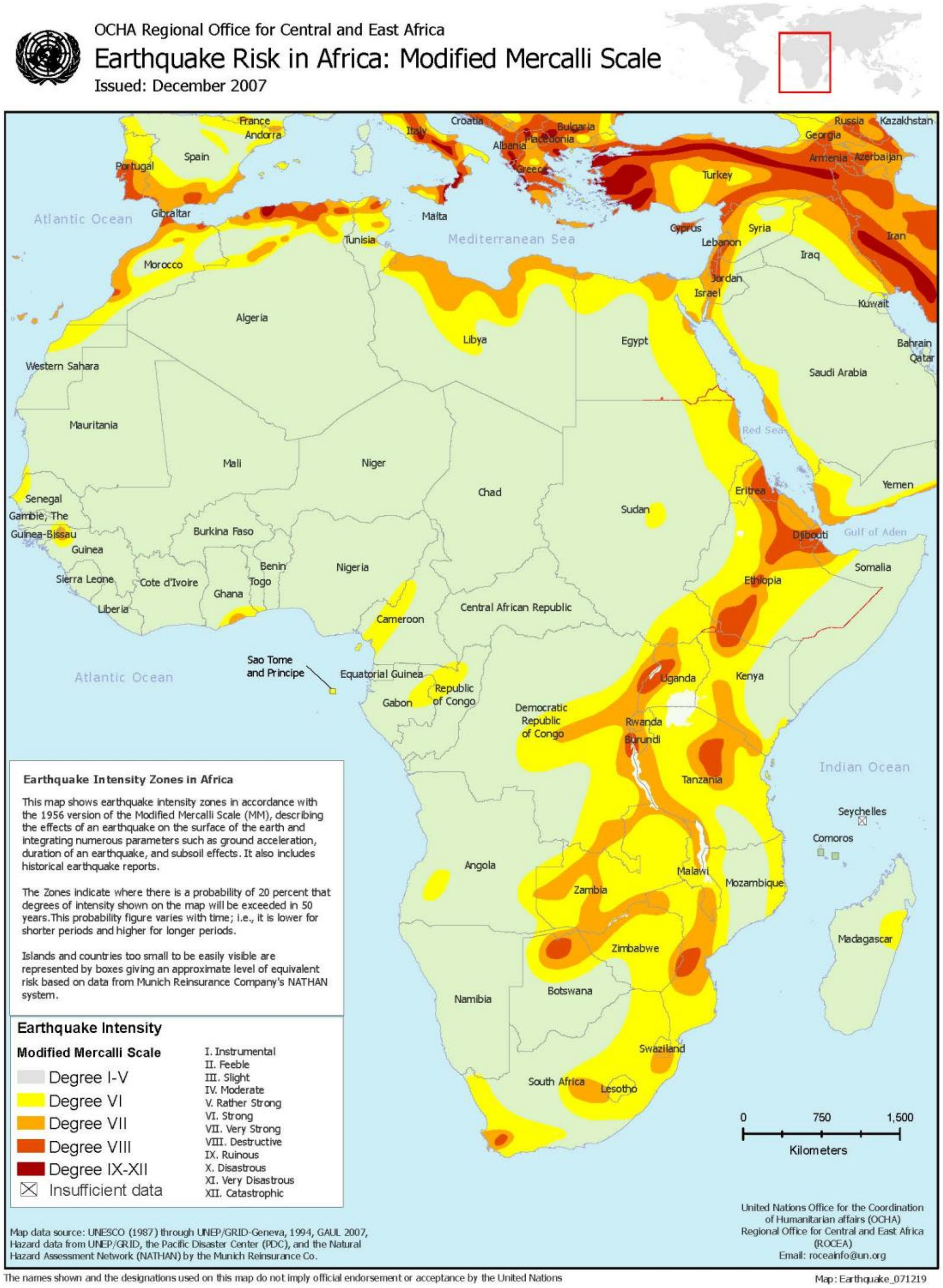


Figure 3.3 Modified Mercalli Scale for Seismic Activity in East Africa

(Reproduced from the United Nations Office for the Coordination of Humanitarian Affairs' [OCHA] *Earthquake Risk in Africa: Modified Mercalli Scale*)

The Richter Scale is another technique to substantiate a seismic event through quantitative results. The Richter Scale logarithmically measures the size of an earthquake comparatively to past earthquakes based on seismograph readings taken during the earthquake and translated to a Richter Scale magnitude. The Richter Scale determines magnitude based on seismograph readings, not damage (*The Richter Magnitude Scale*).

In design, structural engineers use the spectral response acceleration to determine the forces experienced by a structure. The spectral response acceleration is derived from ASCE 7-10 based on data taken from past events at the project location. In the United States, ASCE 7-10 provides spectral response acceleration and equations for seismic design with a 2% probability of being exceeded in fifty years. Thus, a severe earthquake's maximum peak ground acceleration (PGA) will exceed the design capacity for the structure and may produce localized failures within a structure.

Several studies reveal the impact of seismic loading on bamboo structures. The performance of a bamboo structure under seismic loading contributes to the degree of safety of the occupants, sustainability, and economics of the structure. **Figures 3.4** shows bamboo performance during the 2006 Sikkim earthquake in India, which was a 5.7 magnitude event on the Richter Scale with a maximum peak ground acceleration of 0.036g. As noted in the caption, this bamboo structure was undamaged from the earthquake (Sharma, 2011; *Shakemap usjdae_06: Peak Ground Acceleration*, 2006). **Figure 3.4** provides an example of bamboo's stability and strength during seismic loading (Janssen, 2000).

Figure 3.4 Undamaged Bamboo Structure

(Reproduced from Bhavna Sharma's Doctoral Dissertation, *Seismic Performance of Bamboo Structures*)

During a 1991 Costa Rican earthquake of 7.5 magnitude on the Richter Scale (maximum PGA of 0.27g), twenty houses made of bamboo located near the epicenter of the earthquake were undamaged, testifying to bamboo's flexibility and ductility as a structural system (Janssen, 2000; National Commission for Risk Prevention and Response [CNE]). These two examples demonstrate bamboo performance in seismic activity and encourage further exploration of bamboo as a structural material. Further data and testing performed on bamboo shows that it has the ability to safely dissipate seismic forces without damage to the structure (Janssen, 2000).

Bamboo has many mechanical properties allowing it to dissipate forces from seismic activity. Bamboo strength, stiffness, and flexibility allow for safe structural performance during seismic events, as seen in **Figure 3.4** (Janssen, 2000). The low-weight of bamboo contributes to its success because of the contribution of building weight to forces accruing in the structure during seismic activity, thus reinforcing the process in ASCE 7-10 to calculate forces from a seismic event on a structure. Continued use of bamboo structures is advantageous after seismic events because they do not require extensive repairs compared to other structural materials. This provides long-term cost savings for bamboo houses in regions of the world, such as East Africa, where poverty-stricken people cannot afford to replace their homes after natural disasters.

Chapter 4 - Bamboo Construction

This chapter briefly examines the tools, connections, and preservatives used in bamboo construction. Construction of structural bamboo houses influences design of bamboo structures. Thus, the construction process must be understood in order to design an effective structure. Tools and connections to execute construction and stabilize structures are essential for bamboo construction because both of these items impact construction with their influence on efficiency, time, and capabilities of the construction crew. Tools used for construction indicate complexity of construction and skill needed for labor. Connections contribute to the structural integrity of the building, making them pertinent to the structural engineer. Preservatives extend the service life of bamboo; the various preservatives for treating bamboo are discussed in this section. Although construction entails many facets, this section focuses on contributors to structural bamboo design, tools, connections, and preservatives. Construction practices would require a separate document due to the variance in construction practices across the globe. Therefore, specific construction practices are not covered in this research.

Tools

Construction begins and ends with tools used throughout the process. Effective use of tools during construction determines the timeline and cost of a project. The difficulty of working with round culms of bamboo has limited the types of tools used during bamboo construction. Tools used for construction of bamboo housing are shown in **Figure 4.1**. A variety of hand tools and power tools are used in bamboo construction and suffice in completing the needed tasks. However, tools used in bamboo construction are the most rudimentary of all building materials because of the simple techniques of bamboo construction and traditions of bamboo structures.

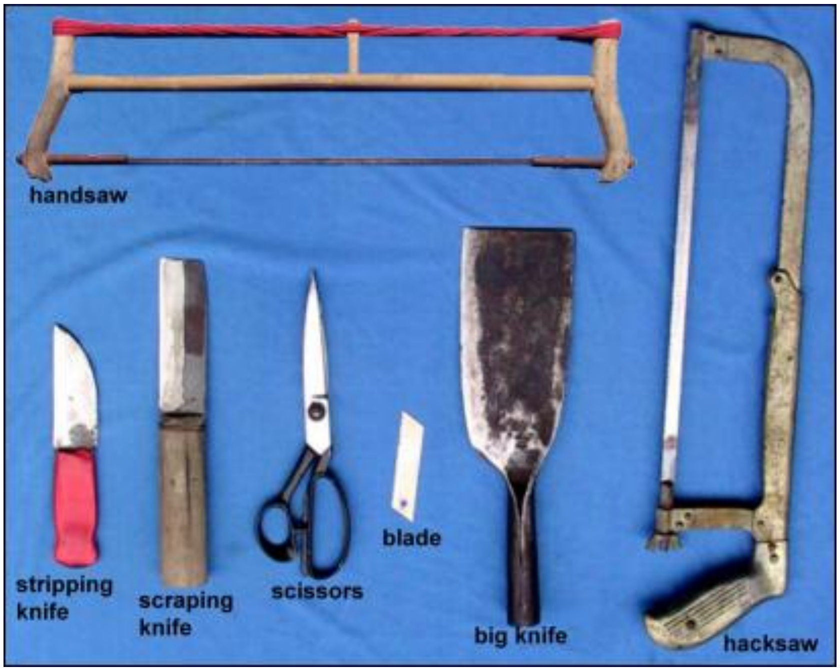


Figure 4.1 Tools for Bamboo Construction

(Reproduced from the United Nations Industrial Development Organization *Cottage Industry Manuals: Raw Materials and Tools for Bamboo Applications*)

Tools shown in **Figure 4.1** and presented by the United Nations Industrial Development Organization (UNIDO) and Kassa include the following hand and power tools:

- Carving Tool
- Chisel
- Chopping Knife
- Drill
- Drill Bits
- Nail Gun
- Planer
- Pliers
- Rotary Saw
- Saw
- Hacksaw
- Hand Drill
- Handsaw
- Jig Saw
- Ladder
- Saw Horses and Jigs
- Scissors
- Scraping Knife
- Shaping Knife
- Torch

(UNIDO, 2008; Kassa, 2009)

Although not an exhaustive list, the tools shown are examples of common tools used for bamboo construction. These tools require limited training, thus enlarging the market of available workers and allowing for a swift transfer of knowledge between parties in the construction process. The simplicity of these tools also provides high constructability because they do not require a high skill level in order to be utilized.

New tools will eventually be used in bamboo construction, but the market for bamboo construction has determined the type of tools used. Since bamboo is largely used in poor, rural regions of East Africa, the tools associated with bamboo construction are simple, inexpensive, and readily accessible. New technology will become a part of bamboo construction if bamboo becomes a widely-used material in all cultures, climates, and classes.

Connections

Structural connections strive to create continuity between bamboo culms and verify that failure of the structure occurs in bamboo members and not in connections (Arce-Villalobos, 1993). The inherent variance of bamboo creates a multiplicity of connections for structural bamboo design. Many bamboo connections provide a way to transfer loads out of the culm and into another element, and connections used are lashings, steel wires, nails, bolts, pins, clamps, glued-wood fittings, grout fills, and proprietary connections (Janssen, 2000; Arce-Villalobos, 1993; *Construction with Bamboo-Bamboo Connection*). The number of connections allows flexibility for structural engineers to implement a connection for a project that effectively supplements the rest of the bamboo structure.

A successful connection affects the economy, rigidity, and structural continuity; thus, these items must influence structural design. Many connections discussed in this section have a practical niche, but in order for bamboo to become an internationally recognized material, several quality connections must be developed. Research has shown that two connections, the glued-wood fitting and grout-filled with rebar connection, are practical for most conceivable situations. Common connections in bamboo design are presented in this section with a brief overview of alternatives in bamboo connections including lashings, nails, bolts, and pins. The glued-wood fitting and grout fill with rebar connections are also examined.

Lashings are traditional connections in bamboo design and demonstrate a natural beauty and flexibility. Natural materials used in lashings include cain, coir, vines, sisal fiber, bark, bamboo strips, and rattan (Socrates; Janssen, 2000). In general, lashings are made from wet, green strips of bamboo because as strips dry, they shrink and tighten the connection, increasing strength (Socrates). The versatility of lashings allows them to be used in numerous situations because of the free-flowing nature of the connection. However, lashings cannot be checked quantitatively due to their variance in craftsmanship and strength (Janssen, 2000). The two pictures in **Figure 4.2** indicate the vast difference in lashing quality, reinforcing why lashings are not practical as a stand-alone connection. Additional lashing connections can be viewed in **Appendix B**.

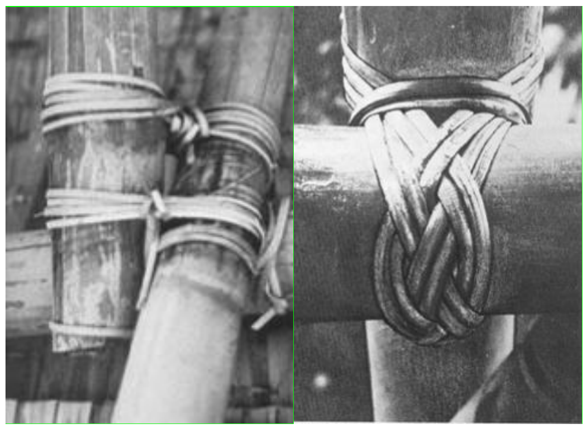


Figure 4.2 Lashing Connections

(Reproduced from Nicholas Socrates' *Bamboo Construction*)

Steel wire is a newer development in lashing connection for bamboo, but steel wire has difficulty fitting tightly to bamboo and transferring forces through tension. Thus, a wire-lacing tool has been invented to assist in wrapping wire around the bamboo, but this method and product have not been widely used in bamboo design (Arce-Villalobos, 1993; Janssen, 2000). Other materials used as lashing include plastic tape and rope.

Although lashing is a popular connection, it does not provide adequate stiffness for structural bamboo design. Lashing connections allow significant displacement because the lashing does not adequately hold the culm, and if green bamboo is used, the culm shrinks and moves (Arce-Villalobos, 1993). In addition, the variability of lashing connections diminishes the ability to verify the strength and adequacy of the field connection. Thus, lashing connections are not feasible for structural bamboo design (Janssen, 2000).

Nail, bolt, and pin connections are frequently used in structural bamboo because they provide a simple means to connect the culms. These connections are not preferred in bamboo structures because they induce splitting in the culm and are not versatile (Socrates). Bamboo culms are damaged and cracked from drilling, causing early splitting that leads to failure. Pre-drilling holes in order to place the bolts and pins can prevent splitting, but nails, bolts, and pins are not versatile connections because they only suffice for situations with two culms and do not provide adequate transfer of forces (Janssen, 2000). **Appendix B** provides examples of nail, bolt, and pin connections.

Additional connections are not discussed due to the limitations of this section, but **Appendix B** has information on additional connections. Connections range from PVC fittings, combination connections with pins and lashings, threaded bolts, cable-tie mounts, adhesives, and clamps. These connections cannot be considered in structural bamboo applications because of expense, labor costs, load transfer, or durability.

The glued-wood fitting and grout-filled connection with steel rebar were chosen based on several parameters, including Arce-Villalobos keys to a successful connection (Arce- Villalobos, 1993):

1. Avoid penetration by nails, screws, or bolts.
2. Avoid open ends.
3. Solve the problem of size variability.
4. Transfer forces by axially distributing them to the fiber of the culm.

The glued-wood fitting and grout-filled with steel rebar connection satisfy these suggestions and may increase bamboo's viability as an internationally recognized structural material. Although bamboo varies in shape, size, and thickness, the glued-wood fitting and grout-filled with steel rebar connection have the flexibility to accommodate changing characteristics.

The glued-wood fitting connection could improve uniformity of structural bamboo design and has gained popularity due to its success, as it is placed within the cavity of the culm to create a structural continuous connection (Arce-Villalobos, 1993; Janssen, 2000). Glue testing has shown that "normal" glue provides a higher strength than the bamboo culm due to the culm's weakness in the tangential direction (Socrates). Thus, the glued-wood fitting is adequate and should not incite failure of the bamboo structure. **Figure 4.3** illustrates a glued-wood fitting, which is a wood fitting cut to fit within the interior cavity of the culm. Two slits are cut into the culm to control cracking while the wood fitting is placed (Arce-Villalobos, 1993). Advantages of this connection include low cost, use of accessible materials, versatility, simplicity, extension, and increase of area (Socrates; Arce-Villalobos, 1993). A disadvantage would be splitting induced by the slits created to place the connection.

For a structural engineer, the glued-wood fitting connection has several viable qualities. The connection transfers forces tracking through the culm into a larger cylindrical wood fitting, and this fitting distributes forces into the next member or element. The glued-wood fitting provides protection for the culm by closing off the end and reinforcing the hollow interior of the culm. This additional strength decreases likelihood of splitting or crushing and redistributes shear stresses, and decreases bending stresses in the connection area. Capping the end of the culm prevents insects from entering and destroying it from the interior (Arce-Villalobos, 1993). Therefore, the glued-wood fitting meets all Arce-Villalobos' suggestions and demonstrates superior performance compared to other bamboo connections. Discussion of the versatility of this connection continues in **Appendix C.**

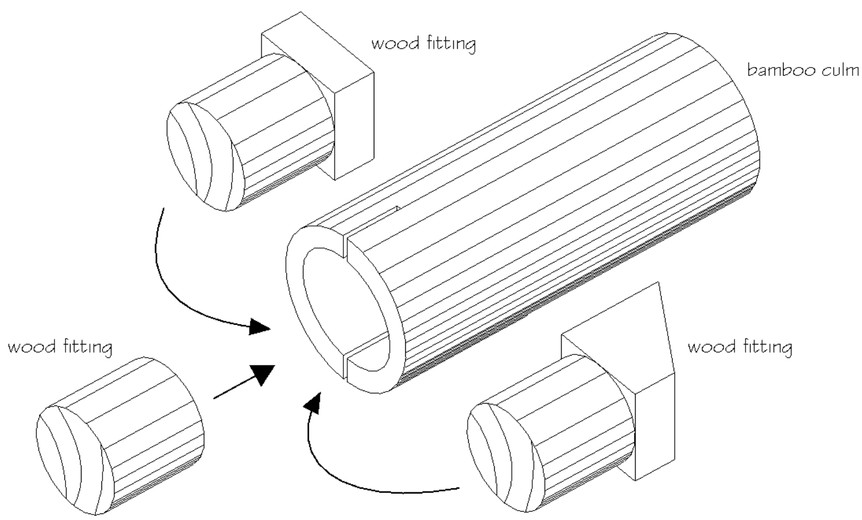


Figure 4.3 Glued-Wood Fitting Connection

(Reproduced based upon figure from Antonio Arce-Villalobos' *Fundamentals of the Design of Bamboo Structures*)

Another simple, successful connection mentioned by researchers is the grout-filled connection with steel rebar. **Figure 4.4** depicts a grout-filled connection with steel rebar, a preferred connection in practice because of its reliability and ease of placing (Janssen, 2000). Grout supports the culm similarly to the glued-wood fitting and transfers compression forces, while steel rebar transfers tension forces. This connection is successful in truss design because of the aforementioned characteristics.

The primary disadvantage of the grout-filled connection with steel rebar is its practicality and interaction with bamboo. This connection may not be practical in most situations except trusses and at the foundation of the structure. When placing grout, moisture produces swelling and splitting of the bamboo culm, and bamboo tends to shrink when it loses moisture. In this case, though, the culm cannot shrink due to the grout, producing splitting (Janssen, 2000). However, this connection provides structural continuity and increases the area in order to decrease stresses transferred from connection to connection.

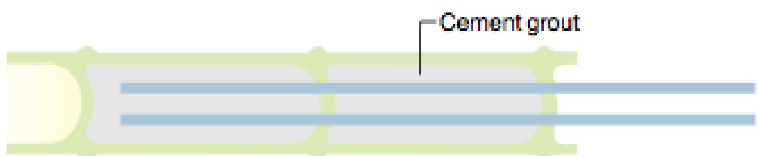


Figure 4.4 Grout-Filled Connection with Steel Rebar

(Reproduced from the INBAR's *Designing and Building with Bamboo*)

A variety of connections are used in bamboo projects because of bamboo variability. Many of these connections are case-specific, and connections used include lashings, steel wires, nails, bolts, pins, clamps, glued-wood fittings, grout-filled, and proprietary connections. With economy, rigidity, and structural continuity, however, a majority of these connections do not suffice. Only two simple, versatile connections, the glued-wood fitting and grout-filled connection with steel rebar, fulfill the goals and suggestions of Arce-Villalobos that a structural engineer must consider. The glued-wood fitting and grout-fill with steel rebar connections, provide minimal adjustment and construction issues and avoid the lead-time of proprietary connections, but the variance in design and construction may force the implementation of several different connections. The design example utilizes the glued-wood fitting coupled with lashing because the combination provides flexibility and adequate strength and rigidity to succeed in a variety of circumstances. Lashings transfer and develop forces from lateral loads into adjacent members.

Preservatives

Preservatives are essential for increasing structural bamboo service life. Bamboo service life may be limited to one to three years when outside in contact with soil and up to ten to fifteen years under very good conditions, including positioning bamboo off the ground away from other organic matter in a dry environment (Janssen, 2000). Preservation begins with consideration of the harvesting process. The time of year and where the bamboo culm is cut has proven to increase the durability and longevity of the culm's service life; culms cut in the dry season have higher durability than culms cut in the rainy season. After flowering, bamboo has lower starch content, decreasing likelihood of insect attacks. Insects are attracted to starch in the culms; thus, lowering the starch content will help protect and preserve the culms. The lower portion and outer layer of culms have higher durability than the rest of the culm; thus, the lower part of the culm should not be cut off during harvesting in order to take advantage of its durability.

Culm characteristics provide various advantages and difficulties for preservation. The exterior layer of the culm is made of a water repellent film, which prevents insects and other organic material from entering from outside the culm. As an organic compound, bamboo requires a preservative to protect it from deterioration. Bamboo has two types of standard preservatives, traditional and chemical (Janssen, 2000). Janssen developed a list of fundamental rules to assist in bamboo durability and preservation:

1. Harvest bamboo when the starch content is low.
2. Select species that locals have determined suitable for the project's purpose.
3. Keep bamboo dry and free from soil.
4. Store culms:
    - Under cover.
    - Away from water.
    - In horizontal layers with room for airflow.
5. Keep bamboo in adequate storage during transportation. (Janssen, 2000)

Traditional

Traditional methods for placing preservatives on or in bamboo culms include curing, smoking, soaking and seasoning, and lime-washing. These methods involve minimal cost and low skill levels. For curing, bamboo is left completely intact outside to air-dry after harvesting.

Transpiration occurs through clumping or air-drying culms, causing starch content to decrease in the culms (Janssen, 2000). Clump-curing, placing newly cut culms against uncut culms, is one of the most economical ways to preserve bamboo. Then, culms are left outside to dry for four to eight days, decreasing the starch level (Kassa, 2009). Air-drying involves storing culms horizontally for three to four weeks in a clean, well-ventilated warehouse or covered yard where culms are protected from direct sunlight and humidity fluctuations (Kassa, 2009). Smoke and ash-type solutions act as preservatives when placed on culms. Smoking involves placing culms over a fire to allow smoke to encompass the culms, deterring fungi and insects from infesting the culms (Janssen, 2000). Soaking and seasoning consist of completely submerging the culms in stationary or moving water for a few weeks, extracting starches. After soaking is complete, the bamboo is air-dried in the shade. Lime-washing protects culms from fungi by washing the culms with limewater (Janssen, 2000). Traditional methods are proven and simple to implement; thus, depending on material availability and application, traditional methods may be appropriate.

Chemical

All safe, cost effective, and applicable chemical methods contain boron. Several chemical preservative mixtures are copper-chrome-boron, boron-based fertilizer (Disodium Octoborate Tetrahydrate with sixty-six percent active boron content) and a borax-boric acid (Adams, 1997; Janssen, 2000). Similar to the exterior layer, bamboo culm interior layers have a waxy film cover; thus, chemicals must enter through the end of the culm to move through and absorb into the culm's fibers. Preservatives must enter through conducting vessels that comprise only 10% of the culm's cross-section. Chemical preservation must occur within twenty-four hours after cutting because conducting vessels close after twenty-four hours. Boron-based fertilizer has provided "good preservation" in extensive use in Costa Rica. Two methods are used to pass these chemicals through culms, modified boucherie and dip-diffusion (Janssen, 2000).

Modified boucherie is used for whole green culms by pushing the mixture through the culms using pressure. This process must occur within twenty-four hours after cutting to allow the preservative to move through the entire culm. A storage drum filled with preservative is connected to one end of the culm with rubber tubes and sleeves clamped around the culm. For the modified boucherie process, an air pump is used to push preservative through conducting vessels of the culm. The process is finished when the concentration exiting the opposite end of the culm matches the preservative concentration in the drum. Another technique to execute this process is to cut the inner wall of the bottom portion of the culm, hang it vertically, and infuse it with the preservative (Janssen, 2000).

Dip-diffusion is used for sawn or split culms where the culm is placed fully in the mixture to allow infiltration into culm vessels. The process lasts ten minutes; then culms are removed from the preservative, wrapped in plastic sheets and left to dry. After a week, the sheets are removed and culms vertically placed to season for one week (Janssen, 2000).

The use of chemical preservation for bamboo culms has ramifications. First, adequate preservation relies on mixture accuracy. Second, culms impregnated with chemical preservatives should not be burnt. Third, overall cost of bamboo increases 30%. Fourth, disposal of toxic waste in chemical preservatives contributes to environmental issues. But for boron-based fertilizer, waste is considered negligible because the preservative can be mixed with starch and sugar from culms and reused as fertilizer. Fifth, the service life of the bamboo increases to fifteen years in the open and twenty-five years under very good conditions (Janssen, 2000).

Bamboo structures have structurally supported buildings longer than twenty-five years, but the previous estimate considers structural integrity and serviceability of bamboo. The increase in bamboo service life overrides the increase in cost to purchase preservatives. Thus, chemical preservation of bamboo is a viable option with various financial setbacks due to the process and transportation.

Chapter 5 - Bamboo Design Example

This section explains the basis behind the calculations, including loads, materials, and layout of the traditional East African, Amhara house. The bamboo design example was executed to provide an example of a structurally engineered bamboo house. The structure is a traditional, lowland, East African house, known as an Amhara bamboo house, which is circular with an eight-meter diameter (Kibwage et al., 2011). The primary difference between the house in the design example and a typical Amhara bamboo house is that the interior column is made of four bamboo culms, not one solid timber column and columns are on a concrete pedestal or curb connected to the foundation, not rammed earth, as shown in **Figure 5.2**. The structure was designed based on the bamboo species *Oxytenanthera abyssinica* (Kibwage et al., 2011).

The designed structure utilizes a similar quantity of bamboo culms, approximately 320, as provided by the INBAR document for the Amhara bamboo house. An INBAR study estimated the cost of a similar structure used for lodging and hotels in East Africa at approximately $12,000. **Figure 5.1** shows the house examined in the INBAR study. This house has more material for the exterior, walls, and foundation; therefore, the design example may have a lower cost associated with its design and construction than the house in **Figure 5.1**. **Figure 5.2** provides an example of a traditional Amhara house (Kibwage et al., 2011).

Figure 5.1 Similar Housing in East Africa

(Reproduced from the INBAR's *Bamboo as a building material for meeting East Africa's housing needs: a value chain study from Ethiopia*)

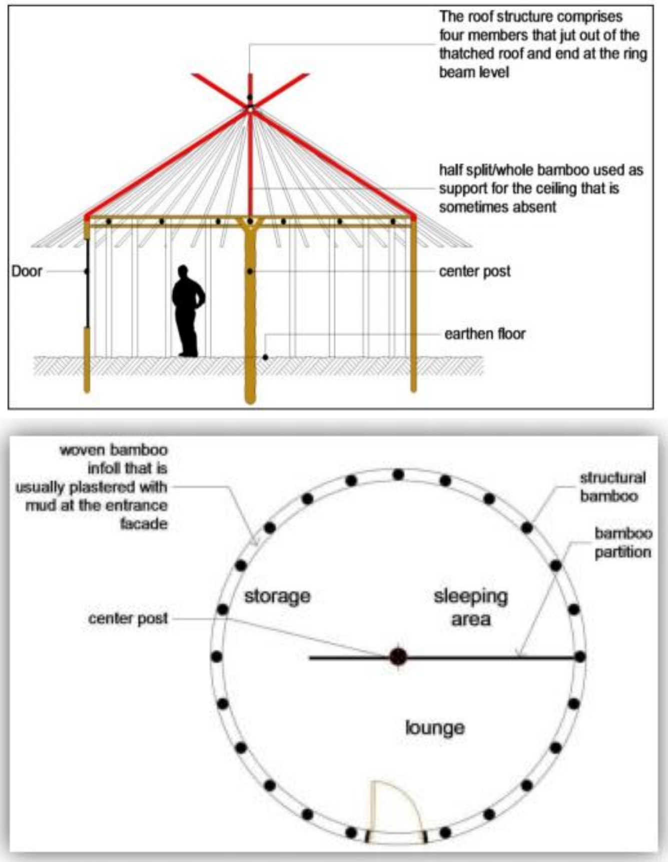


Figure 5.2 Traditional Amhara House in East Africa

(Reproduced from the INBAR's *Bamboo as a building material for meeting East Africa's housing needs: a value chain study from Ethiopia*)

Loads

Loads considered for this structure include dead, roof-live, wind, and seismic loads. Dead loads always reside on the structure, but due to bamboo's lightweight nature, dead load did not significantly impact the structure compared to wind loads except at the roof where grass thatch adds significantly to the dead load. Roof-live loads could be neglected because of the single story nature of the structure and ability to erect the structure without placing workers on the roof. However, this design considered a roof-live load to account for unforeseen loading and maintenance on the roof. Wind loads governed over seismic loads in design of the structure, and all of the loads were calculated based on the ASCE 7-10, which provides a basis for designing structures. **Table 5.1** and **Appendix A** contain further information regarding the loads.

Loads	Force
Roof Dead	2.16 kPa (45 PSF)
Wall Dead	1.00 kPa (20 PSF)
Roof-Live	1.0 kPa (20 PSF)
Seismic	S_s=0.82g & S_1=0.33g
Wind	150 mph

Table 5.1 Loads

Materials & Layout

Materials and layout of the traditional East African structure significantly impact the structural design. Materials used for the roof, walls, and floors influence the member sizes because of the dead loads introduced by various materials. Layout of architectural features influence where the structure can reside and placement of the structure. Items discussed in this section include bamboo specifications, roof, walls, columns, braces, floor and foundation, and connections. Further information and drawings of the example structure are at the end of this chapter. Drawings provide an in-depth look at the layout briefly described in this section.

Bamboo Specification

Oxytenanthera abyssinica, as discussed in **Chapter 3,** is the bamboo species used for the design example of a traditional Amhara bamboo house. Bamboo will be purchased from a supplier such as Kitil Farms and preserved by boron-based fertilizer. All of the *Oxytenanthera abyssinica* bamboo members in this design are six or ten centimeters in diameter with 1.5 or 3.5 centimeter thick culm walls, respectively and harvested at three to six years of age (Kitil Farm). These values were extracted from research determining the average diameter of *Oxytenanthera abyssinica* to range from three to ten centimeters with the thickness deduced from pictures provided by sources similar to **Figure 5.3** (Kitil Farm; & UNIDO 2009).

Figure 5.3 Measurement of *Oxytenanthera abyssinica*

(Reproduced from Kitil Farm's *Oxytenanthera Abyssinica (Solid bamboo)*)

Roof

The roof of the structure consists of architectural and structural elements integral to the service life of the house. The roof is made of a grass thatch exterior, corrugated sheet metal, an air cavity with structural elements and burlap bags of hay, and a woven layer of bamboo on the inside for the ceiling. Grass thatch provides the house with a traditional East African look and acts as a temperature control by absorbing the sun's rays, preventing the corrugated sheet metal from directly heating the entire structure, but also adds significantly to the roof-dead load (1.2 kPa or 25 PSF). Hay-filled burlap sacks insulate the structure. In addition, the roof forms a cone to tie to the structure with an overhang that extends out from the house 0.6 meters. This overhang extends the bamboo wall weaving's service life.

Trusses supplement the structural capacity of the roof. Sixteen trusses will originate from the center of the structure at the interior column and rest on the exterior columns at equal spacing. The trusses are four meters long and two and one half meters high. The top chord of the truss supports loads from the roof overhang and intermediate roof members. These trusses could be constructed on site in an effort to minimize transportation costs or in a factory for quality control.

The half-fink truss is produced from eight bamboo members of varying lengths. **Figure 5.4** accurately depicts the half-fink truss used for the design example. Truss members largely experience tension forces, which utilize the strongest bamboo mechanical property, tension. The previously considered truss produced compression in the majority of the members, which made the truss members larger and less efficient. Sixteen half-fink trusses complete the roof structure with sixteen intermediate roof members at the two joints of the top chord. The roof requires approximately 180 *Oxytenanthera abyssinica* culms. Calculations for the truss are in **Appendix A**.

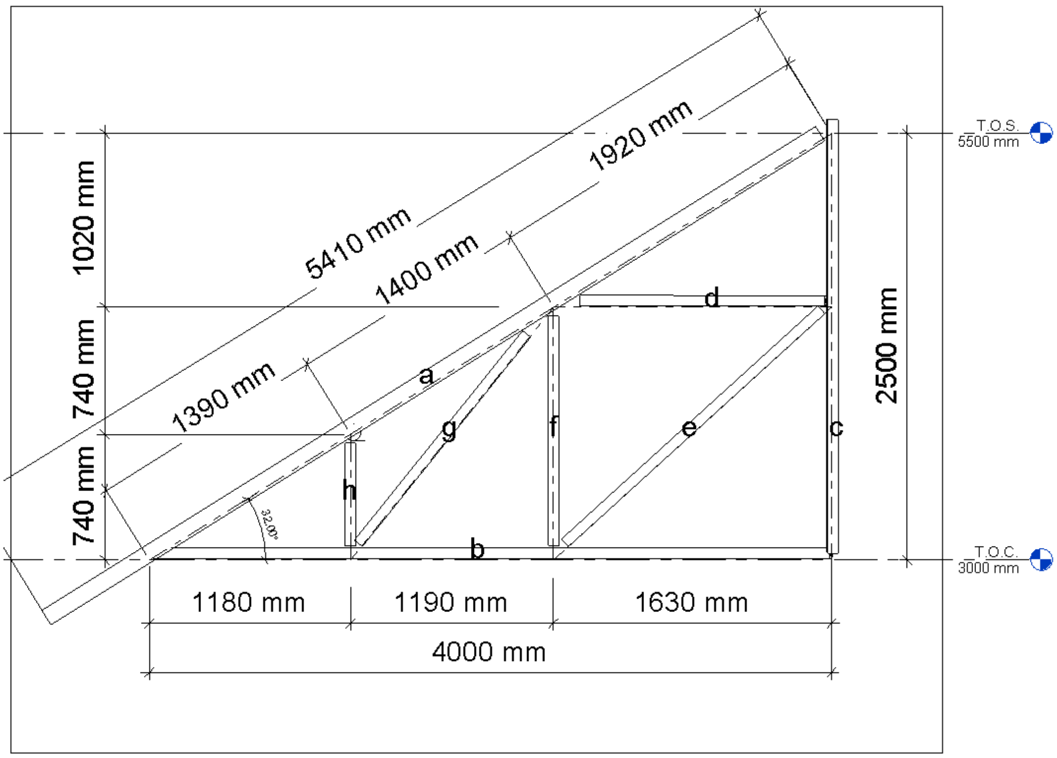


Figure 5.4 Half-fink Truss Dimensions from Design Example

(Reproduced from Author's Drawings)

Walls

The wall materials and layout of the structure provide bamboo and occupants protection from the exterior environment. Wall materials from the outside to inside include a woven layer of bamboo, corrugated sheet metal, an air cavity with structural elements and burlap bags of hay, and a woven layer of bamboo on the inside of the wall. The majority of these materials, including corrugated sheet metal, burlap sacks, and hay are materials available in most of East

Africa (Kassa, 2009). The woven layer of bamboo on the outside of the wall continues the traditional use of bamboo weavings to cover the house and acts as a temperature regulator by absorbing and reflecting the sun's rays to avoid heating the layer of corrugated sheet metal underneath. Corrugated sheet metal provides an attachable surface for the bamboo weavings and burlap bags and becomes a barrier between the exterior and interior environment. Burlap sacks of hay create a layer of insulation to protect the house from the elements. The structure resides within the layer of burlap sacks and is concealed from view. The final layer of bamboo weavings encloses the insulation and structure from view. The layout consists of a continuous, circular wall around the perimeter of the traditional housing unit. Architectural elements found in the exterior wall include one door and multiple windows. Major structural elements are concealed in the exterior wall, including the columns and diagonal bracing. Traditionally, interior walls are included in Amhara houses, and the interior wall is similar to the exterior wall but without hay-filled burlap sacks for insulation. The interior wall is not shown in the drawings shown at the end of this chapter.

Columns

Columns of this structure reside at the center of the structure and at the exterior wall. Exterior columns are spaced equally around the perimeter of the structure at 3.05 meters and intermediate columns spaced at 0.78 meters. The exterior columns carry truss loads, brace loads, and experience lateral wind loads. The interior column is comprised of four culms carrying loads from the trusses including vertical and lateral loads. The interior column allows the sixteen trusses to bear on it through connection to a steel plate. All of the columns are 2.85 meters in height, and the exterior columns generally contain bracing halfway up the member to decrease the slenderness ratio (λ=KL/r per Janssen, 2000).

Braces

Diagonal braces providing lateral support to the structure are located in the exterior walls of the structure. This layout allows for an open floor plan for the rooms within the structure. Diagonal braces are located in each column to column space, with the exception of the entrance. This placement provides adequate lateral resistance to the governing wind loads and flexibility for architectural features within the walls, such as windows and doors. The diagonal braces are 4.15 meters long and extend into the space approximately thirty centimeters at all locations.

Member Sizes

Member	Diameter (cm)	Wall Thickness (cm)
Roof Intermediate 1	6	1.5
Roof Intermediate 2	10	3.5
Top Chord of Truss	10	3.5
Truss Members	6	1.5
Braces	10	3.5
Columns	10	3.5
Wall Member-Intermediate Girt	6	1.5
Intermediate Column-Above Door	6	1.5
Door Frame Beams	10	3.5
Door Frame Columns	10	3.5
Window Frame Beams	6	1.5
Window Frame Columns	10	3.5

Table 5.2 Member Sizes

Floor & Foundation

The concrete floor slab for this project is optional based on the Amhara bamboo house from INBAR. If the concrete floor slab is chosen, it will be cast on the site. The concrete slab will be poured last to decrease the amount of necessary formwork because the curb acts as formwork for the slab.

The foundation for the structure is concrete, and the curb, column cap, continuous footing, and spread footings are cast-in-place concrete. A modular foundation was considered until the need of forming the curb arose, and since curb must be cast-in place, the rest of the foundation is cast-in-place. The curb and piers provide a pedestal for the columns to rest on in order to assure that bamboo culms do not easily absorb water. The curb extends fifteen centimeters above the foundation wall. A foundation wall is used to prevent the curb from cracking or experiencing differential settlement.

Connections

The glued-wood fitting connection is used for all structural connections in the traditional Amhara bamboo house. Lashing acts as additional connection support to strengthen trusses and lateral supporting members. In all lateral load-transferring elements, lashing provides additional strength, stability, and flexibility to the connection and develops and transfers lateral forces to adjacent members including the entire roof and columns where braces and columns connect. Thus, this combination connection may be practical to use for the entire structure.

For design, the assumption is made that the connections are adequate for the loads encountered. Thus, only members were analyzed for failure. Engineers desire failure to occur in individual members to prevent total collapse.

Additional Considerations

Additional considerations not mentioned previously include providing roof vents, lighting, and a tension ring. The best option for providing roof vents and lighting is to create a central vent system that adds to the façade architecture by elevating the center portion of the roof to allow for smoke to leave and light to infiltrate the space. A tension ring is a structural option for this example but due to time limitations, was not considered in the calculations. The tension ring would rid the need for the interior column, which provides additional floor space but complicates construction. These additional considerations would add functionality to the design example if implemented.

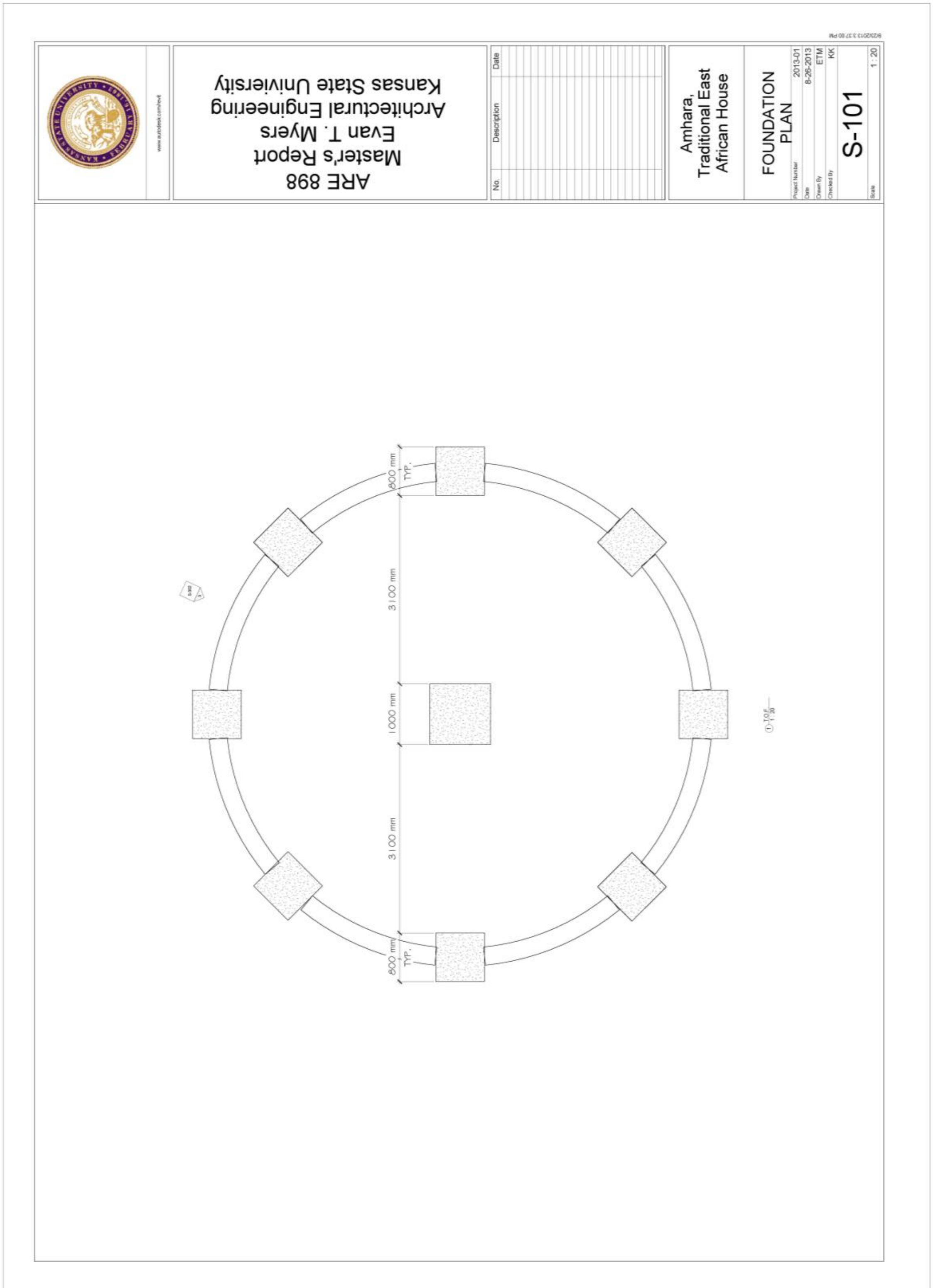
Bill of Materials

Material	**Use**
Wood	Connection
Fasteners	Connection
Steel	Connection
Adhesive	Connection
Steel Rebar	Foundation
Concrete	Floor Slab & Foundation
Corrugated Metal	Wall & Roof
Hay	Wall & Roof
Burlap Sacks	Wall & Roof
Bamboo	Structure
Tools	Construction

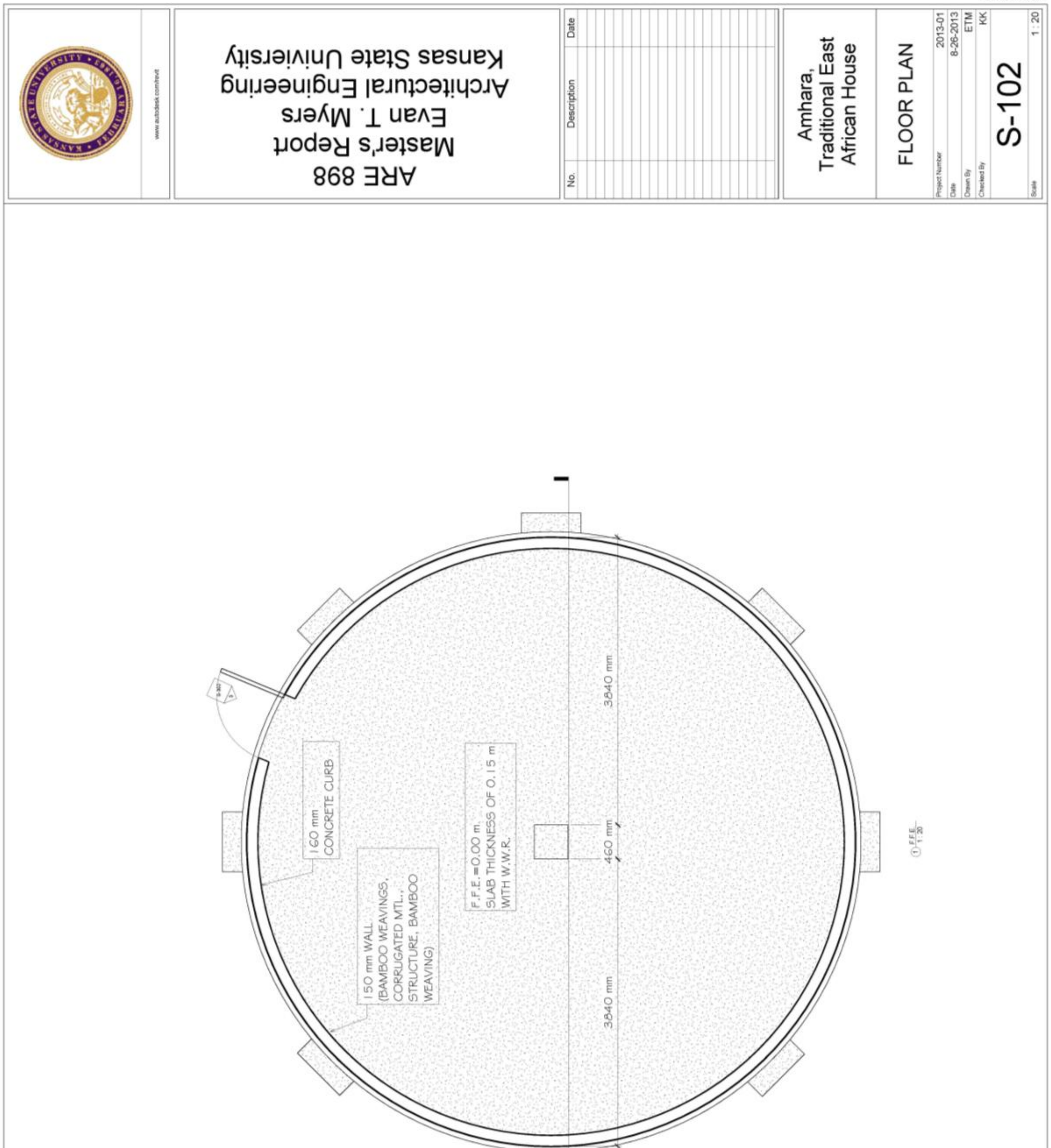
Table 5.3 Bill of Materials List

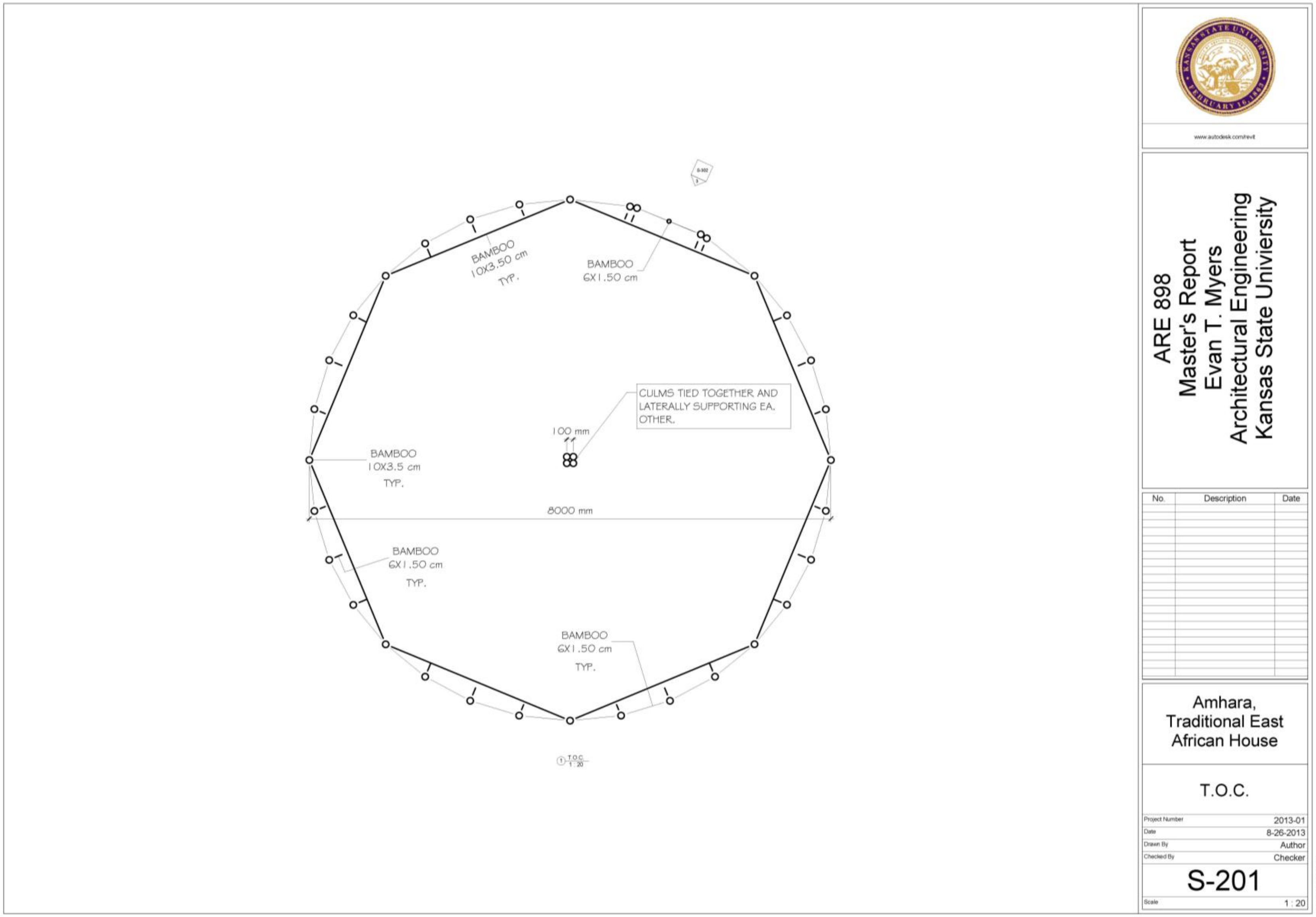
Drawings

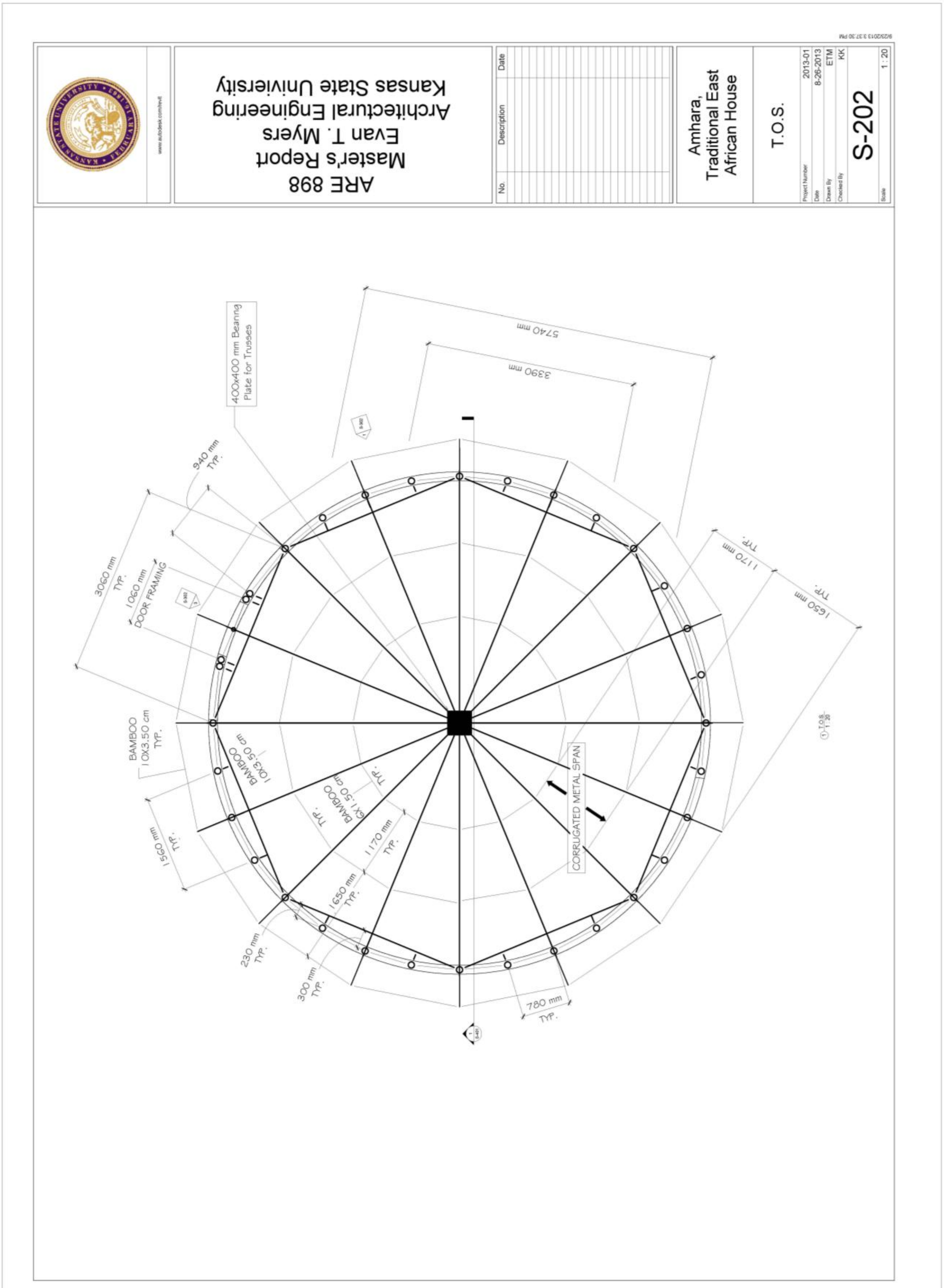
This section provides the building layout and drawings. These drawings show member sizes and design determined through calculations, shown in **Appendix A**. Drawings are meant to provide a brief introduction to the structure and preliminary design and do not provide information required to carry this design to construction.

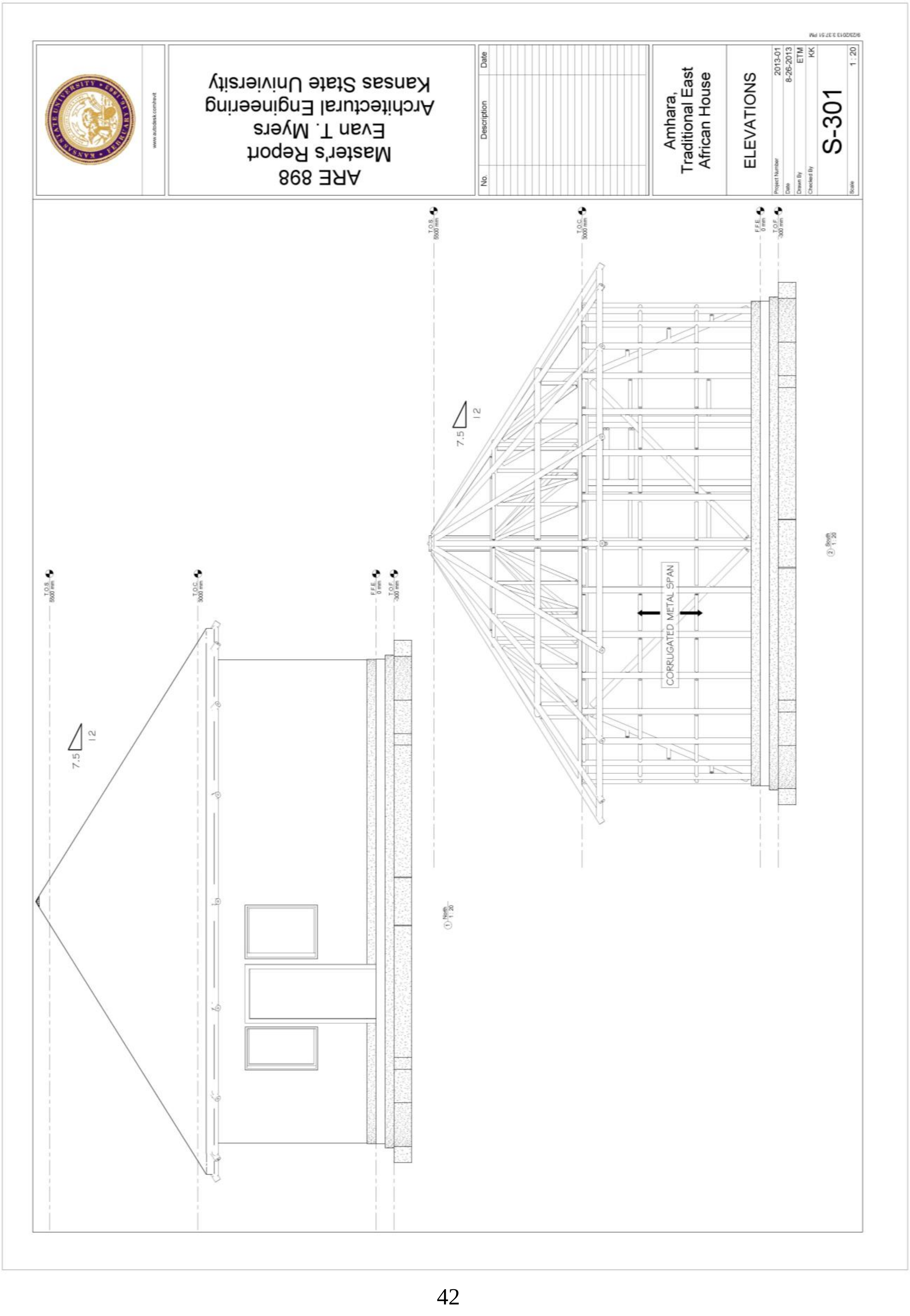


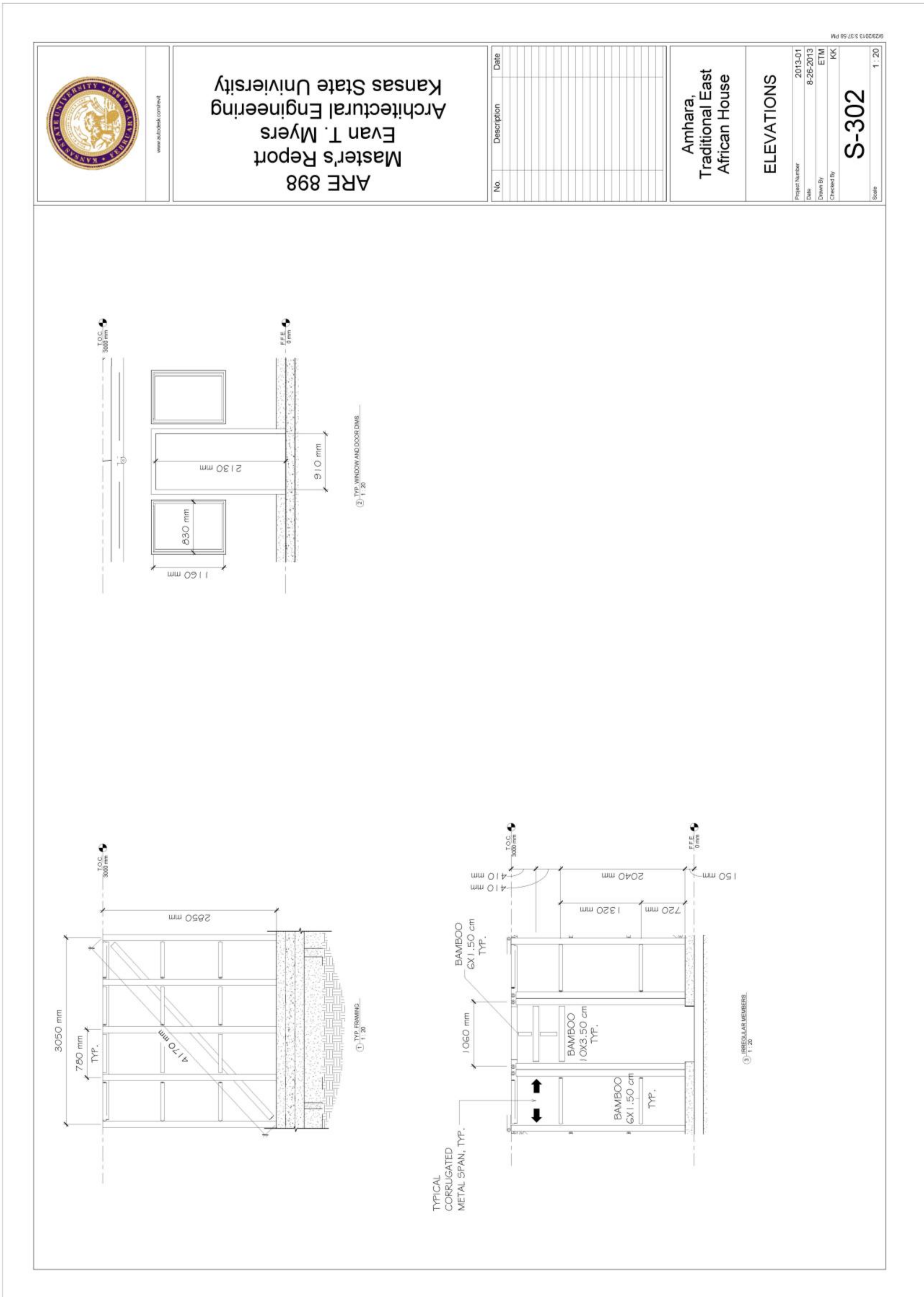
ARE 898
Master's Report
Evan T. Myers
Architectural Engineering
Kansas State Univiersity
No.
Description
Date
Amhara, Traditional East African House
FOUNDATION PLAN
Project Number 2013-01
Date 8-26-2013
Drawn By ETM
Checked By KK
S-101
Scale 1 : 20
800 mm TYP.
3100 mm
1000 mm
3100 mm
800 mm TYP.


ARE 898
Master's Report
Evan T. Myers
Architectural Engineering
Kansas State Univiersity
No.
Description
Date
Amhara,
Traditional East
African House
FLOOR PLAN
2013-01
8-26-2013
ETM
KK
S-102
1 : 20
160 mm
CONCRETE CURB
150 mm WALL
(BAMBOO WEAVINGS,
CORRUGATED MTL.,
STRUCTURE, BAMBOO
WEAVING)
F.F.E. =0.00 m.
SLAB THICKNESS OF 0.15 m
WITH W.W.R.
3840 mm
460 mm
3840 mm

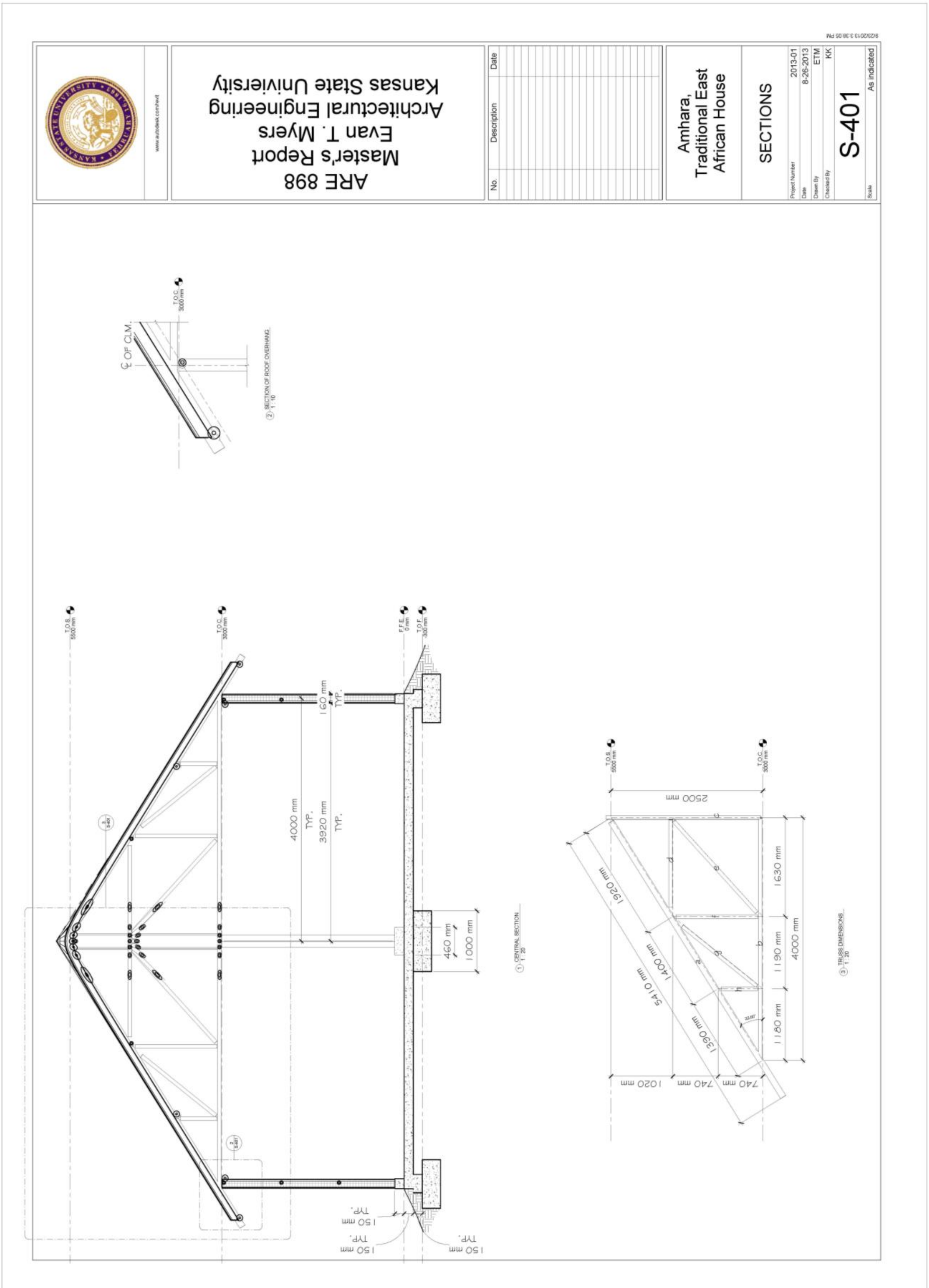

BAMBOO
10X3.50 cm
TYP.
BAMBOO
6X1.50 cm
CULMS TIED TOGETHER AND
LATERALLY SUPPORTING EA.
OTHER.
100 mm
BAMBOO
10X3.5 cm
TYP.
8000 mm
BAMBOO
6X1.50 cm
TYP.
BAMBOO
6X1.50 cm
TYP.
www.autodesk.com/revit
ARE 898
Master's Report
Evan T. Myers
Architectural Engineering
Kansas State Univiersity
No.
Description
Date
Amhara,
Traditional East
African House
T.O.C.
Project Number
2013-01
Date
8-26-2013
Drawn By
Author
Checked By
Checker
S-201
Scale
1 : 20


ARE 898
Master's Report
Evan T. Myers
Architectural Engineering
Kansas State Univiersity
No.
Description
Date
Amhara,
Traditional East
African House
T.O.S.
Project Number
2013-01
Date
8-26-2013
Drawn By
ETM
Checked By
KK
S-202
Scale
1 : 20
5740 mm
3390 mm
400x400 mm Bearing Plate for Trusses
940 mm TYP.
3060 mm TYP.
1060 mm DOOR FRAMING
1170 mm TYP.
1650 mm TYP.
BAMBOO 10X3.50 cm TYP.
BAMBOO 10X3.50 cm
BAMBOO 6X1.50 cm TYP.
TYP.
1170 mm TYP.
1650 mm TYP.
1560 mm TYP.
230 mm TYP.
300 mm TYP.
780 mm TYP.
CORRUGATED METAL SPAN
T.O.S.
1 : 20

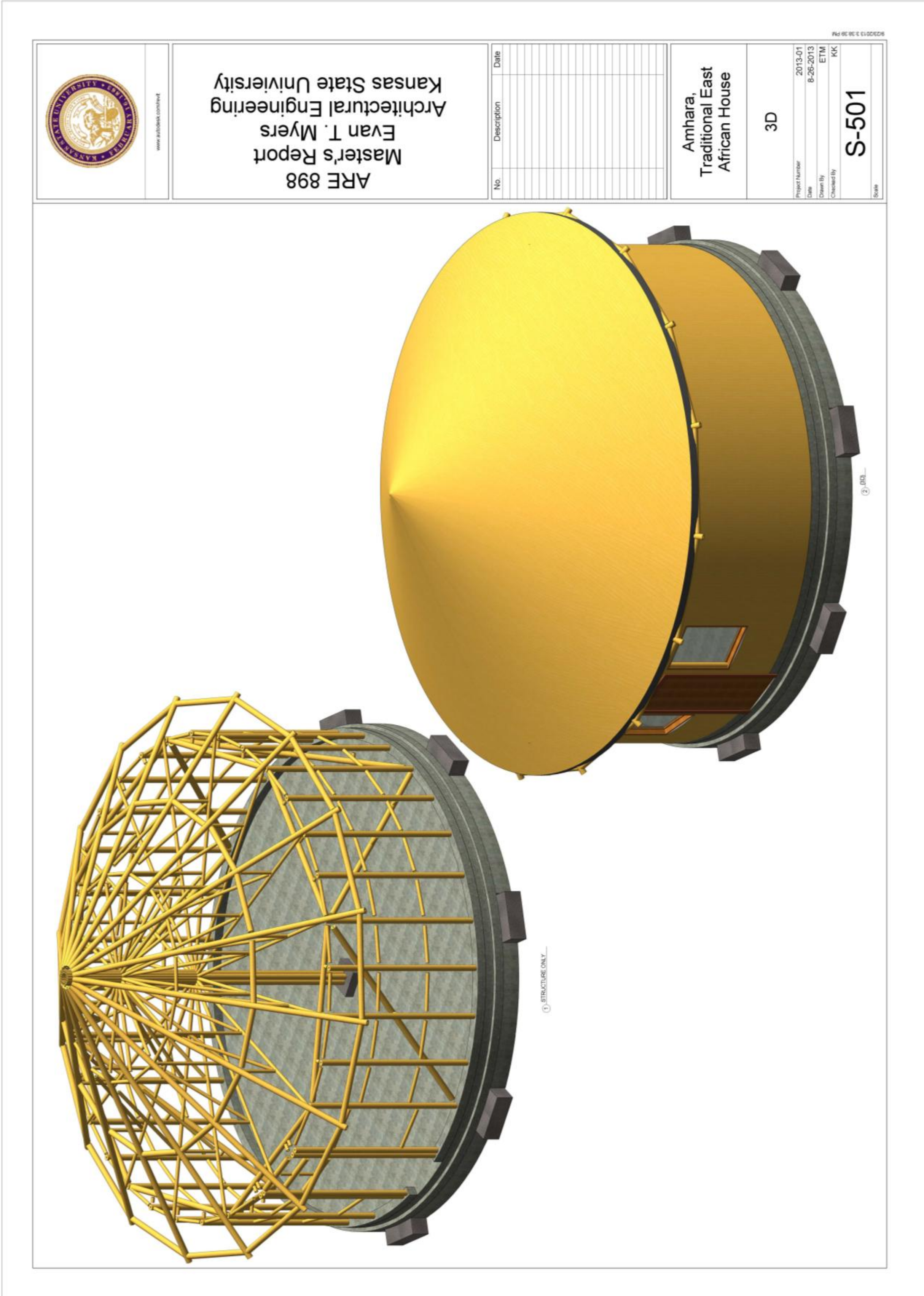

ARE 898
Master's Report
Evan T. Myers
Architectural Engineering
Kansas State Univiersity
No.
Description
Date
Amhara, Traditional East African House
ELEVATIONS
Project Number 2013-01
Date 8-26-2013
Drawn By ETM
Checked By KK
S-301
Scale 1 : 20
T.O.S. 5500 mm
T.O.C. 3000 mm
F.F.E. 0 mm
T.O.F. -300 mm
7.5
12
CORRUGATED METAL SPAN
North 1 : 20
South 1 : 20



ARE 898
Master's Report
Evan T. Myers
Architectural Engineering
Kansas State Univiersity
No.
Description
Date
Amhara,
Traditional East
African House
ELEVATIONS
Project Number 2013-01
Date 8-26-2013
Drawn By ETM
Checked By KK
S-302
Scale 1 : 20
1160 mm
830 mm
2130 mm
910 mm
TYP. WINDOW AND DOOR DIMS
T.O.C. 3000 mm
F.F.E. 0 mm
3050 mm
780 mm TYP.
2850 mm
4170 mm
TYP. FRAMING
TYPICAL CORRUGATED METAL SPAN, TYP.
BAMBOO 6X1.50 cm TYP.
BAMBOO 10X3.50 cm TYP.
1060 mm
410 mm
410 mm
2040 mm
1320 mm
720 mm
150 mm
IRREGULAR MEMBERS



ARE 898
Master's Report
Evan T. Myers
Architectural Engineering
Kansas State Univiersity
Amhara, Traditional East African House
SECTIONS
Project Number 2013-01
Date 8-26-2013
Drawn By ETM
Checked By KK
S-401
Scale As indicated
CENTRAL SECTION 1 : 20
SECTION OF ROOF OVERHANG 1 : 10
TRUSS DIMENSIONS 1 : 20
4000 mm TYP.
3920 mm TYP.
160 mm TYP.
460 mm
1000 mm
150 mm TYP.
2500 mm
1630 mm
1190 mm
1180 mm
4000 mm
1920 mm
1400 mm
5410 mm
1390 mm
1020 mm
740 mm
740 mm
℄ OF CLM.


ARE 898
Master's Report
Evan T. Myers
Architectural Engineering
Kansas State Univiersity
No.
Description
Date
Amhara,
Traditional East
African House
3D
Project Number 2013-01
Date 8-26-2013
Drawn By ETM
Checked By KK
S-501
Scale
1 STRUCTURE ONLY
2 3D

Chapter 6 - Recommendations

Recommendations in this section refer to areas the bamboo industry should develop and standardize in order to create an environment of consistency and growth allowing for frequent use of bamboo as a structural material. Items discussed in this section include standards, farms and plantations, connections, and service life. The bamboo industry needs to address these issues before allowing commercial use of bamboo as a structural material.

Standards

Research has shown that bamboo's hindrance in structural applications is due to its lack of a technical document that provides adequate explanation of bamboo and equations pertaining to its implementation in structural design. Current technical documents generalize bamboo design and construction to cover all situations, creating difficulties for structural design. Technical documents require specific and relevant information regarding design and construction of bamboo structures.

For bamboo to become a prominent structural material, development and publishing of a codebook must occur, similar to the AISC or NDS. A codebook would allow direct use of bamboo in a variety of applications. Research has been conducted for a variety of bamboo species, but all of this research must be centralized and used to formulate an explanation of bamboo behavior and quantitative mechanical properties of prominent species. INBAR could advance the bamboo industry forward by specifying bamboo species used for structures and placing those species in a technical document to begin development of a codebook.

Farms & Plantations

Investment in farms and plantations must be developed in countries where bamboo naturally thrives. *Oxytenanthera abyssinica* has the capability of growing the bamboo industry because of its solid nature and mechanical properties; thus, a commercial plantation could grow and supply *Oxytenanthera abyssinica* to East Africa. If the bamboo industry unifies from INBAR to the farms and plantations, public awareness of bamboo and its capabilities as a structural material will increase.

Support of farms and plantations by organizations such as INBAR and EABP must continue to bring farms and plantations to a standard for quality control. Kitil Farms is currently working in Ethiopia to promote *Oxytenanthera abyssinica* and build awareness of this bamboo species, but farms and plantations need financial support and information on manufacturing practices in order to thrive. As bamboo production becomes commercialized, the industry may begin to receive support from additional structural and sustainability organizations.

Connections

Currently, connections pose a problem for structural bamboo design. Variance in connections and bamboo culms cause difficulties in understanding which connection will perform appropriately in a given circumstance. Thus, a connection that has high variability in use and high strength must be developed to provide bamboo with an economical and consistent connection. Development of a common connection would decrease design problems structural engineers have with using bamboo as a structural material. An increase in consistency for bamboo connections would increase the likelihood of structural engineers using bamboo as a structural material.

Service Life

Service life of bamboo must be considered before structural use of bamboo commences. Lack of long-term service life negates any benefit or sustainable aspect to using bamboo as a structural material for commercial purposes. Thus, the expected service life of bamboo must be extended longer than twenty-five years in order to encourage its use as a structural material. Without this development, the use of bamboo as a structural material is not feasible for commercial use.

Chapter 7 - Conclusion

This report responds to the need in East Africa for safe, sustainable, and affordable housing and promotes bamboo as a structural material. East African housing needs continue to increase because of the growing population and inability for the region to provide housing and infrastructure at a corresponding rate. Bamboo housing provides an alternative to urban slums and could solve the housing sector differential. The bamboo species *Oxytenanthera abyssinica* is available throughout the region and is accepted and used in traditional houses in the culture.

The primary purpose of this report is to promote bamboo as a structural material. Technical documents support use and guide design of bamboo structures, and mechanical properties and behavior promote the advantages of bamboo as a structural material. Bamboo technical documents include the ICC's *Acceptance Criteria* and ISO 22156, which provide information on testing, equations, and general considerations for bamboo use as a structural material. Empirical design introduces various suggestions and equations that provide preliminary knowledge on bamboo structural design. The mechanical properties indicate strength and behavior of bamboo, in general and the specific species *Oxytenanthera abyssinica*. Bamboo behavior impacts structural design and the structure's ability to dissipate loads; for bamboo, the behavior due to P-δ effects and seismic activity successfully convey the flexibility and strength of bamboo as a structural material. Thus, the technical information, mechanical properties, and behavior adequately support the implementation of bamboo as a structural material.

Bamboo construction and the design example indicate bamboo's practicality in construction and design. Bamboo construction utilizes simple tools but has complex connections and preservation techniques. The design example showcases difficulty for bamboo in spanning distances for bending and bamboo's parallelism to wood in layout.

Throughout this report, bamboo demonstrated its practical capabilities for construction and design. Thus, bamboo may have the ability in the future to become recognized as a structural material in commercial design and construction with further development of the items in the **Recommendations** section. Currently, bamboo would suffice as a structural material for the housing crisis in East Africa. However, bamboo needs further development before commercial use commences. The use of bamboo in commercial structural design may begin when the recommendations suggested are fully developed.

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Appendix A-Calculations

The load calculations were all based upon the ASCE 7-10 and the processes indicated within the code. The calculations can be seen in the following pages. Seismic and wind were the governing lateral loads and had some interesting occurrences regarding calculations. Wind governed in design because of the large surface area of the structure and low-weight of bamboo.

Seismic

The seismic forces were determined using several different sources. The Modified Mercalli Scale was used for the East African region. The maximum occurrence provided a PGA of 0.65g (OCHA, 2007; Wald, D.J., Quitoriano V., Heaton T.H., & Kanamori, H, 1999). The USGS's beta program for East Africa spectral responses provided a higher value. The highest spectral response came from Djibouti where the S_s=0.82g and the S_1=0.33g. Thus, the USGS values were used in calculating the seismic force within the structure (*Worldwide Seismic Design Values,* 2011).

Wind

The wind calculations used the ASCE 7-10 and assumed the worst-case for the structure, which is along the coast. So the velocity of the wind taken from the ASCE 7-10 equaled 150 mph. The calculation used in design was miscalculated based upon the pressures going towards or away from the structure. But determining the actual loads revealed that the initial, miscalculated loads were slightly more conservative. Thus, the initial calculations were used for the design, as is noted on one of the calculation sheets.

Design Calculations

All of the calculations for the structure are included in this section, including the mechanical properties, roof and trusses, braces, columns, irregular members, and foundation. These calculations largely use statics to determine the member sizes along with RISA to provide deflections and compare the bending moments, shear forces, and axial forces within members for the roof and trusses, braces, and columns.

3-0235 — 50 SHEETS — 5 SQUARES
3-0236 — 100 SHEETS — 5 SQUARES
3-0237 — 200 SHEETS — 5 SQUARES
3-0137 — 200 SHEETS — FILLER
COMET

- LOADS ON STRUCTURE

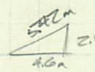
STEP DESCRIPTION	COMPUTATION	REFERENCE
DEAD ROOF	MATERIALS — PSF	
	GRASS-THATCH — 25	WILLIAM COX - THESIS
	CORRUGATED METAL - 18 GAUGE — 7.7	CORRUGATED-METALS.COM
	INSULATION-HAY (4.4 PSF × 6"/12"/FT) — 2.2	NDSU.EDU
	BAMBOO STRUCTURE — 5	ASSUMED
	BAMBOO WEAVING — 5	ASSUMED
	~~44.9~~ → 45	
CORRUGATED MTL	$231^{\#}/SQ / (45'')(96'') \left\| \frac{12''}{FT} \right\|^2 = 7.70\,PSF$	
CONVERT TO N/mm^2	$45.0\,PSF \left\| \frac{FT}{12''} \right\|^2 \left\| \frac{IN}{25.4\,cm} \right\|^2 \left\| \frac{cm}{10\,mm} \right\|^2 \left\| \frac{4.45\,N}{\#} \right\| = 2.155 \times 10^{-3}\,N/mm^2\,(MPa)$ → $2.16 \times 10^3\,Pa$	
- WALLS	MATERIALS — PSF	
	BAMBOO WEAVING — 5	ASSUMED
	CORRUGATED METAL - 18 GAUGE — 7.7	CORRUGATED-METALS.COM
	INSULATION-HAY — 2.2	
	BAMBOO WEAVING — 5	
	~~19.9~~ → 20 PSF	
CONVERT	$20.0\,PSF \left\| \frac{FT}{12''} \right\|^2 \left\| \frac{IN}{25.4\,mm} \right\|^2 \left\| \frac{4.45\,N}{\#} \right\| = 0.958 \times 10^{-3}\,N/mm^2\,(MPa)$ → $1.0 \times 10^3\,Pa$	
ROOF LIVE LOAD	$20\,PSF \rightarrow 958 \times 10^{-6}\,N/mm^2\,(MPa)$	ASCE 7-10 TABLE 4-1
	$L_o = 1.0 \times 10^3\,Pa$ ∴ SECTION 4.7.2 REDUCTION DOES NOT BENEFIT!	

LOADS	VALUE (Pa)
D_{LRF}	2.16×10^3
D_{LW}	1.0×10^3
L_r	1.0×10^3

Seismic

MASTER'S	ARE 598	EVAN MYERS

-SEISMIC LOADS

STEP DESCRIPTION	COMPUTATION	REFERENCE
ROOF AREA	$A = \pi r l = \pi(4.6m)(5.42m) = 78.4\ m^2$  $\frac{h}{4.6} = \frac{2.5}{4.0} \Rightarrow h = 2.875m$	
WEIGHT OF ROOF	$W_{RF} = (2.16 \times 10^3\ Pa)(78.4\ m^2)\left\| \frac{N/m^2}{Pa} \right\|\left\| \frac{kN}{1000\ N} \right\| = 169.3\ kN$	
WALL AREA	$A_w = (\pi \cdot 4m)(3m) = 37.7\ m^2$ ∴ HALF OF THE WALL LD DISTR. DIRECTLY TO GROUND	
WEIGHT OF WALL	$W_w = (0.72 \times 10^3\ Pa)(37.7\ m^2)\left\| \frac{N/m^2}{Pa} \right\|\left\| \frac{kN}{1000\ N} \right\| = 27.1\ kN$	
CALC. SEISMIC COEFF. & FORCES	∴ FOR BLDG FRAME SYSTEM, USE SEEL SCBF AS A BASIS FOR DESIGN. THIS WILL PRODUCE CONSERVATIVE SEISMIC FORCES FOR THE STRUCTURE BUT MAY NOT ADEQUATELY MODEL OR ACCOUNT FOR THE FLEXIBILITY & DEFLECTION OF BAMBOO. ∴ ALTHOUGH THE WORLD HEALTH ORGANIZATION'S DATA DID NOT SHOW STRONG SEISMIC FORCES FOR EAST AFRICA, THE SEISMIC FORCES WILL BE CALCULATED BASED UPON VALUES FROM THE UNIDO MAP & THE CALIFORNIA STUDY RELATING THE MODIFIED MERCALLI SCALE TO ACTUAL PEAK GROUND ACCELERATION	
	$PGA = 0.65g\ (MCE_G) \Rightarrow F_{PGA} = 1.0$	ASCE 7-10 T11.8-1
	SITE-CLASS D ∴ BASED UPON RESEARCH OF EAST-AFRICAN SOIL, CLAY, DID NOT SOUND SOFT FROM DESCRIPTION	T20.3-1
	CATEGORY II: $I_e = 1.0$	T1.5-2
	$PGA_M = F_{PGA} PGA = 0.65g$	EQN 11.8-1
ETHIOPIA	$S_S = 0.59g$ & $S_1 = 0.24g$ ∴ GSHAP	USGS WEB APP. - WORLDWIDE SEISMIC "DESIGN MAPS"
SUDAN	$S_S = 0.19g$ & $S_1 = 0.08g$ ∴ GSHAP	
DJIBOUTI	$S_S = 0.82g$ & $S_1 = 0.33g$ ∴ GSHAP	

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3-0235 — 50 SHEETS — 5 SQUARES
3-0236 — 100 SHEETS — 5 SQUARES
3-0237 — 200 SHEETS — 5 SQUARES
3-0137 — 200 SHEETS — FILLER
COMET

Seismic Loads

Step Description	Computation	Reference
Spectral Response	$S_S = 0.82g$	USGS App.
	$S_1 = 0.33g$	
Site Class	Site Class D	T20.3-1
Site Coeff.	$F_a = 1.2$	T11.4-1
	$F_v = 1.8$	
	$S_{MS} = 1.2(0.82g) = 0.984g$	Eqn 11.4-1
	$S_{M1} = 1.8(0.33g) = 0.594g$	Eqn 11.4-2
Design Spect. Response	$S_{DS} = \frac{2}{3}(0.984g) = 0.656g$	Eqn 11.4-3
	$S_{D1} = \frac{2}{3}(0.594g) = 0.396g$	Eqn 11.4-4
SDC -Cat. II	SDC D	T11.6-1 + 2
Period	$T_a = (0.0488)(5.88m)^{0.75} = 0.184 \le T_L = 8$ ∴ Assumed (Metric)	Eqn 12.8-7, T12.8-2
Str. Sys. As Perf. Sheathed -SCBF	$R = 6$ $\Omega_0 = 2$ $C_d = 5$	T12.2-1
	$I_e = 1.0$	T11.15-2
Seismic Resp. Coeff.	$C_S = \frac{S_{DS}}{(R/I_e)} = 0.109$	
Min	$C_{S_{min}} = 0.044 S_{DS} I_e = 0.029 \ge 0.01$ ∴ $S_1 < 0.6g$	Eqn 12.8-5
Max	$C_{S_{max}} = \frac{S_{D1}}{T(R/I_e)} = 0.359$ $T \le T_L$	Eqn 12.8-3
	$0.029 \le C_S = 0.109 \le 0.359$	
	∴ Use $C_S = 0.109$	
	$V = C_S W = 0.109(187.3\ kN + 777.1\ kN) = 21.4\ kN$	

Wind

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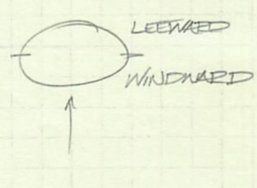
- WIND LOADS

STEP DESCRIPTION	COMPUTATION	REFERENCE
		ASCE 7-10
MWFRS		
BASIC WIND SPEED, V	$V = 150$ MPH ∴ USING FOR A CONSERV. # BASED ON RESEARCH FOR EA (~140 MPH)	T26.5-1A
FLEXIBILITY - APPROX. NAT. FREQ.	$n_a = \frac{75}{h} = \frac{75}{(5.875\,m \times 3.28\,ft/m)}$	
	$n_a = 3.89$ Hz > 1.0 Hz ∴ ASSUMING BAMBOO IS SIMILAR ENOUGH TO STL TO USE ASCE EQN, RIGID	EQN 26.9-4; SECTION 26.2
- GUST EFFECT	$G = 0.85$	
- ENCLOSURE · PARTIALLY ENCLOSED	① ✓ $A_o > 1.10 A_{oi}$ ② ✓ $A_o = 385\ m^2 > 0.01 A_g = 0.37\ m^2$; $< 0.2 A_g = 7.54\ m^2$	SECTION 26.2
	$h_{mean} = 4.44\ m$	
	$\theta = \tan^{-1}\left(\frac{2.5}{4}\right) = 32° > 10°$ ∴ h_{mean} ABOVE EAVE	
- DIR. FACTOR	$K_d = 0.85$	T26.6-1
- SURFACE ROUGH. + EXPOSURE	S.R. = D	SECTION 26.7.2
	EXP. D ∴ WORST-CASE	SECTION 26.7.3
- TOPO. FACTOR	$K_{zt} = 1.0$ ∴ NO EXTRAORDINARY CHANGE IN ELEV. OR. TOPO. FEATURES	
- VEL. PRESS. EXP. COEFF.	0-15' (0-4.6 m) = $1.03 = K_z$ ~~15'-20' (4.6-6.1 m) = 1.08~~ → DO NOT NEED FOR MEAN RF HGT	T27.3-1
WALLS		
- WINDWARD	$C_p = 0.8$	FIG. 27.4-1
- LEEWARD	$C_p = -0.5$	
- SIDE	∴ NO SIDES	
- ROOF NORMAL	$\theta = 32° > 10°$	
	$h/L = 0.73$ m ∴ USE $h/L = 0.75$ + $\theta = 30°$, CONS.	
WW	$C_p = -0.25 + 0.2$ ∴ DOMED RF IS LESS CONS.	
LW	$C_p = -0.6$	
VELOCITY PRESS. - (0-4.6 m)	$q_z = 0.00256(1.03)(1.0)(0.85)(150\ \text{MPH})^2 = 50.4$ PSF	EQN 27.3-1
INT. PRESS.	$GC_{pi} = \pm 0.55$	T26.11-1



Wind: Updated

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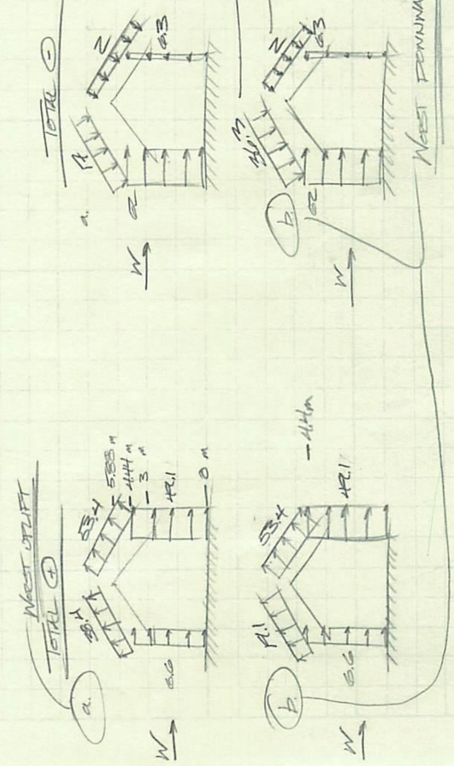
-WIND LOADS

SURFACE	h(m)	q (PSF)	G	Cp	EXT. PRESS. (PSF)	(+) pi (PSF)	(−) pi (PSF)	TOTAL (+) (EQN 27.4-1)	TOTAL (−) (EQN 27.4-1)
WW	0-4.6	50.4	0.85	+0.8	31.3	27.7	-27.7	6.6	62
LW		50.4	↓	-0.5	-21.4	27.7	-27.7	-49.1 / 55.7	6.3 / 55.7
S	NONE								
RF									
·WW, a.		50.4	↓	-0.25	-10.7	27.7	-27.7	-38.4	17
b.		50.4	↓	+0.2	8.6	27.7	-27.7	-19.1	36.3
·LW		50.4	↓	-0.6	-25.7	27.7	-27.7	-53.4	2



∴ OVERHANG EXTENDS DOWN TO 2.625 m

∴ PREVIOUSLY MISCALCULATED WIND DOWNWARD ON RF AS 37.8 PSF + UP ON LW SIDE AS 2.6 PSF. CONSERVATIVE FOR SHEAR + OTHER LOAD-CASES

Wind: Old Calcs for MWFRS (K_d=0.85)

Conservative, thus used for calculations.

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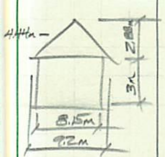
-WIND LOADS (OLD CALCS) => USED (K_d=0.85)

STEP DESCRIPTION	COMPUTATION	REFERENCE
MAX SHEAR AREA	$A_{WALL} = \left(\frac{\pi \cdot 8.15 m}{2}\right)(3 m) = 38.4 m^2$	
	$A_{RF_{TOT}} = \frac{\pi (4.6 m)(5.42 m)}{2} = 39.2 m^2$	
	$A_{RF_H} = 39.2 m^2 - \frac{\pi (2.3 m)(2.71 m)}{2} = 29.4 m^2$	
	A_{CONE} = NTS	∴ SEE PREVIOUS NOTE!
	$32.8 PSF \left(\frac{2.5 m}{4.72 m}\right) = 20.0 PSF$	
WIND	$2.6 PSF \left(\frac{2.5 m}{4.72 m}\right) = 1.40 PSF$	∴ ACTUALLY IN WRONG DIRECTION! (CONSERVATIVE)
	RF TOTAL: 21.4 PSF	
	WALL TOTAL: 62 - 2.5 = 59.5 PSF	
CONVERT	$w_{RF} = (21.4 \frac{\#}{ft^2}) \left\| \frac{KIPS}{1000\#} \right\| \left\| \frac{ft}{12''} \right\|^2 \left\| \frac{4.45 kN}{KIPS} \right\| \left\| \frac{IN}{2.54 cm} \right\|^2 \left\| \frac{100 cm}{m} \right\|^2 = 1.03 kN/m^2$	
	$w_{WALL} = 2.85 kN/m^2$	
SHEAR	$V_{WIND} = (1.03 kN/m^2)(39.2 m^2) + (2.85 kN/m^2)(38.4 m^2 + 29.4 m^2)$	
	$= 235.2 kN \geq V_{SEISMIC} = 21.4 kN$	
	∴ WIND GOVERNS	
ASD	$V_U = 0.6(235.2 kN) = 141.1 kN$	∴ TWO BRACES
	$P_U = 70.6 kN$	



∴ FOR C+C, I LOOKED @ FIG. 30.4-7 ON PAGE 344 IN ASCE 7-10 FOR DOMED RFS, + MY STRUCTURE DOES NOT FALL UNDER NOTES PRESCRIBED. THEREFORE, THE MWFRS CALCS WILL BE USED FOR INDIVIDUAL MEMBERS. ESPECIALLY CONSIDERING THE HIGH ASSUMED VELOCITY.

∴ PAGE 355 DESCRIBES PRESSURE ON OVERHANGS.

MASTER'S	ARE 878	EVAN MYERS

- ULTIMATE LOAD ON STRUCTURE

STEP DESCRIPTION	COMPUTATION	REFERENCE
		ASCE 7-10
VERTICAL: - MAX. DOWN ON ROOF ⊥ TO RF	WIND => $37.8\ PSF \left\lvert \frac{ft}{12''} \right\rvert^2 \left\lvert \frac{in}{25.4\ mm} \right\rvert^2 \left\lvert \frac{4.45\ N}{\#} \right\rvert = 1810 \times 10^{-6}\ N/mm^2\ (MPa)$ $= 1.81 \times 10^3\ Pa$	
	$w_u = 3725\ Pa$ ∴ PERP. TO ROOF	EXCEL (ASD)
- MAX. UPLIFT ON ROOF	WIND => $40.3\ PSF \Rightarrow 1930.3 \times 10^{-6}\ N/mm^2\ (MPa)$ $= 1.93 \times 10^3\ Pa$	
	$w_{u_{min}} = 138\ Pa$ $(-1930\ Pa)$ ∴ DOWNWARD, UPLIFT DOES NOT GOV., EVEN @ OVERHANG - $(-23\ Pa)$	EXCEL $(-2198\ Pa)$
LATERAL: - WIND ONLY	$62\ PSF \Rightarrow 2969.8 \times 10^{-6}\ N/mm^2\ (MPa) = 2.97 \times 10^3\ Pa$	C + C

Member: Intermediate Member 1

Vertical (ASD)

Dead (D)	2160	Pa
Live (L)	0	Pa
Roof Live (L_r)	1000	Pa
Snow (S)	0	Pa
Rain ®	0	1000
Wind (W)	1810.0	Pa
Earthquake (E)	0	Pa

P_u	3724.5	Pa

LOAD COMBOS

YELLOW =INSERT ON OWN

Ultimate Load	
D	ASCE 7-10
D+L	2.4.1
D+(Lr/S/R)	ASD
D+0.75L+.75(Lr/S/R)	
D+(0.6W/0.7E)	
D+0.75L+0.75*0.6W+0.75(L_r/S/R)	
D+0.75L+0.75*0.7E+0.75S	
0.6D+0.6W	
0.6D+0.7E	

Member: Intermediate Member 2

Vertical (ASD)

Dead (D)	2160	Pa
Live (L)	0	Pa
Roof Live (L_r)	1000	Pa
Snow (S)	0	Pa
Rain ®	0	1000
Wind (W)	3384.0	Pa
Earthquake (E)	0	Pa

P_u	4432.8	Pa

LOAD COMBOS

YELLOW =INSERT ON OWN

Ultimate Load	
D	ASCE 7-10
D+L	2.4.1
D+(L_r/S/R)	ASD
D+0.75L+.75(L_r/S/R)	
D+(0.6W/0.7E)	
D+0.75L+0.75*0.6W+0.75(L_r/S/R)	
D+0.75L+0.75*0.7E+0.75S	
0.6D+0.6W	
0.6D+0.7E	

Member: Uplift

Vertical (ASD)

Dead (D)	2160	Pa
Live (L)	0	Pa
Roof Live (L_r)	1000	Pa
Snow (S)	0	Pa
Rain ®	0	1000
Wind (W)	-1930.0	Pa
Earthquake (E)	0	Pa

P_u	138.0	Pa

LOAD COMBOS

YELLOW =INSERT ON OWN

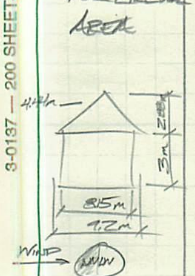
Ultimate Load	
D	ASCE 7-10
D+L	2.4.1
D+(L_r/S/R)	ASD
D+0.75L+.75(L_r/S/R)	
D+(0.6W/0.7E)	
D+0.75L+0.75*0.6W+0.75(L_r/S/R)	
D+0.75L+0.75*0.7E+0.75S	
0.6D+0.6W	
0.6D+0.7E	

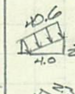
Wind: Circular Surface (K_d=0.95)

MASTER'S	ARE 898	EVAN MYERS

- WIND LOADS ⇒ COMPARING CIRCULAR CALC. (K_d=0.95)

STEP DESCRIPTION	COMPUTATION	REFERENCE
- MAX SHEAR COMPARISON FOR CIRCULAR AREA	$A_{WALL} = \left(\frac{\pi \cdot 8.5\,m}{2}\right)(3\,m) = 38.4\,m^2$	
	$A_{RF} = \pi\left(\frac{4.6m}{2}\right)(5.42m) - \pi\left(\frac{2.3m}{2}\right)(2.71m) = 29.4\,m^2;\ A_{RF_{TOT}} = 39.2\,m^2$	
	$40.6\ PSF\left(\frac{2.5m}{4.72m}\right) = 21.5\ PSF$	
	$-23\ PSF\left(\frac{2.5m}{4.72m}\right) = -1.22\ PSF$	
	RF TOTAL: 20.3 PSF	
	WALL TOTAL: 69.3 − 7.0 = 62.3 PSF	
CONVERT	$w_{RF} = (20.3\ PSF)\left\lvert\frac{KIPS}{1000\#}\right\rvert\left\lvert\frac{FT}{12''}\right\rvert^2\left\lvert\frac{4.45\,kN}{KIPS}\right\rvert\left\lvert\frac{IN}{2.54\,cm}\right\rvert^2\left\lvert\frac{100\,cm}{m}\right\rvert^2$	
	$w_{RF} = 0.972\ kN/m^2$	
	$w_{WALL} = 2.98\ kN/m^2$	
SHEAR	$V_{WIND'} = (0.972\ kN/m^2)(39.2\,m^2) + (2.98\ kN/m^2)(38.4\,m^2 + 29.4\,m^2)$	
	$= 240.2\ kN$	
	$\frac{V_{WIND'} - V_{WIND_o}}{V_{WIND_o}} \times 100 = 2.13\%$ DIFFERENCE	
	∴ THIS DIFFERENCE CAN BE NEGLECTED BECAUSE IT IS MINUTE. BOTH CALCULATIONS ARE CONSERVATIVE BECAUSE THE WIND WILL NOT DIRECTLY IMPACT THE WHOLE WALL AREA ACCOUNTED FOR.	
	∴ BASED ON MY JUDGEMENT, THE STRUCTURE DOES NOT FALL UNDER THE K_d=0.95 FOR CHIMNEYS & TANKS, BUT UNDER THE K_d=0.85 FOR MINARETS.	





Wind Loads

Enclosure Classification	Partially Enclosed			
K_z	1.03	0-15	Ft	(0-4.6 m)
K_{zt}	1			
K_d	0.95			
V	150	MPH		
h	14.6	Ft		
B	26.24	Ft		
L	26.24	Ft		
h/L	0.56			
L/B	1.00			

Yellow Means You Have to Calculate!

All values of q must be determined and imput manually from Equation 23.7-1

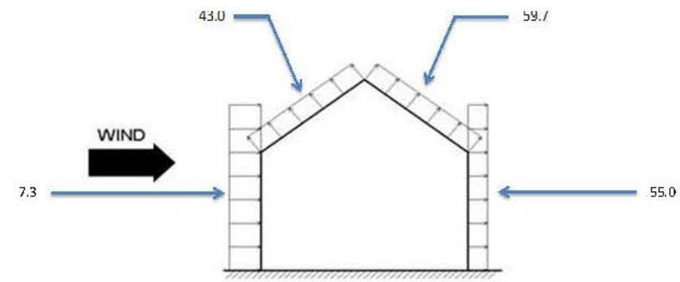
G for rigid buildings is .85 (Section 26.9.1)

Cp (+ and -) must be determiend from 27.4-1 and imput manually

Wind Perpendicular to Short Direction

Surface	Height	q(psf)	G	C_p(+)		External Pressure	(GC_pi)	Internal Pressure (+)	Internal Pressure (-)	*Total (+)*	*Total (-)*
Windward Wall	0-15	56.4	0.85	0.8		38.33	0.55	31.00	-31.00	7.3	69.3
Leeward Wall	-	56.4	0.85	-0.5		-23.95	0.55	31.00	-31.00	-55.0	7.0
Roof		56.4	0.85		-0.25	-11.98	0.55	31.00	-31.00	-43.0	19.0
		56.4	0.85		0.2	9.58	0.55	31.00	-31.00	-21.4	40.6
		56.4	0.85		-0.6	-28.74	0.55	31.00	-31.00	-59.7	2.3

1)



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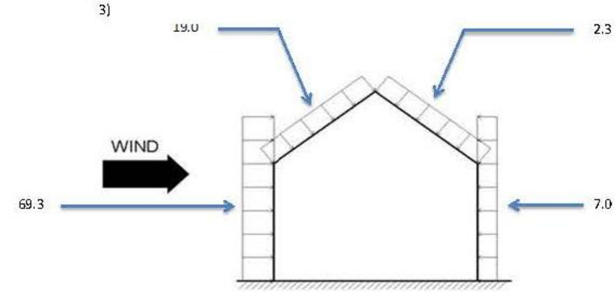

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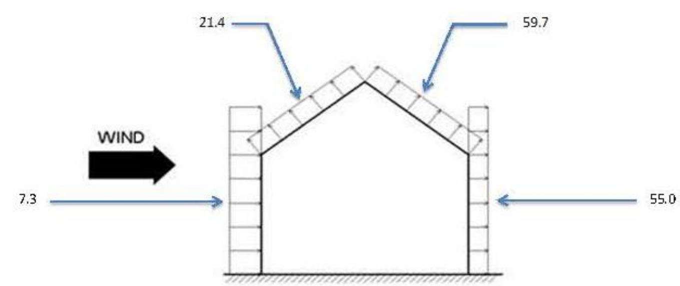
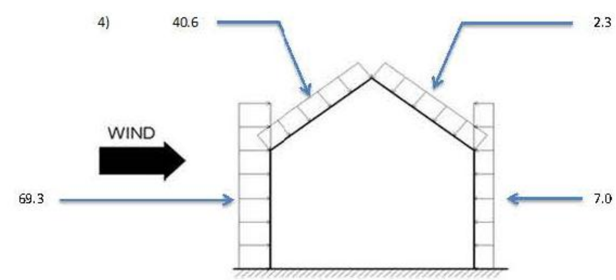


4)



Wind: New Calcs MWFRS (K_d=0.85)

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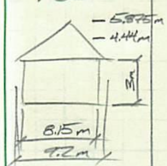
- WIND LOADS (ACTUAL w/ K_d=0.85)

STEP DESCRIPTION	COMPUTATION	REFERENCE

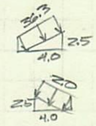
- MAX SHEAR AREA



$A_{WALL} = \frac{(\pi \cdot 8.15m)(3m)}{2} = \overset{x}{38.4}\ m^2$

$A_{RF} = \frac{\pi(4.6m)(5.42m)}{2} - \frac{\pi(2.3m)(2.71m)}{2} = \overset{+}{29.4}\ m^2$; $A_{RF_{TOT}} = 39.2m^2$

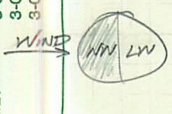
$A_{CONE} = \pi r s$ (s, r; 2.71, 1.44m, 2.3)



$36.3 PSF \left(\frac{2.5m}{4.72m}\right) = \overset{a}{19.24}\ PSF$

$-20\ PSF \left(\frac{2.5m}{4.72m}\right) = -1.06\ PSF$

RF TOTAL: 18.2 PSF



WALL TOTAL: 62.0 - 6.3 = 55.7 PSF

CONVERT

$\omega_{RF} = (18.2 PSF) \left|\frac{KIPS}{1000\#}\right| \left|\frac{FT}{12"}\right|^2 \left|\frac{4.45 kN}{KIPS}\right| \left|\frac{IN}{2.54cm}\right|^2 \left|\frac{100cm}{m}\right|^2$

$\omega_{RF} = \overset{a}{0.872}\ kN/m^2$

$\omega_{WALL} = \overset{b}{2.67}\ kN/m^2$

SHEAR

$V_{WIND} = (\overset{a}{0.872}\ kN/m^2)(39.2m^2) + (\overset{b}{2.67}\ kN/m^2)(\overset{x}{38.4}\ m^2 + \overset{+}{29.4}\ m^2)$

$= 215.1\ kN$

∴ NEW, CORRECTED VALUES ARE SMALLER. WILL KEEP CALCS IN DESIGN WITH OLD CALCS BECAUSE NOT A SIGNIFICANT CHANGE TO IMPACT MEMBER SIZES. AND DEFLECTION HAS BEEN THE MAIN DESIGN ISSUE.

Wind Loads

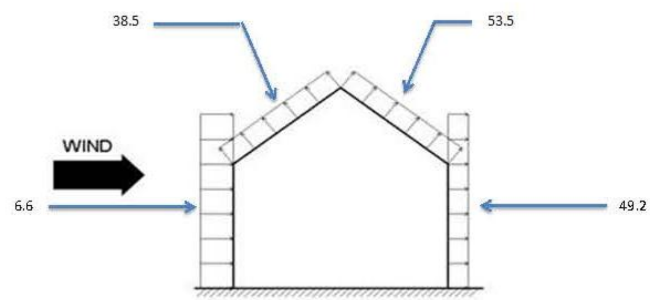
Enclosure Classification	Partially Enclosed			
K_z	1.03	0-15	Ft	(0-4.6 m)
K_{zt}	1			
K_d	0.85			
V	150	MPH		
h	14.6	Ft		
B	26.24	Ft		
L	26.24	Ft		
h/L	0.56			
L/B	1.00			

Yellow Means You Have to Calculate!

All values of q must be determined and imput manually from Equation 23.7-1
G for rigid buildings is .85 (Section 26.9.1)
Cp (+ and -) must be determiend from 27.4-1 and imput manually

Wind Perpendicular to Short Direction

Surface	Height	q(psf)	G	C_p(+)	External Pressure	(GC_pi)	Internal Pressure (+)	Internal Pressure (-)	*Total (+)*	*Total (-)*
Windward Wall	0-15	50.4	0.85	0.8	34.29	0.55	27.74	-27.74	6.6	62.0
Leeward Wall	-	50.4	0.85	-0.5	-21.43	0.55	27.74	-27.74	-49.2	6.3
Roof		50.4	0.85	-0.25	-10.72	0.55	27.74	-27.74	-38.5	17.0
		50.4	0.85	0.2	8.57	0.55	27.74	-27.74	-19.2	36.3
		50.4	0.85	-0.6	-25.72	0.55	27.74	-27.74	-53.5	2.0

1)


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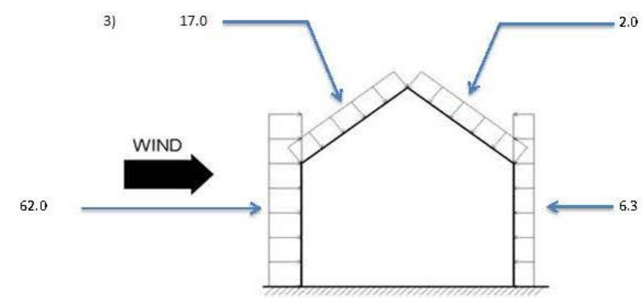

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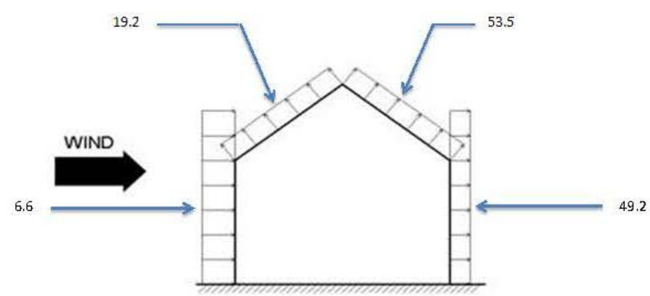

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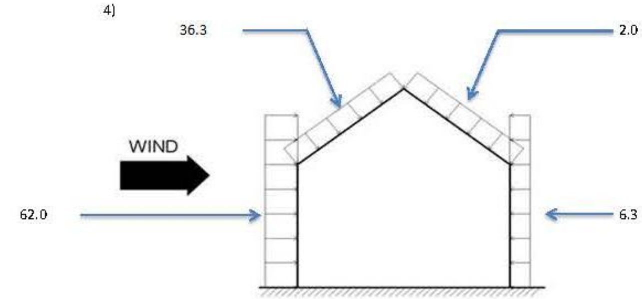

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- WIND UPLIFT

STEP DESCRIPTION	COMPUTATION	REFERENCE
WORST-CASE UPLIFT	$\omega_{UPLIFT} = 53.5$ PSF	
	∴ IN LOAD COMBINATIONS (ASD)	
COMBO. #7	$0.6\omega_D + 0.6\omega_{UPLIFT} = 0.6(45\text{ PSF}) - 0.6(53.5\text{ PSF})$	ASCE 7-10
	$= -5.1$ PSF OR UP	
	∴ NOT A SIGNIFICANT FORCE UPWARD. BENDING MEMBERS DESIGNED FOR HIGHER LOADING, & TRUSS IS CAPABLE OF WITHSTANDING THIS LOAD WHICH WOULD CHANGE MEMBER ROLES FROM TENSION TO COMPRESSION & VICE-VERSA.	
	∴ ADDITIONAL UPLIFT CASES DO NOT OVERCOME DEAD LOAD.	

3-0235 — 50 SHEETS — 5 SQUARES
3-0236 — 100 SHEETS — 5 SQUARES
3-0237 — 200 SHEETS — 5 SQUARES
3-0137 — 200 SHEETS — FILLER
COMET

MASTER'S	ARC 878	EVAN MYERS

- ALLOWABLE STRESS DESIGN:

STEP DESCRIPTION	COMPUTATION	REFERENCE
EQN	$S_{ALL} = \frac{(m - 2.3s) G \cdot D}{S}$ S_{ALL} = ALLOWABLE STRESS (MPa = N/mm^2) m = MEAN ULTIMATE STRENGTH (MPa) FROM TESTS ON SHORT-TERM LOADING s = STD. DEVIATION IN THESE TESTS m - 2.3s = 1% LOWER BOUND. G = MOD. 4 DIFF. BTW LAB. QUALITY & PRACTICE, W/ DEFAULT VALUE OF 0.5 D = MOD. VALUE FOR DURATION OF LOAD: · 1.0 FOR PERMANENT LOAD · 1.25 FOR PERMANENT PLUS TEMP. LOAD · 1.5 FOR PERMANENT + TEMP. LOAD PLUS WIND LOADS S = FACTOR OF SAFETY, W/ DEFAULT VALUE OF 2.25	INBAR 2000 p.81
BENDING	$S_{ALL} = \frac{(82\ MPa)(0.5)(1.5)}{2.25} = 27.3\ MPa$	PROTA
	∴ ASSUME 82 MPa WAS CONSIDERED A LOWER BOUND.	
	$S_{ALL} = \frac{(84 - 2.3 \cdot 0.4)(0.5)(1.5)}{2.25} = 27.7\ MPa$	O.A. STRUCTURAL STUDY
STD. DEVIATION	$s = \frac{\pm 3.4\ MPa}{84\ MPa} = 0.4$	
TENSION	$S_{ALL} = \frac{(127 - 2.3 \cdot 0.08)(0.5)(1.5)}{2.25} = 42.3\ MPa$	O.A. STRUCTURAL STUDY
STD. DEVIATION	$s = \frac{\pm 10\ MPa}{127\ MPa} = 0.08$	
COMPRESSION	$S_{ALL} = \frac{(40 - 2.3 \cdot 0.075)(0.5)(1.5)}{2.25} = 13.3\ MPa$	O.A. STRUCTURAL STUDY
	$s = \frac{\pm 3}{40} = 0.075$	
SHEAR	$S_{ALL} = \frac{(11\ MPa)(0.5)(1.5)}{2.25} = 3.7\ MPa$	PROTA

∴ S_{ALL} EQN ORIGINALLY FROM BRITISH CODE OF PRACTICE 112 FOR TIMBER.

- ALLOWABLE STRESS DESIGN:

STEP DESCRIPTION	COMPUTATION	REFERENCE
ALLOWABLE STRESSES	$b_n = 27$ MPa $(\Omega \simeq 3)$	
	$t_n = 42$ MPa $(\Omega \simeq 3)$	
	$c_n = 13$ MPa $(\Omega \simeq 3)$	
	$v_n = 3.7$ MPa $(\Omega \simeq 3)$	
	$E = 14{,}617$ MPa	DIDIER, NGARGUE, MFESSA, TATESE, 2012
	$\gamma = 778$ kg/m³	
ENGLISH UNITS	$b_n = 27.3\ \text{MPa} \left\lvert \frac{10^6\ N/m^2}{MPa} \right\rvert \left\lvert \frac{kN}{1000\ N} \right\rvert \left\lvert \frac{KIPS}{4.45\ kN} \right\rvert \left\lvert \frac{m}{100\ cm} \right\rvert^2 \left\lvert \frac{2.54\ cm}{IN} \right\rvert^2$	
	$b_n = 3.96$ KSI	
	$t_n = 6.13$ KSI	
	$c_n = 1.93$ KSI	
	$v_n = 0.54$ KSI	
	$E = 2119.2$ KSI => 2120 KSI	
	∴ USE IN CUSTOM WOOD MATERIAL IN RISA	

- PROPERTIES FOR VARIOUS SIZES OF OXYTENANTHERA ABYSSINICA CULMS:

STEP DESCRIPTION	COMPUTATION	REFERENCE
6cm φ, t=1.5 cm; AREA; MOMENT OF INERTIA; RADIUS OF GYRATION; SECTION MODULUS	$A=\frac{\pi(d_o^2-d_i^2)}{4}=21.2\ cm^2$ $I=\frac{\pi(d_o^4-d_i^4)}{64}=59.6\ cm^4$ $r=\sqrt{I/A}=1.68\ cm$ $S=\frac{\pi(d_o^4-d_i^4)}{32d_o}=19.9\ cm^3$	AISC 360-10 + INBAR, 2000 ↓
8cm φ; t=2.5cm	$A=43.2\ cm^2$ $I=197.1\ cm^4$ $r=2.14\ cm$ $S=49.3\ cm^3$	
10cm φ, t=3.5cm	$A=71.5\ cm^2$ $I=486.9\ cm^4$ $r=2.61\ cm$ $S=97.4\ cm^3$	
MEMBER SIZES	∴ SIZES CHOSEN BASED UPON THE RANGE GIVEN FOR OXYTENANTHERA ABYSSINICA CULMS (3-10cm). THE THICKNESSES WERE CHOSEN BASED UPON SCALING PICTURES, ALTHOUGH THIS SPECIES IS CONSIDERED SOLID. CONSERVATIVE THICKNESSES WERE CHOSEN FOR DESIGN ALTHOUGH OXYTENANTHERA ABYSSINICA CULMS GROW MORE SOLID WITH AGE.	

Mechanical Properties

Ultimate Bending Stress:	b_n=	27	MPa	BOXES NEED INPUTS
Ultimate Tension Stress:	t_n=	42	MPa	
Ultimate Compression Stress:	c_n=	13	MPa	
Ultimate Shear Stress:	v_n=	3.7	MPa	
Modulus of Elasticity:	E=	14617	MPa	

Culm: 6 cm Φ, 1.5 cm Thick Wall

Outside Diameter:	d_o=	6	cm			
Inside Diameter:	d_i=	3	cm			
Wall Thickness:	t=	1.5	cm			
Moment of Inertia:	I=	$\pi(d_o^4-d_i^4)/64$	=	$\pi * (6^4 - 3^4)/64$=	**59.64**	cm^4
Area:	A=	$\pi(d_o^2-d_i^2)/4$	=	$\pi * (6^2 - 3^2)/4$ =	**21.21**	cm^2
Radius of Gyration:	r=	$(I/A)^{1/2}$	=(	$59.64 / 21.21)^{1/2}$=	**1.68**	cm
Section Modulus:	S=	$\pi(d_o^4-d_i^4)/(32*d_o)$	=	$\pi * (6^4 - 3^4) / (32* 6)$ =	**19.9**	cm^3

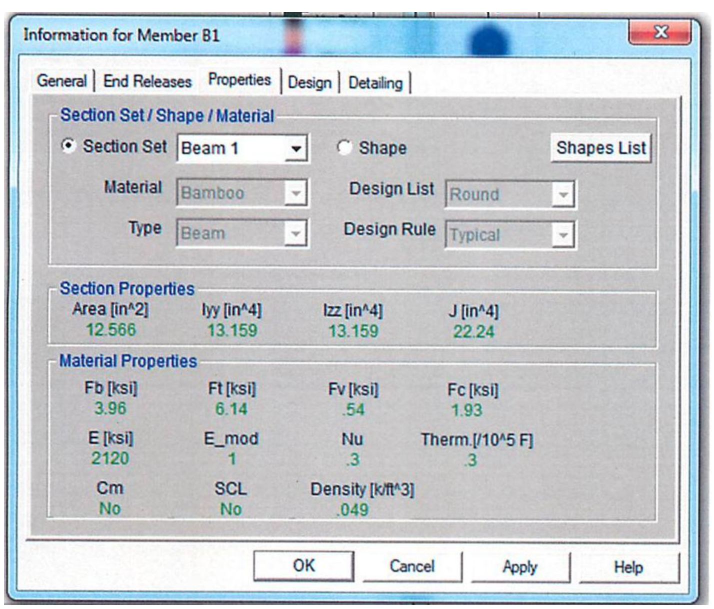
Culm: 8 cm Φ, 2.5 cm Thick Wall

Outside Diameter:	d_o=	8	cm			
Inside Diameter:	d_i=	3	cm			
Wall Thickness:	t=	2.5	cm			
Moment of Inertia:	I=	$\pi(d_o^4-d_i^4)/64$	=	$\pi * (8^4 - 3^4)/64$=	**197.09**	cm^4
Area:	A=	$\pi(d_o^2-d_i^2)/4$	=	$\pi * (8^2 - 3^2)/4$ =	**43.20**	cm^2
Radius of Gyration:	r=	$(I/A)^{1/2}$	=(	$197.09 / 43.20)^{1/2}$=	**2.14**	cm
Section Modulus:	S=	$\pi(d_o^4-d_i^4)/(32*d_o)$	=	$\pi * (8^4 - 3^4) / (32* 8)$ =	**49.3**	cm^3

Culm: 10 cm Φ, 3.5 cm Thick Wall

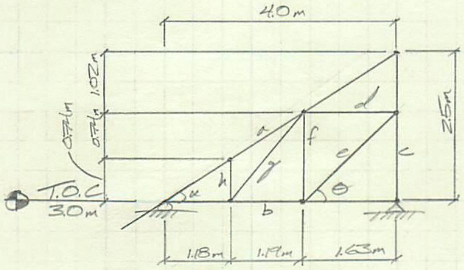
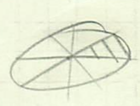
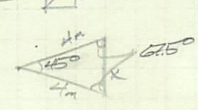
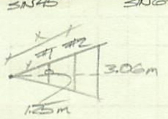
Outside Diameter:	d_o=	10	cm			
Inside Diameter:	d_i=	3	cm			
Wall Thickness:	t=	3.5	cm			
Moment of Inertia:	I=	$\pi(d_o^4-d_i^4)/64$	=	$\pi * (10^4 - 3^4)/64$=	**486.90**	cm^4
Area:	A=	$\pi(d_o^2-d_i^2)/4$	=	$\pi * (10^2 - 3^2)/4$ =	**71.47**	cm^2
Radius of Gyration:	r=	$(I/A)^{1/2}$	=(	$486.90 / 71.47)^{1/2}$=	**2.61**	cm
Section Modulus:	S=	$\pi(d_o^4-d_i^4)/(32*d_o)$	=	$\pi * (10^4 - 3^4) / (32* 10)$ =	**97.4**	cm^3

RISA Custom Member



MASTER'S	ARC 878	EVAN MYERS

- TRUSS GEOMETRY + BRACE GEOMETRY

SET DESCRIPTION	COMPUTATION	REFERENCE
TRUSS DIMS	 ∴ PROVIDES TRAD. AMHARA ARCH. $\alpha = 32°$, $\theta = 45°$	
NOM. MEMBER SIZES	∴ INITIALLY, ALL CULMS ASSUMED 6 cm ϕ w/ 1.5 cm WALL THICKNESS U.N.O.	
LENGTHS (W.P. 2 W.P.)	$l_a = 5.42m$, $l_d = 1.53m$, $l_g = 1.90m$; $l_b = 4.0m$, $l_e = 2.17m$, $l_h = 0.74m$; $l_c = 2.5m$, $l_f = 1.53m$	CALC.
APPROX. LENS.	$l_a = 5.35m$, $l_d = 1.43m$, $l_g = 1.57m$; $l_b = 3.99m$, $l_e = 2.03m$, $l_h = 0.74m$; $l_c = 2.54m$, $l_f = 1.48m$	REVIT
NO. OF TRUSSES	∴ 16 TRUSSES; 8 CULMS EACH (128 TOTAL)	
BRACE GEO.	$l_{BRACE} = \sqrt{2.80^2 + 3.06^2} = 4.15m$  $\frac{360°}{8} = 45°$ 	
LAW OF SINES	$\frac{x}{\sin 45°} = \frac{4m}{\sin 67.5°} \Rightarrow x = 3.06m$	
INTERMEDIATE #1	 $\frac{1.25m}{\sin 45°} = \frac{y}{\sin 67.5°} \Rightarrow y = 1.63m$; $l_{I1} = 0.625m$	
INTERMEDIATE #2	$x = \frac{(4-1.63)m}{2} + 1.63m = 2.82m$; $\frac{y}{\sin 45} = \frac{2.82m}{\sin 67.5m} \Rightarrow y = 2.15m$; $l_{I2} = 1.08m$	

Intermediate Members

Member	Length (m)	Distributed Load (kN/m)	Point Load (kN)	Location (m)
Intermediate 1	0.625	6.2	-	-
Intermediate 2	1.08	7.78	-	-

Bamboo Bending Design

Member: Intermediate 1

Culm Outside Diameter: d_o= 6 cm
Modulus of Elasticity: E= 14617 MPa
Moment of Inertia: I= 59.64 cm^4
Area: A= 21.21 cm^2
Radius of Gyration: r= 1.68 cm
Section Modulus: S= 19.88 cm^3
Effective Length Factor: K= 1.00

Member-
Length: ℓ= **0.625** m
Distributed Load: ω_u= **6.2** kN/m

Bending

Moment (Distributed Load): M_u= $\omega_u \ell^2/8$= 6.2 * 0.625 ^{2}/8 = **0.30** kN*m
Bending Stress: b_u= M_u/S= 0.30 / 19.88 *[100 cm/m]^3*[1000 N/kN]*[MPa/10^6 N/m^2]= **15.23** MPa

b_u= **15.23** MPa ≤ b_n= **27.00** MPa **OK**

Shear

Shear Force: V_u= $\omega_u \ell/2-\omega_u d$= 6.2 * 0.625 /2 - 6.2 * 6 *[m/100 cm]= **1.57** kN
Shear Stress: v_u= $3V_u/(2A)$= 3 * 1.57 /(2* 21.21)*[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2]= 1.11 MPa

v_u= 1.11 MPa ≤ v_n= **3.70** MPa **OK**

Deflection

Max Allowable Deflection: δ_{max}= ℓ/300= 0.625 *[100 cm/m]/300= **0.21** cm
Calculated Deflection (Distributed Load): δ_{calc}= $5\omega_u \ell^4/(384EI)$= (5 * 6.20 * 0.63^4) / (384 * 14617 * 59.64) *[100 cm/m]^5*[1000 N/kN]*[MPa/10^6 N/m^2]= **0.14** cm

δ_{calc}= **0.14** cm ≤ δ_{max}= **0.21** cm **OK**

Buckling

Slenderness: λ= KL/r= (1.00 * 0.625) / 1.68 *[100 cm/m] = **37.3** ≤ 50 **OK**

Bamboo Bending Design

Member: Intermediate 2

Culm Outside Diameter: d_o= 10 cm
Modulus of Elasticity: E= 14617 MPa
Moment of Inertia: I= 486.90 cm^4
Area: A= 71.47 cm^2
Radius of Gyration: r= 2.61 cm
Section Modulus: S= 97.38 cm^3
Effective Length Factor: K= 1.00

Member-
Length: ℓ= **1.08** m
Distributed Load: ω_u= **7.78** kN/m
Point Load: F_u= **0** kN

Bending

Moment (Distributed Load): M_u= $\omega_u \ell^2/8$= 7.78 - 1.08 ^{2}/8 = **1.13** kN-m
Bending Stress: b_u= M_u/S= 1.13 / 97.38 -[100 cm/m]^3-[1000 N/kN]-[MPa/10^6 N/m^2] = **11.65** MPa

b_u= **11.65** MPa ≤ b_n= **27.00** MPa **OK**

Shear

Shear Force: V_u= $\omega_u \ell/2-\omega_u d$= 7.78 - 1.08 /2- 7.78 - 10 -[m/100 cm]= **3.42** kN
Shear Stress: v_u= $3V_u/(2A)$= 3- 3.42 /(2- 71.47)-[100 cm/m]^2-[1000 N/kN]-[MPa/10^6 N/m^2]= **0.72** MPa

v_u= **0.72** MPa ≤ v_n= **3.70** MPa **OK**

Deflection

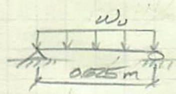
Max Allowable Deflection: δ_{max}= ℓ/300= 1.08 -[100 cm/m]/300= **0.36** cm
Calculated Deflection (Distributed Load): δ_{calc}= $5\omega_u \ell^4/(384EI)$= (5- 7.78 - 1.08^4) / (384- 14617 - 486.90) -[100 cm/m]^5-[1000 N/kN]-[MPa/10^6 N/m^2]= **0.19** cm

δ_{calc}= **0.19** :m ≤ δ_{max}= **0.36** cm **OK**

Buckling

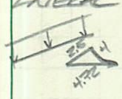
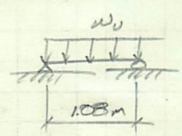
Slenderness: λ= KL/r= (1.00 - 1.08) / 2.61 -[100 cm/m] = **41.4** ≤ 50 **OK**

- ROOF + TRUSS DESIGN

STEP DESCRIPTION	COMPUTATION	REFERENCE
① INTERMEDIATE RF MEMBERS: $l = 0.625\,m$	∴ MEMBER IS ABOVE LATERAL WIND PRESSURE. THUS, MAX. DOWNWARD ON ROOF IS ONLY LOAD.	
FORCES	$w_u = 3725\ Pa$ ∴ PERP. TO RF	EXCEL (ASD)
BENDING	$w_u = 3725\ Pa \left(\frac{1.93\,m}{2} + \frac{1.40\,m}{2}\right) \left\| \frac{N/m^2}{Pa} \right\| \frac{kN}{1000\,N} \right\| = 6.20\ kN/m$ $d_2 = 3.33\,m - 1.93\,m = 1.40\,m$  $M_u = \frac{w_u l^2}{8} = 0.30\ kN{\cdot}m$	
DESIGN BENDING STRESS	$b_u = \frac{M_u}{S} = \frac{0.30\ kN{\cdot}m}{19.7\ cm^3} \left\| \frac{100\ cm}{m} \right\|^3 \left\| \frac{Pa}{N/m^2} \right\| \frac{1000\ N}{kN} \right\| \frac{MPa}{10^6\ Pa} \right\|$ $b_u = 15.2\ MPa \le b_n = 27\ MPa$ ∴ OK	
SHEAR	$V_u = \frac{w_u l}{2} - w_u d = 1.57\ kN$ $v_u = \frac{3V_u}{2 \cdot A} = \frac{3 \cdot 1.57\ kN}{2 \cdot 21.2\ cm^2} \left\| \frac{100\ cm}{m} \right\|^2 \left\| \frac{1000\ N}{kN} \right\| \frac{MPa}{10^6\ N/m^2} \right\|$ $v_u = 1.11\ MPa \le v_n = 3.7\ MPa$ ∴ OK @ d FROM W.P.	NDS 2005
DEFLECTION	$\delta_{max} = \frac{l}{300} = \frac{0.625\ m \cdot 100\ cm}{300} = 0.21\ cm$ $\delta_{calc} = \frac{5(6200\ N/m)(0.625\ m)^4}{384(14612\ MPa)(57.64\ cm^4)} \left\| \frac{MPa}{10^6\ N/m^2} \right\| \frac{100\ cm}{m} \right\|^5$ $\delta_{calc} = 0.141\ cm < \delta_{max} = 0.21\ cm$ ∴ OK	AISC 360-10
BUCKLING	$\frac{KL}{r} = \frac{(1.0)(0.625\ m)}{(1.68\ cm)} \left\| \frac{100\ cm}{m} \right\| = 37.3 < 50$ ∴ OK, ALTHOUGH ADEQ. ATTACH. TO ROOF MAYBE ASSUMED. ∴ USE 6 cm φ, 1.5 cm THICK CULM WALL FOR INTERMEDIATE MEMBER 1	

MASTER'S	ARE 898	EVAN MYERS

- ROOF + TRUSS DESIGN

STEP DESCRIPTION	COMPUTATION	REFERENCE
② INTERMEDIATE MEMBER ℓ = 1.075 m	∴ MEMBER EXPERIENCES LATERAL WIND LOAD ALONG W/ VERTICAL WIND LOAD. CALCS. BASED ON COMBO OF LAT. + DOWNWARD.	
LATERAL 	$62\ PSF \Rightarrow 2970\ Pa \left(\frac{2.5\ m}{4.72\ m}\right) = 1574\ Pa$	
	TOTAL DOWNWARD: $37.8\ PSF = 1810\ Pa$	
	$1574 + 1810 = 3384\ Pa$	
PERP. 2 RF	$w_u = 4133\ Pa \left(\frac{2.11\ m}{2} + \frac{1.40\ m}{2}\right) \frac{N/m^2}{Pa} \frac{kN}{1000\ N} = 7.78\ kN/m$	
	$d_1 = 1.40\ m + 0.707\ m = 2.11\ m$	
	$d_2 = 1.40\ m$ 	
BENDING	$M_u = \frac{w_u \ell^2}{8} = 1.12\ kN \cdot m$	
6 cm ⌀ STRESS	$b_u = \frac{M_u}{S} = \frac{1.12\ kN \cdot m}{19.9\ cm^3} \frac{MPa}{10^6\ N/m^2} \left(\frac{100\ cm}{m}\right)^3 \frac{1000\ N}{kN}$	
	$b_u = 56.5\ MPa \leq b_n = 27\ MPa$	∴ NG, TRY 8 cm ⌀
8 cm ⌀ STRESS	$b_u = 22.8\ MPa \leq b_n = 27\ MPa$	∴ OK
SHEAR	$V_u = \frac{w_u \ell}{2} - w_u d = 3.56\ kN$	
STRESS	$v_u = \frac{3V_u}{2A} = 1.24\ MPa \leq v_n = 3.7\ MPa$	∴ OK
DEFLECTION	$\delta_{max} = \ell/300 = 0.36\ cm$	
	$\delta_{calc} = \frac{5(7780\ N/m)(1.075\ m)^4}{384(14677\ MPa)(177.1\ cm^4)} \frac{MPa}{10^6\ N/m^2} \left(\frac{100\ cm}{m}\right)^5$	
	$\delta_{calc} = 0.47\ cm > \delta_{max} = 0.36\ cm$	∴ TRY 10 cm ⌀
	$\delta_{calc} = 0.19\ cm \leq \delta_{max} = 0.36\ cm$	∴ OK
BUCKLING	$\frac{KL}{r} = 41.2 \leq 50$	∴ OK

∴ USE 10 cm ⌀ w/ .35 cm THICK CULM WALL FOR INTERMEDIATE MEMBER 2.

Bamboo Bending Design

Member:		**Roof OH End Beam**	
Culm Outside Diameter:	d_o=	**10**	cm
Modulus of Elasticity:	E=	**14617**	MPa
Moment of Inertia:	I=	**486.90**	cm^4
Area:	A=	**71.47**	cm^2
Radius of Gyration:	r=	**2.61**	cm
Section Modulus:	S=	**97.38**	cm^3
Effective Length Factor:	K=	**1.00**	
Member-			
Length:	ℓ=	**1.78**	m
Distributed Load:	ω_u=	**2.9**	kN/m
Point Load:	F_u=	**0**	kN

Bending

Moment (Distributed Load):	M_u=	$\omega_u \ell^2/8$=	2.9	*	1.78 ^{2}/8=		1.15	kN*m		
Bending Stress:	b_u=	M_u/S=	1.15	/	97.38 *[100 cm/m]^3*[1000 N/kN]*[MPa/10^6 N/m^2]		=	**11.79**	MPa	
	b_u=	**11.79**	MPa ≤ b_n=	**27.00**	MPa					***OK***

Shear

Shear Force:	V_u=	$\omega_u \ell/2-\omega_u d$=	2.9	*	1.78 /2-		2.9	*	10 *[m/100 cm]=	**2.29**	kN	
Shear Stress:	v_u=	$3V_u/(2A)$=	3*	2.29	/(2*	71.47	)*[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2]=	**0.48**	MPa			
	v_u=	**0.48**	MPa ≤ v_n=	**3.70**	MPa							***OK***

Deflection

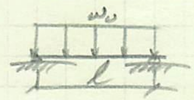
Max Allowable Deflection:	δ_{max}=	$\ell/300$=	1.78	*[100 cm/m]/300=	**0.59** cm					
Calculated Deflection (Distributed Load):	δ_{calc}=	$5\omega_u\ell^4/(384EI)$=	5* / 384*	2.90 / 14617	* / *	1.78 / 486.90	^{4})*[100 cm/m]^3*[1000 N/kN]*[MPa/10^6 N/m^2]=	**0.53**	cm	
	δ_{calc}=	**0.53**	m ≤ δ_{max}=	**0.59**	cm					***OK***

Buckling

Slenderness:	λ=	KL/r=	1.00	*	1.78 / 2.61	*[100 cm/m]	=	**68.2**	≤ 50		**CHECK BUCKLING**
Buckling:	P_{e1}=	$\pi^2EI/(KL)^2$=	π^2 * / (	14617 / 1.00	* / *	486.90 / 1.78	*[10^6 N/m^2/MPa]*[m/100 cm]^4*[kN/1000 N]= /)^2	**221.69**	kN		
	P_{e1}=	**221.69**	kN ≥ F_u=	**5.16**	kN						***OK***

MASTER'S	ARE 5?8	EVAN MYERS

– ROOF + TRUSS DESIGN

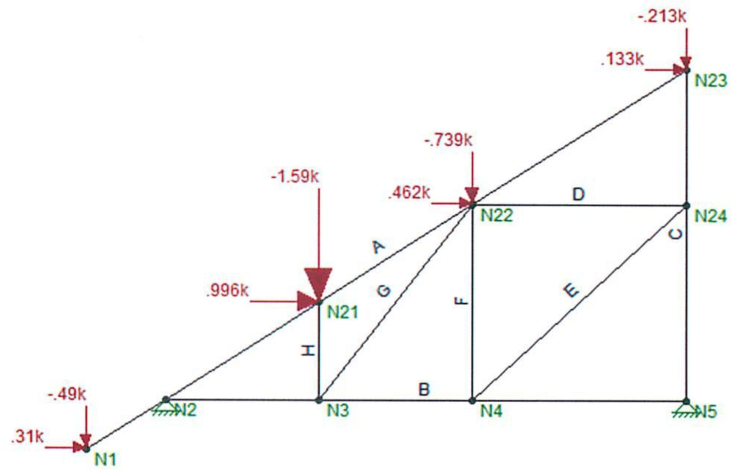
STEP DESCRIPTION	COMPUTATION	REFERENCE
RF OH, END BM $l = 1.78$ m	$w_u = \left[4433\,Pa - 2990\,Pa\left(\frac{4.0\,m}{4.72\,m}\right)\right](0.707\,m) + (4433\,Pa)\left(\frac{2.11\,m}{2} - 0.707\,m\right)$ ← UPLIFT	
	$d = 0.707\,m + 1.40\,m = 2.11\,m$	
	$w_u = 2.90\ kN/m$	
BENDING MOMENT	 $M_u = \frac{w_u l^2}{8} = 1.15\ kN \cdot m$	
STRESS	$b_u = \frac{M_u}{S} = \frac{1.15\,kN \cdot m}{19.9\,cm^3}\left\|\frac{MPa}{10^6\,N/m^2}\right\|\left\|\frac{1000\,N}{kN}\right\|\left\|\frac{100\,cm}{m}\right\|^3$	
6 cm ⌀	$b_u = 57.7\ MPa > b_n = 22\ MPa$ ∴ NG	
8 cm ⌀	$b_u = 23.3\ MPa \leq b_n = 22\ MPa$ ∴ OK	
SHEAR	$V_u = \frac{w_u l}{2} - w_u d = 2.35\ kN$	
STRESS	$v_u = \frac{3V_u}{2A} = 0.82\ MPa \leq v_n = 3.7\ MPa$ ∴ OK	
DEFLECTION	$\delta_{max} = l/300 = 0.593\ cm$	INBAR, 2000
	$\delta_{calc} = \frac{5(2900\,N/m)(1.78\,m)^4}{384(14617\,MPa)(77.1\,cm^4)}\left\|\frac{MPa}{10^6\,N/m^2}\right\|\left\|\frac{100\,cm}{m}\right\|^5$	
	$\delta_{calc} = 1.32\ cm > \delta_{max} = 0.593\ cm$ ∴ NG	
10 cm ⌀	$\delta_{calc} = 0.533\ cm \leq \delta_{max} = 0.593\ cm$ ∴ OK	
SLENDERNESS	$\frac{KL}{r} = 68.2 > 50$ ∴ ✓ BUCKLING	
	$P_{cr} = \frac{\pi^2 EI}{(KL)^2} = 221.7\ kN$ ∴ OK	
	∴ USE 10 cm ⌀ CULM FOR RF OH	

MASTER'S | AE 898 | EVAN MYERS

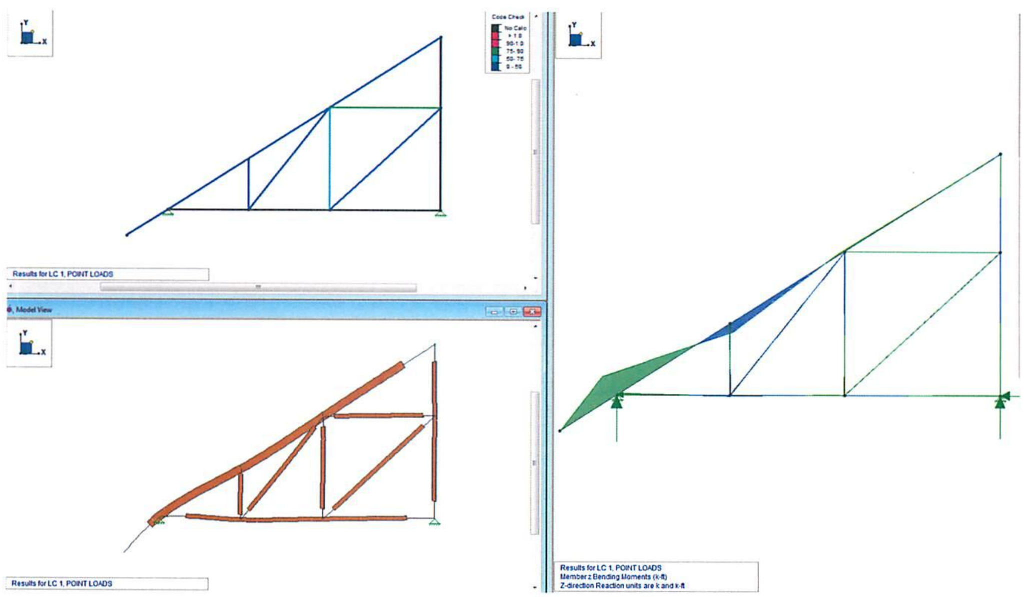
-ROOF & TRUSS DESIGN

STEP DESCRIPTION	COMPUTATION	REFERENCE
FORCES FOR RISA X-DIR.	P_{0x} = 1.12 sin 32° = 0.593 kN (0.133 KIPS)	
	P_{1x} = 3.88 sin 32° = 2.06 kN (0.462 KIPS)	
	P_{2x} = 8.36 sin 32° = 4.43 kN (0.996 KIPS)	
Y-DIR.	P_{0y} = 1.12 cos 32° = 0.95 kN (0.213 KIPS)	
	P_{1y} = 3.88 cos 32° = 3.29 kN (0.739 KIPS)	
	P_{2y} = 8.36 cos 32° = 7.09 kN (1.59 KIPS)	
	∴ PLUG INTO RISA	
	∴ ALL VALUES FROM RISA WERE SLIGHTLY LOWER THAN HAND CALCS, EXCEPT FOR M3's (b) TENSION FORCE. OK.	

Truss Forces



Results



Basic Load Cases

	BLC Description	Category	X Gravity	Y Gravity	Z Gravity	Joint	Point	Distributed	Area(Me...	Surface(Plate/Wall)
1	POINT LOADS	None				8				

Member Section Forces

	LC	Member Label	Sec	Axial[k]	y Shear[k]	z Shear[k]	Torque[k-ft]	y-y Mo...	z-z Mo...
1	1	C	1	1.453	.002	0	0	0	.005
2			2	1.453	.002	0	0	0	.003
3			3	1.453	.002	0	0	0	0
4			4	1.453	.002	0	0	0	-.003
5			5	.282	-.002	0	0	0	-.002
6			6	.282	-.002	0	0	0	0
7			7	.282	-.002	0	0	0	.003
8	1	A	1	.003	-.58	0	0	0	0
9			2	1.37	.381	0	0	0	1.003
10			3	1.37	.381	0	0	0	-.127
11			4	2.257	-.125	0	0	0	-.211
12			5	-.151	.013	0	0	0	.076
13			6	-.151	.013	0	0	0	.036
14			7	-.151	.013	0	0	0	-.003
15	1	B	1	-1.412	.038	0	0	0	.098
16			2	-1.412	.038	0	0	0	.015
17			3	-.16	-.01	0	0	0	-.021
18			4	-.16	-.01	0	0	0	.001
19			5	1.139	-.002	0	0	0	-.002
20			6	1.139	-.002	0	0	0	.002
21			7	1.139	-.002	0	0	0	.005
22	1	H	1	1.634	-.02	0	0	0	-.018
23			2	1.634	-.02	0	0	0	-.01
24			3	1.634	-.02	0	0	0	-.002
25			4	1.634	-.02	0	0	0	.006
26			5	1.634	-.02	0	0	0	.014
27			6	1.634	-.02	0	0	0	.022
28			7	1.634	-.02	0	0	0	.03
29	1	F	1	1.164	.008	0	0	0	.016
30			2	1.164	.008	0	0	0	.01
31			3	1.164	.008	0	0	0	.004
32			4	1.164	.008	0	0	0	-.002
33			5	1.164	.008	0	0	0	-.009
34			6	1.164	.008	0	0	0	-.015
35			7	1.164	.008	0	0	0	-.021
36	1	G	1	-2.032	0	0	0	0	-.005
37			2	-2.032	0	0	0	0	-.005
38			3	-2.032	0	0	0	0	-.006
39			4	-2.032	0	0	0	0	-.006
40			5	-2.032	0	0	0	0	-.006
41			6	-2.032	0	0	0	0	-.006
42			7	-2.032	0	0	0	0	-.006
43	1	D	1	1.295	0	0	0	0	.005
44			2	1.295	0	0	0	0	.004
45			3	1.295	0	0	0	0	.004
46			4	1.295	0	0	0	0	.003
47			5	1.295	0	0	0	0	.003
48			6	1.295	0	0	0	0	.002
49			7	1.295	0	0	0	0	.001
50	1	E	1	-1.745	0	0	0	0	.001
51			2	-1.745	0	0	0	0	.001

Member Section Forces (Continued)

	LC	Member Label	Sec	Axial[k]	y Shear[k]	z Shear[k]	Torque[k-ft]	y-y Mo...	z-z Mo...
52			3	-1.745	0	0	0	0	0
53			4	-1.745	0	0	0	0	0
54			5	-1.745	0	0	0	0	0
55			6	-1.745	0	0	0	0	0
56			7	-1.745	0	0	0	0	0

Member Section Stresses

	LC	Member Label	Sec	Axial[ksi]	y Shear[ksi]	z Shear[ksi]	y top Bending[ksi]	y bot Bending[ksi]	z top Be...	z bot Be...
1	1	C	1	.463	.001	0	-.084	.084	0	0
2			2	.463	.001	0	-.038	.038	0	0
3			3	.463	.001	0	.007	-.007	0	0
4			4	.463	.001	0	.053	-.053	0	0
5			5	.09	0	0	.037	-.037	0	0
6			6	.09	0	0	-.002	.002	0	0
7			7	.09	0	0	-.042	.042	0	0
8	1	A	1	0	-.069	0	0	0	0	0
9			2	.109	.045	0	-1.912	1.912	0	0
10			3	.109	.045	0	.242	-.242	0	0
11			4	.18	-.015	0	.402	-.402	0	0
12			5	-.012	.002	0	-.144	.144	0	0
13			6	-.012	.002	0	-.07	.07	0	0
14			7	-.012	.002	0	.005	-.005	0	0
15	1	B	1	-.449	.018	0	-1.492	1.492	0	0
16			2	-.449	.018	0	-.223	.223	0	0
17			3	-.051	-.005	0	.314	-.314	0	0
18			4	-.051	-.005	0	-.019	.019	0	0
19			5	.363	0	0	.034	-.034	0	0
20			6	.363	0	0	-.025	.025	0	0
21			7	.363	0	0	-.084	.084	0	0
22	1	H	1	.52	-.01	0	.281	-.281	0	0
23			2	.52	-.01	0	.157	-.157	0	0
24			3	.52	-.01	0	.033	-.033	0	0
25			4	.52	-.01	0	-.091	.091	0	0
26			5	.52	-.01	0	-.215	.215	0	0
27			6	.52	-.01	0	-.339	.339	0	0
28			7	.52	-.01	0	-.463	.463	0	0
29	1	F	1	.371	.004	0	-.246	.246	0	0
30			2	.371	.004	0	-.152	.152	0	0
31			3	.371	.004	0	-.057	.057	0	0
32			4	.371	.004	0	.037	-.037	0	0
33			5	.371	.004	0	.131	-.131	0	0
34			6	.371	.004	0	.226	-.226	0	0
35			7	.371	.004	0	.32	-.32	0	0
36	1	G	1	-.647	0	0	.082	-.082	0	0
37			2	-.647	0	0	.084	-.084	0	0
38			3	-.647	0	0	.086	-.086	0	0
39			4	-.647	0	0	.087	-.087	0	0
40			5	-.647	0	0	.089	-.089	0	0
41			6	-.647	0	0	.091	-.091	0	0
42			7	-.647	0	0	.093	-.093	0	0
43	1	D	1	.412	0	0	-.076	.076	0	0
44			2	.412	0	0	-.067	.067	0	0
45			3	.412	0	0	-.057	.057	0	0
46			4	.412	0	0	-.048	.048	0	0
47			5	.412	0	0	-.039	.039	0	0
48			6	.412	0	0	-.029	.029	0	0

Member Section Stresses (Continued)

	LC	Member Label	Sec	Axial[ksi]	y Shear[ksi]	z Shear[ksi]	y top Bending[ksi]	y bot Bending[ksi]	z top Be...	z bot Be...
49			7	.412	0	0	-.02	.02	0	0
50	1	E	1	-.555	0	0	-.018	.018	0	0
51			2	-.555	0	0	-.016	.016	0	0
52			3	-.555	0	0	-.013	.013	0	0
53			4	-.555	0	0	-.011	.011	0	0
54			5	-.555	0	0	-.008	.008	0	0
55			6	-.555	0	0	-.006	.006	0	0
56			7	-.555	0	0	-.003	.003	0	0

Member Section Deflections

	LC	Member Label	Sec	x [in]	y [in]	z [in]	x Rotate[rad]	(n) L/y Ratio	(n) L/z Ratio
1	1	C	1	0	0	0	0	NC	NC
2			2	-.004	-.001	0	0	NC	NC
3			3	-.007	-.007	0	0	NC	NC
4			4	-.011	-.012	0	0	8157.954	NC
5			5	-.013	-.012	0	0	8889.921	NC
6			6	-.014	-.006	0	0	NC	NC
7			7	-.014	0	0	0	NC	NC
8	1	A	1	0	-.326	0	0	681.014	NC
9			2	0	.033	0	0	4674.078	NC
10			3	-.002	-.049	0	0	5803.681	NC
11			4	-.005	-.107	0	0	2252.924	NC
12			5	-.007	-.053	0	0	5232.074	NC
13			6	-.007	-.023	0	0	NC	NC
14			7	-.007	-.013	0	0	NC	NC
15	1	B	1	0	0	0	0	NC	NC
16			2	.006	-.002	0	0	NC	NC
17			3	.01	-.077	0	0	2037.746	NC
18			4	.011	-.059	0	0	2678.204	NC
19			5	.009	-.037	0	0	4271.978	NC
20			6	.004	-.015	0	0	NC	NC
21			7	0	0	0	0	NC	NC
22	1	H	1	-.071	-.01	0	0	NC	NC
23			2	-.073	-.016	0	0	5037.318	NC
24			3	-.074	-.02	0	0	2944.895	NC
25			4	-.075	-.023	0	0	2134.772	NC
26			5	-.076	-.028	0	0	1586.329	NC
27			6	-.077	-.035	0	0	1148.495	NC
28			7	-.079	-.046	0	0	809.936	NC
29	1	F	1	-.044	-.011	0	0	NC	NC
30			2	-.046	-.011	0	0	NC	NC
31			3	-.048	-.017	0	0	NC	NC
32			4	-.05	-.025	0	0	8226.123	NC
33			5	-.051	-.032	0	0	4999.269	NC
34			6	-.053	-.034	0	0	5479.421	NC
35			7	-.055	-.025	0	0	NC	NC
36	1	G	1	-.05	-.052	0	0	NC	NC
37			2	-.046	-.068	0	0	4953.068	NC
38			3	-.042	-.077	0	0	3073.816	NC
39			4	-.038	-.081	0	0	2713.13	NC
40			5	-.034	-.078	0	0	3031.026	NC
41			6	-.031	-.069	0	0	4816.119	NC
42			7	-.027	-.054	0	0	NC	NC
43	1	D	1	.025	-.055	0	0	1530.694	NC
44			2	.023	-.041	0	0	2297.582	NC
45			3	.021	-.03	0	0	3690.082	NC

Member Section Deflections (Continued)

	LC	Member Label	Sec	x [in]	y [in]	z [in]	x Rotate[rad]	(n) L/y Ratio	(n) L/z Ratio
46			4	.019	-.023	0	0	6537.676	NC
47			5	.017	-.017	0	0	NC	NC
48			6	.015	-.014	0	0	NC	NC
49			7	.013	-.013	0	0	NC	NC
50	1	E	1	-.022	-.04	0	0	3895.642	NC
51			2	-.018	-.034	0	0	5538.573	NC
52			3	-.014	-.029	0	0	8245.753	NC
53			4	-.01	-.025	0	0	NC	NC
54			5	-.007	-.022	0	0	NC	NC
55			6	-.003	-.02	0	0	NC	NC
56			7	0	-.018	0	0	NC	NC

Joint Deflections

	LC	Joint Label	X [in]	Y [in]	Z [in]	X Rotation [rad]	Y Rotation [rad]	Z Rotation [rad]
1	1	N2	0	0	0	0	0	6.266e-3
2	1	N5	0	0	0	0	0	1.745e-4
3	1	N21	.046	-.079	0	0	0	-2.654e-3
4	1	N23	0	-.014	0	0	0	2.164e-4
5	1	N22	.025	-.055	0	0	0	1.485e-3
6	1	N3	.01	-.071	0	0	0	-1.463e-3
7	1	N4	.011	-.044	0	0	0	5.128e-4
8	1	N24	.013	-.013	0	0	0	9.581e-5
9	1	N1	.173	-.277	0	0	0	1.433e-2

Joint Reactions

	LC	Joint Label	X [k]	Y [k]	Z [k]	MX [k-ft]	MY [k-ft]	MZ [k-ft]
1	1	N2	-.76	1.578	0	0	0	0
2	1	N5	-1.141	1.454	0	0	0	0
3	1	N21	0	0	0	0	0	0
4	1	N23	0	0	0	0	0	0
5	1	N22	0	0	0	0	0	0
6	1	Totals:	-1.901	3.032	0			
7	1	COG (ft):	X: 32.529	Y: 2.834	Z: 0			

Truss Forces

Member	Length (m)	ℓ_1	ℓ_2	ℓ_3	Force (kN)			Tension or Compression		
					1	2	3	1	2	3
R_{1Y}	-	-	-	-	4.39	-	-	C	-	-
R_{8X}	-	-	-	-	7.08	-	-	C	-	-
R_{8Y}	-	-	-	-	6.94	-	-	C	-	-
a	4.72	1.39	1.4	1.93	5.47	10.76	0.7	C	C	T
b	4	1.18	1.19	1.63	6.22	5.03	5.03	T	C	C
c	2.5	1.48	1.02	-	1.32	6.47	-	T	C	-
d	1.53	-	-	-	7.49	-	-	C	-	-
e	2.17	-	-	-	7.68	-	-	T	-	-
f	1.53	-	-	-	4.98	-	-	C	-	-
g	1.9	-	-	-	9.75	-	-	T	-	-
h	0.74	-	-	-	9.02	-	-	C	-	-

Forces from RISA, after comparing calculations from original truss geometry.

Bamboo Roof & Truss Design

Member: a

Culm Outside Diameter:	d_o=	**10**	cm
Modulus of Elasticity:	E=	**14617**	MPa
Moment of Inertia:	I=	**486.90**	cm^4
Area:	A=	**71.47**	cm^2
Radius of Gyration:	r=	**2.61**	cm
Effective Length Factor:	K=	**1.00**	

1) Section of Member

Length: ℓ_1= **1.39** m

Force: F_u= **5.47** kN

COMPRESSION

KEEP

Compression Stress: c_u= F_u/A= 5.47 / 71.47 *[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2] = **0.77** MPa

c_u= **0.77** MPa ≤ c_n= **13.00** MPa **OK**

Slenderness: λ= KL/r= (1.00 * 1.39) / 2.61 *[100 cm/m] = **53.3** ≤ 50 **CHECK BUCKLING**

Buckling: P_{e1}= $\pi^2EI/(KL)^2$= (π^2 * 14617 * 486.90) / (1.00 * 1.39)^2 *[10^6 N/m^2/MPa]*[m/100 cm]^4*[kN/1000 N]= **363.55** kN

P_{e1}= **363.55** kN ≥ F_u= **5.47** kN **OK**

2) Section of Member

Length: ℓ_2= **1.4** m

Force: F_u= **10.76** kN

COMPRESSION

KEEP

Compression Stress: c_u= F_u/A= 10.76 / 71.47 *[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2] = **1.51** MPa

c_u= **1.51** MPa ≤ c_n= **13.00** MPa **OK**

Slenderness: λ= KL/r= (1.00 * 1.4) / 2.61 *[100 cm/m] = **53.6** ≤ 50 **CHECK BUCKLING**

Buckling: P_{e1}= $\pi^2EI/(KL)^2$= (π^2 * 14617 * 486.90) / (1.00 * 1.4)^2 *[10^6 N/m^2/MPa]*[m/100 cm]^4*[kN/1000 N]= **358.38** kN

P_{e1}= **358.38** kN ≥ F_u= **10.76** kN **OK**

3) Section of Member

Length: ℓ_3= **1.93** m

Force: F_u= **0.7** kN

TENSION

KEEP

Tension Stress: t_u= F_u/A= 0.7 / 71.47 *[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2] = **0.10** MPa

t_u= **0.10** MPa ≤ t_n= **42.00** MPa **OK**

Bamboo Bending Design

Member: **Top Chord of Truss: a**

Culm Outside Diameter:	d_o=	**10**	cm
Modulus of Elasticity:	E=	**14617**	MPa
Moment of Inertia:	I=	**486.90**	cm^4
Area:	A=	**71.47**	cm^2
Radius of Gyration:	r=	**2.61**	cm
Section Modulus:	S=	**97.38**	cm^3
Effective Length Factor:	K=	**1.00**	

Member-

Length:	ℓ=	**5.427**	m
Distributed Load:	ω_u=	**0**	kN/m
Point Load:	F_u=	**2.58**	kN

Bending

Moment (Distributed Load):	M_u=	**1.36**	kN*m							
Bending Stress:	b_u=	M_u/S=	1.36	/	97.38	*[100 cm/m]^3*[1000 N/kN]*[MPa/10^6 N/m^2]	=	**13.97**	MPa	
	b_u=	**13.97**	MPa ≤ b_n=	**27.00**	MPa					**OK**

Shear

Shear Force:	V_u=	**2.58**	kN							
Shear Stress:	v_u=	$3V_u/(2A)$=	3*	2.58	/(2*	71.47	)*[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2]=	**0.54**	MPa	
	v_u=	**0.54**	MPa ≤ v_n=	**3.70**	MPa					**OK**

Deflection

Max Allowable Deflection:	δ_{max}=	ℓ/300=	5.427	*[100 cm/m]/300=	**1.81**	cm	
Calculated Deflection (Distributed Load):	δ_{calc}=	**0.84**	cm				
	δ_{calc}=	**0.84**	m ≤ δ_{max}=	**1.81**	cm		**OK**

Buckling

Slenderness: λ= KL/r= $\frac{1.00 \quad * \quad 5.427}{2.61}$ *[100 cm/m] = **207.9** ≤ 50 **CHECK BUCKLING**

Buckling: P_{e1}= $\pi^2EI/(KL)^2$= $\frac{\pi^2 \quad * \quad 14617 \quad * \quad 486.90}{(\quad 1.00 \quad * \quad 5.427 \quad)^2}$ *[10^6 N/m^2/MPa]*[m/100 cm]^4*[kN/1000 N]= **23.85** kN

P_{e1}= **23.85** kN ≥ F_u= **2.58** kN **OK**

Bamboo Roof & Truss Design

Member: b

Culm Outside Diameter:	d_o=	6	cm
Modulus of Elasticity:	E=	14617	MPa
Moment of Inertia:	I=	59.64	cm^4
Area:	A=	21.21	cm^2
Radius of Gyration:	r=	1.68	cm
Effective Length Factor:	K=	1.00	

1) Section of Member

Length: ℓ_1= **1.18** m

Force: F_u= **6.22** kN

TENSION

KEEP

Tension Stress: t_u= F_u/A= 6.22 / 21.21 *[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2] = **2.93** MPa

t_u= **2.93** MPa ≤ t_n= **42.00** MPa **OK**

2) Section of Member

Length: ℓ_2= **1.19** m

Force: F_u= **5.03** kN

COMPRESSION

KEEP

Compression Stress: c_u= F_u/A= 5.03 / 21.21 *[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2] = **2.37** MPa

c_u= **2.37** MPa ≤ c_n= **13.00** MPa **OK**

Slenderness: λ= KL/r= $\frac{1.00 * 1.19}{1.68}$ *[100 cm/m] = **71.0** ≤ 50 **CHECK BUCKLING**

Buckling: P_{e1}= $\pi^2EI/(KL)^2$= $\frac{\pi^2 * 14617 * 59.64}{(1.00 * 1.19)^2}$ *[10^6 N/m^2/MPa]*[m/100 cm]^4*[kN/1000 N]= **60.76** kN

P_{e1}= **60.76** kN ≥ F_u= **5.03** kN **OK**

3) Section of Member

Length: ℓ_3= **1.63** m

Force: F_u= **5.03** kN

COMPRESSION

KEEP

Compression Stress: c_u= F_u/A= 5.03 / 21.21 *[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2] = **2.37** MPa

c_u= **2.37** MPa ≤ c_n= **13.00** MPa **OK**

Slenderness: λ= KL/r= $\frac{1.00 * 1.63}{1.68}$ *[100 cm/m] = **97.2** ≤ 50 **CHECK BUCKLING**

Buckling: P_{e1}= $\pi^2EI/(KL)^2$= $\frac{\pi^2 * 14617 * 59.64}{(1.00 * 1.63)^2}$ *[10^6 N/m^2/MPa]*[m/100 cm]^4*[kN/1000 N]= **32.38** kN

P_{e1}= **32.38** kN ≥ F_u= **5.03** kN **OK**

Bamboo Roof & Truss Design

Member: c

Culm Outside Diameter: d_o= **6** cm
Modulus of Elasticity: E= **14617** MPa
Moment of Inertia: I= **59.64** cm^4
Area: A= **21.21** cm^2
Radius of Gyration: r= **1.68** cm
Effective Length Factor: K= **1.00**

1) Section of Member
Length: ℓ_1= **1.48** m
Force: F_u= **1.32** kN

TENSION
KEEP
Tension Stress: t_u= F_u/A= 1.32 / 21.21 *[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2] = **0.62** MPa

t_u= **0.62** MPa ≤ t_n= **42.00** MPa **OK**

2) Section of Member
Length: ℓ_2= **1.02** m
Force: F_u= **6.47** kN

COMPRESSION
KEEP
Compression Stress: c_u= F_u/A= 6.47 / 21.21 *[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2] = **3.05** MPa

c_u= **3.05** MPa ≤ c_n= **13.00** MPa **OK**

Slenderness: $\lambda = KL/r = \frac{1.00 * 1.02}{1.68}$ *[100 cm/m] = **60.8** ≤ 50 **CHECK BUCKLING**

Buckling: $P_{e1} = \pi^2EI/(KL)^2 = \frac{\pi^2 * 14617 * 59.64}{(1.00 * 1.02)^2}$ *[10^6 N/m^2/MPa]*[m/100 cm]^4*[kN/1000 N]= **82.70** kN

P_{e1}= **82.70** kN ≥ F_u= **6.47** kN **OK**

Bamboo Roof & Truss Design

Member: d

Culm Outside Diameter: d_o= **6** cm
Modulus of Elasticity: E= **14617** MPa
Moment of Inertia: I= **59.64** cm^4
Area: A= **21.21** cm^2
Radius of Gyration: r= **1.68** cm
Effective Length Factor: K= **1.00**

1) Section of Member
Length: ℓ_1= **1.53** m
Force: F_u= **7.49** kN

COMPRESSION
KEEP
Compression Stress: c_u= F_u/A= 7.49 / 21.21 *[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2] = **3.53** MPa

c_u= **3.53** MPa ≤ c_n= **13.00** MPa **OK**

Slenderness: $\lambda = KL/r = \frac{1.00 * 1.53}{1.68}$ *[100 cm/m] = **91.2** ≤ 50 **CHECK BUCKLING**

Buckling: $P_{e1} = \pi^2EI/(KL)^2 = \frac{\pi^2 * 14617 * 59.64}{(1.00 * 1.53)^2}$ *[10^6 N/m^2/MPa]*[m/100 cm]^4*[kN/1000 N]= **36.76** kN

P_{e1}= **36.76** kN ≥ F_u= **7.49** kN **OK**

Bamboo Roof & Truss Design

Member: e

Culm Outside Diameter:	d_o=	6	cm
Modulus of Elasticity:	E=	**14617**	MPa
Moment of Inertia:	I=	**59.64**	cm^4
Area:	A=	**21.21**	cm^2
Radius of Gyration:	r=	**1.68**	cm
Effective Length Factor:	K=	1.00	

1) Section of Member

Length:	ℓ_1=	**2.17**	m
Force:	F_u=	**7.68**	kN

TENSION

KEEP

Tension Stress: $t_u = F_u/A = 7.68 / 21.21 *[100\ cm/m]^2*[1000\ N/kN]*[MPa/10^6\ N/m^2] =$ **3.62** MPa

$t_u =$ **3.62** MPa $\leq t_n =$ **42.00** MPa **OK**

Bamboo Roof & Truss Design

Member: f

Culm Outside Diameter:	d_o=	6	cm
Modulus of Elasticity:	E=	**14617**	MPa
Moment of Inertia:	I=	**59.64**	cm^4
Area:	A=	**21.21**	cm^2
Radius of Gyration:	r=	**1.68**	cm
Effective Length Factor:	K=	1.00	

1) Section of Member

Length:	ℓ_1=	**1.53**	m
Force:	F_u=	**4.98**	kN

COMPRESSION

KEEP

Compression Stress: $c_u = F_u/A = 4.98 / 21.21 *[100\ cm/m]^2*[1000\ N/kN]*[MPa/10^6\ N/m^2] =$ **2.35** MPa

$c_u =$ **2.35** MPa $\leq c_n =$ **13.00** MPa **OK**

Slenderness: $\lambda = KL/r = \frac{1.00 * 1.53}{1.68} *[100\ cm/m] =$ **91.2** $\leq$ 50 **CHECK BUCKLING**

Buckling: $P_{e1} = \pi^2 EI/(KL)^2 = \frac{\pi^2 * 14617 * 59.64}{(1.00 * 1.53)^2} *[10^6 N/m^2/MPa]*[m/100\ cm]^4*[kN/1000\ N] =$ **36.76** kN

$P_{e1} =$ **36.76** kN $\geq F_u =$ **4.98** kN **OK**

Bamboo Roof & Truss Design

Member: g

Culm Outside Diameter:	d_o=	6	cm
Modulus of Elasticity:	E=	**14617**	MPa
Moment of Inertia:	I=	**59.64**	cm^4
Area:	A=	**21.21**	cm^2
Radius of Gyration:	r=	**1.68**	cm
Effective Length Factor:	K=	1.00	

1) Section of Member

Length:	ℓ_1=	**1.9**	m
Force:	F_u=	**9.75**	kN

TENSION

KEEP

Tension Stress: $t_u = F_u/A = 9.75 / 21.21 *[100\ cm/m]^2*[1000\ N/kN]*[MPa/10^6\ N/m^2] =$ **4.60** MPa

$t_u =$ **4.60** MPa $\leq t_n =$ **42.00** MPa **OK**

Bamboo Roof & Truss Design

Member: h

Culm Outside Diameter:	d_o=	**6**	cm
Modulus of Elasticity:	E=	**14617**	MPa
Moment of Inertia:	I=	**59.64**	cm^4
Area:	A=	**21.21**	cm^2
Radius of Gyration:	r=	**1.68**	cm
Effective Length Factor:	K=	**1.00**	

1) Section of Member

Length:	ℓ_1=	**0.74**	m
Force:	F_u=	**9.02**	kN

COMPRESSION

KEEP

Compression Stress: $c_u = F_u/A =$ 9.02 / 21.21 *[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2] = **4.25** MPa

c_u= **4.25** MPa ≤ c_n= **13.00** MPa **OK**

Slenderness: λ= KL/r= $\frac{1.00 * 0.74}{1.68}$ *[100 cm/m] = **44.1** ≤ 50 **OK**

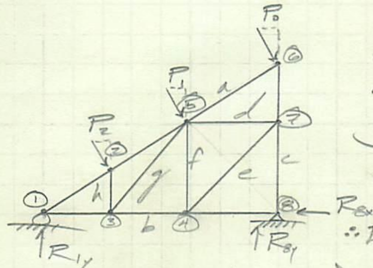
Buckling: P_{e1}= $\pi^2EI/(KL)^2$= $\frac{\pi^2 * 14617 * 59.64}{(1.00 * 0.74)^2}$ *[10^6N/m^2/MPa]*[m/100 cm]^4*[kN/1000 N]= **157.12** kN

P_{e1}= **157.12** kN ≥ F_u= **9.02** kN **OK**

MASTER'S	ARE 898	EVAN MYERS

- ROOF + TRUSS DESIGN

STEP DESCRIPTION	COMPUTATION	REFERENCE
✓ INITIAL TRUSS DESIGN	∴ BEFORE IMPLEMENTATION OF TOP CHORD OVERHANG.	



$r = 3$
$m = 13$
$j = 8$

$r + m = 16 = 2j = 16$

∴ DETERMINATE IF STABLE

FORCES

$P_0 = (\cancel{2}) \times \frac{(3125\,Pa)}{\cancel{2}} \left(\frac{1.15\,m}{2}\right)\left(\frac{0.625\,m}{2}\right) \left| \frac{N/m^2}{Pa} \right| \left| \frac{kN}{1000\,N} \right|$

$= 1.12\ kN$

$P_1 = (\cancel{2}) \times \frac{(6.20\ kN/m)}{\cancel{2}}(0.625\ m) = 3.88\ kN$

$P_2 = (\cancel{2}) \times \frac{(7.74\ kN/m)}{\cancel{2}}(1.08\ m) = 8.36\ kN$

METHOD OF JTS

REACTIONS

SUM OF MOMENTS

$\circlearrowleft^{+} \Sigma M_8 = 0$

$-R_{1y}(4\,m) - (P_0 \cdot 2.5\,m + P_1 \cdot 1.48\,m + P_2 \cdot 0.74\,m)\sin 32^\circ$

$+ (\cancel{P_0 \cdot 0\,m}^{\,0} + P_1 \cdot 1.63\,m + P_2 \cdot 2.82\,m)\cos 32^\circ = 0$

$R_{1y} = 4.39\ kN\ (C)$

SUM OF FORCES IN Y-DIR.

$+\uparrow \Sigma F_y = 0$

$R_{1y} + R_{8y} - (P_0 + P_1 + P_2)\cos 32^\circ = 0$

$R_{8y} = 6.94\ kN\ (C)$

SUM OF FORCES IN X-DIR.

$\overset{+}{\rightarrow} \Sigma F_x = 0$

$(P_0 + P_1 + P_2)\sin 32^\circ - R_{8x} = 0$

$R_{8x} = 7.08\ kN\ (C)$

3-0235 — 50 SHEETS — 5 SQUARES
3-0236 — 100 SHEETS — 5 SQUARES
3-0237 — 200 SHEETS — 5 SQUARES
3-0137 — 200 SHEETS — FILLER

COMET

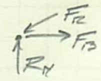
MISTER'S	AE 898	EVAN MYERS

-ROOF & TRUSS DESIGN

STEP DESCRIPTION	COMPUTATION	REFERENCE

ANALYSIS: METHOD OF JTS

①



$+\uparrow \Sigma F_y = 0$

$R_{1Y} - F_{12}\sin 32° = 0$

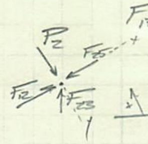
$F_{12} = 8.28\,kN\ (C)$

$\xrightarrow{+} \Sigma F_x = 0$

$F_{13} - F_{12}\cos 32° = 0$

$F_{13} = 7.03\,kN\ (T)$

②



$+\nwarrow \Sigma F_y = 0$

$F_{23}\cos 32° - P_2 = 0$

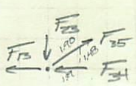
$F_{23} = 9.86\,kN\ (C)$

$+\nearrow \Sigma F_y = 0$

$F_{12} - F_{25} + F_{23}\sin 32° = 0$

$F_{25} = 13.51\,kN\ (C)$

③



$+\uparrow \Sigma F_y = 0$

$F_{35}\left(\frac{1.48\,m}{1.90\,m}\right) - F_{23} = 0$

$F_{35} = 12.66\,kN\ (T)$

$\xrightarrow{+} \Sigma F_x = 0$

$F_{35}\left(\frac{1.19\,m}{1.90\,m}\right) - F_{13} - F_{34} = 0$

$F_{34} = 0.90\,kN\ (C)$

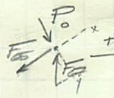
MASTER'S	ARE 898	EVAN MYERS

-ROOF + TRUSS DESIGN

STEP DESCRIPTION	COMPUTATION	REFERENCE

ANALYSIS:

(6)



$+\uparrow \Sigma F_y = 0$

$F_{67} \cos 32° - P_0 = 0$

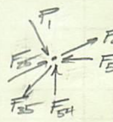
$F_{67} = 1.32 \text{ kN} (C)$

$\overset{+}{\nearrow} \Sigma F_x = 0$

$F_{67} \sin 32° - F_{65} = 0$

$F_{65} = 0.70 \text{ kN} (T)$

(5)



$\xrightarrow{+} \Sigma F_x = 0$

$(F_{65} + F_{25}) \cos 32° + P_1 \sin 32° - F_{35}\left(\frac{1.19\,m}{1.90\,m}\right) - F_{57} = 0$

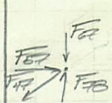
$F_{57} = 6.18 \text{ kN} (C)$

$+\uparrow \Sigma F_y = 0$

$F_{54} - P_1 \cos 32° + (F_{25} + F_{65}) \sin 32° - F_{35}\left(\frac{1.48\,m}{1.90\,m}\right) = 0$

$F_{54} = 5.62 \text{ kN} (C)$ $\quad \therefore$ USE $6.18 \text{ kN} (C)$

(7)



$\xrightarrow{+} \Sigma F_x = 0$

$F_{57} - F_{47} \cos 45° = 0$

$F_{47} = 8.74 \text{ kN} (T)$

$+\uparrow \Sigma F_y = 0$

$F_{78} - F_{47} \sin 45° - F_{67} = 0$

$F_{78} = 7.50 \text{ kN} (C)$

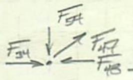
MASTER'S	ARE 878	EVAN MYERS

- ROOF & TRUSS DESIGN

STEP DESCRIPTION	COMPUTATION	REFERENCE

ANALYSIS: METHOD OF JTS

(4)



$\xrightarrow{+} \Sigma F_x = 0$

$F_{34} + F_{47}\cos 45 - F_{48} = 0$

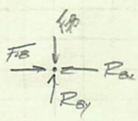
$F_{48} = 7.08\ kN\ (C) = R_{8X}$ ∴ CORRECT

$+\uparrow \Sigma F_y = 0$

$F_{47}\sin 45 - F_{54} = 0$

$F_{54} = 6.18\ kN\ (C)$ ∴ DOES NOT MATCH PREVIOUS CALC, USE HIGHER LOAD

(8)



$\xrightarrow{+} \Sigma F_x = 0$

$F_{48} - R_{8X} = 0$ ∴ TRUE

$+\uparrow \Sigma F_y = 0$

$R_{8Y} - F_{78} = 0$ ∴ FALSE, CALCS /D BUT DO NOT TRACK DUE TO NODES

TABLE OF FORCES

MEMBER	FORCE (kN)	TENSION/COMPRESSION
R_{1Y}	4.37	C
R_{8X}	7.08	C
R_{8Y}	6.94	C
a	8.28/1.35/0.70 (12 / 25 / 45)	C/C/T (12 / 25 / 45)
b	7.03/0.90/7.08 (13 / 34 / 48)	T/C/C (13 / 34 / 48)
c	1.32/7.50 (67 / 78)	T/C (67 / 78)
d	6.18	C
e	8.74	T
f	6.18	C
g	12.66	T
h	9.86	C

COMET

3-0235 — 50 SHEETS — 5 SQUARES
3-0236 — 100 SHEETS — 5 SQUARES
3-0237 — 200 SHEETS — 5 SQUARES
3-0137 — 200 SHEETS — FILLER

MASTER'S	ARE 898	EVAN MYERS

ROOF & TRUSS DESIGN

STEP DESCRIPTION	COMPUTATION	REFERENCE
MEMBER a	∴ MEMBER EXPERIENCES TENSILE & COMPRESSIVE FORCES AND WILL BE ANALYZED AS 3 MEMBERS.	
LENGTHS:	$l_1 = \sqrt{0.74^2 + 1.18^2}\ m = 1.39\ m$ $F_U = \sout{6.47}\ 8.08\ kN\ (C)$	
	$l_2 = \sqrt{0.74^2 + 1.19^2}\ m = 1.40\ m$ $F_U = \sout{10.51}\ 13.51\ kN\ (C)$	
	$l_3 = \sqrt{1.02^2 + 1.63^2}\ m = 1.93\ m$ $F_U = \sout{0.56}\ 0.70\ kN\ (T)$	
① COMPRESSION	$c_U = \frac{F_U}{A} = \frac{\sout{6.47}\ 8.08\ kN}{21.2\ cm^2} \left(\frac{100\ cm}{m}\right)^2 \frac{1000\ N}{kN} \frac{MPa}{10^6\ N/m^2} = \sout{3.17}\ 3.90\ MPa$	
	$c_U = \sout{3.17}\ 3.90\ MPa \le c_n = 13\ MPa$ ∴ OK	
SLENDERNESS	$\frac{KL}{r} = \frac{(1.0)(1.39\ m)}{1.68\ cm} \frac{100\ cm}{m} = 82.9 > 50$ ∴ √ BUCKLING	
BUCKLING	$P_{el} = \frac{\pi^2 (14,617\ MPa)(596\ cm^4)}{(1.0 \cdot 1.39\ m)^2} \frac{10^6\ N/m^2}{MPa} \left(\frac{m}{100\ cm}\right)^4 \frac{kN}{1000\ N}$	ASCE 360-10 EQN A-8-5 16.1-238
	$P_{el} = 44.5\ kN > F_U = \sout{6.47}\ 8.08\ kN$ ∴ OK	
②	$c_U = \frac{F_U}{A} = \sout{5.15}\ 6.51\ MPa \le c_n = 13\ MPa$ ∴ OK	
SLENDERNESS	$\frac{KL}{r} = 83.5 > 50$ ∴ √ BUCKLING	
BUCKLING	$P_{el} = 43.9\ kN > F_U = \sout{10.51}\ 13.51\ kN$ ∴ OK	
③ TENSION	$t_U = \frac{F_U}{A} = \sout{0.33}\ 0.33\ MPa \le t_n = 42\ MPa$ ∴ OK	
	∴ MEMBER IS DEEMED ADEQUATE FOR LOADS EXPERIENCED. MEMBER a DOES NOT EXPERIENCE ANY SUBSTANTIAL BENDING OR SHEAR STRESSES OR DEFLECTION. LOAD CHANGE IS NOT SIGNIFICANT ISSUE.	
	∴ USE ~~6 cm~~ 10 cm ϕ MEMBER	

- ROOF + TRUSS DESIGN

STEP DESCRIPTION	COMPUTATION	REFERENCE
TOP CHORD OF TRUSS	$M_u = 0.492$ KIPS·FT $\left\| \frac{4.45\ kN}{KIPS} \right\| \frac{12"}{FT} \left\| \frac{2.54\ cm}{IN} \right\| = 66.7$ kN·cm	RISA
BENDING MEMBER a	$f_u = \frac{M_u}{S} = \frac{66.7\ kN \cdot cm}{19.9\ cm^3} \left\| \frac{MPa}{10^6\ N/m^2} \right\| \frac{1000\ N}{kN} \left\| \frac{100\ cm}{m} \right\|^2$	
6 cm ϕ	$f_u = 33.5$ MPa > $f_n = 27$ MPa ∴ NG	
8 cm ϕ	$f_u = 13.5$ MPa ≤ $f_n = 27$ MPa ∴ OK	
SHEAR	$V_u = 0.58$ KIPS = 2.58 kN	RISA
STRESS	$v_u = \frac{3V_u}{2A} = 0.90$ MPa ≤ $v_n = 3.7$ MPa ∴ OK	
DEFLECTION JT N1	$\delta_x = 2.43$ IN $\quad \delta_{calc} = 4.04$ IN = 10.27 cm	RISA
	$\delta_y = 3.429$ IN $\quad$ ∴ MTL SECTIONS (OK 2 ASSUME SIMILAR?)	
L = 0.707 m	$\delta_{max} = 0.24$ cm < $\delta_{calc} = 0.84$ cm	
	∴ OK BECAUSE FRAMING + CORRUGATED METAL WILL BRACE + STIFFEN. δ_{max} IS A STRINGENT REQ'MT, ESPECIALLY FOR A CANTILEVERED PORTION.	
TRY 10 cm ϕ BENDING	$M_u = 1.0$ K·FT $\left\| \frac{4.45\ kN}{KIPS} \right\| \frac{12"}{FT} \left\| \frac{2.54\ cm}{IN} \right\| = 135.6$ kN·cm	RISA
STRESS	$f_u = \frac{M_u}{S} = 13.9$ MPa ≤ $f_n = 27$ MPa ∴ OK	
SHEAR	$V_u = 0.58$ KIPS = 2.58 kN	RISA
STRESS	$v_u = \frac{3V_u}{2A} = 0.54$ MPa ≤ $v_n = 3.7$ MPa ∴ OK	
DEFLECTION	$\delta = \left[\delta_x^2 + \delta_y^2\right]^{1/2} = \left[(0.173")^2 + (0.277")^2\right]^{1/2} = 0.33"$	RISA
	$\delta_{calc} = 0.829$ cm	
	$\delta_{max} = \ell/300 = 1.81$ cm > $\delta_{calc} = 0.829$ cm ∴ OK	
	∴ USE 10 cm ϕ CULM FOR TOP CHORD OF TRUSS. DEFLECTION WILL DECREASE WITH STIFFNESS OF CORRUGATED METAL.	

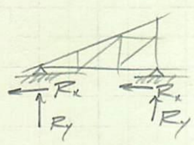
MASTER'S	ARE 898	EVAN MYERS

- ROOF + TRUSS DESIGN

STEP DESCRIPTION	COMPUTATION	REFERENCE
MEMBER b	∴ MEMBER EXPERIENCES TENSILE + COMPRESSIVE FORCES + WILL BE ANALYZED AS 3 MEMBERS.	
LENGTHS:	$l_1 = 1.18\,m$ — $F_u =$ ~~5.47~~ 7.03 kN (T)	
	$l_2 = 1.19\,m$ — $F_u =$ ~~2.64~~ 0.90 kN (C)	
	$l_3 = 1.63\,m$ — $F_u =$ ~~5.96~~ 7.08 kN (C)	
① TENSION	$t_u = \frac{F_u}{A} = \frac{5.70\,kN \to 7.03}{21.2\,cm^2} \left\lvert \frac{100\,cm}{m} \right\rvert^2 \left\lvert \frac{1000\,N}{kN} \right\rvert \left\lvert \frac{MPa}{10^6\,N/m^2} \right\rvert =$ ~~2.69~~ 3.32 MPa	
	$t_u =$ ~~2.69~~ 3.32 $MPa \le t_n = 42\,MPa$ ∴ OK	
② + ③ COMPRESSION - WORST-CASE	$c_u = \frac{F_u}{A} =$ ~~2.73~~ 3.34 $MPa \le c_n = 13\,MPa$ ∴ OK	
SLENDERNESS	$\frac{KL}{r} = \frac{(1.0)(1.63\,m)}{1.68\,cm} \left\lvert \frac{100\,cm}{m} \right\rvert = 97.2 > 50$ ∴ ✓ BUCKLING	
BUCKLING	$P_{cr} = \frac{\pi^2 EI}{(KL)^2} = \frac{\pi^2 (14,672\,MPa)(59.6\,cm^4)}{(1.0 \cdot 1.63\,m)^2} \left\lvert \frac{10^6\,N/m^2}{MPa} \right\rvert \left\lvert \frac{m}{100\,cm} \right\rvert^4 \left\lvert \frac{kN}{1000\,N} \right\rvert$	AISC 360-10 EQN A-8-5 Kal-238
	$P_{cr} = 32.4\,kN > F_u = 5.96\,kN$ ∴ OK	
	∴ MEMBER IS DEEMED ADEQUATE FOR LOADS EXPERIENCED. MEMBER b DOES NOT EXPERIENCE ANY SUBSTANTIAL BENDING OR SHEAR STRESSES OR DEFLECTION. LOAD CHANGE IS NOT A SIGNIFICANT ISSUE.	
	∴ USE 6 cm ⌀ MEMBER	

- ROOF & TRUSS DESIGN

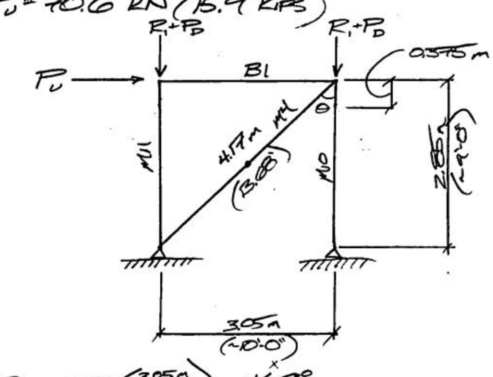
STEP DESCRIPTION	COMPUTATION	REFERENCE
TRUSS REACTIONS		
Jt N2	R_x = 0.77 KIPS = 3.43 kN ←	RISA
	R_y = 1.58 KIPS = 7.03 kN (C)	
Jt N5	R_x = 1.134 KIPS = 5.05 kN ←	
	R_y = 1.45 KIPS = 6.47 kN (C)	



Braces

MASTER'S	ARE 898	EVAN MYERS

- TYPICAL BRACES

STEP DESCRIPTION	COMPUTATION	REFERENCE
DEAD LOAD FROM WALL	$P_D = (1.0\times10^3\ Pa)\left(\frac{2.85\ m}{2}\right)\left(\frac{3.05\ m}{4}\right)\left\lvert\frac{N/m^2}{Pa}\right\rvert\left\lvert\frac{kN}{1000N}\right\rvert$ $P_D = 1.09\ kN\ (0.24\ KIPS)$	LOADS
FORCES FROM ROOF TRUSS & OVERHANG	$R_1 = 7.03\ kN\ (1.58\ kN)$ ~~$R_2 = 0.24\ kN\ (0.21\ KIPS)$~~ (0.05, 0.11) → 0	RISA RF & TRUSS DESIGN
SHEAR FROM WIND	$P_U = 70.6\ kN\ (15.9\ KIPS)$	LOADS
PLUG INTO RISA		
ANGLE	$\theta = \tan^{-1}\left(\frac{3.05m}{2.85m}\right) = 46.9°$	
BEAM (B1) STRESS 6 cm ø	$\sigma_u = \frac{P_U}{A_g} = \frac{70.6\ kN}{21.2\ cm^2}\left\lvert\frac{MPa}{10^6\ N/m^2}\right\rvert\left\lvert\frac{1000N}{kN}\right\rvert\left\lvert\frac{100\ cm}{m}\right\rvert^2 = 33.3\ MPa$ $\sigma_u = 33.3\ MPa > \sigma_n = 13\ MPa$ ∴ NG; TRY 10 cm ø	
10 cm ø	$\sigma_u = 9.87\ MPa \le \sigma_n = 13\ MPa$ ∴ OK	
BUCKLING	$\frac{KL}{r} = \frac{(1.0)\left(\frac{3.05m}{2}\right)}{2.61\ cm}\left\lvert\frac{100\ cm}{m}\right\rvert = 58.4 > 50$ $P_{el} = \frac{\pi^2 EI}{(KL)^2} = \frac{\pi^2(14627\ MPa)(486.9\ cm^4)}{\left(1.0\ \frac{3.05m}{2}\right)^2}\left\lvert\frac{10^6\ N/m^2}{MPa}\right\rvert\left\lvert\frac{m}{100\ cm}\right\rvert^4\left\lvert\frac{kN}{1000N}\right\rvert$	
EULER	$P_{el} = 302\ kN > P_U = 70.6\ kN$ ∴ OK	

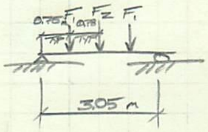
MASTER'S	ARE 898	EVAN MYERS

- TYPICAL BRACES

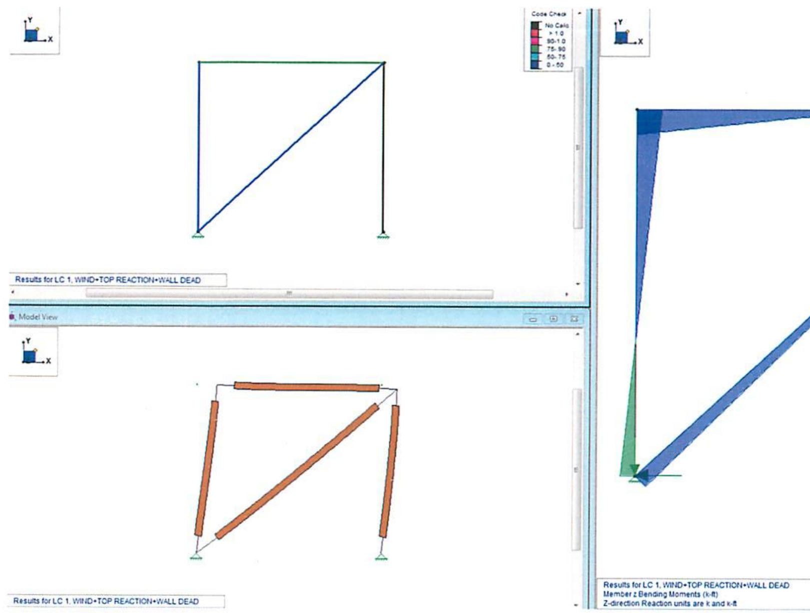
STEP DESCRIPTION	COMPUTATION	REFERENCE
BRACE (M4) TENSION F	$T_u = \frac{70.6\ kN}{\sin 46.9°} = 96.6\ kN\ (21.7\ KIPS)$	
10cm ϕ	$t_u = \frac{T_u}{A_g} = 13.5\ MPa \leq t_n = 42\ MPa$ ∴ OK	
COLUMN (M10) COMPR. F	$C_u = \frac{P_u}{\tan\theta} + R_1 + P_D = 74.2\ kN\ (16.7\ KIPS)$	
	$c_u = \frac{C_u}{A_g} = 10.4\ MPa \leq c_n = 13\ MPa$ ∴ OK	
BUCKLING	$\frac{KL}{r} = \frac{(1.0)(2.85\ m)}{(2.61\ cm)} \left\| \frac{100\ cm}{m} \right\| = 109.2 > 50$	
EULER	$P_{el} = \frac{\pi^2 (11617\ MPa)(486.9\ cm^4)}{(1.0 \cdot 2.85\ m)^2} \left\| \frac{10^6\ N/m^2}{MPa} \right\| \left\| \frac{m}{100\ cm} \right\|^4 \left\| \frac{kN}{1000\ N} \right\|$	
	$P_{el} = 86.5\ kN > C_u = 74.2\ kN$ ∴ OK * ATTACHED TO CORRUGATED MTL	
RISA	∴ RISA CALCS ARE VERY SIMILAR W/ MINIMAL VARIATION	
	- COLUMN IN TENSION NOT CHECKED. ASSUMED ADEQUATE. AND STILL IN COMPRESSION IN RISA (7.77 kN).	
BRACE DEFLECTIONS	$\delta_x = 0.321'' = 0.815\ cm$	RISA
	$\delta_{max} = \ell/300 = 0.95\ cm > \delta_x = 0.82\ cm$ ∴ OK	

- TYPICAL BRACE => BM IN BENDING

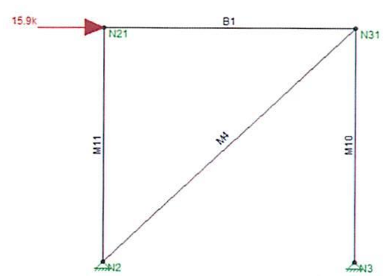
STEP DESCRIPTION	COMPUTATION	REFERENCE
FORCES ON BEAM	$R_{N2x} = 3.43$ kN $F_1 = 2.20$ kN $F_2 = R_{N2x} = 3.43$ kN	RE — TRUSS DESIGN
BENDING MOMENT	$M_u = \frac{PL}{4} + Pa = \frac{(3.43\,kN)(3.05\,m)}{4} + (2.20\,kN)(0.75\,m)$ $M_u = 4.27$ kN·m	
STRESS	$f_b = \frac{M_u}{S} = 43.8$ MPa $> f_b = 27$ MPa	
FROM RISA	$M_u = 0.349$ K·FT $\left\| \frac{4.45\,kN}{KIPS} \right\| \frac{12''}{FT} \left\| \frac{2.54\,cm}{IN} \right\| \frac{m}{100\,cm} \right\| = 0.473$ kN·m $f_b = \frac{M_u}{S} = 4.86$ MPa $\leq f_b = 27$ MPa ∴ OK	
SHEAR	$R_y = 3.92$ kN $V_u = 3.92$ kN	
STRESS	$f_v = \frac{3V_u}{2A} = 0.82$ MPa $\leq F_v = 3.7$ MPa ∴ OK	
DEFLECTION	$\delta_{max} = l/300 = 1.02$ cm $\delta_{calc} = \frac{Pl^3}{48EI} + \frac{Pa}{24EI}(3l^2 - 4a^2) = 5.33$ cm $\delta_{calc} = 5.33$ cm $> \delta_{max} = 1.02$ cm ∴ NG	
RISA	$\delta_{calc} = 0.087'' = 0.221$ cm $\leq \delta_{max} = 1.02$ cm ∴ OK	
SLENDERNESS	$\frac{KL}{r} = 116.7750$ ∴ ✓ BUCKLING	
BUCKLING	$P_{el} = \frac{\pi^2 EI}{(KL)^2} = 75.5$ kN $> F_{tot} = 7.73$ kN ∴ OK	



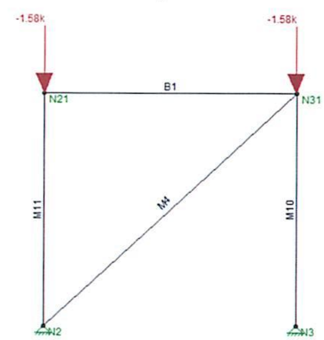
∴ USE 10 cm ⌀ FOR BEAM @ DIAGONAL BRACING



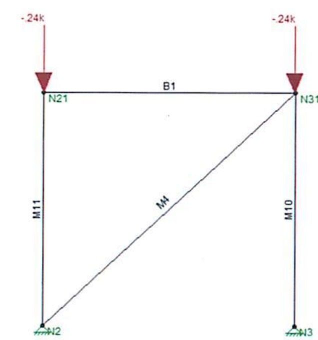
Wind



Truss Top Reaction



Wall Dead Load



Basic Load Cases

	BLC Description	Category	X Gravity	Y Gravity	Z Gravity	Joint	Point	Distributed	Area(Me...	Surface(Plate/Wall)
1	WIND	None				1				
2	TOP REACTION	None				2				
4	WALL DEAD	None				2				

Member Section Forces

	LC	Member Label	Sec	Axial[k]	y Shear[k]	z Shear[k]	Torque[k-ft]	y-y Mo...	z-z Mo...
1	1	B1	1	15.887	-.018	0	0	0	-.104
2			2	15.887	-.018	0	0	0	-.075
3			3	15.887	-.018	0	0	0	-.045
4			4	15.887	-.018	0	0	0	-.016
5			5	15.887	-.018	0	0	0	.014
6			6	15.887	-.018	0	0	0	.043
7			7	15.887	-.018	0	0	0	.072
8	1	M11	1	1.794	.018	0	0	0	.062
9			2	1.794	.018	0	0	0	.035
10			3	1.794	.018	0	0	0	.007
11			4	1.794	.018	0	0	0	-.021
12			5	1.794	.018	0	0	0	-.048
13			6	1.794	.018	0	0	0	-.076
14			7	1.794	.018	0	0	0	-.104
15	1	M10	1	16.694	.009	0	0	0	0
16			2	16.694	.009	0	0	0	-.014
17			3	16.694	.009	0	0	0	-.028
18			4	16.694	.009	0	0	0	-.042
19			5	16.694	.009	0	0	0	-.056
20			6	16.694	.009	0	0	0	-.07
21			7	16.694	.009	0	0	0	-.084
22	1	M4	1	-21.766	-.005	0	0	0	-.062
23			2	-21.766	-.005	0	0	0	-.05
24			3	-21.766	-.005	0	0	0	-.038
25			4	-21.766	-.005	0	0	0	-.026
26			5	-21.766	-.005	0	0	0	-.013
27			6	-21.766	-.005	0	0	0	-.001
28			7	-21.766	-.005	0	0	0	.011

Member Section Stresses

	LC	Member Label	Sec	Axial[ksi]	y Shear[ksi]	z Shear[ksi]	y top Bending[ksi]	y bot Bending[ksi]	z top Be...	z bot Be...
1	1	B1	1	1.264	-.002	0	.198	-.198	0	0
2			2	1.264	-.002	0	.142	-.142	0	0
3			3	1.264	-.002	0	.086	-.086	0	0
4			4	1.264	-.002	0	.03	-.03	0	0
5			5	1.264	-.002	0	-.026	.026	0	0
6			6	1.264	-.002	0	-.082	.082	0	0
7			7	1.264	-.002	0	-.138	.138	0	0
8	1	M11	1	.143	.002	0	-.119	.119	0	0
9			2	.143	.002	0	-.066	.066	0	0
10			3	.143	.002	0	-.013	.013	0	0
11			4	.143	.002	0	.04	-.04	0	0
12			5	.143	.002	0	.092	-.092	0	0
13			6	.143	.002	0	.145	-.145	0	0
14			7	.143	.002	0	.198	-.198	0	0
15	1	M10	1	1.328	.001	0	0	0	0	0
16			2	1.328	.001	0	.027	-.027	0	0
17			3	1.328	.001	0	.053	-.053	0	0

Member Section Stresses (Continued)

	LC	Member Label	Sec	Axial[ksi]	y Shear[ksi]	z Shear[ksi]	y top Bending[ksi]	y bot Bending[ksi]	z top Be...	z bot Be...
18			4	1.328	.001	0	.08	-.08	0	0
19			5	1.328	.001	0	.106	-.106	0	0
20			6	1.328	.001	0	.133	-.133	0	0
21			7	1.328	.001	0	.159	-.159	0	0
22	1	M4	1	-1.732	0	0	.119	-.119	0	0
23			2	-1.732	0	0	.096	-.096	0	0
24			3	-1.732	0	0	.072	-.072	0	0
25			4	-1.732	0	0	.049	-.049	0	0
26			5	-1.732	0	0	.026	-.026	0	0
27			6	-1.732	0	0	.002	-.002	0	0
28			7	-1.732	0	0	-.021	.021	0	0

Member Section Deflections

	LC	Member Label	Sec	x [in]	y [in]	z [in]	x Rotate[rad]	(n) L/y Ratio	(n) L/z Ratio
1	1	B1	1	.321	-.008	0	0	NC	NC
2			2	.309	-.033	0	0	7894.68	NC
3			3	.297	-.046	0	0	6827.539	NC
4			4	.285	-.051	0	0	9847.742	NC
5			5	.273	-.053	0	0	NC	NC
6			6	.261	-.058	0	0	NC	NC
7			7	.249	-.07	0	0	NC	NC
8	1	M11	1	0	0	0	0	NC	NC
9			2	-.001	-.054	0	0	NC	NC
10			3	-.003	-.114	0	0	NC	NC
11			4	-.004	-.175	0	0	7995.131	NC
12			5	-.005	-.232	0	0	6220.754	NC
13			6	-.006	-.282	0	0	7607.251	NC
14			7	-.008	-.321	0	0	NC	NC
15	1	M10	1	0	0	0	0	NC	NC
16			2	-.012	-.054	0	0	9176.043	NC
17			3	-.023	-.106	0	0	5018.149	NC
18			4	-.035	-.153	0	0	3964.957	NC
19			5	-.047	-.194	0	0	4014.519	NC
20			6	-.059	-.227	0	0	5839.3	NC
21			7	-.07	-.249	0	0	NC	NC
22	1	M4	1	0	0	0	0	NC	NC
23			2	.022	-.064	0	0	6022.451	NC
24			3	.045	-.112	0	0	4281.605	NC
25			4	.067	-.148	0	0	4412.629	NC
26			5	.089	-.176	0	0	5905.743	NC
27			6	.112	-.199	0	0	NC	NC
28			7	.134	-.222	0	0	NC	NC

Joint Deflections

	LC	Joint Label	X [in]	Y [in]	Z [in]	X Rotation [rad]	Y Rotation [rad]	Z Rotation [rad]
1	1	N2	0	0	0	0	0	-2.69e-3
2	1	N3	0	0	0	0	0	-2.895e-3
3	1	N21	.321	-.008	0	0	0	-1.69e-3
4	1	N31	.249	-.07	0	0	0	-8.775e-4

Joint Reactions

	LC	Joint Label	X [k]	Y [k]	Z [k]	MX [k-ft]	MY [k-ft]	MZ [k-ft]
1	1	N2	-15.928	-13.054	0	0	0	0
2	1	N3	.028	16.694	0	0	0	0
3	1	N21	0	0	0	0	0	0
4	1	N31	0	0	0	0	0	0
5	1	Totals:	-15.9	3.64	0			
6	1	COG (ft):	X: 33	Y: 9.35	Z: 0			

Brace Forces

Member	Length (m)	Force (kN)	Tension or Compression
N_{2X}	-	70.9	C
N_{2Y}	-	58.1	T
N_{3X}	-	0.125	C
N_{3Y}	-	74.3	C
B1	3.05	70.6	C
M4	4.17	97	T
M10	2.85	74.3	C
M11	2.85	8	C

Bamboo Brace Design

Member: B1

Culm Outside Diameter:	d_o=	10	cm
Modulus of Elasticity:	E=	14617	MPa
Moment of Inertia:	I=	486.90	cm^4
Area:	A=	71.47	cm^2
Radius of Gyration:	r=	2.61	cm
Effective Length Factor:	K=	1.00	

1) Section of Member

Length:	ℓ_1=	3.05	m
Force:	F_u=	70.6	kN

COMPRESSION

KEEP

Compression Stress: $c_u = F_u/A = 70.6 \;/\; 71.47 \; *[100\ cm/m]^2*[1000\ N/kN]*[MPa/10^6\ N/m^2] = $ **9.88** MPa

$c_u =$ **9.88** MPa $\leq c_n =$ **13.00** MPa **OK**

Slenderness: $\lambda = KL/r = \dfrac{1.00 \; * \; 3.05}{2.61} *[100\ cm/m] =$ **116.9** $\leq$ 50 **CHECK BUCKLING**

Buckling: $P_{e1} = \pi^2 EI/(KL)^2 = \dfrac{\pi^2 \; * \; 14617 \; * \; 486.90}{(1.00 \; * \; 3.05)^2} *[10^6\ N/m^2/MPa]*[m/100\ cm]^4*[kN/1000\ N] =$ **75.51** kN

$P_{e1} =$ **75.51** kN $\geq F_u =$ **70.6** kN **OK**

Bamboo Bending Design

Member: B1

Culm Outside Diameter: d_o= 10 cm
Modulus of Elasticity: E= 14617 MPa
Moment of Inertia: I= 486.90 cm^4
Area: A= 71.47 cm^2
Radius of Gyration: r= 2.61 cm
Section Modulus: S= 97.38 cm^3
Effective Length Factor: K= 1.00

Member-
Length: ℓ= 3.05 m
Distributed Load: ω_u= 0 kN/m
Point Load: F_{u1}= 2.2 kN
Axial Load: F_{u2}= 3.43 kN

Bending

Moment (Point Load): M_u= 4.27 kN*m
Bending Stress: b_u= M_u/S= 4.27 / 97.38 *[100 cm/m]^3*[1000 N/kN]*[MPa/10^6 N/m^2] = 43.85 MPa

b_u= 43.85 MPa ≤ t 27.00 MPa OK

Moment (Point Load) **RISA**: M_u= 0.473 kN*m
Bending Stress: b_u= M_u/S= 0.47 / 97.38 *[100 cm/m]^3*[1000 N/kN]*[MPa/10^6 N/m^2] = 4.86 MPa

b_u= 4.86 MPa ≤ b_n= 27.00 MPa OK

Shear

Shear Force: V_u= 3.92 kN
Shear Stress: v_u= $3V_u/(2A)$= 3* 3.92 /(2* 71.47)*[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2]= 0.82 MPa

v_u= 0.82 MPa ≤ v_n= 3.70 MPa OK

Deflection

Max Allowable Deflection: δ_{max}= $\ell/300$= 3.05 *[100 cm/m]/300= 1.02 cm
Calculated Deflection (Point Load): δ_{calc1}= $F_{u2}\ell^3/(48EI)$= (3.43 * 3.05 ^3)/(48* 14617 * 486.90) *[100 cm/m]^3*[1000 N/kN]*[MPa/10^6 N/m^2]= 2.85 cm *

δ_{calc2}= $F_{u1}a/(24EI)*(3\ell^2-4a^2)$= (2.2 * 0.75)/(24* 14617 * 486.90) *(3* 3.05 ^2 - 4* 0.75 ^2) *[100 cm/m]^3*[1000 N/kN]*[MPa/10^6 N/m^2]= 2.48 cm

$\delta_{calcTOTAL}$= 5.33 cm ≤ δ_{max}= 1.02 cm NG

RISA: $\delta_{calcTOTAL}$= 0.22 cm ≤ δ_{max}= 1.02 cm OK

Buckling

Slenderness: λ= KL/r= (1.00 * 3.05)/2.61 *[100 cm/m] = 116.9 ≤ 50 CHECK BUCKLING

Buckling: P_{el}= $\pi^2EI/(KL)^2$= (π^2 * 14617 * 486.90)/((1.00 * 3.05)^2) *[10^6 N/m^2/MPa]*[m/100 cm]^4*[kN/1000 N]= 75.51 kN

P_{el}= 75.51 kN ≥ $F_{TOT.}$ 7.83 kN OK

Compression

Compression Stress: c_u= P_u/A= 3.43 / 71.47 *[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2] = 0.48 MPa

Tension Stress: t_u= P_u/A= 3.43 / 71.47 *[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2] = 0.48 MPa

t_u= 0.48 MPa ≤ t 42.00 MPa OK

(Eqn. from AISC 360-10)

USE c_u/c_n<0.2= $c_u/(2c_n)+b_u/b_n$= 0.48 /(2* 13.00) + 43.85 / 27.00 = 1.64 ≤1.0 NG

RISA c_u/c_n<0.2= $c_u/(2c_n)+b_u/b_n$= 0.48 /(2* 13.00) + 4.86 / 27.00 = 0.20 ≤1.0 OK

Bamboo Brace Design

Member: M4

Culm Outside Diameter: d_o= 10 cm
Modulus of Elasticity: E= **14617** MPa
Moment of Inertia: I= **486.90** cm^4
Area: A= **71.47** cm^2
Radius of Gyration: r= **2.61** cm
Effective Length Factor: K= 1.00

1) Section of Member
Length: ℓ_1= **4.17** m
Force: F_u= **97** kN

TENSION
KEEP
Tension Stress: t_u= F_u/A= 97 / 71.47 *[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2]= **13.57** MPa

t_u= **13.57** MPa ≤ t_n= **42.00** MPa OK

Deflection

Max Allowable Deflection: δ_{max}= $\ell/300$= 4.17 *[100 cm/m]/300= **1.39** cm
Calculated Deflection (RISA): δ_{calc}= **0.66** cm

δ_{calc}= **0.66** cm ≤ δ_{max}= **1.39** cm OK

Bamboo Brace Design

Member: M10

Culm Outside Diameter:	d_o=	10	cm
Modulus of Elasticity:	E=	14617	MPa
Moment of Inertia:	I=	486.90	cm^4
Area:	A=	71.47	cm^2
Radius of Gyration:	r=	2.61	cm
Effective Length Factor:	K=	1.00	

1) Section of Member

Length:	ℓ_1=	2.85	m
Force:	F_u=	74.3	kN

COMPRESSION

KEEP

Compression Stress: $c_u = F_u/A = 74.3 \;/\; 71.47$ *[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2] = **10.40** MPa

c_u= **10.40** MPa ≤ c_n= **13.00** MPa **OK**

Slenderness: $\lambda = KL/r = \frac{1.00 \;*\; 2.85}{2.61}$ *[100 cm/m] = **109.2** ≤ 50 **CHECK BUCKLING**

Buckling: $P_{e1} = \pi^2 EI/(KL)^2 = \frac{\pi^2 \;*\; 14617 \;*\; 486.90}{(1.00 \;*\; 2.85)^2}$ *[10^6 N/m^2/MPa]*[m/100 cm]^4*[kN/1000 N]= **86.48** kN

P_{e1}= **86.48** kN ≥ F_u= **74.3** kN **OK**

Deflection

Max Allowable Deflection: $\delta_{max} = \ell/300 =$ 2.85 *[100 cm/m]/300= **0.95** cm

Calculated Deflection (RISA): δ_{calc}= **0.63** cm

δ_{calc}= **0.63** cm ≤ δ_{max}= **0.95** cm **OK**

Bamboo Brace Design

Member: M11

Culm Outside Diameter:	d_o=	10	cm
Modulus of Elasticity:	E=	14617	MPa
Moment of Inertia:	I=	486.90	cm^4
Area:	A=	71.47	cm^2
Radius of Gyration:	r=	2.61	cm
Effective Length Factor:	K=	1.00	

1) Section of Member

Length:	ℓ_1=	2.85	m
Force:	F_u=	8	kN

COMPRESSION

KEEP

Compression Stress: $c_u = F_u/A = 8 \;/\; 71.47$ *[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2] = **1.12** MPa

c_u= **1.12** MPa ≤ c_n= **13.00** MPa **OK**

Slenderness: $\lambda = KL/r = \frac{1.00 \;*\; 2.85}{2.61}$ *[100 cm/m] = **109.2** ≤ 50 **CHECK BUCKLING**

Buckling: $P_{e1} = \pi^2 EI/(KL)^2 = \frac{\pi^2 \;*\; 14617 \;*\; 486.90}{(1.00 \;*\; 2.85)^2}$ *[10^6 N/m^2/MPa]*[m/100 cm]^4*[kN/1000 N]= **86.48** kN

P_{e1}= **86.48** kN ≥ F_u= **8** kN **OK**

Deflection

Max Allowable Deflection: $\delta_{max} = \ell/300 =$ 2.85 *[100 cm/m]/300= **0.95** cm

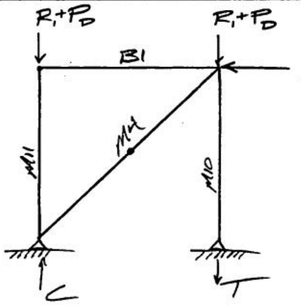
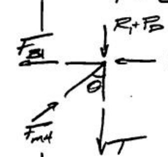
Calculated Deflection (RISA): δ_{calc}= **0.82** cm

δ_{calc}= **0.82** cm ≤ δ_{max}= **0.95** cm **OK**

Brace Load Reversal

MASTER'S	AE 878	EVAN MYERS

- TYPICAL BRACES

STEP DESCRIPTION	COMPUTATION	REFERENCE
✓ LOAD REVERSAL		
DETERMINE F	$M = P_u(2.85m) = 201.2\ kN\cdot m$	
T/C	$T = C = \frac{M}{L} = \frac{201.2\ kN\cdot m}{3.05m} = 65.97\ kN\ (14.8\ KIPS)$	
		
	$+\uparrow \Sigma F_y = 0$	
	$F_{M4}\cos 46.9° + P_2 - (R_1+P_D) - T = 0$	
	$F_{M4} = 108.4\ kN\ (C)\ (24.4\ KIPS)$	
	$\overset{+}{\rightarrow} \Sigma F_x = 0$	
	$F_{M4}\sin 46.9° - P_u - F_{B1} = 0$	
	$F_{B1} = 8.57\ kN\ (T)\ (1.93\ KIPS)$	
BRACE (M4) COMP. STRESS	$c_u = \frac{F_{M4}}{A_g} = 15.2\ MPa > c_r = 13\ MPa$	
	∴ CONSERVATIVE ASSUMPTION THAT ONLY TWO BRACES PICK UP WIND LOAD. OK	
BUCKLING	$\frac{KL}{r} = 77.97 > 50$	
EULER $L = \frac{4.17}{2}m$	$P_{el} = 161.6\ kN > F_{M4} = 108.4\ kN$ ∴ OK	
RISA	∴ CALCS ARE CONSERVATIVE IN COMPARISON TO RISA	
RISA	$c_u = 13.5\ MPa > c_r = 13\ MPa$ ∴ CLMS OK IN T & C	∴ WITHIN 5% & ROUNDING HAS OCCURRED FOR c_r

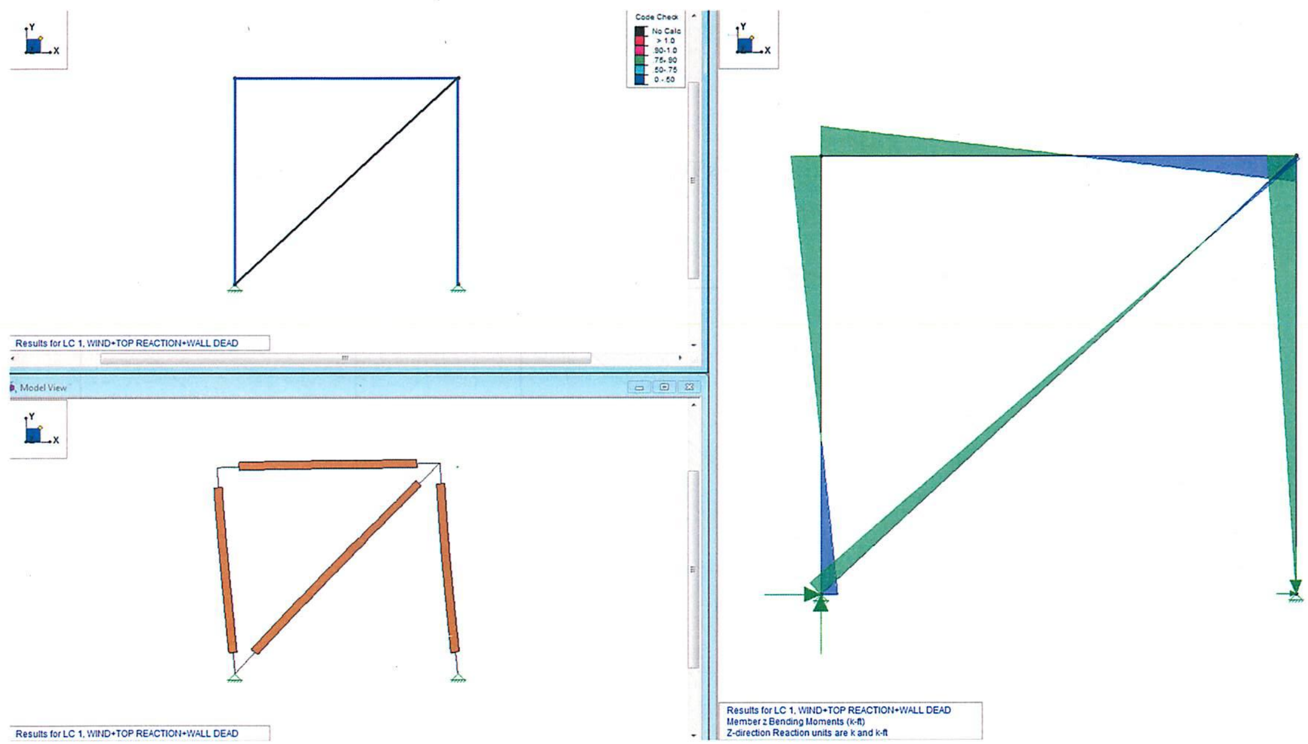
3-0235 — 50 SHEETS — 5 SQUARES
3-0236 — 100 SHEETS — 5 SQUARES
3-0237 — 200 SHEETS — 5 SQUARES
3-0137 — 200 SHEETS — FILLER

COMET

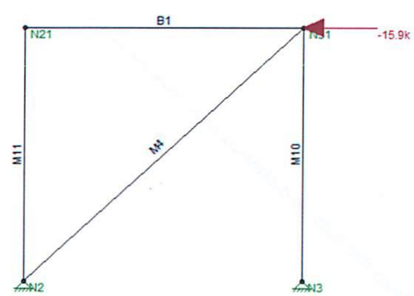
MASTER'S	ARE 898	EVAN MYERS

- TYPICAL BRACES

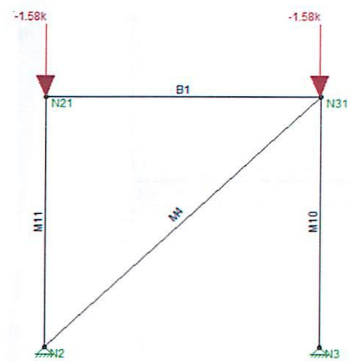
STEP DESCRIPTION	COMPUTATION	REFERENCE
✓ LD REV. COLUMNS (M10, M11)		
COMP.	$c_u = \frac{C + R_r + P_D}{A_g} = 10.4\ MPa \leq c_n = 13\ MPa$ ∴ OK	
TENSION	$t_u = \frac{T}{A_g} = 9.23\ MPa \leq t_n = 42\ MPa$ ∴ OK	
SLENDERNESS	$\frac{KL}{r} = 109.2 > 50$ ∴ ✓ BUCKLING	
BUCKLING	$P_{el} = \frac{\pi^2 E_t I}{(KL)^2} = 86.5\ kN > C_u = 74.09\ kN$ ∴ OK	
BRACE DEFLECTION	$\delta_x = 0.235'' = 0.60\ cm$	
	$\delta_{max} = \ell/300 = 0.95\ cm > \delta_x = 0.60\ cm$ ∴ OK	


Code Check
No Calc
> 1.0
.90-1.0
.75-.90
.50-.75
0-.50
Results for LC 1, WIND+TOP REACTION+WALL DEAD
Model View
Results for LC 1, WIND+TOP REACTION+WALL DEAD
Results for LC 1, WIND+TOP REACTION+WALL DEAD
Member z Bending Moments (k-ft)
Z-direction Reaction units are k and k-ft

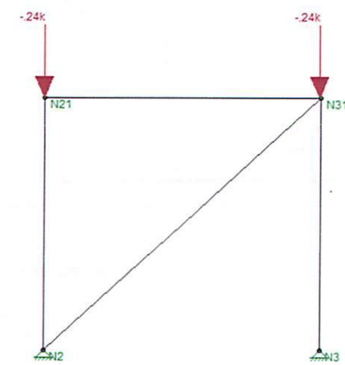
Wind



Truss Top Reaction



Wall Dead Load



Basic Load Cases

	BLC Description	Category	X Gravity	Y Gravity	Z Gravity	Joint	Point	Distributed	Area(Me...	Surface(Plate/Wall)
1	WIND	None				1				
2	TOP REACTION	None				2				
4	WALL DEAD	None				2				

Member Section Forces

	LC	Member Label	Sec	Axial[k]	y Shear[k]	z Shear[k]	Torque[k-ft]	y-y Mo...	z-z Mo...
1	1	B1	1	.008	.013	0	0	0	.073
2			2	.008	.013	0	0	0	.05
3			3	.008	.013	0	0	0	.028
4			4	.008	.013	0	0	0	.005
5			5	.008	.013	0	0	0	-.017
6			6	.008	.013	0	0	0	-.039
7			7	.008	.013	0	0	0	-.062
8	1	M11	1	1.833	-.012	0	0	0	-.039
9			2	1.833	-.012	0	0	0	-.021
10			3	1.833	-.012	0	0	0	-.002
11			4	1.833	-.012	0	0	0	.017
12			5	1.833	-.012	0	0	0	.035
13			6	1.833	-.012	0	0	0	.054
14			7	1.833	-.012	0	0	0	.073
15	1	M10	1	-13.061	-.008	0	0	0	0
16			2	-13.061	-.008	0	0	0	.012
17			3	-13.061	-.008	0	0	0	.023
18			4	-13.061	-.008	0	0	0	.035
19			5	-13.061	-.008	0	0	0	.047
20			6	-13.061	-.008	0	0	0	.059
21			7	-13.061	-.008	0	0	0	.07
22	1	M4	1	21.737	.003	0	0	0	.039
23			2	21.737	.003	0	0	0	.031
24			3	21.737	.003	0	0	0	.023
25			4	21.737	.003	0	0	0	.015
26			5	21.737	.003	0	0	0	.007
27			6	21.737	.003	0	0	0	0
28			7	21.737	.003	0	0	0	-.009

Member Section Stresses

	LC	Member Label	Sec	Axial[ksi]	y Shear[ksi]	z Shear[ksi]	y top Bending[ksi]	y bot Bending[ksi]	z top Be...	z bot Be...
1	1	B1	1	0	.002	0	-.138	.138	0	0
2			2	0	.002	0	-.096	.096	0	0
3			3	0	.002	0	-.053	.053	0	0
4			4	0	.002	0	-.01	.01	0	0
5			5	0	.002	0	.032	-.032	0	0
6			6	0	.002	0	.075	-.075	0	0
7			7	0	.002	0	.118	-.118	0	0
8	1	M11	1	.146	-.001	0	.075	-.075	0	0
9			2	.146	-.001	0	.039	-.039	0	0
10			3	.146	-.001	0	.004	-.004	0	0
11			4	.146	-.001	0	-.032	.032	0	0
12			5	.146	-.001	0	-.067	.067	0	0
13			6	.146	-.001	0	-.103	.103	0	0
14			7	.146	-.001	0	-.138	.138	0	0
15	1	M10	1	-1.039	0	0	0	0	0	0
16			2	-1.039	0	0	-.022	.022	0	0
17			3	-1.039	0	0	-.045	.045	0	0

Member Section Stresses (Continued)

	LC	Member Label	Sec	Axial[ksi]	y Shear[ksi]	z Shear[ksi]	y top Bending[ksi]	y bot Bending[ksi]	z top Be...	z bot Be...
18			4	-1.039	0	0	-.067	.067	0	0
19			5	-1.039	0	0	-.089	.089	0	0
20			6	-1.039	0	0	-.112	.112	0	0
21			7	-1.039	0	0	-.134	.134	0	0
22	1	M4	1	1.73	0	0	-.075	.075	0	0
23			2	1.73	0	0	-.06	.06	0	0
24			3	1.73	0	0	-.044	.044	0	0
25			4	1.73	0	0	-.029	.029	0	0
26			5	1.73	0	0	-.014	.014	0	0
27			6	1.73	0	0	.001	-.001	0	0
28			7	1.73	0	0	.016	-.016	0	0

Member Section Deflections

	LC	Member Label	Sec	x [in]	y [in]	z [in]	x Rotate[rad]	(n) L/y Ratio	(n) L/z Ratio
1	1	B1	1	-.235	-.008	0	0	NC	NC
2			2	-.235	.011	0	0	NC	NC
3			3	-.235	.022	0	0	NC	NC
4			4	-.235	.028	0	0	NC	NC
5			5	-.235	.033	0	0	NC	NC
6			6	-.235	.04	0	0	NC	NC
7			7	-.235	.055	0	0	NC	NC
8	1	M11	1	0	0	0	0	NC	NC
9			2	-.001	.041	0	0	NC	NC
10			3	-.003	.085	0	0	NC	NC
11			4	-.004	.129	0	0	9958.688	NC
12			5	-.005	.17	0	0	8160.07	NC
13			6	-.006	.207	0	0	NC	NC
14			7	-.008	.235	0	0	NC	NC
15	1	M10	1	0	0	0	0	NC	NC
16			2	.009	.049	0	0	NC	NC
17			3	.018	.097	0	0	5968.47	NC
18			4	.028	.141	0	0	4715.828	NC
19			5	.037	.18	0	0	4774.776	NC
20			6	.046	.212	0	0	6945.129	NC
21			7	.055	.235	0	0	NC	NC
22	1	M4	1	0	0	0	0	NC	NC
23			2	-.022	.05	0	0	9877.7	NC
24			3	-.045	.09	0	0	7086.119	NC
25			4	-.067	.123	0	0	7391.338	NC
26			5	-.089	.15	0	0	NC	NC
27			6	-.112	.175	0	0	NC	NC
28			7	-.134	.201	0	0	NC	NC

Joint Deflections

	LC	Joint Label	X [in]	Y [in]	Z [in]	X Rotation [rad]	Y Rotation [rad]	Z Rotation [rad]
1	1	N2	0	0	0	0	0	2.044e-3
2	1	N3	0	0	0	0	0	2.659e-3
3	1	N21	-.235	-.008	0	0	0	1.241e-3
4	1	N31	-.235	.055	0	0	0	9.621e-4

Joint Reactions

	LC	Joint Label	X [k]	Y [k]	Z [k]	MX [k-ft]	MY [k-ft]	MZ [k-ft]
1	1	N2	15.865	16.701	0	0	0	0
2	1	N3	.035	-13.061	0	0	0	0
3	1	N21	0	0	0	0	0	0
4	1	N31	0	0	0	0	0	0
5	1	Totals:	15.9	3.64	0			
6	1	COG (ft):	X: 33	Y: 9.35	Z: 0			

Brace Forces-Reversal

Member	Length (m)	Force (kN)	Tension or Compression
N_{2X}	-	70.6	C
N_{2Y}	-	74.3	C
N_{3X}	-	0.16	C
N_{3Y}	-	58.1	T
B1	3.05	0.04	C
M4	4.17	96.74	C
M10	2.85	58.1	T
M11	2.85	8.2	C

Bamboo Brace Design-Reversal

Member: B1

Culm Outside Diameter:	d_o=	10	cm
Modulus of Elasticity:	E=	14617	MPa
Moment of Inertia:	I=	486.90	cm^4
Area:	A=	71.47	cm^2
Radius of Gyration:	r=	2.61	cm
Effective Length Factor:	K=	1.00	

1) Section of Member

Length:	ℓ_1=	3.05	m
Force:	F_u=	0.04	kN

COMPRESSION

KEEP

Compression Stress: $c_u = F_u/A = 0.04 / 71.47 \cdot [100\ cm/m]^2 \cdot [1000\ N/kN] \cdot [MPa/10^6\ N/m^2] =$ **0.01** MPa

$c_u =$ **0.01** MPa $\leq c_n =$ **13.00** MPa **OK**

Slenderness: $\lambda = KL/r = \dfrac{1.00 \cdot 3.05}{2.61} \cdot [100\ cm/m] =$ **116.9** $\leq$ 50 **CHECK BUCKLING**

Buckling: $P_{e1} = \pi^2 EI/(KL)^2 = \dfrac{\pi^2 \cdot 14617 \cdot 486.90}{(1.00 \cdot 3.05)^2} \cdot [10^6\ N/m^2/MPa] \cdot [m/100\ cm]^4 \cdot [kN/1000\ N] =$ **75.51** kN

$P_{e1} =$ **75.51** kN $\geq F_u =$ **0.04** kN **OK**

Bamboo Brace Design-Reversal

Member: M4

Culm Outside Diameter:	d_o=	10	cm
Modulus of Elasticity:	E=	14617	MPa
Moment of Inertia:	I=	486.90	cm^4
Area:	A=	71.47	cm^2
Radius of Gyration:	r=	2.61	cm
Effective Length Factor:	K=	1.00	

1) Section of Member

Length:	ℓ_1=	4.17	m
Force:	F_u=	96.74	kN

COMPRESSION

KEEP

Compression Stress: c_u= F_u/A= 96.74 / 71.47 *[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2] = **13.54** MPa

c_u= **13.54** MPa ≤ c_n= **13.00** MPa — ***OK, within 5% and allowable stress was rounded down.** **NG**

Slenderness: λ= KL/r= $\frac{1.00 \quad * \quad 4.17}{2.61}$ *[100 cm/m] = **159.8** ≤ 50 **CHECK BUCKLING**

Buckling: P_{e1}= $\pi^2EI/(KL)^2$= $\frac{\pi^2 \;*\; 14617 \;*\; 486.90}{(1.00 \;*\; 2.085)^2}$ *[10^6 N/m^2/MPa]*[m/100 cm]^4*[kN/1000 N]= **161.58** kN

P_{e1}= **161.58** kN ≥ F_u= **96.74** kN — ***OK, brace will be attached to intermediate columns. Thus, effective length divided by two.** **OK**

COMPRESSION

HIDE

Tension Stress: t_u= F_u/A= 96.74 / 71.47 *[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2] = **13.54** MPa

t_u= **13.54** MPa ≤ t_n= **42.00** MPa **OK**

Deflection

Max Allowable Deflection: δ_{max}= ℓ/300= 4.17 *[100 cm/m]/300= **1.39** cm

Calculated Deflection (RISA): δ_{calc}= **0.61** cm

δ_{calc}= **0.61** cm ≤ δ_{max}= **1.39** cm **OK**

Bamboo Brace Design-Reversal

Member: M10

Culm Outside Diameter:	d_o=	10	cm
Modulus of Elasticity:	E=	14617	MPa
Moment of Inertia:	I=	486.90	cm^4
Area:	A=	71.47	cm^2
Radius of Gyration:	r=	2.61	cm
Effective Length Factor:	K=	1.00	

1) Section of Member

Length:	ℓ_1=	2.85	m
Force:	F_u=	58.1	kN

TENSION

KEEP

Tension Stress: t_u= F_u/A= 58.1 / 71.47 *[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2]= **8.13** MPa

t_u= **8.13** MPa ≤ t_n= **42.00** MPa **OK**

Deflection

Max Allowable Deflection: δ_{max}= ℓ/300= 2.85 *[100 cm/m]/300= **0.95** cm

Calculated Deflection (RISA): δ_{calc}= **0.597** cm

δ_{calc}= **0.60** cm ≤ δ_{max}= **0.95** cm **OK**

Bamboo Brace Design-Reversal

Member:		**M11**	
Culm Outside Diameter:	d_o=	**10**	cm
Modulus of Elasticity:	E=	**14617**	MPa
Moment of Inertia:	I=	**486.90**	cm^4
Area:	A=	**71.47**	cm^2
Radius of Gyration:	r=	**2.61**	cm
Effective Length Factor:	K=	**1.00**	

1) Section of Member

Length: ℓ_1= **2.85** m

Force: F_u= **8.2** kN

COMPRESSION

KEEP

Compression Stress: c_u= F_u/A= 8.2 / 71.47 *[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2] = **1.15** MPa

c_u= **1.15** MPa ≤ c_n= **13.00** MPa **OK**

Slenderness: λ= KL/r= (1.00 * 2.85 *[100 cm/m]) / 2.61 = **109.2** ≤ 50 **CHECK BUCKLING**

Buckling: P_{e1}= $\pi^2EI/(KL)^2$= (π^2 * 14617 * 486.90 *[10^6 N/m^2/MPa]*[m/100 cm]^4*[kN/1000 N]=) / (1.00 * 2.85)^2 **86.48** kN

P_{e1}= **86.48** kN ≥ F_u= **8.2** kN **OK**

Deflection

Max Allowable Deflection: δ_{max}= ℓ/300= 2.85 *[100 cm/m]/300= **0.95** cm

Calculated Deflection (RISA): δ_{calc}= **0.597** cm

δ_{calc}= **0.60** cm ≤ δ_{max}= **0.95** cm **OK**

Columns

Exterior Column

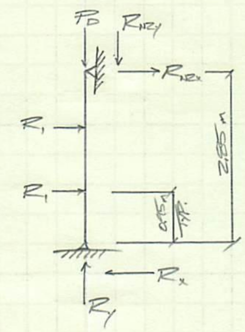
Bamboo Bending Design

Member:		Typical Column				
Culm Outside Diameter:	d_o=	10	cm			
Modulus of Elasticity:	E=	14617	MPa			
Moment of Inertia:	I=	486.90	cm^4			
Area:	A=	71.47	cm^2			
Radius of Gyration:	r=	2.61	cm			
Section Modulus:	S=	97.38	cm^3			
Effective Length Factor:	K=	1.00				
Member-Length:	ℓ=	2.85	m			
Distributed Load:	ω_u=	0	kN/m			
Point Load:	F_u=	2.2	kN			
Axial Load:	P_u=	7.83	kN			
Bending						
Moment (Point Load):	M_u=	$F_u(\ell/3)$=	2.2 * 2.85 /3 =	2.09	kN*m	
Bending Stress:	b_u=	M_u/S=	2.09 / 97.38 *[100 cm/m]³*[1000 N/kN]*[MPa/10⁶ N/m²] =	21.46	MPa	
	b_u=	21.46	MPa ≤ b_n= 27.00 MPa			OK
Shear						
Shear Force:	V_u=	2.2	kN			
Shear Stress:	v_u=	$3V_u/(2A)$=	3* 2.20 /(2* 71.47)*[100 cm/m]²*[1000 N/kN]*[MPa/10⁶ N/m²]=	0.46	MPa	
	v_u=	0.46	MPa ≤ v_n= 3.70 MPa			OK
Deflection						
Max Allowable Deflection:	δ_{max}=	$\ell/300$=	2.85 *[100 cm/m]/300=	0.95	cm	
Calculated Deflection (Point Load):	δ_{calc}=	$F_u(\ell/3)*[3\ell^2-4(\ell/3)^2]/(24EI)$=	2.20 * 2.85 /3) * [3* 2.85 ² - 4*(2.85 /3)²]* [100 cm/m]³*[1000 N/kN]*[MPa/10⁶ N/m²]= / 24* 14617 * 486.90	2.54	cm	
	δ_{calc}=	2.54	cm ≤ δ_{max}= 0.95 cm	❖OK, Column attached to corrugated metal and stiffened by framing. Deflection due to wind gust and not permanent loading.		NG
Calculated Deflection (RISA-Panel):	δ_{calc}=	0.73	cm			
	δ_{calc}=	0.73	cm ≤ δ_{max}= 0.95 cm			OK
Buckling						
Slenderness:	λ=	KL/r=	1.00 * 2.85 / 2.61 *[100 cm/m] =	109.2	≤ 50	CHECK BUCKLING
Buckling:	P_{el}=	$\pi^2EI/(KL)^2$=	π² * 14617 * 486.90 / (1.00 * 2.85)² *[10⁶ N/m²/MPa]*[m/100 cm]⁴*[kN/1000 N]=	86.48	kN	
	P_{el}=	86.48	kN ≥ F_u= 2.2 kN			OK
Compression						
Compression Stress:	c_u=	P_u/A=	7.83 / 71.47 *[100 cm/m]²*[1000 N/kN]*[MPa/10⁶ N/m²] =	1.10	MPa	
	c_u=	1.10	MPa ≤ c_n= 13.00 MPa			OK
Slenderness:	λ=	KL/r=	1.00 * 2.85 / 2.61 *[100 cm/m] =	109.2	≤ 50	CHECK BUCKLING
Buckling:	P_{el}=	$\pi^2EI/(KL)^2$=	π² * 14617 * 486.90 / (1.00 * 2.85)² *[10⁶ N/m²/MPa]*[m/100 cm]⁴*[kN/1000 N]=	86.48	kN	
	P_{el}=	86.48	kN ≥ P_u= 7.83 kN			OK
Combination Loading (Eqn. from AISC 360-10)						
USE	c_u/c_n<0.2=	$c_u/(2c_n)+b_u/b_n$=	1.10 /(2* 13.00) + 21.46 / 27.00 =	0.84	≤1.0	OK

MASTER'S	ARC 898	EVAN MYERS

- TYPICAL COLUMNS

STEP DESCRIPTION	COMPUTATION	REFERENCE
TYP. CLM FORCES	62 PSF => 2970 Pa	
WALL MEMBER,	TRIB. WIDTH $= 2\left(\frac{2.85\,m}{3}\right)/2 = 0.95$ m	
	$w_u = (2970\,Pa)(0.95\,m)\left\|\frac{N/m^2}{Pa}\right\|\left\|\frac{kN}{1000\,N}\right\| = 2.82\ kN/m$	
PT LOAD	$R_1 = \frac{2 w_u l}{2} = (2.82\ kN/m)(0.78\,m) = 2.20$ kN	



$R_{NRx} = 3.43$ kN
$R_{NRy} = 7.03$ kN
$R_1 = 2.20$ kN
$P_D = 0.80$ kN

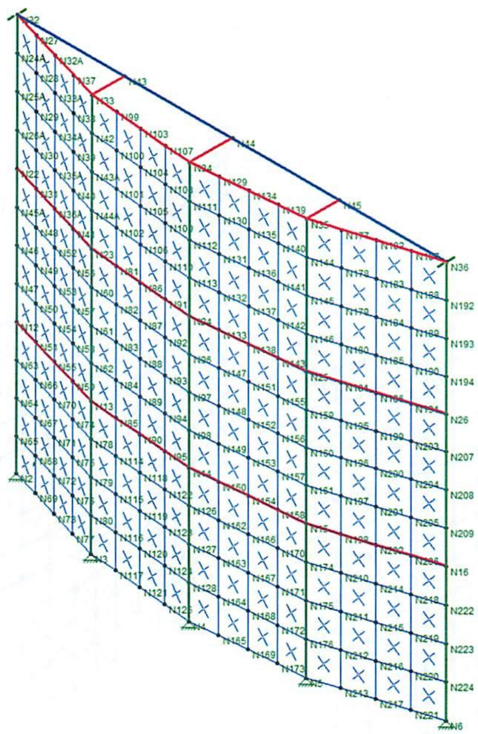
STEP DESCRIPTION	COMPUTATION	REFERENCE
BENDING MOMENT	$M_u = R_1 a = 2.09\ kN\cdot m$	AISC 360-10 p. 3-215
STRESS	$b_u = \frac{M_u}{S} = \frac{(2.09\ kN\cdot m)}{97.4\ cm^3}\left\|\frac{MPa}{10^6\,N/m^2}\right\|\left\|\frac{1000\,N}{kN}\right\|\left\|\frac{100\,cm}{m}\right\|^3$	
	$b_u = 21.5\ MPa \le b_n = 27\ MPa$ ∴ OK	
SHEAR	$V_u = R_1 = 2.20\ kN + 7.03\ kN = 9.23$ kN	
STRESS	$v_u = \frac{3V_u}{2A} = 1.94\ MPa \le v_n = 3.7\ MPa$ ∴ OK	
DEFLECTION	$\delta_{max} = l/300 = 0.95$ cm	
	$\delta_{calc} = \frac{Pa}{24EI}(3l^2 - 4a^2)$	AISC 360-10
	$= \frac{(2.20\,kN)(0.95\,m)(3.285^2 - 4\cdot 0.95^2)\,m^2}{24(11627\,MPa)(486.9\,cm^4)}\left\|\frac{MPa}{10^6\,N/m^2}\right\|\left\|\frac{100\,cm}{m}\right\|\left\|\frac{1000\,N}{kN}\right\|$	
∴ √ ON RISA	$\delta_{calc} = 2.54$ cm (~1") ∴ OK BECAUSE BAMBOO DOES NOT CREEP & UNDER DYNAMIC LOADING	
SLENDERNESS	$\frac{KL}{r} = 109.2 > 50$ ∴ √ BUCKLING	
BUCKLING	$P_{cr} = \frac{\pi^2 EI}{(KL)^2} = 86.5\ kN > R_1 = 2.2$ kN	

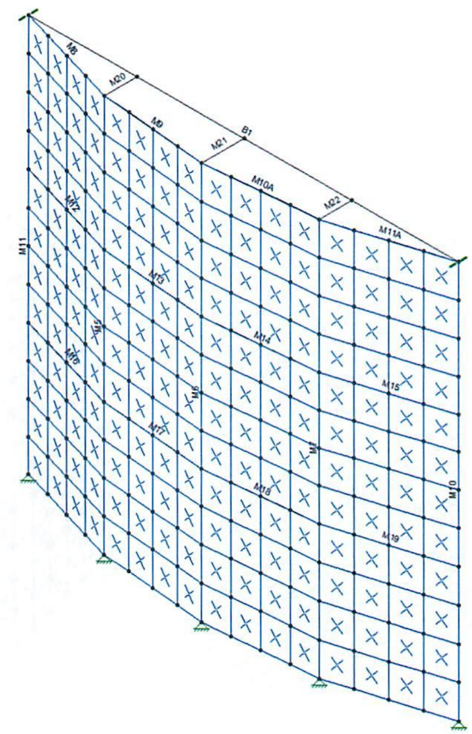
3-0235 — 50 SHEETS — 5 SQUARES
3-0236 — 100 SHEETS — 5 SQUARES
3-0237 — 200 SHEETS — 5 SQUARES
3-0137 — 200 SHEETS — FILLER

COMET

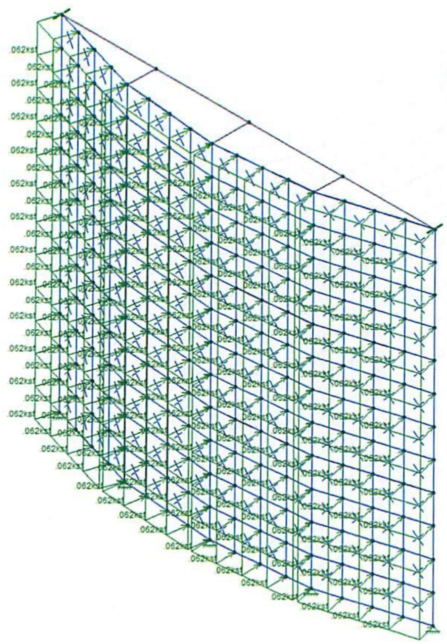
- TYPICAL COLUMNS

STEP DESCRIPTION	COMPUTATION	REFERENCE
COMPRESSION	$C_U = P_D + R_{NZy} = 7.83\ kN$	
STRESS	$c_U = \frac{C_U}{A} = 1.10\ MPa \leq c_n = 13\ MPa$ ∴ OK	
COMBO. LDS	$\frac{c_U}{c_n} = 0.08 \leq 0.2$	
	$\frac{c_U}{2c_n} + \frac{b_U}{b_n} = 0.84 \leq 1.0$ ∴ OK	
REACTIONS CLM w/ TRUSS	$\xrightarrow{+} \Sigma F_x = 0$	
	$\Sigma R_1 + R_{NZx} - R_x = 0$	
	$R_x = 7.83\ kN \leftarrow$	
	$+\uparrow \Sigma F_y = 0$	
	$R_y - P_D - R_{NZy} = 0$	
	$R_y = 7.83\ kN \uparrow$	
REACTIONS CLM w/o TRUSS	$R_x = 2.20\ kN \leftarrow$	
	$R_y = 0.80\ kN \uparrow$	

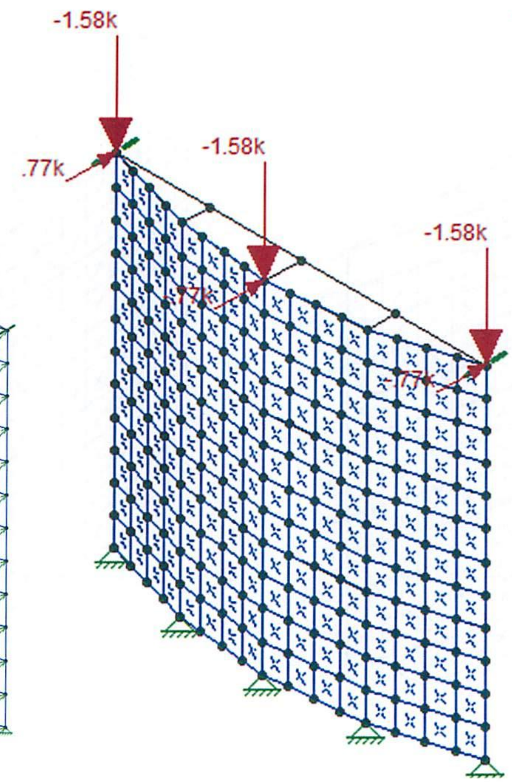

N36
N192
N193
N194
N26
N207
N208
N209
N16
N222
N223
N224


M20
B1
M21
M10A
M22
M11A
M11
M10

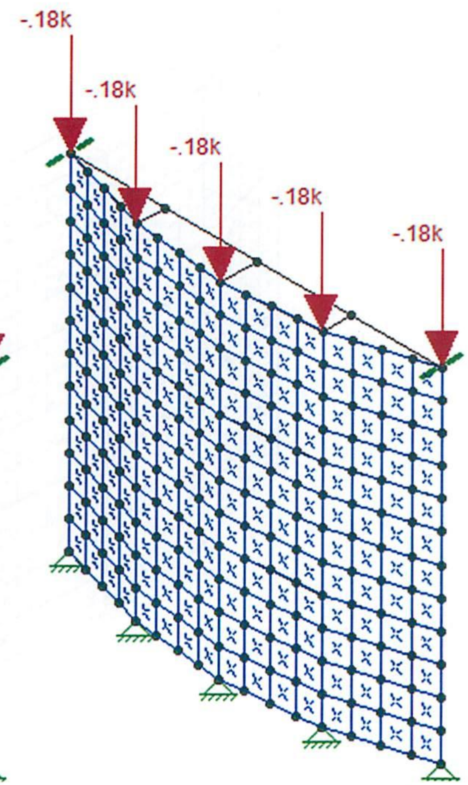
Wind



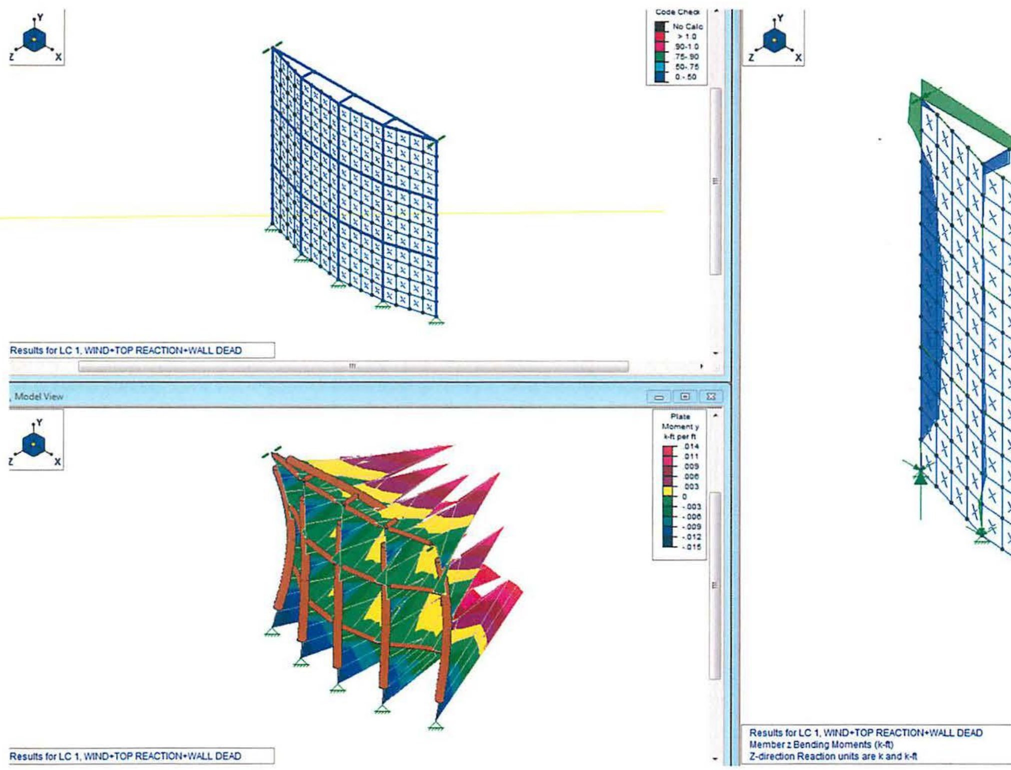
Truss Reactions



Dead Load



Results


Code Check
No Calc
> 1.0
.90-1.0
.75-.90
.50-.75
0.-.50
Results for LC 1, WIND+TOP REACTION+WALL DEAD
Model View
Plate
Moment y
k-ft per ft
.014
.011
.009
.006
.003
0
-.003
-.006
-.009
-.012
-.015
Results for LC 1, WIND+TOP REACTION+WALL DEAD
Results for LC 1, WIND+TOP REACTION+WALL DEAD
Member z Bending Moments (k-ft)
Z-direction Reaction units are k and k-ft

Member Section Forces

	LC	Member Label	Sec	Axial[k]	y Shear[k]	z Shear[k]	Torque[k-ft]	y-y Mo...	z-z Mo...
1	1	B1	1	-4.061	.013	-.034	.101	.042	.108
2			2	-4.061	.013	-.034	.101	-.015	.087
3			3	-4.077	.036	.176	.021	.057	.044
4			4	-4.077	.036	.176	.021	.349	-.016
5			5	-4.076	-.036	-.177	-.02	.056	.044
6			6	-4.056	-.013	.035	-.1	-.017	.086
7			7	-4.056	-.013	.035	-.1	.041	.108
8	1	M11	1	3.444	-.018	.209	.013	.027	-.008
9			2	2.296	.122	.105	.062	.346	-.112
10			3	.562	-.001	.057	.074	.48	-.131
11			4	-.633	-.01	-.033	.015	.516	-.141
12			5	-.726	-.017	-.078	-.053	.424	-.109
13			6	-.507	-.15	-.113	-.039	.243	-.057
14			7	.593	.02	-.207	-.008	-.09	.069
15	1	M10	1	3.441	.018	.209	-.013	.027	.008
16			2	2.294	-.122	.105	-.062	.344	.111
17			3	.563	.001	.057	-.074	.477	.131
18			4	-.629	.01	-.033	-.015	.513	.14
19			5	-.722	.017	-.077	.054	.422	.108
20			6	-.504	.149	-.112	.04	.242	.056
21			7	.594	-.021	-.206	.008	-.09	-.069
22	1	M5	1	-1.09	-.035	.086	0	.023	-.004
23			2	-.42	.058	-.016	-.004	.096	-.026
24			3	1.054	-.007	.036	-.055	.125	-.024
25			4	1.343	-.002	-.008	-.057	.083	-.011
26			5	1.313	-.004	-.053	-.126	.113	-.014
27			6	.797	-.004	-.034	-.127	.01	.002
28			7	.108	.004	.066	-.128	.075	-.014
29	1	M6	1	-.143	0	.039	0	.012	0
30			2	-.274	0	-.032	0	.037	0
31			3	-.419	0	-.021	0	-.037	0
32			4	-.409	0	-.007	0	-.064	0
33			5	-.243	0	.011	0	-.066	0
34			6	.376	0	.051	0	-.044	0
35			7	.818	0	.097	0	.126	0
36	1	M7	1	-1.078	.035	.085	0	.022	.004
37			2	-.413	-.058	-.016	.004	.095	.026
38			3	1.052	.007	.036	.055	.124	.024
39			4	1.339	.002	-.008	.056	.082	.011
40			5	1.308	.004	-.054	.126	.112	.014
41			6	.793	.004	-.034	.127	.009	-.002
42			7	.106	-.004	.067	.127	.075	.014
43	1	M8	1	2.075	-.061	.014	.007	-.029	-.034
44			2	2.075	-.061	.014	.007	-.023	-.007
45			3	1.388	.012	.011	.011	.015	.003
46			4	1.388	.012	.011	.028	.032	-.002
47			5	.939	-.003	-.001	.028	.032	0
48			6	.65	-.005	-.004	.032	.023	.002
49			7	.65	-.005	-.004	.032	.021	.004
50	1	M9	1	.505	-.006	.017	-.003	-.059	-.002
51			2	.505	-.006	.017	-.003	-.052	0
52			3	.494	.003	.015	0	-.008	.001
53			4	.536	.003	.015	.015	.019	0
54			5	.536	-.006	.003	.015	.02	.002
55			6	.636	.016	.001	.018	.025	0
56			7	.636	.016	.001	.018	.026	-.007

Member Section Forces (Continued)

	LC	Member Label	Sec	Axial[k]	y Shear[k]	z Shear[k]	Torque[k-ft]	y-y Mo...	z-z Mo...
57	1	M10A	1	.636	-.016	-.001	-.018	.026	-.007
58			2	.636	-.016	-.001	-.018	.025	0
59			3	.537	.006	-.003	-.015	.02	.002
60			4	.537	-.003	-.015	-.015	.019	0
61			5	.496	-.003	-.015	0	-.008	.001
62			6	.509	.006	-.017	.003	-.052	0
63			7	.509	.006	-.017	.003	-.06	-.002
64	1	M11A	1	.653	.005	.004	-.032	.021	.004
65			2	.653	.005	.004	-.032	.023	.002
66			3	.942	.003	.001	-.028	.031	0
67			4	1.389	-.012	-.011	-.028	.032	-.002
68			5	1.389	-.012	-.011	-.011	.015	.003
69			6	2.075	.061	-.014	-.007	-.023	-.007
70			7	2.075	.061	-.014	-.007	-.029	-.034
71	1	M12	1	.044	0	0	.011	.086	0
72			2	.044	0	0	.011	.086	0
73			3	.071	0	-.004	.012	.076	0
74			4	.118	0	-.016	.012	.074	0
75			5	.118	0	-.016	.011	.016	0
76			6	.177	-.003	-.02	.012	-.087	0
77			7	.177	-.003	-.02	.012	-.096	.002
78	1	M13	1	.234	.002	.01	.004	-.053	.001
79			2	.234	.002	.01	.004	-.049	0
80			3	.26	0	.008	.006	-.002	0
81			4	.276	0	.008	.006	.007	0
82			5	.276	0	-.005	.004	.005	0
83			6	.288	.002	-.008	.006	-.03	0
84			7	.288	.002	-.008	.006	-.033	-.001
85	1	M14	1	.288	-.002	.008	-.006	-.033	-.001
86			2	.288	-.002	.008	-.006	-.029	0
87			3	.276	0	.005	-.004	.005	0
88			4	.276	0	-.008	-.006	.007	0
89			5	.259	0	-.008	-.006	-.002	0
90			6	.233	-.002	-.011	-.004	-.049	0
91			7	.233	-.002	-.011	-.004	-.053	.001
92	1	M15	1	.176	.003	.02	-.012	-.096	.002
93			2	.176	.003	.02	-.012	-.087	0
94			3	.117	0	.017	-.011	.015	0
95			4	.117	0	.017	-.012	.074	0
96			5	.07	0	.004	-.012	.076	0
97			6	.044	0	0	-.011	.086	0
98			7	.044	0	0	-.011	.086	0
99	1	M16	1	.032	.013	0	-.008	.095	.007
100			2	.032	.013	0	-.008	.095	.002
101			3	.108	-.002	-.005	-.008	.084	0
102			4	.189	-.002	-.016	-.009	.082	0
103			5	.189	-.002	-.016	-.009	.022	0
104			6	.253	.013	-.021	-.009	-.081	-.002
105			7	.253	.013	-.021	-.009	-.09	-.007
106	1	M17	1	.301	.006	.012	-.003	-.065	.002
107			2	.301	.006	.012	-.003	-.06	0
108			3	.319	-.001	.007	-.002	-.01	0
109			4	.324	-.001	.007	-.003	-.007	0
110			5	.324	0	-.004	-.003	0	0
111			6	.324	-.001	-.008	-.003	-.031	0
112			7	.324	-.001	-.008	-.003	-.034	0
113	1	M18	1	.323	0	.008	.002	-.034	0

Member Section Forces (Continued)

	LC	Member Label	Sec	Axial[k]	y Shear[k]	z Shear[k]	Torque[k-ft]	y-y Mo...	z-z Mo...
114			2	.323	0	.008	.002	-.031	0
115			3	.324	0	.004	.003	0	0
116			4	.324	.001	-.007	.003	-.007	0
117			5	.318	.001	-.007	.002	-.01	0
118			6	.3	-.006	-.012	.003	-.06	0
119			7	.3	-.006	-.012	.003	-.065	.002
120	1	M19	1	.252	-.013	.021	.009	-.09	-.007
121			2	.252	-.013	.021	.009	-.081	-.002
122			3	.188	.002	.016	.009	.022	0
123			4	.188	.002	.016	.009	.081	0
124			5	.107	.002	.005	.008	.083	0
125			6	.031	-.013	0	.008	.094	.002
126			7	.031	-.013	0	.008	.095	.007
127	1	M20	1	-.209	.028	-.016	.001	-.033	-.059
128			2	-.209	.028	-.016	.001	-.035	-.063
129			3	-.209	.028	-.016	.001	-.037	-.066
130			4	-.209	.028	-.016	.001	-.039	-.069
131			5	-.209	.028	-.016	.001	-.042	-.073
132			6	-.209	.028	-.016	.001	-.044	-.076
133			7	-.209	.028	-.016	.001	-.046	-.08
134	1	M21	1	.364	-.073	.001	0	0	-.113
135			2	.364	-.073	.001	0	0	-.101
136			3	.364	-.073	.001	0	0	-.089
137			4	.364	-.073	.001	0	0	-.077
138			5	.364	-.073	.001	0	0	-.065
139			6	.364	-.073	.001	0	0	-.054
140			7	.364	-.073	.001	0	0	-.042
141	1	M22	1	-.212	.027	.019	-.002	.032	-.059
142			2	-.212	.027	.019	-.002	.034	-.063
143			3	-.212	.027	.019	-.002	.037	-.066
144			4	-.212	.027	.019	-.002	.039	-.069
145			5	-.212	.027	.019	-.002	.042	-.073
146			6	-.212	.027	.019	-.002	.044	-.076
147			7	-.212	.027	.019	-.002	.047	-.08

Member Section Stresses

	LC	Member Label	Sec	Axial[ksi]	y Shear[ksi]	z Shear[ksi]	y top Bending[ksi]	y bot Bending[ksi]	z top Be...	z bot Be...
1	1	B1	1	-.323	.002	-.004	-.206	.206	.081	-.081
2			2	-.323	.002	-.004	-.166	.166	-.029	.029
3			3	-.324	.004	.021	-.085	.085	.108	-.108
4			4	-.324	.004	.021	.031	-.031	.666	-.666
5			5	-.324	-.004	-.021	-.084	.084	.106	-.106
6			6	-.323	-.002	.004	-.165	.165	-.033	.033
7			7	-.323	-.002	.004	-.206	.206	.079	-.079
8	1	M11	1	.274	-.002	.025	.016	-.016	.052	-.052
9			2	.183	.015	.013	.213	-.213	.66	-.66
10			3	.045	0	.007	.251	-.251	.915	-.915
11			4	-.05	-.001	-.004	.268	-.268	.984	-.984
12			5	-.058	-.002	-.009	.207	-.207	.809	-.809
13			6	-.04	-.018	-.013	.108	-.108	.463	-.463
14			7	.047	.002	-.025	-.132	.132	-.172	.172
15	1	M10	1	.274	.002	.025	-.016	.016	.052	-.052
16			2	.183	-.015	.013	-.212	.212	.657	-.657
17			3	.045	0	.007	-.25	.25	.91	-.91
18			4	-.05	.001	-.004	-.267	.267	.979	-.979
19			5	-.057	.002	-.009	-.207	.207	.805	-.805

Member Section Stresses (Continued)

	LC	Member Label	Sec	Axial[ksi]	y Shear[ksi]	z Shear[ksi]	y top Bending[ksi]	y bot Bending[ksi]	z top Be...	z bot Be...
20			6	-.04	.018	-.013	-.108	.108	.461	-.461
21			7	.047	-.002	-.025	.132	-.132	-.171	.171
22	1	M5	1	-.087	-.004	.01	.008	-.008	.043	-.043
23			2	-.033	.007	-.002	.05	-.05	.183	-.183
24			3	.084	0	.004	.045	-.045	.238	-.238
25			4	.107	0	0	.022	-.022	.158	-.158
26			5	.104	0	-.006	.027	-.027	.215	-.215
27			6	.063	0	-.004	-.004	.004	.019	-.019
28			7	.009	0	.008	.026	-.026	.143	-.143
29	1	M6	1	-.011	0	.005	0	0	.023	-.023
30			2	-.022	0	-.004	0	0	.071	-.071
31			3	-.033	0	-.002	0	0	-.07	.07
32			4	-.033	0	0	0	0	-.123	.123
33			5	-.019	0	.001	0	0	-.125	.125
34			6	.03	0	.006	0	0	-.083	.083
35			7	.065	0	.012	0	0	.24	-.24
36	1	M7	1	-.086	.004	.01	-.008	.008	.043	-.043
37			2	-.033	-.007	-.002	-.049	.049	.181	-.181
38			3	.084	0	.004	-.045	.045	.236	-.236
39			4	.107	0	0	-.021	.021	.157	-.157
40			5	.104	0	-.006	-.026	.026	.213	-.213
41			6	.063	0	-.004	.005	-.005	.017	-.017
42			7	.008	0	.008	-.026	.026	.143	-.143
43	1	M8	1	.661	-.029	.007	.519	-.519	-.443	.443
44			2	.661	-.029	.007	.112	-.112	-.352	.352
45			3	.442	.006	.005	-.052	.052	.228	-.228
46			4	.442	.006	.005	.026	-.026	.49	-.49
47			5	.299	-.002	0	.004	-.004	.481	-.481
48			6	.207	-.003	-.002	-.024	.024	.345	-.345
49			7	.207	-.003	-.002	-.06	.06	.318	-.318
50	1	M9	1	.161	-.003	.008	.032	-.032	-.905	.905
51			2	.161	-.003	.008	-.007	.007	-.797	.797
52			3	.157	.002	.007	-.016	.016	-.123	.123
53			4	.171	.002	.007	.006	-.006	.291	-.291
54			5	.171	-.003	.002	-.031	.031	.311	-.311
55			6	.202	.007	0	0	0	.383	-.383
56			7	.202	.007	0	.1	-.1	.391	-.391
57	1	M10A	1	.202	-.007	0	.1	-.1	.395	-.395
58			2	.202	-.007	0	0	0	.387	-.387
59			3	.171	.003	-.002	-.031	.031	.313	-.313
60			4	.171	-.002	-.007	.006	-.006	.292	-.292
61			5	.158	-.002	-.007	-.016	.016	-.124	.124
62			6	.162	.003	-.008	-.007	.007	-.8	.8
63			7	.162	.003	-.008	.033	-.033	-.909	.909
64	1	M11A	1	.208	.003	.002	-.06	.06	.318	-.318
65			2	.208	.003	.002	-.024	.024	.344	-.344
66			3	.3	.002	0	.004	-.004	.478	-.478
67			4	.442	-.006	-.005	.026	-.026	.486	-.486
68			5	.442	-.006	-.005	-.052	.052	.225	-.225
69			6	.66	.029	-.007	.112	-.112	-.351	.351
70			7	.66	.029	-.007	.519	-.519	-.443	.443
71	1	M12	1	.014	0	0	.009	-.009	1.312	-1.312
72			2	.014	0	0	.003	-.003	1.309	-1.309
73			3	.022	0	-.002	0	0	1.16	-1.16
74			4	.038	0	-.008	.001	-.001	1.133	-1.133
75			5	.038	0	-.008	.004	-.004	.237	-.237
76			6	.056	-.001	-.01	-.005	.005	-1.324	1.324

Member Section Stresses (Continued)

	LC	Member Label	Sec	Axial[ksi]	y Shear[ksi]	z Shear[ksi]	y top Bending[ksi]	y bot Bending[ksi]	z top Be...	z bot Be...
77			7	.056	-.001	-.01	-.024	.024	-1.458	1.458
78	1	M13	1	.074	.001	.005	-.018	.018	-.81	.81
79			2	.074	.001	.005	-.005	.005	-.743	.743
80			3	.083	0	.004	.002	-.002	-.027	.027
81			4	.088	0	.004	0	0	.109	-.109
82			5	.088	0	-.002	0	0	.076	-.076
83			6	.092	0	-.004	.005	-.005	-.45	.45
84			7	.092	0	-.004	.016	-.016	-.501	.501
85	1	M14	1	.092	0	.004	.015	-.015	-.498	.498
86			2	.092	0	.004	.005	-.005	-.448	.448
87			3	.088	0	.002	0	0	.078	-.078
88			4	.088	0	-.004	0	0	.11	-.11
89			5	.083	0	-.004	.002	-.002	-.027	.027
90			6	.074	-.001	-.005	-.005	.005	-.745	.745
91			7	.074	-.001	-.005	-.018	.018	-.812	.812
92	1	M15	1	.056	.001	.01	-.024	.024	-1.459	1.459
93			2	.056	.001	.01	-.005	.005	-1.326	1.326
94			3	.037	0	.008	.004	-.004	.23	-.23
95			4	.037	0	.008	.001	-.001	1.126	-1.126
96			5	.022	0	.002	0	0	1.154	-1.154
97			6	.014	0	0	.003	-.003	1.308	-1.308
98			7	.014	0	0	.009	-.009	1.312	-1.312
99	1	M16	1	.01	.006	0	-.111	.111	1.446	-1.446
100			2	.01	.006	0	-.027	.027	1.445	-1.445
101			3	.034	0	-.002	.011	-.011	1.276	-1.276
102			4	.06	0	-.008	0	0	1.244	-1.244
103			5	.06	0	-.008	-.012	.012	.335	-.335
104			6	.081	.006	-.01	.025	-.025	-1.235	1.235
105			7	.081	.006	-.01	.111	-.111	-1.373	1.373
106	1	M17	1	.096	.003	.006	-.037	.037	-.989	.989
107			2	.096	.003	.006	-.002	.002	-.915	.915
108			3	.102	0	.004	.011	-.011	-.158	.158
109			4	.103	0	.004	.003	-.003	-.11	.11
110			5	.103	0	-.002	.004	-.004	-.003	.003
111			6	.103	0	-.004	0	0	-.474	.474
112			7	.103	0	-.004	-.005	.005	-.524	.524
113	1	M18	1	.103	0	.004	-.005	.005	-.524	.524
114			2	.103	0	.004	.001	-.001	-.474	.474
115			3	.103	0	.002	.003	-.003	-.002	.002
116			4	.103	0	-.004	.003	-.003	-.109	.109
117			5	.101	0	-.004	.011	-.011	-.156	.156
118			6	.095	-.003	-.006	-.002	.002	-.912	.912
119			7	.095	-.003	-.006	-.038	.038	-.986	.986
120	1	M19	1	.08	-.006	.01	.112	-.112	-1.374	1.374
121			2	.08	-.006	.01	.025	-.025	-1.236	1.236
122			3	.06	0	.008	-.012	.012	.328	-.328
123			4	.06	0	.008	0	0	1.235	-1.235
124			5	.034	0	.002	.011	-.011	1.268	-1.268
125			6	.01	-.006	0	-.027	.027	1.442	-1.442
126			7	.01	-.006	0	-.111	.111	1.444	-1.444
127	1	M20	1	-.067	.013	-.008	.901	-.901	-.507	.507
128			2	-.067	.013	-.008	.954	-.954	-.539	.539
129			3	-.067	.013	-.008	1.007	-1.007	-.571	.571
130			4	-.067	.013	-.008	1.06	-1.06	-.602	.602
131			5	-.067	.013	-.008	1.113	-1.113	-.634	.634
132			6	-.067	.013	-.008	1.166	-1.166	-.665	.665
133			7	-.067	.013	-.008	1.219	-1.219	-.697	.697

Member Section Stresses (Continued)

	LC	Member Label	Sec	Axial[ksi]	y Shear[ksi]	z Shear[ksi]	y top Bending[ksi]	y bot Bending[ksi]	z top Be...	z bot Be...
134	1	M21	1	.116	-.035	0	1.726	-1.726	-.008	.008
135			2	.116	-.035	0	1.544	-1.544	-.005	.005
136			3	.116	-.035	0	1.362	-1.362	-.002	.002
137			4	.116	-.035	0	1.18	-1.18	.001	-.001
138			5	.116	-.035	0	.998	-.998	.005	-.005
139			6	.116	-.035	0	.816	-.816	.008	-.008
140			7	.116	-.035	0	.635	-.635	.011	-.011
141	1	M22	1	-.067	.013	.009	.902	-.902	.489	-.489
142			2	-.067	.013	.009	.954	-.954	.526	-.526
143			3	-.067	.013	.009	1.007	-1.007	.564	-.564
144			4	-.067	.013	.009	1.059	-1.059	.601	-.601
145			5	-.067	.013	.009	1.112	-1.112	.638	-.638
146			6	-.067	.013	.009	1.164	-1.164	.676	-.676
147			7	-.067	.013	.009	1.217	-1.217	.713	-.713

Member Section Deflections

	LC	Member Label	Sec	x [in]	y [in]	z [in]	x Rotate[rad]	(n) L/y Ratio	(n) L/z Ratio
1	1	B1	1	-.009	-.002	0	7.452e-3	NC	NC
2			2	-.006	.021	-.031	6.115e-3	5319.524	3848.404
3			3	-.003	.029	-.065	5.305e-3	3956.684	1848.477
4			4	0	.029	-.087	5.025e-3	3928.933	1380.908
5			5	.003	.028	-.065	5.294e-3	3966.005	1855.835
6			6	.006	.021	-.031	6.089e-3	5334.89	3889.013
7			7	.009	-.002	0	7.415e-3	NC	NC
8	1	M11	1	0	0	0	2.239e-3	NC	NC
9			2	-.002	-.038	-.151	1.907e-3	2846.021	742.339
10			3	-.003	-.064	-.254	1.065e-3	1685.677	441.653
11			4	-.003	-.07	-.286	1.181e-3	1509.7	391.994
12			5	-.002	-.056	-.243	9.132e-4	1820.791	461.511
13			6	-.002	-.025	-.138	1.482e-3	3423.357	813.228
14			7	-.002	.009	0	1.663e-3	NC	NC
15	1	M10	1	0	0	0	-2.182e-3	NC	NC
16			2	-.002	.038	-.15	-1.852e-3	2852.721	746.172
17			3	-.003	.063	-.253	-1.014e-3	1689.865	443.956
18			4	-.003	.07	-.285	-1.135e-3	1513.472	394.036
19			5	-.002	.055	-.242	-8.722e-4	1825.393	463.913
20			6	-.002	.025	-.137	-1.45e-3	3432.026	817.372
21			7	-.002	-.009	0	-1.641e-3	NC	NC
22	1	M5	1	0	0	0	-5.395e-3	NC	NC
23			2	0	-.004	-.042	-5.372e-3	NC	3314.888
24			3	0	-.007	-.069	-5.321e-3	NC	2093.706
25			4	0	-.007	-.081	-4.634e-3	NC	1957.696
26			5	-.002	-.005	-.079	-3.93e-3	NC	2352.86
27			6	-.002	-.002	-.065	-2.365e-3	NC	4392.869
28			7	-.002	.001	-.047	-7.874e-4	NC	NC
29	1	M6	1	0	0	0	-8.089e-6	NC	NC
30			2	0	0	-.006	-8.102e-6	NC	NC
31			3	0	0	-.009	-8.127e-6	NC	NC
32			4	0	0	-.016	-8.262e-6	NC	6992.676
33			5	0	0	-.033	-8.392e-6	NC	3432.834
34			6	0	0	-.059	-5.789e-6	NC	1916.401
35			7	0	0	-.088	-3.174e-6	NC	1281.608
36	1	M7	1	0	0	0	5.356e-3	NC	NC
37			2	0	.004	-.041	5.335e-3	NC	3345.918
38			3	0	.007	-.069	5.287e-3	NC	2113.347
39			4	0	.007	-.08	4.604e-3	NC	1976.349

Member Section Deflections (Continued)

	LC	Member Label	Sec	x [in]	y [in]	z [in]	x Rotate[rad]	(n) L/y Ratio	(n) L/z Ratio
40			5	-.002	.005	-.078	3.905e-3	NC	2376.224
41			6	-.002	.002	-.064	2.349e-3	NC	4443.219
42			7	-.002	-.001	-.046	7.816e-4	NC	NC
43	1	M8	1	-.009	-.002	.003	7.586e-3	NC	NC
44			2	-.01	-.003	-.009	7.217e-3	NC	9205.627
45			3	-.012	-.002	-.023	6.722e-3	NC	3020.276
46			4	-.013	-.002	-.036	6.102e-3	NC	2047.405
47			5	-.014	-.002	-.044	4.568e-3	NC	2020.968
48			6	-.014	-.002	-.047	2.913e-3	NC	3144.284
49			7	-.015	-.002	-.045	1.136e-3	NC	NC
50	1	M9	1	-.006	-.002	-.047	1.132e-3	NC	NC
51			2	-.006	-.002	-.048	1.311e-3	NC	5251.22
52			3	-.006	0	-.057	1.406e-3	NC	9358.761
53			4	-.007	0	-.068	1.418e-3	NC	NC
54			5	-.007	0	-.078	6.08e-4	NC	6209.626
55			6	-.007	0	-.085	-2.842e-4	NC	6598.38
56			7	-.008	0	-.087	-1.259e-3	NC	NC
57	1	M10A	1	.008	0	-.087	-1.259e-3	NC	NC
58			2	.008	0	-.085	-2.864e-4	NC	6555.269
59			3	.007	0	-.078	6.037e-4	NC	6180.57
60			4	.007	0	-.068	1.411e-3	NC	NC
61			5	.006	0	-.057	1.398e-3	NC	9284.45
62			6	.006	-.002	-.047	1.3e-3	NC	5222.146
63			7	.006	-.002	-.046	1.119e-3	NC	NC
64	1	M11A	1	.015	-.002	-.044	1.123e-3	NC	NC
65			2	.014	-.002	-.046	2.889e-3	NC	3172.377
66			3	.014	-.002	-.044	4.534e-3	NC	2041.248
67			4	.013	-.002	-.036	6.059e-3	NC	2070.327
68			5	.012	-.002	-.023	6.68e-3	NC	3059.657
69			6	.01	-.003	-.008	7.176e-3	NC	9375.519
70			7	.009	-.002	.003	7.549e-3	NC	NC
71	1	M12	1	-.017	-.002	-.249	4.325e-3	NC	NC
72			2	-.017	-.002	-.245	3.736e-3	NC	1239.491
73			3	-.017	-.002	-.226	3.102e-3	NC	904.149
74			4	-.017	-.002	-.193	2.423e-3	NC	1060.61
75			5	-.017	-.002	-.15	1.83e-3	NC	2026.257
76			6	-.017	-.002	-.106	1.194e-3	NC	NC
77			7	-.018	-.002	-.077	5.162e-4	NC	NC
78	1	M13	1	-.002	-.002	-.079	5.068e-4	NC	647.583
79			2	-.002	-.001	-.064	2.718e-4	NC	962.546
80			3	-.002	0	-.056	-2.427e-6	NC	1276.701
81			4	-.002	0	-.05	-3.16e-4	NC	1757.635
82			5	-.003	0	-.043	-5.492e-4	NC	2993.131
83			6	-.003	0	-.035	-8.21e-4	NC	NC
84			7	-.003	0	-.033	-1.131e-3	NC	NC
85	1	M14	1	.003	0	-.033	-1.131e-3	NC	NC
86			2	.003	0	-.035	-8.213e-4	NC	NC
87			3	.003	0	-.042	-5.5e-4	NC	3062.462
88			4	.002	0	-.049	-3.171e-4	NC	1796.693
89			5	.002	0	-.056	-3.917e-6	NC	1305.693
90			6	.002	-.001	-.063	2.7e-4	NC	983.661
91			7	.002	-.002	-.078	5.045e-4	NC	658.979
92	1	M15	1	.018	-.002	-.076	5.139e-4	NC	NC
93			2	.017	-.002	-.105	1.188e-3	NC	NC
94			3	.017	-.002	-.149	1.82e-3	NC	2065.328
95			4	.017	-.002	-.191	2.411e-3	NC	1073.88
96			5	.017	-.002	-.225	3.086e-3	NC	912.895

Member Section Deflections (Continued)

	LC	Member Label	Sec	x [in]	y [in]	z [in]	x Rotate[rad]	(n) L/y Ratio	(n) L/z Ratio
97			6	.017	-.002	-.244	3.717e-3	NC	1249.014
98			7	.017	-.002	-.247	4.303e-3	NC	NC
99	1	M16	1	-.013	-.003	-.262	-3.814e-3	NC	NC
100			2	-.013	-.002	-.258	-3.367e-3	NC	1086.158
101			3	-.013	-.002	-.237	-2.925e-3	NC	780.483
102			4	-.013	-.001	-.2	-2.489e-3	NC	882.529
103			5	-.013	0	-.153	-1.993e-3	NC	1520.295
104			6	-.013	0	-.104	-1.505e-3	NC	8209.591
105			7	-.013	0	-.068	-1.026e-3	NC	NC
106	1	M17	1	0	0	-.07	-1.05e-3	NC	493.656
107			2	0	0	-.048	-9.058e-4	NC	756.512
108			3	0	0	-.037	-7.849e-4	NC	1074.475
109			4	0	0	-.028	-6.876e-4	NC	1581.923
110			5	0	0	-.019	-5.038e-4	NC	2823.604
111			6	0	0	-.011	-3.449e-4	NC	NC
112			7	0	0	-.008	-2.109e-4	NC	NC
113	1	M18	1	0	0	-.008	-2.108e-4	NC	NC
114			2	0	0	-.011	-3.431e-4	NC	NC
115			3	0	0	-.019	-5.003e-4	NC	2869.138
116			4	0	0	-.027	-6.824e-4	NC	1604.316
117			5	0	0	-.036	-7.779e-4	NC	1089.136
118			6	0	0	-.048	-8.971e-4	NC	766.312
119			7	0	0	-.069	-1.04e-3	NC	499.111
120	1	M19	1	.013	0	-.068	-1.016e-3	NC	NC
121			2	.013	0	-.103	-1.493e-3	NC	8589.431
122			3	.013	0	-.152	-1.978e-3	NC	1546.343
123			4	.013	-.001	-.199	-2.473e-3	NC	893.591
124			5	.013	-.002	-.236	-2.908e-3	NC	788.543
125			6	.013	-.002	-.257	-3.348e-3	NC	1095.655
126			7	.013	-.003	-.26	-3.794e-3	NC	NC
127	1	M20	1	.047	-.002	-.001	-2.338e-4	NC	NC
128			2	.047	0	0	-2.572e-4	4238.204	9696.96
129			3	.047	.003	0	-2.806e-4	1723.775	6891.487
130			4	.047	.007	0	-3.041e-4	962.899	8172.806
131			5	.047	.012	0	-3.275e-4	618.358	NC
132			6	.047	.019	-.002	-3.509e-4	430.645	7593.897
133			7	.047	.026	-.005	-3.744e-4	316.528	2701.596
134	1	M21	1	.088	0	0	-1.457e-7	NC	NC
135			2	.087	0	0	2.445e-7	NC	NC
136			3	.087	.001	0	6.347e-7	NC	NC
137			4	.087	.005	0	1.025e-6	2421.5	NC
138			5	.087	.011	0	1.415e-6	1068.498	NC
139			6	.087	.019	0	1.805e-6	622.442	NC
140			7	.087	.029	0	2.196e-6	416.999	NC
141	1	M22	1	.046	-.002	.001	2.314e-4	NC	NC
142			2	.046	0	0	2.556e-4	4276.028	9679.103
143			3	.046	.003	0	2.798e-4	1736.077	6806.182
144			4	.047	.007	0	3.041e-4	968.61	7899.895
145			5	.047	.012	0	3.283e-4	621.501	NC
146			6	.047	.019	.002	3.525e-4	432.569	8134.383
147			7	.047	.026	.005	3.767e-4	317.798	2773.125

Joint Deflections

	LC	Joint Label	X [in]	Y [in]	Z [in]	X Rotation [rad]	Y Rotation [rad]	Z Rotation [rad]
1	1	N2	0	0	0	-8.628e-3	2.239e-3	-2.065e-3
2	1	N6	0	0	0	-8.584e-3	-2.182e-3	2.061e-3

Member Section Deflections (Continued)

	LC	Member Label	Sec	x [in]	y [in]	z [in]	x Rotate[rad]	(n) L/y Ratio	(n) L/z Ratio
97			6	.017	-.002	-.244	3.717e-3	NC	1249.014
98			7	.017	-.002	-.247	4.303e-3	NC	NC
99	1	M16	1	-.013	-.003	-.262	-3.814e-3	NC	NC
100			2	-.013	-.002	-.258	-3.367e-3	NC	1086.158
101			3	-.013	-.002	-.237	-2.925e-3	NC	780.483
102			4	-.013	-.001	-.2	-2.489e-3	NC	882.529
103			5	-.013	0	-.153	-1.993e-3	NC	1520.295
104			6	-.013	0	-.104	-1.505e-3	NC	8209.591
105			7	-.013	0	-.068	-1.026e-3	NC	NC
106	1	M17	1	0	0	-.07	-1.05e-3	NC	493.656
107			2	0	0	-.048	-9.058e-4	NC	756.512
108			3	0	0	-.037	-7.849e-4	NC	1074.475
109			4	0	0	-.028	-6.876e-4	NC	1581.923
110			5	0	0	-.019	-5.038e-4	NC	2823.604
111			6	0	0	-.011	-3.449e-4	NC	NC
112			7	0	0	-.008	-2.109e-4	NC	NC
113	1	M18	1	0	0	-.008	-2.108e-4	NC	NC
114			2	0	0	-.011	-3.431e-4	NC	NC
115			3	0	0	-.019	-5.003e-4	NC	2869.138
116			4	0	0	-.027	-6.824e-4	NC	1604.316
117			5	0	0	-.036	-7.779e-4	NC	1089.136
118			6	0	0	-.048	-8.971e-4	NC	766.312
119			7	0	0	-.069	-1.04e-3	NC	499.111
120	1	M19	1	.013	0	-.068	-1.016e-3	NC	NC
121			2	.013	0	-.103	-1.493e-3	NC	8589.431
122			3	.013	0	-.152	-1.978e-3	NC	1546.343
123			4	.013	-.001	-.199	-2.473e-3	NC	893.591
124			5	.013	-.002	-.236	-2.908e-3	NC	788.543
125			6	.013	-.002	-.257	-3.348e-3	NC	1095.655
126			7	.013	-.003	-.26	-3.794e-3	NC	NC
127	1	M20	1	.047	-.002	-.001	-2.338e-4	NC	NC
128			2	.047	0	0	-2.572e-4	4238.204	9696.96
129			3	.047	.003	0	-2.806e-4	1723.775	6891.487
130			4	.047	.007	0	-3.041e-4	962.899	8172.806
131			5	.047	.012	0	-3.275e-4	618.358	NC
132			6	.047	.019	-.002	-3.509e-4	430.645	7593.897
133			7	.047	.026	-.005	-3.744e-4	316.528	2701.596
134	1	M21	1	.088	0	0	-1.457e-7	NC	NC
135			2	.087	0	0	2.445e-7	NC	NC
136			3	.087	.001	0	6.347e-7	NC	NC
137			4	.087	.005	0	1.025e-6	2421.5	NC
138			5	.087	.011	0	1.415e-6	1068.498	NC
139			6	.087	.019	0	1.805e-6	622.442	NC
140			7	.087	.029	0	2.196e-6	416.999	NC
141	1	M22	1	.046	-.002	.001	2.314e-4	NC	NC
142			2	.046	0	0	2.556e-4	4276.028	9679.103
143			3	.046	.003	0	2.798e-4	1736.077	6806.182
144			4	.047	.007	0	3.041e-4	968.61	7899.895
145			5	.047	.012	0	3.283e-4	621.501	NC
146			6	.047	.019	.002	3.525e-4	432.569	8134.383
147			7	.047	.026	.005	3.767e-4	317.798	2773.125

Joint Deflections

	LC	Joint Label	X [in]	Y [in]	Z [in]	X Rotation [rad]	Y Rotation [rad]	Z Rotation [rad]
1	1	N2	0	0	0	-8.628e-3	2.239e-3	-2.065e-3
2	1	N6	0	0	0	-8.584e-3	-2.182e-3	2.061e-3

Joint Deflections (Continued)

	LC	Joint Label	X [in]	Y [in]	Z [in]	X Rotation [rad]	Y Rotation [rad]	Z Rotation [rad]
3	1	N32	-.009	-.002	0	7.452e-3	1.663e-3	1.564e-3
4	1	N36	.009	-.002	0	7.415e-3	-1.641e-3	-1.56e-3
5	1	N3	0	0	0	-2.486e-3	-5.395e-3	-2.028e-4
6	1	N4	0	0	0	-4.394e-4	-8.089e-6	-1.039e-6
7	1	N5	0	0	0	-2.463e-3	5.356e-3	1.991e-4
8	1	N33	-.001	-.002	-.047	1.116e-3	-7.874e-4	2.338e-4
9	1	N34	0	0	-.088	-1.264e-3	-3.174e-6	1.457e-7
10	1	N35	.001	-.002	-.046	1.103e-3	7.816e-4	-2.314e-4
11	1	N13	.007	0	-.069	-1.047e-3	-5.321e-3	-8.106e-5
12	1	N43	-.005	.026	-.047	5.445e-3	1.672e-3	3.744e-4
13	1	N14	0	0	-.009	-2.117e-4	-8.127e-6	-4.559e-7
14	1	N44	0	.029	-.087	5.024e-3	-1.069e-5	-2.196e-6
15	1	N45	.005	.026	-.047	5.43e-3	-1.674e-3	-3.767e-4
16	1	N15	-.007	0	-.069	-1.037e-3	5.287e-3	7.916e-5
17	1	N23	.005	-.002	-.079	4.957e-4	-3.929e-3	1.44e-4
18	1	N24	0	0	-.033	-1.136e-3	-8.392e-6	1.569e-8
19	1	N25	-.005	-.002	-.078	4.934e-4	3.905e-3	-1.438e-4
20	1	N12	.064	-.003	-.254	-3.718e-3	1.065e-3	-8.789e-4
21	1	N22	.056	-.002	-.243	4.142e-3	9.131e-4	1.247e-3
22	1	N16	-.063	-.003	-.253	-3.699e-3	-1.014e-3	8.765e-4
23	1	N26	-.055	-.002	-.242	4.12e-3	-8.721e-4	-1.244e-3
24	1	N24A	.007	-.002	-.071	7.492e-3	1.617e-3	1.875e-3
25	1	N25A	.025	-.002	-.138	6.837e-3	1.482e-3	1.926e-3
26	1	N26A	.042	-.002	-.197	5.687e-3	1.241e-3	1.643e-3
27	1	N27	-.006	-.002	-.019	6.703e-3	2.988e-3	2.127e-3
28	1	N28	.182	-.003	-.651	1.284e-1	1.529e-1	3.872e-2
29	1	N29	.369	-.002	-1.278	5.783e-3	3.023e-1	1.744e-3
30	1	N30	.212	-.002	-.761	-1.164e-1	1.491e-1	-3.511e-2
31	1	N31	.052	-.002	-.233	3.291e-3	-3.717e-3	1.008e-3
32	1	N32A	-.002	-.002	-.038	5.846e-3	2.117e-3	1.747e-3
33	1	N33A	.354	-.003	-1.223	2.474e-1	-4.161e-4	7.464e-2
34	1	N34A	.707	-.002	-2.399	3.971e-3	-3.734e-3	1.198e-3
35	1	N35A	.374	-.002	-1.298	-2.395e-1	-6.064e-3	-7.224e-2
36	1	N36A	.039	-.002	-.189	2.315e-3	-7.796e-3	7.164e-4
37	1	N37	0	-.002	-.048	3.634e-3	4.081e-4	1.116e-3
38	1	N38	.178	-.002	-.642	1.233e-1	-1.545e-1	3.719e-2
39	1	N39	.354	-.002	-1.229	2.27e-3	-3.079e-1	6.846e-4
40	1	N40	.187	-.002	-.68	-1.198e-1	-1.587e-1	-3.613e-2
41	1	N41	.02	-.002	-.127	1.459e-3	-8.73e-3	4.695e-4
42	1	N42	0	-.002	-.056	9.168e-4	-1.576e-3	1.85e-4
43	1	N43A	.002	-.002	-.065	8.965e-4	-2.365e-3	1.749e-4
44	1	N44A	.004	-.002	-.073	8.043e-4	-3.148e-3	1.733e-4
45	1	N45A	.065	-.002	-.274	2.341e-3	1.086e-3	7.724e-4
46	1	N46	.07	-.003	-.286	3.341e-4	1.181e-3	2.273e-4
47	1	N47	.069	-.003	-.28	-1.735e-3	1.162e-3	-3.37e-4
48	1	N48	.232	-.002	-.827	1.239e-1	1.464e-1	3.738e-2
49	1	N49	.408	-.002	-1.408	3.779e-4	2.978e-1	1.14e-4
50	1	N50	.236	-.002	-.834	-1.232e-1	1.464e-1	-3.717e-2
51	1	N51	.06	-.002	-.243	-3.027e-3	-4.045e-3	-8.465e-4
52	1	N52	.388	-.002	-1.343	2.445e-1	-8.906e-3	7.376e-2
53	1	N53	.734	-.002	-2.488	2.996e-4	-1.011e-2	9.038e-5
54	1	N54	.391	-.001	-1.348	-2.44e-1	-9.294e-3	-7.36e-2
55	1	N55	.046	-.001	-.196	-2.41e-3	-8.528e-3	-6.302e-4
56	1	N56	.194	-.001	-.704	1.219e-1	-1.616e-1	3.678e-2
57	1	N57	.367	-.001	-1.274	6.324e-5	-3.133e-1	1.908e-5
58	1	N58	.197	0	-.704	-1.218e-1	-1.623e-1	-3.675e-2
59	1	N59	.025	0	-.126	-1.687e-3	-9.809e-3	-4.458e-4

Joint Deflections (Continued)

	LC	Joint Label	X [in]	Y [in]	Z [in]	X Rotation [rad]	Y Rotation [rad]	Z Rotation [rad]
60	1	N60	.007	-.001	-.082	8.512e-5	-4.282e-3	9.038e-5
61	1	N61	.007	0	-.081	-2.533e-4	-4.633e-3	4.428e-5
62	1	N62	.007	0	-.077	-5.994e-4	-4.978e-3	-4.228e-6
63	1	N63	.053	-.002	-.211	-5.55e-3	1.524e-3	-1.376e-3
64	1	N64	.038	-.002	-.151	-7.081e-3	1.907e-3	-1.84e-3
65	1	N65	.019	-.001	-.079	-8.191e-3	2.156e-3	-2.061e-3
66	1	N66	.217	-.002	-.756	1.128e-1	1.437e-1	3.404e-2
67	1	N67	.412	-.001	-1.391	2.312e-2	3.284e-1	6.975e-3
68	1	N68	.437	0	-1.464	-7.239e-3	3.669e-1	-2.184e-3
69	1	N69	.454	0	-1.513	1.782e-2	4.008e-1	5.376e-3
70	1	N70	.372	-.001	-1.268	2.32e-1	-7.137e-3	6.997e-2
71	1	N71	.778	0	-2.606	5.421e-2	-4.64e-3	1.635e-2
72	1	N72	.85	0	-2.833	-5.398e-3	-2.115e-3	-1.628e-3
73	1	N73	.908	0	-3.02	4.549e-2	6.051e-4	1.372e-2
74	1	N74	.188	0	-.659	1.158e-1	-1.552e-1	3.494e-2
75	1	N75	.392	0	-1.325	2.67e-2	-3.366e-1	8.054e-3
76	1	N76	.428	0	-1.434	-3.222e-3	-3.707e-1	-9.718e-4
77	1	N77	.457	0	-1.521	2.207e-2	-3.998e-1	6.656e-3
78	1	N78	.006	0	-.057	-1.485e-3	-5.349e-3	-1.417e-4
79	1	N79	.004	0	-.042	-1.85e-3	-5.372e-3	-2.266e-4
80	1	N80	.002	0	-.022	-2.261e-3	-5.39e-3	-2.402e-4
81	1	N81	.003	0	-.059	1.472e-4	-1.346e-3	8.462e-5
82	1	N82	.053	0	-.592	1.138e-1	1.403e-1	1.044e-2
83	1	N83	.103	0	-1.122	-4.308e-4	2.82e-1	-3.955e-5
84	1	N84	.054	0	-.583	-1.149e-1	1.398e-1	-1.055e-2
85	1	N85	.004	0	-.041	-8.281e-4	-2.149e-3	-9.731e-5
86	1	N86	.002	0	-.05	-3.216e-4	-1.296e-3	4.668e-5
87	1	N87	.101	0	-1.112	2.275e-1	-1.726e-3	2.089e-2
88	1	N88	.199	0	-2.172	-6.82e-4	-2.122e-3	-6.261e-5
89	1	N89	.101	0	-1.1	-2.287e-1	-1.881e-3	-2.099e-2
90	1	N90	.002	0	-.027	-6.857e-4	-1.652e-3	-5.291e-5
91	1	N91	0	0	-.039	-6.701e-4	-1.583e-3	1.601e-5
92	1	N92	.05	0	-.564	1.131e-1	-1.442e-1	1.038e-2
93	1	N93	.099	0	-1.09	-6.013e-4	-2.862e-1	-5.521e-5
94	1	N94	.05	0	-.552	-1.145e-1	-1.441e-1	-1.051e-2
95	1	N95	0	0	-.015	-4.121e-4	-1.662e-3	-1.65e-5
96	1	N96	0	0	-.023	-8.914e-4	-8.329e-6	-1.221e-7
97	1	N97	0	0	-.016	-6.319e-4	-8.262e-6	-2.424e-7
98	1	N98	0	0	-.011	-3.921e-4	-8.196e-6	-3.631e-7
99	1	N99	-.001	-.001	-.052	1.382e-3	2.013e-3	2.671e-4
100	1	N100	.049	-.001	-.591	1.14e-1	1.441e-1	1.046e-2
101	1	N101	.099	-.001	-1.124	1.039e-4	2.847e-1	9.539e-6
102	1	N102	.051	-.001	-.592	-1.14e-1	1.415e-1	-1.047e-2
103	1	N103	0	0	-.069	1.402e-3	2.348e-3	2.325e-4
104	1	N104	.099	0	-1.137	2.272e-1	1.461e-3	2.086e-2
105	1	N105	.197	0	-2.194	-1.07e-3	3.711e-4	-9.826e-5
106	1	N106	.1	0	-1.12	-2.287e-1	-5.713e-4	-2.099e-2
107	1	N107	0	0	-.083	1.998e-4	1.307e-3	4.738e-5
108	1	N108	.05	0	-.608	1.123e-1	-1.425e-1	1.031e-2
109	1	N109	.099	0	-1.127	-1.31e-3	-2.847e-1	-1.203e-4
110	1	N110	.05	0	-.581	-1.154e-1	-1.431e-1	-1.059e-2
111	1	N111	0	0	-.074	-1.618e-3	-4.482e-6	2.338e-7
112	1	N112	0	0	-.059	-1.593e-3	-5.789e-6	2.219e-7
113	1	N113	0	0	-.045	-1.395e-3	-7.09e-6	1.584e-7
114	1	N114	.05	0	-.542	1.078e-1	1.345e-1	9.899e-3
115	1	N115	.105	0	-1.144	2.109e-2	2.992e-1	1.936e-3
116	1	N116	.112	0	-1.222	-4.412e-3	3.251e-1	-4.05e-4

Joint Deflections (Continued)

	LC	Joint Label	X [in]	Y [in]	Z [in]	X Rotation [rad]	Y Rotation [rad]	Z Rotation [rad]
117	1	N117	.119	0	-1.295	1.991e-2	3.505e-1	1.827e-3
118	1	N118	.096	0	-1.042	2.177e-1	-1.16e-3	1.998e-2
119	1	N119	.208	0	-2.267	4.429e-2	-1.94e-4	4.066e-3
120	1	N120	.224	0	-2.444	-6.282e-3	5.001e-4	-5.767e-4
121	1	N121	.24	0	-2.616	4.308e-2	1.671e-3	3.955e-3
122	1	N122	.048	0	-.522	1.089e-1	-1.373e-1	1.e-2
123	1	N123	.104	0	-1.136	2.231e-2	-3.011e-1	2.048e-3
124	1	N124	.112	0	-1.225	-3.246e-3	-3.254e-1	-2.98e-4
125	1	N125	.12	0	-1.311	2.17e-2	-3.494e-1	1.992e-3
126	1	N126	0	0	-.007	-1.124e-4	-8.113e-6	-5.912e-7
127	1	N127	0	0	-.006	-1.549e-4	-8.102e-6	-5.485e-7
128	1	N128	0	0	-.004	-3.284e-4	-8.093e-6	-7.644e-7
129	1	N129	0	0	-.082	1.965e-4	-1.326e-3	-4.73e-5
130	1	N130	-.05	0	-.608	1.123e-1	1.424e-1	-1.031e-2
131	1	N131	-.098	0	-1.127	-1.312e-3	2.847e-1	1.204e-4
132	1	N132	-.05	0	-.581	-1.154e-1	1.43e-1	1.059e-2
133	1	N133	0	0	-.039	-6.706e-4	1.557e-3	-1.612e-5
134	1	N134	0	0	-.068	1.396e-3	-2.371e-3	-2.319e-4
135	1	N135	-.099	0	-1.137	2.272e-1	-1.488e-3	-2.086e-2
136	1	N136	-.197	0	-2.194	-1.073e-3	-4.009e-4	9.854e-5
137	1	N137	-.099	0	-1.12	-2.287e-1	5.415e-4	2.099e-2
138	1	N138	-.002	0	-.049	-3.227e-4	1.266e-3	-4.666e-5
139	1	N139	.001	-.001	-.052	1.372e-3	-2.031e-3	-2.662e-4
140	1	N140	-.049	-.001	-.591	1.14e-1	-1.442e-1	-1.046e-2
141	1	N141	-.099	-.001	-1.124	9.859e-5	-2.847e-1	-9.051e-6
142	1	N142	-.051	-.001	-.591	-1.14e-1	-1.415e-1	1.047e-2
143	1	N143	-.003	0	-.059	1.456e-4	1.316e-3	-8.453e-5
144	1	N144	0	-.002	-.056	9.055e-4	1.565e-3	-1.829e-4
145	1	N145	-.002	-.002	-.064	8.884e-4	2.349e-3	-1.735e-4
146	1	N146	-.004	-.002	-.072	7.992e-4	3.127e-3	-1.726e-4
147	1	N147	-.05	0	-.564	1.131e-1	1.442e-1	-1.038e-2
148	1	N148	-.099	0	-1.09	-6.e-4	2.862e-1	5.508e-5
149	1	N149	-.05	0	-.552	-1.145e-1	1.441e-1	1.051e-2
150	1	N150	0	0	-.015	-4.095e-4	1.645e-3	1.627e-5
151	1	N151	-.101	0	-1.112	2.275e-1	1.696e-3	-2.089e-2
152	1	N152	-.199	0	-2.172	-6.787e-4	2.093e-3	6.231e-5
153	1	N153	-.101	0	-1.1	-2.287e-1	1.857e-3	2.099e-2
154	1	N154	-.002	0	-.027	-6.804e-4	1.631e-3	5.213e-5
155	1	N155	-.053	0	-.591	1.138e-1	-1.403e-1	-1.044e-2
156	1	N156	-.102	0	-1.121	-4.271e-4	-2.821e-1	3.921e-5
157	1	N157	-.053	0	-.582	-1.149e-1	-1.398e-1	1.055e-2
158	1	N158	-.004	0	-.041	-8.203e-4	2.123e-3	9.635e-5
159	1	N159	-.006	-.001	-.081	8.571e-5	4.254e-3	-9.066e-5
160	1	N160	-.007	0	-.08	-2.498e-4	4.604e-3	-4.505e-5
161	1	N161	-.007	0	-.076	-5.927e-4	4.946e-3	2.915e-6
162	1	N162	-.048	0	-.522	1.089e-1	1.373e-1	-1.e-2
163	1	N163	-.104	0	-1.136	2.231e-2	3.011e-1	-2.048e-3
164	1	N164	-.112	0	-1.225	-3.241e-3	3.254e-1	2.975e-4
165	1	N165	-.12	0	-1.311	2.17e-2	3.494e-1	-1.992e-3
166	1	N166	-.096	0	-1.042	2.177e-1	1.146e-3	-1.998e-2
167	1	N167	-.208	0	-2.267	4.43e-2	1.903e-4	-4.067e-3
168	1	N168	-.224	0	-2.444	-6.271e-3	-4.96e-4	5.757e-4
169	1	N169	-.24	0	-2.617	4.31e-2	-1.654e-3	-3.956e-3
170	1	N170	-.05	0	-.541	1.078e-1	-1.345e-1	-9.9e-3
171	1	N171	-.105	0	-1.144	2.11e-2	-2.992e-1	-1.937e-3
172	1	N172	-.112	0	-1.222	-4.394e-3	-3.251e-1	4.034e-4
173	1	N173	-.119	0	-1.295	1.993e-2	-3.505e-1	-1.83e-3

Joint Deflections (Continued)

	LC	Joint Label	X [in]	Y [in]	Z [in]	X Rotation [rad]	Y Rotation [rad]	Z Rotation [rad]
174	1	N174	-.006	0	-.057	-1.471e-3	5.312e-3	1.391e-4
175	1	N175	-.004	0	-.041	-1.832e-3	5.335e-3	2.234e-4
176	1	N176	-.002	0	-.022	-2.239e-3	5.35e-3	2.366e-4
177	1	N177	0	-.002	-.048	3.605e-3	-4.09e-4	-1.11e-3
178	1	N178	-.177	-.002	-.637	1.224e-1	1.539e-1	-3.703e-2
179	1	N179	-.352	-.002	-1.22	2.254e-3	3.067e-1	-6.818e-4
180	1	N180	-.186	-.002	-.675	-1.19e-1	1.581e-1	3.599e-2
181	1	N181	-.02	-.002	-.126	1.452e-3	8.698e-3	-4.683e-4
182	1	N182	.002	-.002	-.038	5.804e-3	-2.102e-3	-1.739e-3
183	1	N183	-.352	-.003	-1.214	2.457e-1	4.289e-4	-7.434e-2
184	1	N184	-.704	-.002	-2.382	3.945e-3	3.741e-3	-1.193e-3
185	1	N185	-.372	-.002	-1.289	-2.379e-1	6.063e-3	7.195e-2
186	1	N186	-.039	-.002	-.188	2.303e-3	7.791e-3	-7.147e-4
187	1	N187	.006	-.002	-.018	6.662e-3	-2.96e-3	-2.12e-3
188	1	N188	-.181	-.003	-.646	1.275e-1	-1.523e-1	-3.856e-2
189	1	N189	-.367	-.002	-1.269	5.748e-3	-3.01e-1	-1.739e-3
190	1	N190	-.211	-.002	-.756	-1.156e-1	-1.485e-1	3.496e-2
191	1	N191	-.052	-.002	-.231	3.273e-3	3.745e-3	-1.005e-3
192	1	N192	-.007	-.002	-.07	7.454e-3	-1.589e-3	-1.871e-3
193	1	N193	-.025	-.002	-.137	6.801e-3	-1.45e-3	-1.921e-3
194	1	N194	-.042	-.002	-.196	5.656e-3	-1.205e-3	-1.639e-3
195	1	N195	-.194	-.001	-.699	1.211e-1	1.609e-1	-3.664e-2
196	1	N196	-.366	-.001	-1.265	6.34e-5	3.121e-1	-1.918e-5
197	1	N197	-.196	0	-.699	-1.21e-1	1.617e-1	3.66e-2
198	1	N198	-.024	0	-.125	-1.674e-3	9.768e-3	4.434e-4
199	1	N199	-.386	-.002	-1.334	2.429e-1	8.898e-3	-7.346e-2
200	1	N200	-.731	-.002	-2.471	2.967e-4	1.01e-2	-8.975e-5
201	1	N201	-.39	-.001	-1.339	-2.423e-1	9.283e-3	7.33e-2
202	1	N202	-.045	-.001	-.194	-2.394e-3	8.516e-3	6.275e-4
203	1	N203	-.231	-.002	-.822	1.231e-1	-1.458e-1	-3.723e-2
204	1	N204	-.406	-.002	-1.399	3.75e-4	-2.965e-1	-1.134e-4
205	1	N205	-.235	-.002	-.828	-1.224e-1	-1.458e-1	3.702e-2
206	1	N206	-.06	-.002	-.241	-3.01e-3	4.072e-3	8.436e-4
207	1	N207	-.065	-.002	-.272	2.329e-3	-1.043e-3	-7.707e-4
208	1	N208	-.07	-.003	-.285	3.323e-4	-1.135e-3	-2.269e-4
209	1	N209	-.069	-.003	-.278	-1.727e-3	-1.113e-3	3.361e-4
210	1	N210	-.187	0	-.654	1.149e-1	1.544e-1	-3.477e-2
211	1	N211	-.389	0	-1.313	2.618e-2	3.346e-1	-7.92e-3
212	1	N212	-.425	0	-1.419	-3.372e-3	3.679e-1	1.02e-3
213	1	N213	-.453	0	-1.505	2.183e-2	3.966e-1	-6.604e-3
214	1	N214	-.37	-.001	-1.259	2.302e-1	7.126e-3	-6.963e-2
215	1	N215	-.774	0	-2.583	5.315e-2	4.632e-3	-1.608e-2
216	1	N216	-.844	0	-2.804	-5.716e-3	2.108e-3	1.729e-3
217	1	N217	-.901	0	-2.987	4.5e-2	-6.128e-4	-1.361e-2
218	1	N218	-.216	-.002	-.75	1.12e-1	-1.43e-1	-3.387e-2
219	1	N219	-.409	-.001	-1.379	2.262e-2	-3.264e-1	-6.841e-3
220	1	N220	-.434	0	-1.449	-7.376e-3	-3.64e-1	2.231e-3
221	1	N221	-.45	0	-1.497	1.76e-2	-3.975e-1	-5.324e-3
222	1	N222	-.053	-.002	-.209	-5.52e-3	-1.471e-3	1.373e-3
223	1	N223	-.038	-.002	-.15	-7.044e-3	-1.852e-3	1.835e-3
224	1	N224	-.019	-.001	-.079	-8.149e-3	-2.099e-3	2.056e-3

Joint Reactions

	LC	Joint Label	X [k]	Y [k]	Z [k]	MX [k-ft]	MY [k-ft]	MZ [k-ft]
1	1	N2	2.163	5.123	.932	0	0	0
2	1	N6	-2.155	5.116	.93	0	0	0

Joint Reactions (Continued)

	LC	Joint Label	X [k]	Y [k]	Z [k]	MX [k-ft]	MY [k-ft]	MZ [k-ft]
3	1	N32	0	0	2.314	0	0	0
4	1	N36	0	0	2.314	0	0	0
5	1	N3	1.871	-2.201	.741	0	0	0
6	1	N4	-.007	-.22	.137	0	0	0
7	1	N5	-1.871	-2.178	.74	0	0	0
8	1	Totals:	0	5.64	8.107			
9	1	COG (ft):	X: 33.001	Y: 9.35	Z: .355			

Plate Primary Data

	Label	A Joint	B Joint	C Joint	D Joint	Material	Thickness[in]
1	P13A	N32	N24A	N28	N27	Corrugated Metal-Steel	.048
2	P14	N24A	N25A	N29	N28	Corrugated Metal-Steel	.048
3	P15	N25A	N26A	N30	N29	Corrugated Metal-Steel	.048
4	P16	N26A	N22	N31	N30	Corrugated Metal-Steel	.048
5	P17	N27	N28	N33A	N32A	Corrugated Metal-Steel	.048
6	P18	N28	N29	N34A	N33A	Corrugated Metal-Steel	.048
7	P19	N29	N30	N35A	N34A	Corrugated Metal-Steel	.048
8	P20	N30	N31	N36A	N35A	Corrugated Metal-Steel	.048
9	P21	N32A	N33A	N38	N37	Corrugated Metal-Steel	.048
10	P22	N33A	N34A	N39	N38	Corrugated Metal-Steel	.048
11	P23	N34A	N35A	N40	N39	Corrugated Metal-Steel	.048
12	P24	N35A	N36A	N41	N40	Corrugated Metal-Steel	.048
13	P25	N37	N38	N42	N33	Corrugated Metal-Steel	.048
14	P26	N38	N39	N43A	N42	Corrugated Metal-Steel	.048
15	P27	N39	N40	N44A	N43A	Corrugated Metal-Steel	.048
16	P28	N40	N41	N23	N44A	Corrugated Metal-Steel	.048
17	P28A	N22	N45A	N48	N31	Corrugated Metal-Steel	.048
18	P29	N45A	N46	N49	N48	Corrugated Metal-Steel	.048
19	P30	N46	N47	N50	N49	Corrugated Metal-Steel	.048
20	P31	N47	N12	N51	N50	Corrugated Metal-Steel	.048
21	P32	N31	N48	N52	N36A	Corrugated Metal-Steel	.048
22	P33	N48	N49	N53	N52	Corrugated Metal-Steel	.048
23	P34	N49	N50	N54	N53	Corrugated Metal-Steel	.048
24	P35	N50	N51	N55	N54	Corrugated Metal-Steel	.048
25	P36	N36A	N52	N56	N41	Corrugated Metal-Steel	.048
26	P37	N52	N53	N57	N56	Corrugated Metal-Steel	.048
27	P38	N53	N54	N58	N57	Corrugated Metal-Steel	.048
28	P39	N54	N55	N59	N58	Corrugated Metal-Steel	.048
29	P40	N41	N56	N60	N23	Corrugated Metal-Steel	.048
30	P41	N56	N57	N61	N60	Corrugated Metal-Steel	.048
31	P42	N57	N58	N62	N61	Corrugated Metal-Steel	.048
32	P43	N58	N59	N13	N62	Corrugated Metal-Steel	.048
33	P43A	N12	N63	N66	N51	Corrugated Metal-Steel	.048
34	P44	N63	N64	N67	N66	Corrugated Metal-Steel	.048
35	P45	N64	N65	N68	N67	Corrugated Metal-Steel	.048
36	P46	N65	N2	N69	N68	Corrugated Metal-Steel	.048
37	P47	N51	N66	N70	N55	Corrugated Metal-Steel	.048
38	P48	N66	N67	N71	N70	Corrugated Metal-Steel	.048
39	P49	N67	N68	N72	N71	Corrugated Metal-Steel	.048
40	P50	N68	N69	N73	N72	Corrugated Metal-Steel	.048
41	P51	N55	N70	N74	N59	Corrugated Metal-Steel	.048
42	P52	N70	N71	N75	N74	Corrugated Metal-Steel	.048
43	P53	N71	N72	N76	N75	Corrugated Metal-Steel	.048
44	P54	N72	N73	N77	N76	Corrugated Metal-Steel	.048
45	P55	N59	N74	N78	N13	Corrugated Metal-Steel	.048
46	P56	N74	N75	N79	N78	Corrugated Metal-Steel	.048

Plate Primary Data (Continued)

	Label	A Joint	B Joint	C Joint	D Joint	Material	Thickness[in]
47	P57	N75	N76	N80	N79	Corrugated Metal-Steel	.048
48	P58	N76	N77	N3	N80	Corrugated Metal-Steel	.048
49	P58A	N23	N60	N82	N81	Corrugated Metal-Steel	.048
50	P59	N60	N61	N83	N82	Corrugated Metal-Steel	.048
51	P60	N61	N62	N84	N83	Corrugated Metal-Steel	.048
52	P61	N62	N13	N85	N84	Corrugated Metal-Steel	.048
53	P62	N81	N82	N87	N86	Corrugated Metal-Steel	.048
54	P63	N82	N83	N88	N87	Corrugated Metal-Steel	.048
55	P64	N83	N84	N89	N88	Corrugated Metal-Steel	.048
56	P65	N84	N85	N90	N89	Corrugated Metal-Steel	.048
57	P66	N86	N87	N92	N91	Corrugated Metal-Steel	.048
58	P67	N87	N88	N93	N92	Corrugated Metal-Steel	.048
59	P68	N88	N89	N94	N93	Corrugated Metal-Steel	.048
60	P69	N89	N90	N95	N94	Corrugated Metal-Steel	.048
61	P70	N91	N92	N96	N24	Corrugated Metal-Steel	.048
62	P71	N92	N93	N97	N96	Corrugated Metal-Steel	.048
63	P72	N93	N94	N98	N97	Corrugated Metal-Steel	.048
64	P73	N94	N95	N14	N98	Corrugated Metal-Steel	.048
65	P73A	N33	N42	N100	N99	Corrugated Metal-Steel	.048
66	P74	N42	N43A	N101	N100	Corrugated Metal-Steel	.048
67	P75	N43A	N44A	N102	N101	Corrugated Metal-Steel	.048
68	P76	N44A	N23	N81	N102	Corrugated Metal-Steel	.048
69	P77	N99	N100	N104	N103	Corrugated Metal-Steel	.048
70	P78	N100	N101	N105	N104	Corrugated Metal-Steel	.048
71	P79	N101	N102	N106	N105	Corrugated Metal-Steel	.048
72	P80	N102	N81	N86	N106	Corrugated Metal-Steel	.048
73	P81	N103	N104	N108	N107	Corrugated Metal-Steel	.048
74	P82	N104	N105	N109	N108	Corrugated Metal-Steel	.048
75	P83	N105	N106	N110	N109	Corrugated Metal-Steel	.048
76	P84	N106	N86	N91	N110	Corrugated Metal-Steel	.048
77	P85	N107	N108	N111	N34	Corrugated Metal-Steel	.048
78	P86	N108	N109	N112	N111	Corrugated Metal-Steel	.048
79	P87	N109	N110	N113	N112	Corrugated Metal-Steel	.048
80	P88	N110	N91	N24	N113	Corrugated Metal-Steel	.048
81	P88A	N13	N78	N114	N85	Corrugated Metal-Steel	.048
82	P89	N78	N79	N115	N114	Corrugated Metal-Steel	.048
83	P90	N79	N80	N116	N115	Corrugated Metal-Steel	.048
84	P91	N80	N3	N117	N116	Corrugated Metal-Steel	.048
85	P92	N85	N114	N118	N90	Corrugated Metal-Steel	.048
86	P93	N114	N115	N119	N118	Corrugated Metal-Steel	.048
87	P94	N115	N116	N120	N119	Corrugated Metal-Steel	.048
88	P95	N116	N117	N121	N120	Corrugated Metal-Steel	.048
89	P96	N90	N118	N122	N95	Corrugated Metal-Steel	.048
90	P97	N118	N119	N123	N122	Corrugated Metal-Steel	.048
91	P98	N119	N120	N124	N123	Corrugated Metal-Steel	.048
92	P99	N120	N121	N125	N124	Corrugated Metal-Steel	.048
93	P100	N95	N122	N126	N14	Corrugated Metal-Steel	.048
94	P101	N122	N123	N127	N126	Corrugated Metal-Steel	.048
95	P102	N123	N124	N128	N127	Corrugated Metal-Steel	.048
96	P103	N124	N125	N4	N128	Corrugated Metal-Steel	.048
97	P103A	N34	N111	N130	N129	Corrugated Metal-Steel	.048
98	P104	N111	N112	N131	N130	Corrugated Metal-Steel	.048
99	P105	N112	N113	N132	N131	Corrugated Metal-Steel	.048
100	P106	N113	N24	N133	N132	Corrugated Metal-Steel	.048
101	P107	N129	N130	N135	N134	Corrugated Metal-Steel	.048
102	P108	N130	N131	N136	N135	Corrugated Metal-Steel	.048
103	P109	N131	N132	N137	N136	Corrugated Metal-Steel	.048

Plate Primary Data (Continued)

	Label	A Joint	B Joint	C Joint	D Joint	Material	Thickness[in]
104	P110	N132	N133	N138	N137	Corrugated Metal-Steel	.048
105	P111	N134	N135	N140	N139	Corrugated Metal-Steel	.048
106	P112	N135	N136	N141	N140	Corrugated Metal-Steel	.048
107	P113	N136	N137	N142	N141	Corrugated Metal-Steel	.048
108	P114	N137	N138	N143	N142	Corrugated Metal-Steel	.048
109	P115	N139	N140	N144	N35	Corrugated Metal-Steel	.048
110	P116	N140	N141	N145	N144	Corrugated Metal-Steel	.048
111	P117	N141	N142	N146	N145	Corrugated Metal-Steel	.048
112	P118	N142	N143	N25	N146	Corrugated Metal-Steel	.048
113	P118A	N24	N96	N147	N133	Corrugated Metal-Steel	.048
114	P119	N96	N97	N148	N147	Corrugated Metal-Steel	.048
115	P120	N97	N98	N149	N148	Corrugated Metal-Steel	.048
116	P121	N98	N14	N150	N149	Corrugated Metal-Steel	.048
117	P122	N133	N147	N151	N138	Corrugated Metal-Steel	.048
118	P123	N147	N148	N152	N151	Corrugated Metal-Steel	.048
119	P124	N148	N149	N153	N152	Corrugated Metal-Steel	.048
120	P125	N149	N150	N154	N153	Corrugated Metal-Steel	.048
121	P126	N138	N151	N155	N143	Corrugated Metal-Steel	.048
122	P127	N151	N152	N156	N155	Corrugated Metal-Steel	.048
123	P128	N152	N153	N157	N156	Corrugated Metal-Steel	.048
124	P129	N153	N154	N158	N157	Corrugated Metal-Steel	.048
125	P130	N143	N155	N159	N25	Corrugated Metal-Steel	.048
126	P131	N155	N156	N160	N159	Corrugated Metal-Steel	.048
127	P132	N156	N157	N161	N160	Corrugated Metal-Steel	.048
128	P133	N157	N158	N15	N161	Corrugated Metal-Steel	.048
129	P133A	N14	N126	N162	N150	Corrugated Metal-Steel	.048
130	P134	N126	N127	N163	N162	Corrugated Metal-Steel	.048
131	P135	N127	N128	N164	N163	Corrugated Metal-Steel	.048
132	P136	N128	N4	N165	N164	Corrugated Metal-Steel	.048
133	P137	N150	N162	N166	N154	Corrugated Metal-Steel	.048
134	P138	N162	N163	N167	N166	Corrugated Metal-Steel	.048
135	P139	N163	N164	N168	N167	Corrugated Metal-Steel	.048
136	P140	N164	N165	N169	N168	Corrugated Metal-Steel	.048
137	P141	N154	N166	N170	N158	Corrugated Metal-Steel	.048
138	P142	N166	N167	N171	N170	Corrugated Metal-Steel	.048
139	P143	N167	N168	N172	N171	Corrugated Metal-Steel	.048
140	P144	N168	N169	N173	N172	Corrugated Metal-Steel	.048
141	P145	N158	N170	N174	N15	Corrugated Metal-Steel	.048
142	P146	N170	N171	N175	N174	Corrugated Metal-Steel	.048
143	P147	N171	N172	N176	N175	Corrugated Metal-Steel	.048
144	P148	N172	N173	N5	N176	Corrugated Metal-Steel	.048
145	P148A	N35	N144	N178	N177	Corrugated Metal-Steel	.048
146	P149	N144	N145	N179	N178	Corrugated Metal-Steel	.048
147	P150	N145	N146	N180	N179	Corrugated Metal-Steel	.048
148	P151	N146	N25	N181	N180	Corrugated Metal-Steel	.048
149	P152	N177	N178	N183	N182	Corrugated Metal-Steel	.048
150	P153	N178	N179	N184	N183	Corrugated Metal-Steel	.048
151	P154	N179	N180	N185	N184	Corrugated Metal-Steel	.048
152	P155	N180	N181	N186	N185	Corrugated Metal-Steel	.048
153	P156	N182	N183	N188	N187	Corrugated Metal-Steel	.048
154	P157	N183	N184	N189	N188	Corrugated Metal-Steel	.048
155	P158	N184	N185	N190	N189	Corrugated Metal-Steel	.048
156	P159	N185	N186	N191	N190	Corrugated Metal-Steel	.048
157	P160	N187	N188	N192	N36	Corrugated Metal-Steel	.048
158	P161	N188	N189	N193	N192	Corrugated Metal-Steel	.048
159	P162	N189	N190	N194	N193	Corrugated Metal-Steel	.048
160	P163	N190	N191	N26	N194	Corrugated Metal-Steel	.048

Plate Primary Data (Continued)

	Label	A Joint	B Joint	C Joint	D Joint	Material	Thickness[in]
161	P163A	N25	N159	N195	N181	Corrugated Metal-Steel	.048
162	P164	N159	N160	N196	N195	Corrugated Metal-Steel	.048
163	P165	N160	N161	N197	N196	Corrugated Metal-Steel	.048
164	P166	N161	N15	N198	N197	Corrugated Metal-Steel	.048
165	P167	N181	N195	N199	N186	Corrugated Metal-Steel	.048
166	P168	N195	N196	N200	N199	Corrugated Metal-Steel	.048
167	P169	N196	N197	N201	N200	Corrugated Metal-Steel	.048
168	P170	N197	N198	N202	N201	Corrugated Metal-Steel	.048
169	P171	N186	N199	N203	N191	Corrugated Metal-Steel	.048
170	P172	N199	N200	N204	N203	Corrugated Metal-Steel	.048
171	P173	N200	N201	N205	N204	Corrugated Metal-Steel	.048
172	P174	N201	N202	N206	N205	Corrugated Metal-Steel	.048
173	P175	N191	N203	N207	N26	Corrugated Metal-Steel	.048
174	P176	N203	N204	N208	N207	Corrugated Metal-Steel	.048
175	P177	N204	N205	N209	N208	Corrugated Metal-Steel	.048
176	P178	N205	N206	N16	N209	Corrugated Metal-Steel	.048
177	P178A	N15	N174	N210	N198	Corrugated Metal-Steel	.048
178	P179	N174	N175	N211	N210	Corrugated Metal-Steel	.048
179	P180	N175	N176	N212	N211	Corrugated Metal-Steel	.048
180	P181	N176	N5	N213	N212	Corrugated Metal-Steel	.048
181	P182	N198	N210	N214	N202	Corrugated Metal-Steel	.048
182	P183	N210	N211	N215	N214	Corrugated Metal-Steel	.048
183	P184	N211	N212	N216	N215	Corrugated Metal-Steel	.048
184	P185	N212	N213	N217	N216	Corrugated Metal-Steel	.048
185	P186	N202	N214	N218	N206	Corrugated Metal-Steel	.048
186	P187	N214	N215	N219	N218	Corrugated Metal-Steel	.048
187	P188	N215	N216	N220	N219	Corrugated Metal-Steel	.048
188	P189	N216	N217	N221	N220	Corrugated Metal-Steel	.048
189	P190	N206	N218	N222	N16	Corrugated Metal-Steel	.048
190	P191	N218	N219	N223	N222	Corrugated Metal-Steel	.048
191	P192	N219	N220	N224	N223	Corrugated Metal-Steel	.048
192	P193	N220	N221	N6	N224	Corrugated Metal-Steel	.048

✗ ALLOWABLE STRESS OF 26.7 KSI FROM CMI PDF.

Plate Principal Stresses

	LC	Plate Label	Loc	Sigma1[ksi]	Sigma2[ksi]	Tau Max[k...	Angle[rad]	Von Mises[ksi]
1	1	P13A	T	-3.043	-19.317	8.137	.633	17.99
2			B	6.146	3.752	1.197	-.361	5.365
3	1	P14	T	-.249	-21.661	10.706	.272	21.538
4			B	20.509	.41	10.049	1.721	20.307
5	1	P15	T	-.526	-20.708	10.091	-.191	20.45
6			B	21.111	.038	10.537	1.324	21.093
7	1	P16	T	-3.462	-11.704	4.121	-.681	10.414
8			B	12.49	3.04	4.725	.836	11.281
9	1	P17	T	1.604	-16.446	9.025	1.161	17.304
10			B	12.605	-7.053	9.829	-.092	17.249
11	1	P18	T	29.475	16.439	6.518	.961	25.583
12			B	-22.294	-28.833	3.269	-.371	26.183
13	1	P19	T	27.959	19.394	4.283	2.039	24.812
14			B	-19.09	-30.78	5.845	.594	26.912
15	1	P20	T	3.565	-14.296	8.93	1.798	16.372
16			B	13.732	-4.882	9.307	.277	16.717
17	1	P21	T	.244	-13.862	7.053	1.782	13.985
18			B	14.367	-8.004	11.185	.288	19.633
19	1	P22	T	26.044	19.412	3.316	2.057	23.443
20			B	-18.84	-32.436	6.798	.574	28.212
21	1	P23	T	28.941	17.165	5.888	.992	25.208

Plate Principal Stresses (Continued)

	LC	Plate Label	Loc	Sigma1[ksi]	Sigma2[ksi]	Tau Max[k...	Angle[rad]	Von Mises[ksi]
22			B	-21.561	-28.997	3.718	-.467	26.086
23	1	P24	T	3.327	-15.452	9.39	1.299	17.357
24			B	12.719	-4.383	8.551	-.217	15.386
25	1	P25	T	-5.673	-13.486	3.906	-.539	11.728
26			B	11.81	.926	5.442	.761	11.375
27	1	P26	T	-2.038	-22.905	10.433	-.15	21.957
28			B	20.065	-1.157	10.611	1.286	20.668
29	1	P27	T	-1.407	-23.354	10.974	.254	22.683
30			B	19.594	-.3	9.947	1.73	19.745
31	1	P28	T	-4.68	-14.604	4.962	.705	12.916
32			B	10.67	3.175	3.748	2.218	9.49
33	1	P28A	T	-3.191	-11.783	4.296	.686	10.555
34			B	12.12	3.362	4.379	2.313	10.838
35	1	P29	T	-.01	-20.484	10.237	.196	20.48
36			B	20.594	.219	10.188	1.812	20.486
37	1	P30	T	.338	-21.02	10.679	-.249	21.191
38			B	20.065	.537	9.764	1.386	19.802
39	1	P31	T	-2.241	-13.313	5.536	-.729	12.346
40			B	10.524	4.238	3.143	.882	9.172
41	1	P32	T	3.672	-14.363	9.017	1.328	16.508
42			B	13.586	-4.582	9.084	-.246	16.366
43	1	P33	T	28.457	19.531	4.463	1.06	25.209
44			B	-19.531	-30.181	5.325	-.551	26.512
45	1	P34	T	29.659	18.24	5.71	2.146	25.911
46			B	-20.784	-29.072	4.144	.475	25.941
47	1	P35	T	4.332	-15.225	9.778	1.881	17.79
48			B	12.807	-4.214	8.511	.171	15.355
49	1	P36	T	3.1	-15.127	9.113	1.822	16.891
50			B	13.132	-4.758	8.945	.256	16.049
51	1	P37	T	28.599	17.868	5.366	2.131	25.023
52			B	-20.6	-29.538	4.469	.529	26.237
53	1	P38	T	27.326	19.124	4.101	1.081	24.287
54			B	-19.383	-30.819	5.718	-.582	26.985
55	1	P39	T	2.364	-14.351	8.357	1.389	15.667
56			B	13.948	-5.721	9.834	-.313	17.524
57	1	P40	T	-5.259	-14.137	4.439	-.697	12.376
58			B	11.431	2.423	4.504	.912	10.432
59	1	P41	T	-1.987	-23.123	10.568	-.235	22.196
60			B	20.293	-.74	10.516	1.381	20.673
61	1	P42	T	-2.449	-22.657	10.104	.175	21.537
62			B	20.755	-1.197	10.976	1.814	21.379
63	1	P43	T	-6.401	-12.903	3.251	.63	11.174
64			B	12.584	1.287	5.648	2.275	11.992
65	1	P43A	T	-5.372	-10.205	2.417	.699	8.842
66			B	13.079	.825	6.127	2.288	12.687
67	1	P44	T	-3.668	-21.887	9.109	.168	20.303
68			B	23.753	-.938	12.346	1.899	24.236
69	1	P45	T	-10.569	-32.528	10.98	-.074	28.74
70			B	33.49	5.976	13.757	1.712	30.938
71	1	P46	T	-14.721	-41.7	13.489	-.114	36.629
72			B	33.334	7.891	12.721	1.772	30.172
73	1	P47	T	2.674	-13.379	8.026	1.437	14.897
74			B	14.091	-5.973	10.032	-.345	17.844
75	1	P48	T	26.766	16.603	5.082	1.302	23.403
76			B	-13.981	-31.994	9.007	-.556	27.781
77	1	P49	T	34.295	12.397	10.949	1.675	30.078
78			B	-14.065	-36.378	11.157	-.213	31.773

Plate Principal Stresses (Continued)

	LC	Plate Label	Loc	Sigma1[ksi]	Sigma2[ksi]	Tau Max[k...	Angle[rad]	Von Mises[ksi]
79	1	P50	T	34.589	7.484	13.552	1.612	31.521
80			B	-7.84	-37.506	14.833	-.109	34.265
81	1	P51	T	3.883	-15.56	9.722	1.917	17.822
82			B	12.125	-4.049	8.087	.125	14.578
83	1	P52	T	30.06	12.785	8.638	2.13	26.13
84			B	-17.886	-28.064	5.089	.25	24.608
85	1	P53	T	34.903	13.24	10.832	1.764	30.519
86			B	-13.343	-35.425	11.041	-.104	30.988
87	1	P54	T	37.316	7.684	14.816	1.662	34.13
88			B	-7.712	-34.665	13.476	-.044	31.524
89	1	P55	T	-3.183	-15.288	6.052	-.695	13.971
90			B	9.16	4.323	2.418	.92	7.937
91	1	P56	T	-1.208	-25.698	12.245	-.319	25.116
92			B	21.007	2.189	9.409	1.405	20.002
93	1	P57	T	-7.932	-34.379	13.224	-.125	31.179
94			B	32.006	9.041	11.483	1.629	28.579
95	1	P58	T	-9.869	-33.415	11.773	-.158	29.736
96			B	40.651	13.32	13.666	1.644	35.895
97	1	P58A	T	-5.383	-13.09	3.853	.668	11.395
98			B	10.642	1.784	4.429	2.238	9.872
99	1	P59	T	-2.692	-22.215	9.761	.194	20.999
100			B	19.651	-.751	10.201	1.792	20.037
101	1	P60	T	-2.267	-22.604	10.168	-.229	21.56
102			B	19.306	-.378	9.842	1.381	19.498
103	1	P61	T	-4.558	-13.847	4.645	-.663	12.223
104			B	10.012	2.623	3.694	.898	8.992
105	1	P62	T	2.407	-13.683	8.045	1.331	15.032
106			B	11.665	-5.552	8.609	-.264	15.221
107	1	P63	T	25.938	17.025	4.456	1.073	22.826
108			B	-18.891	-29.154	5.132	-.501	25.614
109	1	P64	T	26.427	16.587	4.92	2.11	23.134
110			B	-19.254	-28.698	4.722	.461	25.332
111	1	P65	T	2.563	-13.654	8.108	1.849	15.1
112			B	11.798	-5.328	8.563	.23	15.18
113	1	P66	T	2.815	-13.629	8.222	1.85	15.233
114			B	11.767	-5.283	8.525	.231	15.117
115	1	P67	T	26.54	16.888	4.826	2.115	23.267
116			B	-18.923	-28.657	4.867	.455	25.24
117	1	P68	T	26.204	17.286	4.459	1.037	23.076
118			B	-18.536	-28.95	5.207	-.471	25.398
119	1	P69	T	2.559	-13.137	7.848	1.303	14.586
120			B	12.292	-5.451	8.872	-.242	15.742
121	1	P70	T	-4.066	-13.044	4.489	-.623	11.561
122			B	10.747	2.947	3.9	.841	9.619
123	1	P71	T	-1.235	-22.278	10.522	-.204	21.687
124			B	19.546	.758	9.394	1.356	19.179
125	1	P72	T	-1.218	-22.224	10.503	.195	21.641
126			B	19.596	.745	9.425	1.797	19.234
127	1	P73	T	-4.082	-12.841	4.379	.6	11.363
128			B	11.001	2.905	4.048	2.323	9.874
129	1	P73A	T	-4.439	-13.83	4.695	.578	12.23
130			B	10.12	2.601	3.76	2.341	9.103
131	1	P74	T	-1.856	-23.094	10.619	.204	22.224
132			B	18.895	.227	9.334	1.779	18.782
133	1	P75	T	-2.177	-22.64	10.231	-.206	21.633
134			B	19.333	-.254	9.793	1.354	19.461
135	1	P76	T	-4.863	-13.574	4.356	-.672	11.912

Plate Principal Stresses (Continued)

	LC	Plate Label	Loc	Sigma1[ksi]	Sigma2[ksi]	Tau Max[k...	Angle[rad]	Von Mises[ksi]
136			B	10.32	2.218	4.051	.902	9.409
137	1	P77	T	1.913	-12.801	7.357	1.288	13.856
138			B	12.327	-6.182	9.254	-.23	16.321
139	1	P78	T	25.665	17.16	4.252	1.006	22.644
140			B	-18.796	-29.483	5.343	-.439	25.853
141	1	P79	T	26.23	16.531	4.85	2.124	22.972
142			B	-19.167	-29.046	4.94	.453	25.58
143	1	P80	T	2.617	-14.013	8.315	1.846	15.488
144			B	11.501	-5.383	8.442	.235	14.939
145	1	P81	T	2.222	-13.036	7.629	1.883	14.277
146			B	12.124	-6.295	9.209	.212	16.215
147	1	P82	T	26.37	16.532	4.919	2.165	23.081
148			B	-19.207	-29.228	5.01	.403	25.725
149	1	P83	T	25.717	17.311	4.203	1.049	22.713
150			B	-18.648	-29.457	5.405	-.475	25.809
151	1	P84	T	2.368	-13.417	7.893	1.326	14.745
152			B	12.025	-5.603	8.814	-.256	15.601
153	1	P85	T	-4.102	-14.469	5.183	-.615	12.916
154			B	9.011	2.389	3.311	.791	8.086
155	1	P86	T	-1.576	-22.98	10.702	-.223	22.234
156			B	18.538	.284	9.127	1.374	18.398
157	1	P87	T	-1.755	-22.281	10.263	.183	21.457
158			B	19.298	.09	9.604	1.809	19.253
159	1	P88	T	-4.62	-12.687	4.033	.611	11.122
160			B	11.026	2.431	4.298	2.308	10.034
161	1	P88A	T	-5.059	-12.396	3.669	.605	10.796
162			B	10.588	1.793	4.397	2.284	9.815
163	1	P89	T	-2.62	-23.402	10.391	.217	22.208
164			B	21.064	1.298	9.883	1.837	20.446
165	1	P90	T	-8.319	-31.806	11.743	.031	28.57
166			B	30.835	8.512	11.161	1.605	27.582
167	1	P91	T	-10.734	-34.615	11.94	.023	30.69
168			B	34.336	11.656	11.34	1.61	30.243
169	1	P92	T	2.274	-12.639	7.457	1.308	13.916
170			B	11.715	-5.317	8.516	-.249	15.093
171	1	P93	T	26.014	14.37	5.822	1.099	22.57
172			B	-15.11	-28.045	6.467	-.411	24.312
173	1	P94	T	31.477	12.241	9.618	1.529	27.484
174			B	-12.464	-32.537	10.037	-.036	28.434
175	1	P95	T	32.551	6.965	12.793	1.547	29.688
176			B	-7.161	-32.746	12.792	-.035	29.817
177	1	P96	T	2.464	-12.444	7.454	1.84	13.842
178			B	11.882	-5.161	8.521	.236	15.137
179	1	P97	T	26.029	14.637	5.696	2.033	22.6
180			B	-15.053	-28.073	6.51	.407	24.333
181	1	P98	T	31.506	12.355	9.575	1.605	27.496
182			B	-12.451	-32.777	10.163	.034	28.657
183	1	P99	T	32.779	7.072	12.853	1.598	29.878
184			B	-7.125	-32.849	12.862	.023	29.93
185	1	P100	T	-4.004	-12.129	4.062	-.594	10.704
186			B	10.63	2.683	3.974	.815	9.575
187	1	P101	T	-2.067	-22.953	10.443	-.225	21.993
188			B	20.917	1.716	9.6	1.309	20.114
189	1	P102	T	-8.317	-31.63	11.657	-.027	28.4
190			B	30.156	8.277	10.939	1.536	26.987
191	1	P103	T	-10.977	-33.919	11.471	-.033	29.977
192			B	33.897	11.135	11.381	1.544	29.926

Plate Principal Stresses (Continued)

	LC	Plate Label	Loc	Sigma1[ksi]	Sigma2[ksi]	Tau Max[k...	Angle[rad]	Von Mises[ksi]
193	1	P103A	T	-4.107	-14.462	5.177	.615	12.908
194			B	9.016	2.382	3.317	2.351	8.092
195	1	P104	T	-1.579	-22.976	10.699	.222	22.229
196			B	18.539	.281	9.129	1.768	18.4
197	1	P105	T	-1.752	-22.281	10.264	-.184	21.459
198			B	19.295	.093	9.601	1.333	19.249
199	1	P106	T	-4.616	-12.689	4.037	-.611	11.124
200			B	11.022	2.434	4.294	.834	10.029
201	1	P107	T	2.216	-13.033	7.624	1.258	14.27
202			B	12.126	-6.3	9.213	-.212	16.221
203	1	P108	T	26.363	16.539	4.912	.977	23.077
204			B	-19.202	-29.233	5.016	-.403	25.728
205	1	P109	T	25.724	17.307	4.209	2.093	22.717
206			B	-18.652	-29.45	5.399	.475	25.805
207	1	P110	T	2.373	-13.418	7.895	1.816	14.748
208			B	12.025	-5.599	8.812	.256	15.598
209	1	P111	T	1.91	-12.805	7.358	1.854	13.859
210			B	12.324	-6.184	9.254	.23	16.32
211	1	P112	T	25.672	17.153	4.259	2.136	22.648
212			B	-18.801	-29.476	5.338	.439	25.848
213	1	P113	T	26.229	16.537	4.846	1.018	22.972
214			B	-19.161	-29.046	4.942	-.454	25.579
215	1	P114	T	2.62	-14.009	8.315	1.295	15.486
216			B	11.505	-5.379	8.442	-.235	14.94
217	1	P115	T	-4.437	-13.844	4.703	-.578	12.244
218			B	10.11	2.603	3.754	.8	9.092
219	1	P116	T	-1.852	-23.095	10.621	-.204	22.227
220			B	18.896	.232	9.332	1.363	18.782
221	1	P117	T	-2.175	-22.633	10.229	.206	21.628
222			B	19.341	-.251	9.796	1.788	19.468
223	1	P118	T	-4.859	-13.567	4.354	.672	11.906
224			B	10.327	2.222	4.052	2.24	9.415
225	1	P118A	T	-4.065	-13.042	4.489	.623	11.559
226			B	10.748	2.946	3.901	2.301	9.619
227	1	P119	T	-1.233	-22.277	10.522	.204	21.687
228			B	19.546	.759	9.393	1.786	19.177
229	1	P120	T	-1.219	-22.221	10.501	-.195	21.637
230			B	19.599	.743	9.428	1.345	19.238
231	1	P121	T	-4.089	-12.833	4.372	-.6	11.355
232			B	11.008	2.898	4.055	.819	9.883
233	1	P122	T	2.818	-13.628	8.223	1.292	15.233
234			B	11.769	-5.28	8.525	-.231	15.117
235	1	P123	T	26.545	16.889	4.828	1.026	23.271
236			B	-18.923	-28.653	4.865	-.455	25.237
237	1	P124	T	26.203	17.292	4.455	2.104	23.076
238			B	-18.531	-28.951	5.21	.471	25.398
239	1	P125	T	2.558	-13.132	7.845	1.838	14.581
240			B	12.296	-5.452	8.874	.243	15.746
241	1	P126	T	2.411	-13.68	8.045	1.811	15.031
242			B	11.669	-5.548	8.608	.264	15.221
243	1	P127	T	25.941	17.031	4.455	2.068	22.829
244			B	-18.885	-29.151	5.133	.501	25.611
245	1	P128	T	26.436	16.587	4.924	1.032	23.14
246			B	-19.254	-28.69	4.718	-.461	25.327
247	1	P129	T	2.571	-13.656	8.113	1.293	15.106
248			B	11.797	-5.321	8.559	-.229	15.174
249	1	P130	T	-5.378	-13.084	3.853	-.668	11.391

Plate Principal Stresses (Continued)

	LC	Plate Label	Loc	Sigma1[ksi]	Sigma2[ksi]	Tau Max[k...	Angle[rad]	Von Mises[ksi]
250			B	10.649	1.79	4.43	.904	9.876
251	1	P131	T	-2.687	-22.209	9.761	-.194	20.994
252			B	19.658	-.746	10.202	1.349	20.041
253	1	P132	T	-2.261	-22.599	10.169	.229	21.557
254			B	19.311	-.372	9.842	1.76	19.5
255	1	P133	T	-4.548	-13.846	4.649	.664	12.224
256			B	10.012	2.632	3.69	2.243	8.989
257	1	P133A	T	-3.994	-12.138	4.072	.594	10.715
258			B	10.62	2.694	3.963	2.327	9.562
259	1	P134	T	-2.062	-22.959	10.449	.225	22.001
260			B	20.912	1.722	9.595	1.832	20.106
261	1	P135	T	-8.316	-31.635	11.66	.028	28.405
262			B	30.154	8.279	10.937	1.605	26.984
263	1	P136	T	-10.972	-33.907	11.467	.033	29.968
264			B	33.913	11.14	11.386	1.597	29.94
265	1	P137	T	2.472	-12.45	7.461	1.301	13.852
266			B	11.878	-5.154	8.516	-.236	15.128
267	1	P138	T	26.039	14.626	5.707	1.108	22.608
268			B	-15.062	-28.064	6.501	-.407	24.326
269	1	P139	T	31.506	12.356	9.575	1.536	27.495
270			B	-12.45	-32.777	10.163	-.033	28.657
271	1	P140	T	32.783	7.073	12.855	1.543	29.881
272			B	-7.124	-32.845	12.861	-.023	29.926
273	1	P141	T	2.273	-12.634	7.454	1.833	13.911
274			B	11.72	-5.318	8.519	.25	15.098
275	1	P142	T	26.006	14.38	5.813	2.042	22.564
276			B	-15.102	-28.052	6.475	.411	24.318
277	1	P143	T	31.475	12.24	9.618	1.611	27.482
278			B	-12.466	-32.541	10.038	.037	28.437
279	1	P144	T	32.545	6.966	12.79	1.594	29.682
280			B	-7.161	-32.755	12.797	.035	29.826
281	1	P145	T	-5.063	-12.384	3.66	-.605	10.784
282			B	10.599	1.789	4.405	.858	9.828
283	1	P146	T	-2.626	-23.391	10.383	-.217	22.195
284			B	21.071	1.29	9.89	1.304	20.457
285	1	P147	T	-8.326	-31.803	11.739	-.03	28.565
286			B	30.833	8.504	11.164	1.536	27.582
287	1	P148	T	-10.745	-34.629	11.942	-.022	30.701
288			B	34.316	11.643	11.336	1.531	30.225
289	1	P148A	T	-5.659	-13.45	3.896	.537	11.697
290			B	11.76	.912	5.424	-.761	11.331
291	1	P149	T	-2.065	-22.876	10.405	.149	21.916
292			B	20.041	-1.125	10.583	1.855	20.626
293	1	P150	T	-1.433	-23.32	10.944	-.254	22.638
294			B	19.575	-.267	9.921	1.412	19.71
295	1	P151	T	-4.662	-14.554	4.946	-.704	12.872
296			B	10.634	3.166	3.734	.926	9.458
297	1	P152	T	.253	-13.762	7.008	1.359	13.891
298			B	14.266	-8.022	11.144	-.288	19.553
299	1	P153	T	25.959	19.324	3.318	1.089	23.36
300			B	-18.761	-32.337	6.788	-.572	28.124
301	1	P154	T	28.849	17.089	5.88	2.147	25.126
302			B	-21.468	-28.907	3.719	.464	25.998
303	1	P155	T	3.345	-15.349	9.347	1.843	17.266
304			B	12.622	-4.393	8.508	.217	15.299
305	1	P156	T	1.62	-16.35	8.985	1.981	17.217
306			B	12.504	-7.07	9.787	.092	17.168

Plate Principal Stresses (Continued)

	LC	Plate Label	Loc	Sigma1[ksi]	Sigma2[ksi]	Tau Max[k...	Angle[rad]	Von Mises[ksi]
307	1	P157	T	29.378	16.364	6.507	2.179	25.497
308			B	-22.198	-28.75	3.276	.367	26.099
309	1	P158	T	27.878	19.304	4.287	1.106	24.732
310			B	-19.011	-30.679	5.834	-.592	26.821
311	1	P159	T	3.581	-14.196	8.889	1.343	16.285
312			B	13.633	-4.892	9.263	-.277	16.628
313	1	P160	T	-3.031	-19.27	8.119	-.632	17.947
314			B	6.1	3.741	1.18	.359	5.328
315	1	P161	T	-.282	-21.629	10.674	-.272	21.49
316			B	20.486	.437	10.024	1.421	20.271
317	1	P162	T	-.556	-20.681	10.063	.191	20.409
318			B	21.083	.068	10.508	1.817	21.05
319	1	P163	T	-3.449	-11.662	4.107	.68	10.377
320			B	12.443	3.028	4.707	2.304	11.239
321	1	P163A	T	-5.241	-14.087	4.423	.695	12.332
322			B	11.393	2.417	4.488	2.229	10.397
323	1	P164	T	-2.012	-23.09	10.539	.235	22.153
324			B	20.273	-.705	10.489	1.76	20.634
325	1	P165	T	-2.474	-22.625	10.075	-.174	21.495
326			B	20.735	-1.162	10.949	1.328	21.34
327	1	P166	T	-6.382	-12.856	3.237	-.628	11.134
328			B	12.544	1.28	5.632	.868	11.955
329	1	P167	T	3.118	-15.023	9.07	1.319	16.8
330			B	13.035	-4.767	8.901	-.257	15.961
331	1	P168	T	28.509	17.789	5.36	1.013	24.941
332			B	-20.511	-29.442	4.465	-.525	26.147
333	1	P169	T	27.242	19.038	4.102	2.057	24.206
334			B	-19.3	-30.719	5.71	.58	26.894
335	1	P170	T	2.383	-14.251	8.317	1.752	15.58
336			B	13.849	-5.729	9.789	.314	17.434
337	1	P171	T	3.688	-14.261	8.975	1.814	16.419
338			B	13.487	-4.594	9.04	.246	16.277
339	1	P172	T	28.37	19.445	4.462	2.079	25.126
340			B	-19.447	-30.085	5.319	.549	26.424
341	1	P173	T	29.564	18.161	5.702	.998	25.826
342			B	-20.693	-28.983	4.145	-.472	25.855
343	1	P174	T	4.346	-15.124	9.735	1.261	17.702
344			B	12.708	-4.226	8.467	-.171	15.267
345	1	P175	T	-3.179	-11.74	4.28	-.685	10.517
346			B	12.075	3.35	4.362	.83	10.797
347	1	P176	T	-.041	-20.458	10.209	-.195	20.438
348			B	20.568	.248	10.16	1.33	20.445
349	1	P177	T	.305	-20.992	10.648	.249	21.146
350			B	20.041	.564	9.738	1.756	19.765
351	1	P178	T	-2.233	-13.266	5.516	.728	12.302
352			B	10.484	4.222	3.131	2.258	9.137
353	1	P178A	T	-3.167	-15.23	6.032	.694	13.92
354			B	9.114	4.308	2.403	2.219	7.897
355	1	P179	T	-1.221	-25.611	12.195	.318	25.023
356			B	20.936	2.189	9.374	1.735	19.932
357	1	P180	T	-7.916	-34.239	13.161	.124	31.047
358			B	31.868	9.004	11.432	1.512	28.456
359	1	P181	T	-9.82	-33.234	11.707	.158	29.573
360			B	40.442	13.247	13.597	1.497	35.711
361	1	P182	T	3.895	-15.452	9.674	1.225	17.724
362			B	12.018	-4.057	8.037	-.125	14.479
363	1	P183	T	29.943	12.75	8.596	1.013	26.026

Plate Principal Stresses (Continued)

	LC	Plate Label	Loc	Sigma1[ksi]	Sigma2[ksi]	Tau Max[k...	Angle[rad]	Von Mises[ksi]
364			B	-17.837	-27.963	5.063	-.248	24.522
365	1	P184	T	34.734	13.155	10.79	1.378	30.374
366			B	-13.254	-35.274	11.01	.105	30.861
367	1	P185	T	37.117	7.637	14.74	1.479	33.949
368			B	-7.662	-34.479	13.409	.045	31.358
369	1	P186	T	2.688	-13.275	7.981	1.704	14.803
370			B	13.981	-5.979	9.98	.346	17.743
371	1	P187	T	26.667	16.551	5.058	1.837	23.317
372			B	-13.949	-31.875	8.963	.555	27.676
373	1	P188	T	34.142	12.304	10.919	1.465	29.95
374			B	-13.984	-36.21	11.113	.212	31.628
375	1	P189	T	34.399	7.433	13.483	1.529	31.351
376			B	-7.793	-37.309	14.758	.109	34.087
377	1	P190	T	-5.353	-10.159	2.403	-.697	8.802
378			B	13.023	.815	6.104	.854	12.635
379	1	P191	T	-3.671	-21.814	9.072	-.167	20.23
380			B	23.67	-.925	12.297	1.243	24.146
381	1	P192	T	-10.537	-32.395	10.929	.075	28.621
382			B	33.35	5.956	13.697	1.43	30.807
383	1	P193	T	-14.653	-41.497	13.422	.115	36.451
384			B	33.152	7.836	12.658	1.369	30.011

Plate Forces

	LC	Plate Label	Qx[k]	Qy[k]	Mx[k-ft]	My[k-ft]	Mxy[k-ft]	Fx[k]	Fy[k]	Fxy[k]
1	1	P13A	.131	-.11	-.003	-.003	.002	-.83	-2.745	2
2	1	P14	.118	-.022	0	-.008	.002	-.269	-.015	.739
3	1	P15	.07	-.053	0	-.008	-.002	.011	-.035	.351
4	1	P16	.06	-.019	-.003	-.003	-.002	.159	-.055	.192
5	1	P17	0	-.06	-.005	.001	.002	-.328	-2.336	1.373
6	1	P18	-.027	.006	.008	.01	.002	-.698	-.798	1.123
7	1	P19	-.022	-.026	.008	.01	-.002	-.463	-.258	.566
8	1	P20	-.051	.037	-.005	.001	-.002	-.301	-.239	.28
9	1	P21	.06	-.004	-.005	.001	-.002	-.194	-1.887	.916
10	1	P22	.011	.019	.008	.01	-.002	-.569	-1.1	.991
11	1	P23	-.002	-.013	.008	.01	.002	-.683	-.594	.689
12	1	P24	-.044	.094	-.005	.001	.002	-.622	-.465	.365
13	1	P25	-.054	.046	-.003	-.003	-.002	-.315	-1.527	.571
14	1	P26	.003	.048	0	-.008	-.002	-.57	-1.161	.758
15	1	P27	.01	.014	0	-.008	.002	-.744	-.823	.639
16	1	P28	.041	.149	-.003	-.004	.002	-.846	-.714	.371
17	1	P28A	.047	-.015	-.003	-.003	.002	.206	-.06	-.043
18	1	P29	.029	-.047	0	-.007	.002	.172	-.081	-.237
19	1	P30	-.008	-.047	0	-.007	-.002	.069	-.092	-.449
20	1	P31	-.027	-.017	-.003	-.003	-.002	-.108	-.119	-.693
21	1	P32	.024	.029	-.005	.001	.002	-.233	-.251	-.024
22	1	P33	-.004	-.017	.008	.01	.002	-.225	-.269	-.271
23	1	P34	-.002	-.019	.008	.01	-.002	-.258	-.303	-.528
24	1	P35	-.029	.034	-.005	.001	-.002	-.314	-.346	-.809
25	1	P36	.045	.097	-.005	.001	-.002	-.579	-.469	0
26	1	P37	.006	-.007	.008	.01	-.002	-.567	-.486	-.269
27	1	P38	-.005	-.006	.008	.01	.002	-.546	-.53	-.53
28	1	P39	-.046	.094	-.005	.001	.002	-.496	-.582	-.804
29	1	P40	-.018	.141	-.003	-.004	-.002	-.892	-.697	-.002
30	1	P41	0	.023	0	-.008	-.002	-.897	-.697	-.257
31	1	P42	0	.022	0	-.008	.002	-.855	-.736	-.481
32	1	P43	.025	.145	-.003	-.004	.002	-.757	-.801	-.711

Plate Forces (Continued)

	LC	Plate Label	Qx[k]	Qy[k]	Mx[k-ft]	My[k-ft]	Mxy[k-ft]	Fx[k]	Fy[k]	Fxy[k]
33	1	P43A	-.035	-.015	-.003	-.003	.002	-.359	-.121	-1.058
34	1	P44	-.061	-.044	-.001	-.008	.002	-.731	-.055	-1.299
35	1	P45	-.102	-.062	-.003	-.012	0	-1.196	.155	-1.563
36	1	P46	-.133	-.064	-.005	-.014	0	-1.767	-2.591	-2.305
37	1	P47	.044	.033	-.005	.001	.002	-.374	-.368	-1.226
38	1	P48	.018	-.02	.007	.01	.002	-.48	-.268	-1.569
39	1	P49	.024	-.018	.005	.013	0	-.696	-.38	-1.97
40	1	P50	.03	-.022	.003	.014	0	-.189	-.749	-1.234
41	1	P51	.039	.099	-.005	.001	-.002	-.416	-.616	-1.204
42	1	P52	-.004	-.014	.007	.01	-.002	-.249	-.641	-1.528
43	1	P53	-.009	.027	.005	.013	0	.131	-.31	-1.822
44	1	P54	0	.02	.003	.014	0	.048	.705	-1.113
45	1	P55	-.018	.146	-.003	-.003	-.002	-.586	-.845	-1.039
46	1	P56	.006	.01	-.001	-.008	-.002	-.261	-.803	-1.212
47	1	P57	-.005	.071	-.003	-.013	0	.222	-.585	-1.316
48	1	P58	-.044	.062	-.005	-.014	0	.865	2.2	-1.619
49	1	P58A	-.021	-.08	-.003	-.003	.002	-.909	-.825	-.16
50	1	P59	.004	-.035	0	-.008	.002	-.913	-.81	-.196
51	1	P60	-.002	-.033	0	-.008	-.002	-.857	-.847	-.242
52	1	P61	.026	-.087	-.003	-.003	-.002	-.743	-.912	-.26
53	1	P62	.04	-.038	-.004	.001	.002	-.653	-.827	-.177
54	1	P63	.002	-.005	.008	.01	.002	-.631	-.826	-.168
55	1	P64	-.003	-.005	.008	.01	-.002	-.558	-.857	-.163
56	1	P65	-.041	-.037	-.004	.001	-.002	-.437	-.888	-.138
57	1	P66	.036	.023	-.004	.001	-.002	-.433	-.808	-.157
58	1	P67	0	.007	.008	.01	-.002	-.381	-.809	-.123
59	1	P68	-.002	.01	.008	.01	.002	-.311	-.835	-.087
60	1	P69	-.038	.015	-.004	.001	.002	-.222	-.85	-.039
61	1	P70	-.009	.065	-.003	-.003	-.002	-.202	-.777	-.108
62	1	P71	.008	.037	0	-.008	-.002	-.14	-.781	-.075
63	1	P72	-.003	.037	0	-.008	.002	-.091	-.799	-.035
64	1	P73	.015	.065	-.003	-.003	.002	-.056	-.81	.012
65	1	P73A	-.053	-.123	-.003	-.003	.002	-.285	-1.307	.154
66	1	P74	.01	-.023	0	-.008	.002	-.488	-1.183	.125
67	1	P75	.01	-.036	0	-.008	-.002	-.681	-.965	.009
68	1	P76	.046	-.085	-.003	-.003	-.002	-.832	-.86	-.086
69	1	P77	.044	-.077	-.004	.001	.002	-.083	-1.277	-.047
70	1	P78	-.001	.006	.008	.01	.002	-.324	-1.24	-.076
71	1	P79	-.007	-.009	.008	.01	-.002	-.532	-1.032	-.128
72	1	P80	-.047	-.032	-.004	.001	-.002	-.63	-.884	-.152
73	1	P81	.052	-.03	-.004	.001	-.002	-.081	-1.349	-.195
74	1	P82	.009	.022	.008	.01	-.002	-.324	-1.263	-.272
75	1	P83	.004	.005	.008	.01	.002	-.433	-1.023	-.219
76	1	P84	-.034	.019	-.004	.001	.002	-.457	-.87	-.174
77	1	P85	-.075	.017	-.003	-.003	-.002	-.542	-1.514	-.452
78	1	P86	-.022	.051	0	-.008	-.002	-.469	-1.176	-.316
79	1	P87	-.025	.032	0	-.008	.002	-.367	-.966	-.208
80	1	P88	.005	.072	-.003	-.003	.002	-.277	-.828	-.14
81	1	P88A	-.022	-.084	-.002	-.003	.001	-.539	-.916	-.263
82	1	P89	.002	-.026	-.001	-.008	.002	-.264	-.786	-.185
83	1	P90	.002	-.065	-.003	-.012	0	.056	-.28	-.009
84	1	P91	-.054	-.06	-.004	-.013	0	.271	-.086	-.098
85	1	P92	.041	-.042	-.004	.001	.001	-.275	-.864	-.096
86	1	P93	.001	0	.006	.009	.002	-.114	-.681	-.006
87	1	P94	-.003	-.023	.005	.012	0	-.062	-.306	.021
88	1	P95	.011	-.02	.003	.012	0	-.061	-.051	-.083
89	1	P96	.028	.02	-.004	.001	-.001	-.126	-.809	.015

Plate Forces (Continued)

	LC	Plate Label	Qx[k]	Qy[k]	Mx[k-ft]	My[k-ft]	Mxy[k-ft]	Fx[k]	Fy[k]	Fxy[k]
90	1	P97	-.006	.007	.006	.009	-.002	-.054	-.651	.053
91	1	P98	-.004	.021	.005	.012	0	-.028	-.364	.011
92	1	P99	0	.02	.003	.012	0	-.013	-.022	-.033
93	1	P100	.015	.062	-.002	-.003	-.001	-.035	-.773	.057
94	1	P101	.023	.032	-.001	-.008	-.002	-.028	-.657	.077
95	1	P102	.005	.063	-.003	-.012	0	-.009	-.425	.034
96	1	P103	-.023	.06	-.004	-.013	0	.043	-.004	-.041
97	1	P103A	-.075	-.017	-.003	-.003	.002	-.542	-1.514	.448
98	1	P104	-.022	-.051	0	-.008	.002	-.469	-1.176	.312
99	1	P105	-.025	-.032	0	-.008	-.002	-.367	-.966	.204
100	1	P106	.005	-.072	-.003	-.003	-.002	-.276	-.827	.137
101	1	P107	.051	.031	-.004	.001	.002	-.081	-1.35	.192
102	1	P108	.009	-.022	.008	.01	.002	-.324	-1.262	.268
103	1	P109	.004	-.005	.008	.01	-.002	-.433	-1.021	.216
104	1	P110	-.034	-.019	-.004	.001	-.002	-.457	-.868	.172
105	1	P111	.044	.078	-.004	.001	-.002	-.083	-1.281	.043
106	1	P112	-.001	-.006	.008	.01	-.002	-.324	-1.24	.072
107	1	P113	-.007	.009	.008	.01	.002	-.531	-1.03	.125
108	1	P114	-.047	.032	-.004	.001	.002	-.629	-.881	.15
109	1	P115	-.054	.123	-.003	-.003	-.002	-.285	-1.312	-.158
110	1	P116	.01	.023	0	-.008	-.002	-.487	-1.182	-.128
111	1	P117	.01	.036	0	-.008	.002	-.679	-.961	-.011
112	1	P118	.046	.085	-.003	-.003	.002	-.829	-.856	.086
113	1	P118A	-.009	-.065	-.003	-.003	.002	-.202	-.777	.108
114	1	P119	.008	-.037	0	-.008	.002	-.139	-.78	.076
115	1	P120	-.003	-.037	0	-.008	-.002	-.09	-.798	.038
116	1	P121	.016	-.065	-.003	-.003	-.002	-.056	-.809	-.008
117	1	P122	.036	-.023	-.004	.001	.002	-.433	-.807	.157
118	1	P123	0	-.007	.008	.01	.002	-.38	-.808	.125
119	1	P124	-.002	-.01	.008	.01	-.002	-.31	-.833	.09
120	1	P125	-.038	-.015	-.004	.001	-.002	-.221	-.849	.043
121	1	P126	.04	.038	-.004	.001	-.002	-.651	-.825	.177
122	1	P127	.002	.005	.008	.01	-.002	-.629	-.824	.169
123	1	P128	-.003	.005	.008	.01	.002	-.557	-.855	.166
124	1	P129	-.041	.037	-.004	.001	.002	-.436	-.886	.142
125	1	P130	-.021	.08	-.003	-.003	-.002	-.906	-.822	.16
126	1	P131	.004	.035	0	-.008	-.002	-.91	-.807	.197
127	1	P132	-.002	.033	0	-.008	.002	-.855	-.843	.244
128	1	P133	.026	.087	-.003	-.003	.002	-.741	-.908	.263
129	1	P133A	.015	-.062	-.002	-.003	.001	-.035	-.773	-.051
130	1	P134	.023	-.032	-.001	-.008	.002	-.028	-.657	-.071
131	1	P135	.005	-.063	-.003	-.012	0	-.008	-.427	-.028
132	1	P136	-.023	-.06	-.004	-.013	0	.045	.004	.048
133	1	P137	.028	-.02	-.004	.001	.001	-.126	-.808	-.009
134	1	P138	-.006	-.007	.006	.009	.002	-.054	-.651	-.046
135	1	P139	-.004	-.021	.005	.012	0	-.027	-.365	-.004
136	1	P140	0	-.02	.003	.012	0	-.013	-.02	.038
137	1	P141	.041	.042	-.004	.001	-.001	-.274	-.861	.101
138	1	P142	.001	0	.006	.009	-.002	-.115	-.679	.013
139	1	P143	-.003	.023	.005	.012	0	-.063	-.307	-.013
140	1	P144	.011	.02	.003	.012	0	-.061	-.055	.087
141	1	P145	-.022	.084	-.002	-.003	-.001	-.538	-.913	.268
142	1	P146	.002	.026	-.001	-.008	-.002	-.265	-.784	.191
143	1	P147	.002	.065	-.003	-.012	0	.053	-.28	.016
144	1	P148	-.054	.06	-.004	-.013	0	.265	-.097	.106
145	1	P148A	-.054	-.046	-.003	-.003	.002	-.315	-1.531	-.572
146	1	P149	.003	-.048	0	-.008	.002	-.569	-1.159	-.758

Plate Forces (Continued)

	LC	Plate Label	Qx[k]	Qy[k]	Mx[k-ft]	My[k-ft]	Mxy[k-ft]	Fx[k]	Fy[k]	Fxy[k]
147	1	P150	.01	-.014	0	-.008	-.002	-.742	-.819	-.639
148	1	P151	.041	-.149	-.003	-.003	-.002	-.843	-.71	-.371
149	1	P152	.06	.004	-.005	.001	.002	-.194	-1.89	-.916
150	1	P153	.011	-.019	.008	.01	.002	-.57	-1.098	-.99
151	1	P154	-.002	.013	.008	.01	-.002	-.682	-.591	-.688
152	1	P155	-.044	-.094	-.005	.001	-.002	-.62	-.463	-.364
153	1	P156	0	.06	-.005	.001	-.002	-.329	-2.337	-1.373
154	1	P157	-.027	-.006	.008	.01	-.002	-.698	-.795	-1.12
155	1	P158	-.022	.026	.008	.01	.002	-.463	-.256	-.564
156	1	P159	-.051	-.037	-.005	.001	.002	-.3	-.237	-.279
157	1	P160	.131	.11	-.003	-.003	-.002	-.83	-2.743	-1.998
158	1	P161	.118	.022	0	-.008	-.002	-.27	-.014	-.737
159	1	P162	.069	.053	0	-.008	.002	.01	-.035	-.35
160	1	P163	.06	.018	-.003	-.003	.002	.158	-.054	-.191
161	1	P163A	-.018	-.141	-.003	-.004	.002	-.889	-.694	.003
162	1	P164	0	-.023	0	-.008	.002	-.894	-.693	.257
163	1	P165	0	-.022	0	-.008	-.002	-.853	-.732	.481
164	1	P166	.025	-.145	-.003	-.004	-.002	-.755	-.798	.71
165	1	P167	.045	-.097	-.005	.001	.002	-.577	-.466	0
166	1	P168	.006	.007	.008	.01	.002	-.565	-.483	.269
167	1	P169	-.005	.006	.008	.01	-.002	-.545	-.528	.529
168	1	P170	-.046	-.094	-.005	.001	-.002	-.496	-.579	.803
169	1	P171	.024	-.03	-.005	.001	-.002	-.232	-.249	.024
170	1	P172	-.004	.017	.008	.01	-.002	-.225	-.267	.27
171	1	P173	-.002	.019	.008	.01	.002	-.258	-.302	.527
172	1	P174	-.029	-.035	-.005	.001	.002	-.314	-.344	.807
173	1	P175	.047	.015	-.003	-.003	-.002	.205	-.06	.043
174	1	P176	.029	.047	0	-.007	-.002	.171	-.08	.236
175	1	P177	-.008	.047	0	-.007	.002	.068	-.092	.448
176	1	P178	-.027	.016	-.003	-.003	.002	-.108	-.119	.691
177	1	P178A	-.018	-.146	-.003	-.003	.002	-.586	-.841	1.038
178	1	P179	.006	-.01	-.001	-.008	.002	-.263	-.8	1.211
179	1	P180	-.004	-.071	-.003	-.012	0	.218	-.586	1.314
180	1	P181	-.044	-.062	-.005	-.014	0	.86	2.191	1.615
181	1	P182	.038	-.099	-.005	.001	.002	-.417	-.614	1.201
182	1	P183	-.004	.014	.007	.01	.002	-.251	-.64	1.524
183	1	P184	-.009	-.027	.005	.013	0	.128	-.312	1.819
184	1	P185	0	-.02	.003	.014	0	.048	.701	1.113
185	1	P186	.044	-.033	-.005	.001	-.002	-.374	-.367	1.223
186	1	P187	.018	.021	.007	.01	-.002	-.48	-.267	1.565
187	1	P188	.024	.018	.005	.013	0	-.695	-.38	1.967
188	1	P189	.03	.022	.003	.014	0	-.19	-.748	1.235
189	1	P190	-.034	.014	-.003	-.003	-.002	-.359	-.121	1.056
190	1	P191	-.06	.045	-.001	-.008	-.002	-.731	-.055	1.297
191	1	P192	-.101	.062	-.003	-.012	0	-1.195	.155	1.561
192	1	P193	-.133	.064	-.005	-.014	0	-1.765	-2.583	2.302

Interior Column

Bamboo Bending Design

Member: **Interior Column**

Culm Outside Diameter:	d_o=	**10**	cm
Modulus of Elasticity:	E=	**14617**	MPa
Moment of Inertia:	I=	**486.90**	cm^4
Area:	A=	**71.47**	cm^2
Radius of Gyration:	r=	**2.61**	cm
Section Modulus:	S=	**97.38**	cm^3
Effective Length Factor:	K=	**1.00**	

Member-

Length:	ℓ=	**2.85**	m
Axial Load:	P_u=	**92.8**	kN

Shear

Shear Force: V_u= **21.5** kN

Shear Stress: v_u= $3V_u/(2*2A)$= 3* 21.50 /(2*2* 71.47)*[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2]= **2.26** MPa

v_u= **2.26** MPa ≤ v_n= **3.70** MPa ***Using two 10 cm Ø culms** ***OK***

Compression

Compression Stress: c_u= $P_u/(2*A)$= 92.8 / (2* 71.47)*[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2] = **6.49** MPa

c_u= **6.49** MPa ≤ c_n= **13.00** MPa ***Using two 10 cm Ø culms** ***OK***

Slenderness: λ= KL/r= $\frac{1.00 * 2.85}{2.61}$ *[100 cm/m] = **109.2** ≤ 50 **CHECK BUCKLING**

Buckling: P_{e1}= $2*\pi^2EI/(KL)^2$= $\frac{2*\pi^2 * 14617 * 486.90}{(1.00 * 2.85)^2}$ *[10^6 N/m^2/MPa]*[m/100 cm]^4*[kN/1000 N]= **172.96** kN

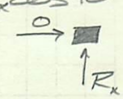
P_{e1}= **172.96** kN ≥ P_u= **92.8** kN ***Using two 10 cm Ø culms** ***OK***

Combination Loading
(Eqn. from AISC 360-10)

USE c_u/c_n≥0.2= $c_u/c_n+8b_u/(9b_n)$= 6.49 / 13.00 + 8 0.00 / (9* 27.00) = **0.50** ≤1.0 **OK**

Master's	ARE 898	Evan Myers

- Typical clms

Step Description	Computation	Reference
Center Clm	$l = 2.85\,m$	
	∴ Loads from wind. Assumed wind loads picked up by five trusses	
Loads	$R_x = 5.05\ kN$ $R_y = 6.47\ kN\ (C)$  $\theta = 22.5°$	Roof & Truss Design
	$R_{x_T} = R_x + 2R_x\cos 22.5° + 2R_x\cos 45°$ 	
	$R_{x_T} = 21.5\ kN$	
Reaction for y Dead + L_r	$\frac{(2260+1000)\,Pa}{3825\,Pa} = 0.85$	
	$R_{y_T} = 5R_y + 11(0.85R_y) = 92.8\ kN$	
	∴ Min. bending	
Shear	$V_u = R_{x_T} = 21.5\ kN$	
10 cm ϕ (2) Stress	$v_u = \frac{3V_u}{2A} = \frac{3(21.5\,kN)}{2(71.5\,cm^2)\cdot 2} \left\lvert \frac{MPa}{10^6\,N/m^2} \right\rvert \left\lvert \frac{100\,cm}{m} \right\rvert^2 \left\lvert \frac{1000\,N}{kN} \right\rvert$ (2 → 2 10 cm ϕ clms)	
	$v_u = 2.26\ MPa > v_n = 3.7\ MPa$ ∴ OK	
	∴ Assume all 4 culms are engaged	
10 cm ϕ (4)	$v_u = 1.13\ MPa \le v_n = 3.7\ MPa$ ∴ OK	
Compression	$C_u = R_{y_T} = 92.8\ kN$	
10 cm ϕ (2)	$c_u = \frac{C_u}{2A} = 6.49\ MPa \le c_n = 13\ MPa$ ∴ OK, one is adeq.	
Slenderness	$\frac{Kl}{r} = 109.2 > 50$ ∴ √ Buckling	
Buckling 10 cm ϕ (2)	$P_{el} = \frac{\pi^2 EI}{(Kl)^2} = 173\ kN > C_u = 92.8\ kN$ ∴ OK	
	∴ Use (4) 10 cm ϕ for int. clm. Two columns adequate but want symm. look	

Irregular Members

Bamboo Bending Design

Member:		**Wall Member**	
Culm Outside Diameter:	d_o=	6	cm
Modulus of Elasticity:	E=	14617	MPa
Moment of Inertia:	I=	59.64	cm^4
Area:	A=	21.21	cm^2
Radius of Gyration:	r=	1.68	cm
Section Modulus:	S=	19.88	cm^3
Effective Length Factor:	K=	1.00	
Member-			
Length:	ℓ=	0.78	m
Distributed Load:	ω_u=	2.82	kN/m
Point Load:	F_u=	0	kN

Bending

Moment (Distributed Load): M_u= $\omega_u \ell^2/8$= 2.82 * 0.78 ^{2}/8= **0.21** kN*m

Bending Stress: b_u= M_u/S= 0.21 / 19.88 *[100 cm/m]^3*[1000 N/kN]*[MPa/10^6 N/m^2] = **10.79** MPa

b_u= **10.79** MPa ≤ b_a= **27.00** MPa **OK**

Shear

Shear Force: V_u= $\omega_u \ell/2-\omega_u d$= 2.82 * 0.78 /2- 2.82 * 6 *[m/100 cm]= **0.93** kN

Shear Stress: v_u= $3V_u/(2A)$= 3* 0.93 /(2* 21.21)*[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2]= **0.66** MPa

v_u= **0.66** MPa ≤ v_a= **3.70** MPa **OK**

Deflection

Max Allowable Deflection: δ_{max}= ℓ/300= 0.78 *[100 cm/m]/300= **0.26** cm

Calculated Deflection (Distributed Load): δ_{calc}= $5\omega_u \ell^4/(384EI)$= (5* 2.82 * 0.78 ^{4}) / (384* 14617 * 59.64) *[100 cm/m]^3*[1000 N/kN]*[MPa/10^6 N/m^2]= **0.16** cm

δ_{calc}= **0.16** cm ≤ δ_{max}= **0.26** cm **OK**

Buckling

Slenderness: λ= KL/r= (1.00 * 0.78 *[100 cm/m]) / 1.68 = **46.5** ≤ 50 **OK**

Bamboo Bending Design

Member:		Intermediate Column Member	Above Door Frame
Culm Outside Diameter:	d_o=	6	cm
Modulus of Elasticity:	E=	14617	MPa
Moment of Inertia:	I=	59.64	cm^4
Area:	A=	21.21	cm^2
Radius of Gyration:	r=	1.68	cm
Section Modulus:	S=	19.88	cm^3
Effective Length Factor:	K=	1.00	
Member-			
Length:	ℓ=	0.41	m
Distributed Load:	ω_u=	1.57	kN/m
Point Load:	F_u=	0	kN
Axial Load:	P_u=	7.03	kN

Bending

Moment (Distributed Load): M_u= $\omega_u \ell^2/8$= 1.57 * 0.41 ^{2}/8= 0.03 kN*m

Bending Stress: b_u= M_u/S= 0.03 / 19.88 *[100 cm/m]^3*[1000 N/kN]*[MPa/10^6 N/m^2] = 1.66 MPa

b_u= 1.66 MPa ≤ b_a= 27.00 MPa OK

Shear

Shear Force: V_u= 4.08 kN

Shear Stress: v_u= $3V_u/(2A)$= 3* 4.08 /(2* 21.21)*[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2]= 2.89 MPa

v_u= 2.89 MPa ≤ v_a= 3.70 MPa OK

Deflection

Max Allowable Deflection: δ_{max}= ℓ/300= 0.41 *[100 cm/m]/300= 0.14 cm

Calculated Deflection (Point Load): δ_{calc}= $5\omega_u \ell^4/(384EI)$= (5* 1.57 * 0.41) / (384* 14617 * 59.64) ^{4})*[100 cm/m]^3*[1000 N/kN]*[MPa/10^6 N/m^2]= 0.01 cm

δ_{calc}= 0.01 cm ≤ δ_{max}= 0.14 cm OK

Compression

Compression Stress: c_u= P_u/A= 7.03 / 21.21 *[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2] = 3.32 MPa

c_u= 3.32 MPa ≤ c_a= 13.00 MPa OK

Slenderness: λ= KL/r= (1.00 * 0.41 *[100 cm/m]) / 1.68 = 24.4 ≤ 50 OK

Combination Loading
(Eqn. from AISC 360-10)

USE $c_u/c_a \geq 0.2$= $c_u/c_a+8b_u/(9b_a)$= 3.32 / 13.00 + 8 1.66 / (9* 27.00) = 0.31 ≤1.0 OK

Bamboo Bending Design

Member:		Door Frame Beams	
Culm Outside Diameter:	d_o=	10	cm
Modulus of Elasticity:	E=	14617	MPa
Moment of Inertia:	I=	486.90	cm^4
Area:	A=	71.47	cm^2
Radius of Gyration:	r=	2.61	cm
Section Modulus:	S=	97.38	cm^3
Effective Length Factor:	K=	1.00	
Member-Length:	ℓ=	1.06	m
Distributed Load:	ω_u=	0	kN/m
Point Load:	F_{ux}=	4.08	kN
Point Load:	F_{uy}=	7.03	kN
Axial Load:	P_u=	0	kN

Bending (x-axis)

Moment (Point Load):	M_u=	$F_x\ell/4$=	4.08	*	1.06 /4	=	1.08	kN*m			
Bending Stress:	b_u=	M_u/S=	1.08	/	97.38 *[100 cm/m]³*[1000 N/kN]*[MPa/10⁶ N/m²]	=	11.10	MPa			
	b_u=	11.10	MPa ≤ b_n=	27.00	MPa						OK

Bending (y-axis)

Moment (Point Load):	M_u=	$F_y\ell/4$=	7.03	*	1.06 /4	=	1.86	kN*m			
Bending Stress:	b_u=	M_u/S=	1.86	/	97.38 *[100 cm/m]³*[1000 N/kN]*[MPa/10⁶ N/m²]	=	19.13	MPa			
	b_u=	19.13	MPa ≤ b_n=	27.00	MPa						OK

Shear (x-axis)

Shear Force:	V_u=	4.08	kN							
Shear Stress:	v_u=	$3V_u/(2A)$=	3*	4.08	/(2*	71.47	)*[100 cm/m]²*[1000 N/kN]*[MPa/10⁶ N/m²]=	0.86	MPa	
	v_u=	0.86	MPa ≤ v_n=	3.70	MPa					OK

Shear (y-axis)

Shear Force:	V_u=	7.03	kN							
Shear Stress:	v_u=	$3V_u/(2A)$=	3*	7.03	/(2*	71.47	)*[100 cm/m]²*[1000 N/kN]*[MPa/10⁶ N/m²]=	1.48	MPa	
	v_u=	1.48	MPa ≤ v_n=	3.70	MPa					OK
	$v_{u,total}$=	2.33	MPa ≤ v_n=	3.70	MPa					OK

Deflection

Max Allowable Deflection:	δ_{max}=	$\ell/300$=	1.06	*[100 cm/m]/300=	0.35	cm					
Calculated Deflection (Point Load):	δ_{calc}=	$P_u\ell^3/(48EI)$=		7.03	*	1.06	³)*[100 cm/m]³*[1000 N/kN]*[MPa/10⁶ N/m²] =	0.25	cm		
			48*	14617	*	486.90					
	δ_{calc}=	0.25	cm ≤ δ_{max}=	0.35	cm						OK

Buckling

Slenderness:	λ=	KL/r=	1.00	*	1.06	*[100 cm/m]	=	40.6	≤ 50		OK
				2.61							

Combination Loading
(Eqn. from AISC 360-10)

USE	c_u/c_n<0.2=	$c_u/(2c_n)+b_u/b_n$=	0.00	/(2*	13.00	)	+	30.23	/	27.00	=	1.12	≤1.0	NG

*OK, because the forces presented will be distributed among three beams.

Bamboo Bending Design

Member:		Door Frame Column	
Culm Outside Diameter:	d_o=	10	cm
Modulus of Elasticity:	E=	14617	MPa
Moment of Inertia:	I=	486.90	cm^4
Area:	A=	71.47	cm^2
Radius of Gyration:	r=	2.61	cm
Section Modulus:	S=	97.38	cm^3
Effective Length Factor:	K=	1.00	
Member-Length:	ℓ=	2.85	m
Distributed Load:	ω_u=	1.8	kN/m
Point Load:	F_u=	0	kN
Axial Load:	P_u=	4.38	kN

Bending

Moment (Distributed Load):	M_u=	$\omega_u\ell^2/8$=	1.8	*	2.85	²/8=		1.83	kN*m		
Bending Stress:	b_u=	M_u/S=	1.83		97.38	*[100 cm/m]³*[1000 N/kN]*[MPa/10⁶ N/m²]	=	18.77	MPa		
	b_u=	18.77	MPa ≤ b_n=	27.00	MPa						OK

Shear

Shear Force:	V_u=	4.43	kN							
Shear Stress:	v_u=	$3V_u/(2A)$=	3*	4.43	/(2*	71.47	)*[100 cm/m]²*[1000 N/kN]*[MPa/10⁶ N/m²]=	0.93	MPa	
	v_u=	0.93	MPa ≤ v_n=	3.70	MPa					OK

Deflection

Max Allowable Deflection:	δ_{max}=	$\ell/300$=	2.85	*[100 cm/m]/300=	0.95	cm					
Calculated Deflection (Point Load):	δ_{calc}=	$5\omega_u\ell^4/(384EI)$=	5*	1.80	*	2.85	⁴)*[100 cm/m]³*[1000 N/kN]*[MPa/10⁶ N/m²]=	2.17	cm		
			384*	14617	*	486.90					
	δ_{calc}=	2.17	cm ≤ δ_{max}=	0.95	cm			*OK, door frame, corrugated metal, and additional column connection will provide adequate stiffness.			NG

Compression

Compression Stress:	c_u=	P_u/A=	4.38	/	71.47	*[100 cm/m]²*[1000 N/kN]*[MPa/10⁶ N/m²]	=	0.61	MPa		
	c_u=	0.61	MPa ≤ c_n=	13.00	MPa						OK
Slenderness:	λ=	KL/r=	1.00	*	2.85	*[100 cm/m]	=	109.2	≤ 50		CHECK BUCKLING
				2.61							
Buckling:	P_{el}=	$\pi^2EI/(KL)^2$=	π^2 *	14617	*	486.90	*[10⁶ N/m²/MPa]*[m/100 cm]⁴*[kN/1000 N]=	86.48	kN		
			(	1.00	*	2.85	)²				
	P_{el}=	86.48	kN ≥ P_u=	4.38	kN						OK

Combination Loading
(Eqn. from AISC 360-10)

USE	c_u/c_n<0.2=	$c_u/(2c_n)+b_u/b_n$=	0.61	/(2*	13.00	)	+	18.77	/	27.00	=	0.72	≤1.0	OK

Bamboo Bending Design

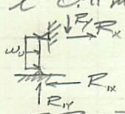
Member:		Window Frame Columns										
Culm Outside Diameter:	d_o=	10	cm									
Modulus of Elasticity:	E=	14617	MPa									
Moment of Inertia:	I=	486.90	cm^4									
Area:	A=	71.47	cm^2									
Radius of Gyration:	r=	2.61	cm									
Section Modulus:	S=	97.38	cm^3									
Effective Length Factor:	K=	1.00										
Member-Length:	ℓ=	2.85	m									
Distributed Load:	ω_u=	1.39	kN/m									
Point Load:	F_u=	0	kN									
Axial Load:	P_u=	0.67	kN									
Bending												
Moment (Distributed Load):	M_u=	$\omega_u\ell^2/8$=	1.39	*	2.85	$^2/8$=	1.41	kN*m				
Bending Stress:	b_u=	M_u/S=	1.41		97.38	*[100 cm/m]^3*[1000 N/kN]*[MPa/10^6 N/m^2]	=	14.49	MPa			
	b_u=	14.49	MPa ≤ b_n=	27.00	MPa							OK
Shear												
Shear Force:	V_u=	1.84	kN									
Shear Stress:	v_u=	$3V_u/(2A)$=	3*	1.84	/(2*	71.47	)*[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2]=	0.39	MPa			
	v_u=	0.39	MPa ≤ v_n=	3.70	MPa							OK
Deflection												
Max Allowable Deflection:	δ_{max}=	$\ell/300$=	2.85	*[100 cm/m]/300=	0.95	cm						
Calculated Deflection (Point Load):	δ_{calc}=	$5\omega_u\ell^4/(384EI)$=	5* / 384*	1.39 / 14617	* / *	2.85 / 48690	^{4})*[100 cm/m]^3*[1000 N/kN]*[MPa/10^6 N/m^2]=	1.68	cm			
	δ_{calc}=	1.68	cm ≤ δ_{max}=	0.95	cm		*OK, door frame, corrugated metal, and additional column connection will provide adequate stiffness.					NG
Compression												
Compression Stress:	c_u=	P_u/A=	0.67	/	71.47	*[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2]	=	0.09	MPa			
	c_u=	0.09	MPa ≤ c_n=	13.00	MPa							OK
Slenderness:	λ=	KL/r=	1.00 / 2.61	*	2.85	*[100 cm/m]	=	109.2	≤ 50			CHECK BUCKLING
Buckling:	P_{al}=	$\pi^2EI/(KL)^2$=	π^2 * / (	14617 / 1.00	* / *	48690 / 2.85	*[10^6 N/m^2/MPa]*[m/100 cm]^4*[kN/1000 N]= /)^2	86.48	kN			
	P_{al}=	86.48	kN ≥ P_u=	0.67	kN							OK
Combination Loading (Eqn. from AISC 360-10)												
USE	c_u/c_n<0.2=	$c_u/(2c_n)+b_u/b_n$=	0.09	/(2*	13.00)	+	14.49	/	27.00	=	0.54 ≤1.0	OK

Bamboo Bending Design

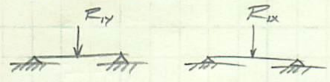
Member:		Window Frame Beams										
Culm Outside Diameter:	d_o=	6	cm									
Modulus of Elasticity:	E=	14617	MPa									
Moment of Inertia:	I=	59.64	cm^4									
Area:	A=	21.21	cm^2									
Radius of Gyration:	r=	1.68	cm									
Section Modulus:	S=	19.88	cm^3									
Effective Length Factor:	K=	1.00										
Member-Length:	ℓ=	0.94	m									
Distributed Load:	ω_u=	0.7	kN/m									
Bending												
Moment (Distributed Load):	M_u=	$\omega_u\ell^2/8$=	0.7	*	0.94	$^2/8$=	0.08	kN*m				
Bending Stress:	b_u=	M_u/S=	0.08	/	19.88	*[100 cm/m]^3*[1000 N/kN]*[MPa/10^6 N/m^2]	=	3.89	MPa			
	b_u=	3.89	MPa ≤ b_n=	27.00	MPa							OK
Shear												
Shear Force:	V_u=	0.29	kN									
Shear Stress:	v_u=	$3V_u/(2A)$=	3*	0.29	/(2*	21.21	)*[100 cm/m]^2*[1000 N/kN]*[MPa/10^6 N/m^2]=	0.21	MPa			
	v_u=	0.21	MPa ≤ v_n=	3.70	MPa							OK
Deflection												
Max Allowable Deflection:	δ_{max}=	$\ell/300$=	0.94	*[100 cm/m]/300=	0.31	cm						
Calculated Deflection (Point Load):	δ_{calc}=	$5\omega_u\ell^4/(384EI)$=	5* / 384*	0.70 / 14617	* / *	0.94 / 59.64	^{4})*[100 cm/m]^3*[1000 N/kN]*[MPa/10^6 N/m^2]=	0.09	cm			
	δ_{calc}=	0.09	cm ≤ δ_{max}=	0.31	cm							OK
Buckling												
Slenderness:	λ=	KL/r=	1.00 / 1.68	*	0.94	*[100 cm/m]	=	56.1	≤ 50			CHECK BUCKLING
Buckling:	P_{al}=	$\pi^2EI/(KL)^2$=	π^2 * / (	14617 / 1.00	* / *	59.64 / 0.94	*[10^6 N/m^2/MPa]*[m/100 cm]^4*[kN/1000 N]= /)^2	97.38	kN			
	P_{al}=	97.38	kN ≥ P_i	0.58	kN							OK
Combination Loading (Eqn. from AISC 360-10)												
USE	c_u/c_n<0.2=	$c_u/(2c_n)+b_u/b_n$=	0.00	/(2*	13.00)	+	3.89	/	27.00	=	0.14 ≤1.0	OK

Master's	ARE 878	Evan Myers

-IRREGULAR MEMBERS

Step Description	Computation	Reference
Intermediate Column Member	$\ell = 0.41\ m$  $R_x = 3.43\ kN$, $R_y = 7.03\ kN$	Roof & Truss Design
Distributed Load	62 PSF => 2970 Pa	
	$w_u = (2970\ Pa)\left(2 \cdot \frac{0.053\ m}{2}\right)\left\lvert\frac{N/m^2}{Pa}\right\rvert\left\lvert\frac{kN}{1000\ N}\right\rvert = 157\ kN/m$	
Bending (6 cm ϕ)	$M_u = \frac{w_u \ell^2}{8} = 0.03\ kN \cdot m$	
Stress	$f_u = \frac{M_u}{S} = 1.66\ MPa \le F_n = 27\ MPa$ ∴ OK	
Shear Reactions	$\rightarrow \Sigma F_x = 0$	
	$R_x + w_u \ell - R_{1x} = 0$	
	$R_{1x} = 4.08\ kN$	
	$V_u = R_{1x} = 4.08\ kN$	
Stress	$v_u = \frac{3V_u}{2A} = 2.88\ MPa \le v_n = 3.7\ MPa$ ∴ OK	
Compression	$c_u = \frac{R_y}{A} = 3.32\ MPa \le c_n = 13\ MPa$ ∴ OK	
Combo.	$\frac{c_u}{c_n} = 0.26$	AISC 360-10 p.16.1-73
	$\frac{c_u}{c_n} + \frac{8 f_u}{9 F_n} = 0.31 < 1.0$ ∴ OK	
Deflection	$\delta_{max} = \ell/300 = 0.14\ cm$	
	$\delta_{calc} = \frac{5 w_u \ell^4}{384EI} = 0.006\ cm \le \delta_{max} = 0.14\ cm$ ∴ OK	
Buckling	$\frac{KL}{r} = 21.4 \le 50$ ∴ OK	

-IRREGULAR MEMBERS

STEP DESCRIPTION	COMPUTATION		REFERENCE
DOOR FRAME BMS	$\ell = 1.06\ m$	$R_{1x} = 4.08\ kN$ $R_{1y} = 7.03\ kN$	
			
BENDING Y-AXIS	$M_u = \frac{P\ell}{4} = 1.86\ kN{\cdot}m$		
STRESS	$b_u = \frac{M_u}{S} = 73.6\ MPa$		∴ NG, TRY 10 cm ϕ
	$b_u = 19.1\ MPa \le b_n = 27\ MPa$		∴ OK
X-AXIS	$M_u = \frac{P\ell}{4} = 1.08\ kN{\cdot}m$		
STRESS	$b_u = 11.1\ MPa \le b_n = 27\ MPa$		∴ OK
SHEAR Y-AXIS	$V_u = 7.03\ kN$		
STRESS	$v_u = \frac{3V_u}{2A} = 1.47\ MPa \le v_n = 3.7\ MPa$		∴ OK
X-AXIS	$V_u = 4.08\ kN$		
	$v_u = 0.86\ MPa \le v_n = 3.7\ MPa$		∴ OK
	$V_{u\,tot} = 2.33\ MPa \le v_n = 3.7\ MPa$		∴ OK IN COMBINED SHEAR
DEFLECTION Y-AXIS	$\delta_{max} = \ell/300 = 0.35\ cm$		
	$\delta_{calc} = \frac{P\ell^3}{48EI} = \frac{(7.03\ kN)(106\ cm)^3}{48(14617\ MPa)(486.9\ cm^4)} \left\lvert \frac{MPa}{10^6\ N/m^2} \right\rvert \left\lvert \frac{100\ cm}{m} \right\rvert^5 \left\lvert \frac{1000\ N}{kN} \right\rvert$		
	$\delta_{calc} = 0.245\ cm \le \delta_{max} = 0.35\ cm$		∴ OK + IN X-AXIS
SLENDERNESS	$\frac{KL}{r} = 40.6 \le 50$		∴ OK
COMBO LDC	AXIAL = 0		
	$\frac{b_{u_x} + b_{u_y}}{b_n} = 1.12 > 1.0$	∴ OK BECAUSE THE FORCES PRESENTED WILL BE DISTRIBUTED AMONG 3 BMS.	
	∴ USE 10 cm ϕ		

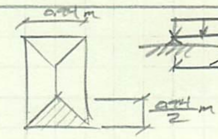
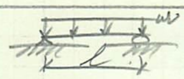
MASTER'S	ARE 898	EVAN MYERS

- IRREGULAR MEMBERS

STEP DESCRIPTION	COMPUTATION	REFERENCE
DOOR COLUMNS	$l = 2.85$ ∴ DR SPANS SHORT DIRECTION	
LOADS WIND	62 PSF => 2970 Pa	
	$w_u = (2970\ Pa)\left(\frac{1.06\,m}{2} + \frac{0.15\,m}{2}\right)\frac{N/m^2}{Pa}\cdot\frac{kN}{1000\,N} = 1.80\ kN/m$	
BENDING MOMENT	$M_u = \frac{w_u l^2}{8} = 1.83\ kN \cdot m$	
STRESS	$f_b = \frac{M_u}{S} = 18.8\ MPa < f_n = 27\ MPa$ ∴ OK	
SHEAR	$V_u = \frac{w_u l}{2} - w_u d = 2.39\ kN + \frac{R_H}{2} = 4.43\ kN$	
STRESS	$v_u = \frac{3V_u}{2A} = 0.93\ MPa < v_n = 3.7\ MPa$ ∴ OK	
COMPRESSION	$R_H = 7.03\ kN$	RF + TRUSS DESIGN
DEAD LD	$P_D = (1.0 \times 10^3\ Pa)\left(\frac{1.06 + 0.15\,m}{2}\right)\left(\frac{2.85\,m}{2}\right)\frac{N/m^2}{Pa}\cdot\frac{kN}{1000\,N} = 0.86\ kN$	
	$C_u = \frac{R_H}{2} + P_D = 4.38\ kN$	
	$c_u = \frac{C_u}{A} = 0.61\ MPa < c_n = 13\ MPa$ ∴ OK	
	∴ BY INSPECTION, OK IN COMBO. LOADING	
DEFLECTION	$\delta_{max} = 0.95\ cm$	
	$\delta_{calc} = \frac{5 w_u l^4}{384EI} = 2.17\ cm > \delta_{max} = 0.95\ cm$	
	∴ OK, DOOR FRAME WILL PROVIDE STIFFNESS ALONG WITH CONNECTION TO ADDITIONAL COLUMN & CORRUGATED METAL	
SLENDERNESS	$\frac{Kl}{r} = 109.2 > 50$ ∴ √ BUCKLING	
BUCKLING	$P_{cr} = \frac{\pi^2 EI}{(Kl)^2} = 86.5\ kN > C_u = 4.38\ kN$ ∴ OK	
	∴ USE 10 cm ϕ FOR DR FRAME CLMS	

MASTER'S	AE 878	EVAN MYERS

- IRREGULAR MEMBERS

STEP DESCRIPTION	COMPUTATION	REFERENCE
WINDOW FRAME BMS	$l = 0.74$ m  	
WIND LOADS	62 PSF ⇒ 2970 Pa	
	$w_u = (2970\ Pa)\left(\frac{0.74\ m}{2}\right)/2 \left\lvert \frac{N/m^2}{Pa} \right\rvert \left\lvert \frac{kN}{1000\ N} \right\rvert = 0.70\ kN/m$	
BENDING MOMENT	$M_u = \frac{w_u l^2}{8} = 0.08\ kN{\cdot}m$	
6 cm ⌀ STRESS	$f_b = \frac{M_u}{S} = 3.89\ MPa \le f_n = 27\ MPa$ ∴ OK	
SHEAR	$V_u = \frac{w_u l}{2} - w_u d = 0.29\ kN$	
STRESS	$v_u = \frac{3V_u}{2A} = 0.20\ MPa \le v_n = 3.7\ MPa$ ∴ OK	
DEFLECTION	$\delta_{max} = l/300 = 0.31\ cm$	
	$\delta_{calc} = \frac{5 w_u l^4}{384EI} = 0.082\ cm \le \delta_{max} = 0.31\ cm$ ∴ OK	
SLENDERNESS	$\frac{KL}{r} = 56.0 > 50$ ∴ √ BUCKLING	
BUCKLING	$P_{cr} = \frac{\pi^2 EI}{(KL)^2} = 97.3\ kN > F_u = 0.58\ kN$ ∴ OK	
	∴ USE 6 cm ⌀ FOR WINDOW FRAME BMS	

MASTER'S	ARE 898	EVAN MYERS

-IRREGULAR MEMBERS

STEP DESCRIPTION	COMPUTATION	REFERENCE
WINDOW FRAME COLMS	$l = 2.85\ m$	
WIND LOAD	$62\ Psf \Rightarrow 2970\ Pa$	
	$w_u = (2970\ Pa)\left(\frac{0.935\ m}{2}\right)\left\lvert\frac{N/m^2}{Pa}\right\rvert\left\lvert\frac{kN}{1000\ N}\right\rvert = 1.39\ kN/m$	
BENDING MOMENT	$M_u = \frac{w_u l^2}{8} = 1.41\ kN\cdot m$	
STRESS	$f_b = \frac{M_u}{S} = 14.5\ MPa \le f_n = 27\ MPa$ ∴ OK	
SHEAR	$V_u = \frac{w_u l}{2} - w_u d = 1.84\ kN$	
STRESS	$v_u = \frac{3V_u}{2A} = 0.39\ MPa \le v_n = 3.7\ MPa$ ∴ OK	
COMPRESSION DEAD	$P_D = (1.0\times10^3\ Pa)\left(\frac{0.935\ m}{2}\right)\left(\frac{2.85\ m}{2}\right)\left\lvert\frac{N/m^2}{Pa}\right\rvert\left\lvert\frac{kN}{1000\ N}\right\rvert = 0.67\ kN$	
	∴ OK BY INSPECTION	
DEFLECTION	$\delta_{max} = 0.95\ cm$	
	$\delta_{calc} = \frac{5 w_u l^4}{384 EI} = 1.68\ cm > \delta_{max} = 0.95\ cm$	
	∴ OK, WINDOW FRAME, CORRUGATED METAL, & ADD. COLM WILL PROVIDE ADEQ. STIFF.	
SLENDERNESS	$\frac{Kl}{r} = 109.2 > 50$ ∴ √ BUCKLING	
BUCKLING	$P_{cr} = 86.5\ kN > P_D = 0.67\ kN$ ∴ OK	
	∴ USE 10 cm ⌀ FOR WINDOW FRAME COLM	

Foundation

Master's	AE 878	Evan Myers

-Foundation

Step Description	Computation		Reference
Properties	$f'_c = 20$ MPa	(3000 PSI)	
	$\gamma_c = 2400$ kg/m^3	(150 PCF)	
	$f_y = 413$ MPa	(60 KSI)	
	$\gamma_s = 19.22$ MPa	(120 PCF)	
	$q = 0.1436$ MPa	(3000 PSF)	
	Below Grade = 30 cm	(12")	
	$c_1 = 15.24$ cm	(6")	
	$c_2 = 15.24$ cm	(6")	
Forces Typ. Clm	$R_x = 2.20$ kN		
	$R_y = 7.83$ kN @ 0.78 m O.C.	∴ Cont. Ftg.	
Braces	$R_x = 70.6$ kN	(15.9 KIPS)	
	$R_y = 74.3$ kN	(16.7 KIPS)	
	∴ Spread Ftg.		
Int. Clm.	$R_x = 2.15$ kN		
	$R_y = 92.8$ kN	(20.9 KIPS)	
	∴ Using 460 mm × 460 mm Clm Cap (18" × 18")		
Distributed Load-Typ. Clm.	$w = \frac{(7.83\ kN)}{(0.78\ m)} \left\| \frac{KIPS}{4.45\ kN} \right\| \frac{m}{100\ cm} \left\| \frac{2.54\ cm}{in} \right\| \frac{12\ in}{FT} \right\|$		
	$w = 0.688$ KLF $= 688$ PLF	∴ Excel	

MASTER'S	AEE 898	EVAN MYERS

-FOUNDATION

STEP DESCRIPTION	COMPUTATION	REFERENCE
-GLOBAL ISSUE w/ SLIDING	$F_x = 141.1\ kN = 31.7$ KIPS	
·WGT OF STRUCTURE ·CONCRETE	$V_{CURB} = (\pi \cdot 407^2 - \pi \cdot 393^2)cm^2(15\,cm) = 5.28 \times 10^5\ cm^3$	
	$V_{SLAB} = (\pi \cdot 407^2)cm^2(10.2\,cm) = 5.31 \times 10^6\ cm^3$	
	$V_{FDN\,WALL} = (\pi \cdot 407^2 - \pi \cdot 376.5^2)cm^2(15\,cm) = 1.13 \times 10^6\ cm^3$	
	$V_{CONT.\,FTG} = (\pi \cdot 407^2 - \pi \cdot 376.5^2)cm^2(30\,cm) = 2.25 \times 10^6\ cm^3$	
	$V_{SPREAD\,FTG} = 8[80 \times 80 \times 30 - 80 \times 30 \times 30]cm^3 + [100 \times 100 \times 30]cm^3 = 1.26 \times 10^6\ cm^3$	
	$V_{TOT.} = 10.47 \times 10^6\ cm^3 \left(\frac{IN}{2.54\,cm}\right)^3 \left(\frac{FT}{12\,IN}\right)^3 = 369.7\ FT^3$	
·WGT OF FDN	$W_{FDN} = \frac{(150\ PCF)(369.7\ FT^3)}{1000\#/K} = 55.5$ KIPS	
·BAMBOO, DL	$A_{RF} = 2(39.2\ m^2) = 78.4\ m^2$	WIND LOAD CALCS
	$W_{RF} = (2.16 \times 10^3\ Pa)(78.4\ m^2)\left(\frac{N/m^2}{Pa}\right)\left(\frac{kN}{1000\,N}\right)\left(\frac{KIPS}{4.45\,kN}\right) = 38.0$ KIPS	
	$A_{WALLS} = (\pi \cdot 8.15\ m)(3\ m) = 76.8\ m^2$	
	$W_{WALLS} = (1 \times 10^3\ Pa)(76.8\ m^2)\left(\frac{N/m^2}{Pa}\right)\left(\frac{kN}{1000\,N}\right)\left(\frac{KIPS}{4.45\,kN}\right) = 17.3$ KIPS	
OVERALL	$W_{TOT} = W_{FDN} + W_{RF} + W_{WALLS} = 110.8$ KIPS	
	$\mu W_{TOT} = 0.55(110.8\ KIPS) = 60.9$ KIPS	
	$\mu = 0.55$ ∴ μ BASED ON EAST AFRICAN SOIL QUALITIES	FOUNDATIONS-KK
	$\frac{\mu W_{TOT}}{F_x} = 1.92 > 1.50$ ∴ OK IN GLOBAL SLIDING	

-FOUNDATION

STEP DESCRIPTION	COMPUTATION	REFERENCE
EXTERIOR CLM -DESIGN FOR SLIDING ·LOCAL	$R_x = 70.6\ kN = 15.9\ KIPS$ ∴ 3 COLUMNS @ 0.80·0.80×0.30 m FTG	
	$W_{FTG} = \frac{(150\ PCF)(2.62')^2(1')}{1000^{\#}/K} = 1.03^K$	
	$W_{CONT.FTG} = 2\frac{(150\ PCF)(3.69')(1')^2}{1000^{\#}/K} = 1.11^K$	
	DISTANCE BETWEEN CLMS = 3.05m	
	$d = (\frac{1}{2} \cdot 3.05m - \frac{1}{2} 0.80m) \frac{3.281'}{m} = 3.69'$	
	$W_{FDN\ WALL} = \frac{(150\ PCF)(10')(0.5')(1')}{1000^{\#}/K} = 0.75^K$	
	$d = 3.05m \frac{3.281'}{m} = 10'$	
	$W_{CURB} = \frac{(150\ PCF)(10')(0.5')^2}{1000^{\#}/K} = 0.38^K$	
	$W_{SLAB} = \frac{(150\ PCF)(3')(10')(0.33')}{1000^{\#}/K} = 1.50^K$	
·FDN	$W_{FDN} = 3(4.77\ KIPS) = 14.3^K$	
·RF	$W_{RF} = \frac{3(38\ KIPS)}{8} = 14.3\ KIPS$	
·WALLS	$W_{WALLS} = \frac{3(17.3\ KIPS)}{8} = 6.5\ KIPS$	
·TOTAL	$W_{TOTAL} = 35.1\ KIPS$	
	$\mu W_{TOTAL} = 0.55(35.1\ KIPS) = 19.3\ KIPS$	
	$\mu = 0.55$ ∴ μ BASED ON EAST AFRICAN SOIL QUALITIES	FOUNDATIONS-KK
	$\frac{\mu W_{TOTAL}}{R_x} = 1.21 < 1.50$ ∴ NG	
	∴ LOCALIZED SLIDING MAY BE AN ISSUE. FACTOR IS GREATER THAN ONE, SO SHOULD BE ADEQUATE.	

Exterior Footing

Spread Footing Calculations (Square)

YELLOW= INSERT ON OWN

Columns		ACI 318-11	AISC Steel Construction Manual	ASCE 7-10	
Concrete:		NW			
Frost Line:		0	In.		
Column Location:		Corner			
Soil Bearing:	$q=$	3000	PSF Given		
Concrete Weight:	$\gamma_c=$	150	PCF Assumed		
Soil Weight:	$\gamma_s=$	150	PCF Concrete Above		
Concrete Factor:	$\lambda=$	1	ACI 318-11, Section 8.6.1		
Concrete Strength:	$f'_c=$	3000	PSI		
Steel Yield Strength:	$f_y=$	60	KSI		
Modulus of Rupture:	$f_r=$	$7.5\lambda(f'_c)^{1/2}=$	7.5* 1 * (3000)$^{1/2}$ =	**410.79**	PSI, Eqn. 9-10
Moment of Inertia:	$I_g=$	$bh^3/12=$	2.50 * 12 * 12 ^{3}/12 =	**4320.00**	In^4
Center of Gravity:	$y_t=$	$h/2=$	12 /2 =	**6**	In.
Cracking Moment:	$M_{cr}=$	$f_rI_g/y_t=$	410.79 * 4320 / 6 *[Kips/1000 #]*[Ft/12"]=	**24.6**	K*Ft Eqn 9-8
Column Coefficient:	$\alpha=$	20	ACI 318-11, Section 11.11.2		
Bending Beta:	$\beta_1=$	0.85	β_1=0.85-0.05*(f'c-4000)/1000		
Shear Beta:	$\beta=$	1			
Bottom of Footing Below Grade:		24	In.		
Height of Footing:	$h=$	12	In.		
Depth of Soil:	$y=$	12	In.		
Length of Plate:	$c_1=$	6	In.		
Width of Plate:	$c_2=$	6	In.		
Effective Soil Bearing Capacity:	$q_e=$	2.70	KSF	$q_e=q-h*W_c-y*W_s$	
Column Force:	$P=$	16.7	K		
Footing Area:	$A_{reg}=$	$P/q_e=$	16.7 / 2.70 =	**6.2**	SF
Square Footing Width:	$b=$	$(A_{reg})^{1/2}=$	6.2 $^{1/2}$ =	**2.49**	Ft
Use:	$b=$	2.5	Ft		
	q_u	$P/b^2=$	16.7 / 2.50 ^{2} =	**2.67**	KSF OK

Bending

Safety Factor:	$\Phi=$	0.9			
Bending Length:	$\ell_c=(b-c_1)/2=$		(2.5 *12 - 6)/2 =	**12**	in.
Ultimate Moment:	$M_u=$	$1/2q_u\ell_c^2b$ (Square)=	1/2* 2.67 * 12 ^{2} 2.5 [Ft/12"]^2=	**3.34**	K*Ft
Cracking vs. Ultimate Moment:	$M_{cr}=$	**24.6**	K*Ft ≥ M_u = **3.34** K*Ft		Does Not Crack
Steel to Concrete Strength:	$m=$	$f_y/(0.85*f'_c)=$	60 / (0.85* 3000 [1000 #/Kips]=	**23.53**	
Ultimate Bending Stress:	$R_u=$	$M_u/(\phi bd^2)=$	3.34 / (0.9 * 2.5 * 7.88 ^{2})[12 in./Ft]=	**0.29**	KSI
Reinforcement Ratio Req'd:	$\rho_{req}=$	$[1-(1-2mR_u/f_y)^{1/2}]/m=$	[1-(1-2* 23.53 * 0.29 / 60)$^{1/2}$] / 23.53 =	**0.0051**	
Reinforcement Ratio Min.:	$\rho_{min}=$	$3(f'_c)^{1/2}/f_y$ or $200/f_y=$	**0.0033**		
Reinforcement Ratio Max:	$\rho_{max}=$	$0.319\beta f'_c/f_y=$	0.319* 0.85 * 3000 / 60 *[Kips/1000 #]=	**0.0136**	
Reinforcement Ratio:	$\rho=$	0.0051			
Area of Steel:	$A_s=$	$\rho bd=$	*TEMPERATURE & SHRINKAGE ONLY*		
Temperature & Shrinkage Steel:	$A_{T\&S}=$	.0018bh (Gr.60) or .002bh (Gr. 40, 50)	0.0018* 2.5 * 12 * 12 =	0.648	In^2
Use:	$A_s=$	0.65	In^2		

Clear Cover		
Earth	3	ASCE 7-10
		2.3.2

Bending Rebar			
Size	#6		ASCE 7-10
d_b	0.75		App. E
Area	**0.44**	In^2	
Spacing	**7**	In	Eqn 10-4 ACI 318-11
No. of Bars	**4**		
Actual Spacing	6	In.	
A_s	**1.76**	In^2	

2-Way Shear

Safety Factor:	$\Phi=$	0.75			
Assumed Depth:	$d_{assumed}=$	h-Clear Cover-1.5*d_b=	12 - 3 - 1.5* 0.75 =	**7.875**	in. Section 9.3.2
Column Perimeter:	$b_o=$	$2*c_1+2*c_2=$	2* 6 + 2* 6 =	**24**	In.
Ultimate Shear:	$V_{u2}=$	$P-q_u*(d_{assumed}-c_1)^2=$	16.7 - 2.67 * (7.875 + 6)^2*[Ft/12"]^2=	**13.13**	Kips
Depth From Equation 11-33:	$d_1=$	$V_{u2}/[\phi4\lambda(f'_c)^{1/2}*b_o]=$	13.13 / [0.75 * 4 * 1 (3000)$^{1/2}$ * 24] *[1000 #/Kips]=	**3.33**	in.
Depth From Equation 11-31:	$d_2=$	$V_{u2}/[\phi(2+4/\beta)\lambda(f'_c)^{1/2}b_o]=$	13.13 / [0.75 * (2+4/ 1) * 1 * (3000)$^{1/2}$ * 24] *[1000 #/Kips]=	**2.22**	in.
Depth From Equation 11-32:	$a=$	$\phi\alpha\lambda(f'_c)^{1/2}=$	0.75 * 20.00 * 1.00 * (3000)$^{1/2}$ =	**821.58**	
$V_{u2}=\phi(\alpha d/b_o+2)\lambda(f'_c)^{1/2}b_od$	$b=$	$\phi2\alpha\lambda(f'_c)^{1/2}b_o=$	0.75 * 2 * 20.00 * 1.00 * (3000)$^{1/2}$ * 24.00 =	**39436.02**	
	$c=$	$-V_{u2}=$	**-13127.77** Pounds		
	$d_3=$	$-b\pm(b^2-4ac)^{1/2}/2a=$	[-39436.02 ± (39436.02 ^{2} - 4* 821.58 * -13127.77)$^{1/2}$] / [2 * 821.58] =	**0.33**	in.
Use:	$d=$	7.88	In.		
	$\Phi V_c=$	31.06	K		OK
	$\Phi V_c=$	31.06	K ≥ 13.13 K		OK

1-Way Shear

Point of Max Shear:	$k=$	$b/2-c/2-d=$	2.5 /2 - 6 /2*[12"/Ft] 7.88 *[Ft/12"] =	**0.34375**	Ft
Ultimate Shear:	$V_{u1}=$	$kq_ub=$	0.34375 * 2.67 * 2.5 =	**2.30**	K
Depth Required:	$d_{req}=$	$V_{u1}/[\phi2\lambda(f'_c)^{1/2}*bd]=$	2.30 / [0.75 * 2 * 1 * (3000)$^{1/2}$* 6 * 7.88] *[1000 #/Kips]=	**0.59**	in.
	$d=$	7.88	in. ≥ d_{req} = 0.59 in.		

Development Length

Fresh Concrete:		Other	ACI 318-11		
Epoxy-Coating:		No Epoxy	Section 12.2.4		
Fresh Concrete Factor:	$\Psi_t=$	**1**			
Epoxy-Coating Factor:	$\Psi_e=$	**1**			
	$\Psi_t\Psi_e=$	**1**	$\Psi_t\Psi_e \le 1.7$		
Bar Factor:	$\Psi_s=$	**0.8**			
Spacing Factor:	$c_{b1}=$	$s/2=$	6 /2 =	**3.00**	In.
Spacing Factor:	$c_{b2}=$	Clear Cover+ 1.5d_b=	3 + 1.5* 0.75 =	**4.13**	In.
Spacing Factor:	$c_{b3}=$	Clear Cover+ 1.5d_b=	3 + 1.5* 0.75 =	**4.13**	In.
Spacing Factor:	$c_b=$	**3.00**			
Transverse Reinforcement Area:	A_{tr}	**1.76**			
	$n=$	1			
Confinement Reinforcement Factor:	$K_{tr}=$	0	Assume 0 or use $K_{tr}=40A_{tr}/(s*n)$	Eqn 12-2	
Confinement Term:	$(c_b+K_{tr})/d_b=$	**2.5**	$(c_b+K_{tr})/d_b \le 2.5$		
Development Length:	$\ell_d=[3/40*f_y*\Psi_t\Psi_e\Psi_s/(\lambda(f'_c)^{1/2}*(c_b+K_{tr})/d_b)]*d_b=$		3/40 * (60 * 1 * 0.8) / [1 *(3000)$^{1/2}$ * 2.5] * 0.75 *[1000 #/Kips]=	**19.72**	in.

No Development Req'd

Bearing

Safety Factor:	Φ=	0.65																
Column Material:		Bamboo																
Bearing Area:	A_1=	c_1c_2=		6		*		6		=	36	in^2						
Area Below Bearing Area:	A_2=	b^2=		2.5	^{2}*[12"/Ft]^2=			900	in^2									
Bearing Strength:	ΦN_1=	Φ*(.85*f'$_c$*A_1)=		0.65	*	0.85	*	3000.0		*	36	*[Kips/1000 #]=		59.67	Kips			
	ΦN_1=	**59.67**	Kips	≥		**16.7**	Kips											**OK**
	$(A_2/A_1)^{1/2}$=	**2**																
Bearing Strength:	ΦN_2=	Φ*(.85*f'$_c$*A_1)*$(A_2/A_1)^{1/2}$=		0.65	*	0.85	*	3000		*	36		*	2	*[Kips/1000#]=	**119.34**	Kips	
	ΦN_2=	**119.34**	Kips	≥		**16.7**	Kips											**OK**

2'-6" Square Spread Footing with 4 #6 Reinforcement Evenly Spaced, 12" Deep (Use 0.80x0.80x0.30 m)

Interior Footing

Spread Footing Calculations (Square)

Columns — ACI 318-11 — AISC Steel Construction Manual — ASCE 7-10

YELLOW= INSERT ON OWN

Concrete:		NW	
Frost Line:		0	In.
Column Location:		Interior	
Soil Bearing:	$q=$	3000	PSF Given
Concrete Weight:	$\gamma_c=$	150	PCF Assumed
Soil Weight:	$\gamma_s=$	150	PCF Concrete Above
Concrete Factor:	$\lambda=$	1	ACI 318-11, Section 8.6.1
Concrete Strength:	$f'_c=$	3000	PSI
Steel Yield Strength:	$f_y=$	60	KSI

Modulus of Rupture: $f_r = 7.5\lambda(f'_c)^{1/2} =$ 7.5* 1 * (3000)$^{1/2}$ = **410.79** PSI, Eqn. 9-10

Moment of Inertia: $I_g = bh^3/12 =$ 3.00 * 12 * 12 $^3/12$ = **5184.00** In^4

Center of Gravity: $y_t = h/2 =$ 12 /2 = 6 In.

Cracking Moment: $M_{cr} = f_r I_g / y_t =$ 410.79 * 5184 / 6 *[Kips/1000 #]*[Ft/12"]= **29.6** K*Ft Eqn 9-8

Column Coefficient: $\alpha=$ 20 ACI 318-11, Section 11.11.2

Bending Beta:	$\beta_b=$	0.85	$\beta_b=0.85-0.05*(f'_c-4000)/1000$
Shear Beta:	$\beta=$	1	
Bottom of Footing Below Grade:		24	In.
Height of Footing:	$h=$	12	In.
Depth of Soil:	$y=$	12	In.
Length of Plate:	$c_1=$	6	In.
Width of Plate:	$c_2=$	6	In.
Effective Soil Bearing Capacity:	$q_e=$	2.70	KSF — $q_e=q-h*W_c-y*W_s$
Column Force:	$P=$	20.9	K

Footing Area: $A_{req} = P/q_e =$ 20.9 / 2.70 = **7.7** SF

Square Footing Width: $b = (A_{req})^{1/2} =$ 7.7 $^{1/2}$ = **2.78** Ft

Use: $b=$ 3 Ft

q_u $P/b^2=$ 20.9 / 3.00 ^{2} = **2.32** KSF — OK

Bending

Safety Factor: $\Phi=$ 0.9

Bending Length: $\ell_c = (b-c_1)/2 =$ (3 *12 - 6)/2 = **15** in.

Ultimate Moment: $M_u = 1/2 q_u \ell_c^2 b$ (Square)= 1/2* 2.32 * 15 ^{2} 3 [Ft/12"]^2= **5.44** K*Ft

Cracking vs. Ultimate Moment: $M_{cr}=$ **29.6** K*Ft ≥ $M_u=$ **5.44** K*Ft — Does Not Crack

Steel to Concrete Strength: $m = f_y/(0.85*f'_c) =$ 60 / (0.85* 3000 [1000 #/Kips]= **23.53**

Ultimate Bending Stress: $R_u = M_u/(\phi b d^2) =$ 5.44 / (0.9 * 3 * 7.88 ^{2})[12 in./Ft]= **0.39** KSI

Reinforcement Ratio Req'd: $\rho_{req} = [1-(1-2mR_u/f_y)^{1/2}]/m =$ [1-(1-2* 23.53 * 0.39 / 60)$^{1/2}$] / 23.53 = **0.0071**

Reinforcement Ratio Min.: $\rho_{min} = 3(f'_c)^{1/2}/f_y$ or $200/f_y =$ **0.0033**

Reinforcement Ratio Max: $\rho_{max} = 0.319\beta f'_c/f_y =$ 0.319* 0.85 * 3000 / 60 *[Kips/1000 #]= **0.0136**

Reinforcement Ratio: $\rho=$ 0.0071

Area of Steel: $A_s = \rho b d =$ *TEMPERATURE & SHRINKAGE ONLY*

Temperature & Shrinkage Steel: $A_{T\&S}=$ 0018bh (Gr.60) or .002bh (Gr. 40, 50) 0.0018* 3 * 12 * 12 = 0.7776 In^2

Use: $A_s=$ **0.78** In^2

Clear Cover		
Earth	3	ASCE 7-10
		2.3.2

Bending Rebar			
Size	#6	ASCE 7-10	
d_b	0.75	App. E	
Area	**0.44**	In^2	
Spacing	6	In	Eqn 10-4 ACI 318-11
No. of Bars	5		
Actual Spacing	6	In.	
A_s	**2.20**	In^2	

2-Way Shear

Safety Factor: $\Phi=$ 0.75

Assumed Depth: $d_{assumed} = h -$ Clear Cover $- 1.5*d_b =$ 12 - 3 - 1.5* 0.75 = **7.875** in. Section 9.3.2

Column Perimeter: $b_o = 2*c_1 + 2*c_2 =$ 2* 6 + 2* 6 = **24** In.

Ultimate Shear: $V_{u2} = P - q_u*(d_{assumed}+c_1)^2 =$ 20.9 - 2.32 * (7.875 + 6)^2*[Ft/12"]^2= **17.80** Kips

Depth From Equation 11-33: $d_1 = V_u/[\phi 4\lambda(f'_c)^{1/2}*b_o] =$ 17.80 *[1000 #/Kips]= / [0.75 * 4 * 1 (3000)$^{1/2}$ * 24] = **4.51** in.

Depth From Equation 11-31: $d_2 = V_u/[\phi(2+4/\beta)\lambda(f'_c)^{1/2} b_o] =$ 17.80 *[1000 #/Kips]= / [0.75 * (2+4/ 1) * 1 (3000)$^{1/2}$ * 24] = **3.01** in.

Depth From Equation 11-32: $a = \phi\alpha\lambda(f'_c)^{1/2} =$ 0.75 * 20.00 * 1.00 * (3000)$^{1/2}$ = **821.58**

$V_{c2} = \phi(\alpha d/b_o+2)\lambda(f'_c)^{1/2} b_o d$ — $b = \phi 2\lambda(f'_c)^{1/2} b_o =$ 0.75 * 2 * 20.00 * 1.00 * (3000)$^{1/2}$ * 24.00 = **39436.02**

$c = -V_{u2} =$ **-17795.39** Pounds

$d_3 = -b \pm (b^2-4ac)^{1/2}/2a =$ -39436.02 ± (39436.02 ^{2} - 4* 821.58 * -17795.39)$^{1/2}$ / [2 * 821.58] = **0.45** in.

Use: $d=$ 7.88 In.

$\Phi V_c =$ 31.06 K — OK

$\Phi V_c =$ 31.06 K ≥ 17.80 K — OK

1-Way Shear

Point of Max Shear: $k = b/2 - c/2 - d =$ 3 /2 - 6 /2*[12"/Ft] 7.88 *[Ft/12"] = **0.59375** Ft

Ultimate Shear: $V_{u1} = k q_u b =$ 0.59375 * 2.32 * 3.0 = **4.14** K

Depth Required: $d_{req} = V_{u1}/[\phi 2\lambda(f'_c)^{1/2}*bd] =$ 4.14 *[1000 #/Kips]= / [0.75 * 2 * 1 * (3000)$^{1/2}$* 6 * 7.88] = **1.07** in.

$d=$ 7.88 in. ≥ $d_{req}=$ 1.07 in.

Development Length

Fresh Concrete:		Other	ACI 318-11
Epoxy-Coating:		No Epoxy	Section 12.2.4
Fresh Concrete Factor:	$\psi_t=$	1	
Epoxy-Coating Factor:	$\psi_e=$	1	
	$\psi_t\psi_e=$	1	$\psi_t\psi_e \le 1.7$
Bar Factor:	$\psi_s=$	0.8	

Spacing Factor: $c_{b1} = s/2 =$ 6 /2 = **3.00** In.

Spacing Factor: $c_{b2} =$ Clear Cover$+1.5d_b =$ 3 + 1.5* 0.75 = **4.13** In.

Spacing Factor: $c_{b3} =$ Clear Cover$+1.5d_b =$ 3 + 1.5* 0.75 = **4.13** In.

Spacing Factor: $c_b=$ **3.00**

Transverse Reinforcement Area: A_{tr} **2.20**

$n=$ 1

Confinement Reinforcement Factor: $K_{tr}=$ 0 — Assume 0 or use $K_{tr}=40A_{tr}/(s*n)$ — Eqn 12-2

Confinement Term: $(c_b+K_{tr})/d_b=$ **2.5** — $(c_b+K_{tr})/d_b \le 2.5$

Development Length: $\ell_d = [3/40*f_y*\psi_t\psi_e\psi_s/(\lambda(f'_c)^{1/2}*(c_b+K_{tr})/d_b)]*d_b =$ 3/40 * (60 * 1 * 0.8) / [1 *(3000)$^{1/2}$ * 2.5] * 0.75 *[1000 #/Kips]= **19.72** in.

No Development Req'd

Bearing													
Safety Factor:	Φ=	0.65											
Column Material:		Bamboo											
Bearing Area:	A_1=	c_1c_2=	6	*	6	=	36	in^2					
Area Below Bearing Area:	A_2=	b^2=	3	^{2}*[12"/Ft]^2=	1296	in^2							
Bearing Strength:	ΦN_1=	Φ*(.85*f'_c*A_1)=	0.65	*	0.85	*	3000.0	*	36	*[Kips/1000 #]=	59.67	Kips	
	ΦN_1=	59.67	Kips	≥	20.9	Kips							OK
	$(A_2/A_1)^{1/2}$=	2											
Bearing Strength:	ΦN_2=	Φ*(.85*f'_c*A_1)*$(A_2/A_1)^{1/2}$=	0.65	*	0.85	*	3000	*	36	*	2	*[Kips/1000#]=	119.34 Kips
	ΦN_2=	119.34	Kips	≥	20.9	Kips							OK

3'-0" Square Spread Footing with 5 #6 Reinforcement Evenly Spaced, 12" Deep (Use 1.00x1.00x0.30 m)

Continuous Footing

Spread Footing Calculations (Square)

YELLOW= INSERT ON OWN

Columns		ACI 318-11	AISC Steel Construction Manual	ASCE 7-10											
Concrete:		NW													
Frost Line:		0	In.												
Column Location:		Corner													
Soil Bearing:	q=	3000	PSF												
Concrete Weight:	γ_c=	150	PCF Assumed												
Soil Weight:	γ_s=	150	PCF Concrete Above												
Concrete Factor:	λ=	1	ACI 318-11, Section 8.6.1												
Concrete Strength:	f'_c=	3000	PSI												
Steel Yield Strength:	f_y=	60	KSI												
Modulus of Rupture:	f_r=	$7.5\lambda(f'_c)^{1/2}$=	7.5*	1	*	(	3000	)$^{1/2}$	=	410.79	PSI, Eqn. 9-10				
Moment of Inertia:	I_g=	$bh^3/12$=	1.00	*	12	*	12	^{3}/12	=	1728.00	In^4				
Center of Gravity:	y_t=	h/2=	12	/2	=	6	In.								
Cracking Moment:	M_{cr}=	f_rI_g/y_t=	410.79	*	1728	/	6	*[Kips/1000 #]*[Ft/12"]=	9.9	K*Ft	Eqn 9-8				
Column Coefficient:	α_s=	20	ACI 318-11, Section 11.11.2												
Bending Beta:	β_b=	0.85	β_b=0.85-0.05*(f'c-4000)/1000												
Shear Beta:	β=	1													
Bottom of Footing Below Grade:		24	In.												
Length Analyzed:	b=	12	In.												
Height of Footing:	h=	12	In.												
Depth of Soil:	y=	12	In.												
Width of Plate:	c_1=	6	In.												
Effective Soil Bearing Capacity:	q_e=	2.70	KSF	q_e=q-h*W_c-y*W_s											
Distributed Load:	$W_{[illegible]}$=	688.0	PLF												
Square Footing Width:	w=	w/q_e=	688.0	/	2.70	*[Kips/1000 #] =	0.3	Ft							
Use	w=	1	Ft												
	q_u	w/b=	688.0	/	1.00	[Kips/1000 #]=	0.69	KSF							OK
1-Way Shear															
Safety Factor:	Φ=	0.75													
Depth Assumed:	$d_{assumed}$=	h-Clear Cover-1.5d_b=	12	-	3	-1.5	*	0.375	=	8.44	In.				
Ultimate Shear:	V_u=	q_u*(w/2-c/2)=	0.69	*	(	1.00	/2	-	6.0	/2*[Ft/12"]) =	0.52	K			
Depth Required:	d_{req}=	$V_u/[\phi 2\lambda(f'_c)^{1/2}b]$=	0.52	/	[	0.75	* 2 *	1	* (	3000	)$^{1/2}$ *	12	*[1000 #/Kips]=	0.52	In.
	d=	8.44	In.	≥	0.52	In.									
Bending															
Safety Factor:	Φ=	0.9													
Bending Length:	ℓ_u=	(w-c_1)/2=	(	1	*12	-	6	)/2	=	3	In.				
Ultimate Moment:	M_u=	$1/2q_u\ell_u^2$=	1/2	*	0.69	*	3	^{2}*[Ft/12"]^2=	0.02	K*Ft					
Cracking vs. Ultimate Moment:	M_{cr}=	9.9	K*Ft	≥	0.02	K*Ft									Does Not Crack
Steel to Concrete Strength:	m=	$f_y/(0.85*f'_c)$=	60	/	(0.85*	3000	[1000 #/Kips]=	23.53							
Ultimate Bending Stress:	R_u=	$M_u/(\phi bd^2)$=	0.0215	/	(	0.9	*	12	*	8.44	^{2})[12 in./ft]=	0.0003	KSI		
Reinforcement Ratio Req'd:	ρ_{req}=	$[1-(1-2mR_u/f_y)^{1/2}]/m$=	[1-(1-2 *	23.53	*	0.0003	/	60	)$^{1/2}$	0.000006					
				23.53											
Reinforcement Ratio Min.:	ρ_{min}=	$3(f'_c)^{1/2}/f_y$ or $200/f_y$=	0.0033												
Reinforcement Ratio Max:	ρ_{max}=	$0.319\beta f'_c/f_y$=	0.319	*	0.85	*	3000	/	60	*[Kips/1000 #]=	0.0136				
Reinforcement Ratio:	ρ=	0.0033													
Area of Steel:	A_s=	ρbd=	*TEMPERATURE & SHRINKAGE ONLY*												
Temperature & Shrinkage Steel:	$A_{T\&S}$=	0018bh (Gr.60) or .002bh (Gr. 40, 50)	0.0018*	1	*12*	12	=	0.2592	In^2						
Use	A_s=	0.26	In^2												

Clear Cover		
Earth	3	ASCE 7-10
		2.3.2

Bending Rebar		
Size	#3	ASCE 7-10
d_b	0.375	App. E
Area	0.11	In^2
Spacing	5	In Eqn 10-4 ACI 318-11
No. of Bars	2	
Actual Spacing	3	In.
A_s	0.22	In^2

Development Length														
Fresh Concrete:		Other	ACI 318-11											
Epoxy-Coating:		No Epoxy	Section 12.2.4											
Fresh Concrete Factor:	Ψ_t=	1												
Epoxy-Coating Factor:	Ψ_e=	1												
	$\Psi_t\Psi_e$=	1	$\Psi_t\Psi_e \le 1.7$											
Bar Factor:	Ψ_s=	0.8												
Spacing Factor:	c_{b1}=	s/2=	3	/2	=	1.50	In.							
Spacing Factor:	c_{b2}=	Clear Cover+1.5d_b=	3	+	1.5*	0.375	=	3.56	In.					
Spacing Factor:	c_{b3}=	Clear Cover+1.5d_b=	3	+	1.5*	0.375	=	3.56	In.					
Spacing Factor:	c_b=	1.50												
Transverse Reinforcement Area:	A_{tr}	0.22												
	n=	1												
Confinement Reinforcement Factor:	K_{tr}=	0	Assume 0 or use K_{tr}= 40A_{tr}/(s*n)	Eqn 12-2										
Confinement Term:	$(c_b+K_{tr})/d_b$=	2.5	$(c_b+K_{tr})/d_b \le 2.5$											
Development Length:	ℓ_d=	$[3/40*f_y*\Psi_t\Psi_e\Psi_s/(\lambda(f'_c)^{1/2}*(c_b+K_{tr})/d_b)]*d_b$=	3/40	* (	60	*	1	*	0.8	*	0.375	*[1000 #/Kips]=	9.86	In.
			[		1	* (	3000	)$^{1/2}$ *	2.5	]				No Development Req'd

1'-0" Wide Continuous Footing with 2 #3 Reinforcement Evenly Spaced, 12" Deep (Use 0.30x0.30 m)

Appendix B – Additional Connections

This appendix provides pictures of additional connections for bamboo as indicated in **Chapter 3**, including PVC type fittings, combination connections with pins and lashings, threaded bolts, cable-tie mounts, adhesives, clamps, and others. These connections are case-specific and generally have disadvantages that cannot be overcome in design or detailing. They have a niche but may not have the strength or flexibility to be used in other situations.

Figure B.1 PVC Type Fittings

(Reproduced from Nicholas Socrates' *Bamboo Construction*)

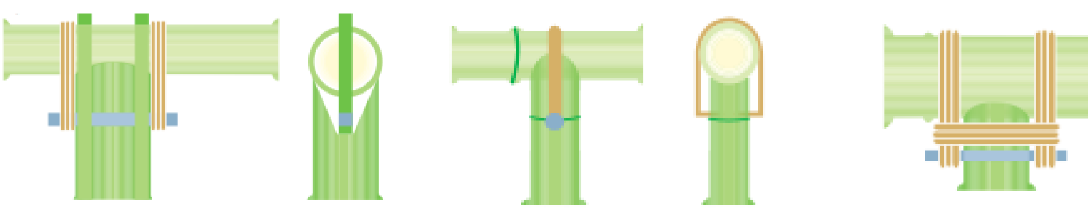


Figure B.2 Combination Connections with Pins and Lashing

(Reproduced from INBAR's *Designing and Building with Bamboo*)

Figure B.3 Threaded Bolt Connections

(Reproduced from Nicholas Socrates' *Bamboo Construction*)

Figure B.4 Cable Tie Mount Connection

(Reproduced from Nicholas Socrates' *Bamboo Construction*)

Figure B.5 Adhesive Connection

(Reproduced from INBAR's *Designing and Building with Bamboo*)

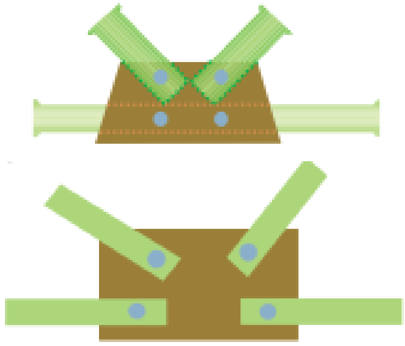


Figure B.6 Clamping Connections

(Reproduced from INBAR's *Designing and Building with Bamboo*)

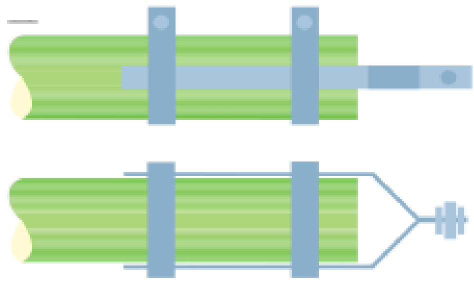


Figure B.7 Steel Wire and Clamping Connection

(Reproduced from INBAR's *Designing and Building with Bamboo*)

Figure B.8 Double Post Connection

(Reproduced from Nicholas Socrates' *Bamboo Construction*)

Figure B.9 Drilled Hole Lashing Connection

(Reproduced from Nicholas Socrates' *Bamboo Construction*)

Lashing connections are captured in **Figure B.10**, starting from left to right. The first connection is lashing that supports both culms but only in one direction. This is not practical due to its high displacement and ability to only resist shear once displacement has occurred. The second example is widely used in trusses because truss forces enable the connection to succeed. Compressive force in the vertical culm keeps the diagonal culm in place, while lashings keep the vertical culm relatively stable. The third connection is only used for fencing in Asia but has simplicity that may provide practicality in other situations. The vertical culm has a tongue portion that is wrapped around the horizontal culm and tied on the backside with lashing. The fourth connection is another example of a traditional lashing bamboo connection (Janssen, 2000).

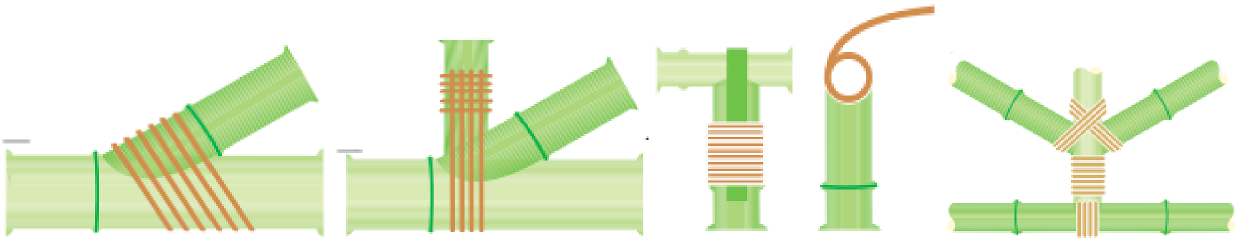


Figure B.10 Further Bamboo Lashing Connections

(Reproduced from the INBAR's *Designing and Building with Bamboo*)

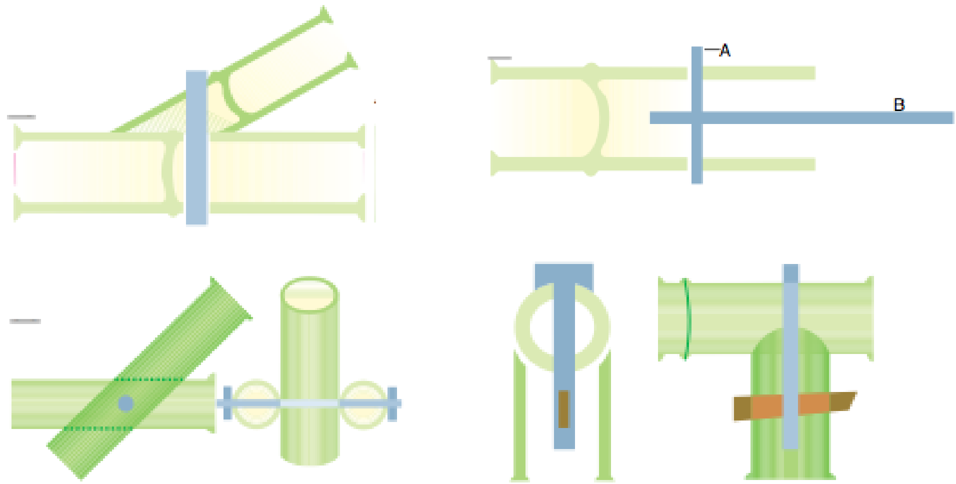


Figure B.11 Bolt and Pin Connections

(Reproduced from the INBAR's *Designing and Building with Bamboo*)

Appendix C - Glued-Wood Fitting Connection

The glued-wood fitting connection's high versatility provides the bamboo industry with an option that should improve bamboo's feasibility as a structural material. **Figures C.1** through **C.6** give examples of this connections uses. In **Figure C.1**, **A** is the culm, **B** the wood fitting, and **C-E** are the different type of steel plates used for this conneciton.

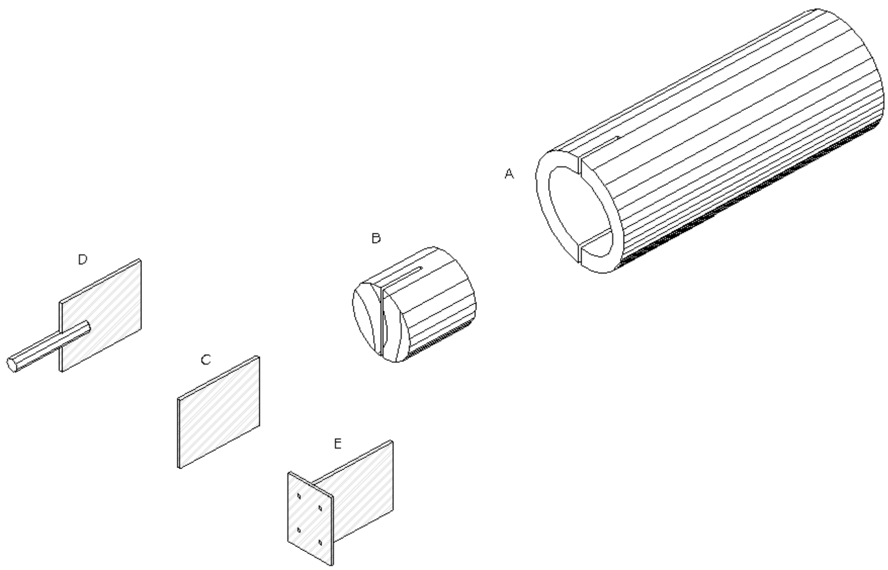


Figure C.1 Glued-Wood Fitting with Steel Plate Connection

(Reproduced based upon a figure from Antonio Arce-Villalobos' *Fundamentals of the Design of Bamboo Structures*)

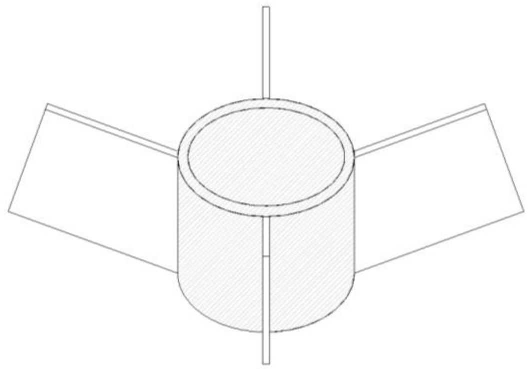


Figure C.2 Steel Plates Welded to Steel Ring Connection

(Reproduced based upon a figure from Antonio Arce-Villalobos' *Fundamentals of the Design of Bamboo Structures*)

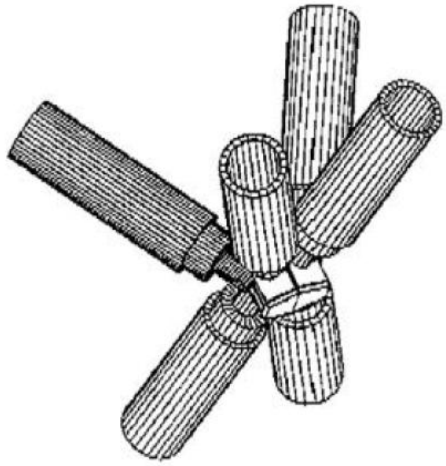


Figure C.3 Glued-Wood Fitting with Steel Plates, Welded Connection

(Reproduced from Nicholas Socrates' *Bamboo Construction*)

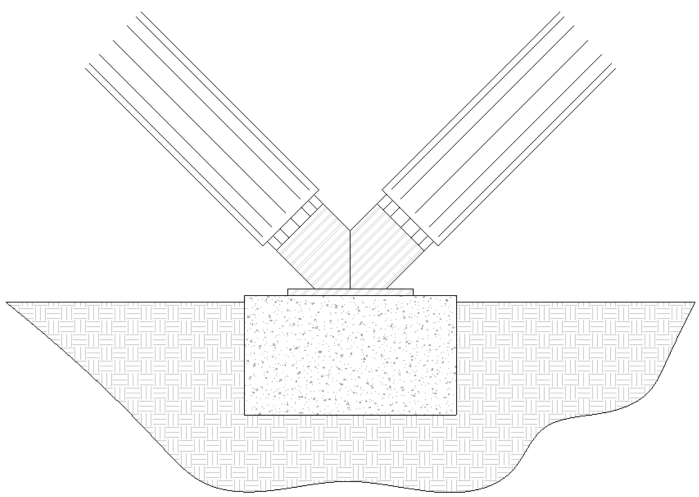


Figure C.4 Glued-Wood Fitting with Steel Plates Connected to the Foundation

(Reproduced based upon a figure from Antonio Arce-Villalobos' *Fundamentals of the Design of Bamboo Structures*)

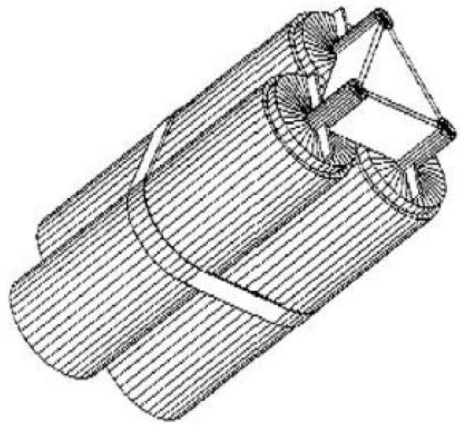


Figure C.5 Glued-Wood Fitting with Steel Plate and Pin Bundle

(Reproduced from Nicholas Socrates' *Bamboo Construction*)

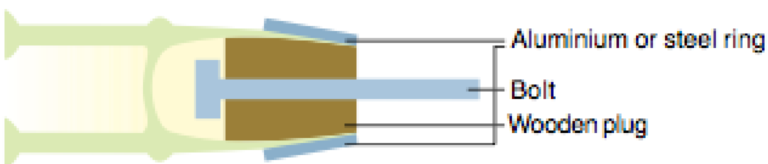


Figure C.6 Wood Fitting with Steel Plate and Pin Bundle

(Reproduced from INBAR's *Designing and Building with Bamboo*)

The connection in **Figure C.6** is a slight variation from the glued-wood fitting because it uses an aluminum or steel ring to keep the plug in place and a bolt to extend the connection. This connection has a quantitative strength of twenty-seven kilo-Newton for a 6.4 cm diameter culm of no specific bamboo species (Janssen, 2000). This connection is viable but more labor intensive, more expensive, and not versatile outside the culm, where the glued-wood fitting has flexibility in use of the wood platform or steel plates.

Appendix D – Source Permission

SENT:

Date: Tue, 9 Jul 2013 20:39:15 -0700
Subject: Citing Master's Report
From: emyers89@gmail.com
To: nicholassocrates@live.com

Dear Nicholas Socrates,

My name is Evan Myers, and I am a graduate student in Architectural Engineering at Kansas State University. I am currently researching for my master's report on *Structural Bamboo Design in East Africa*.

Through my research, I have found some of your work that I would like to include in my report. I am seeking your permission to use your work directly or as a reference for the original composition of my report. I would like to include the following materials:

1. Text and images from your document *Bamboo Construction* (2012).

Additionally, I welcome any other information you would like to provide on bamboo as a structural material. I appreciate your consideration and assistance, and look forward to your reply. Thank you.

Evan Myers

emyers89@gmail.com
(785)819-3106

REPLY:

Dear Evan,

Feel free to use the material, but please do reference it as in any academic work.

Feel free to use my images also.

Please do reference and if you like I will be interested to read your work after you complete it.

Thank you for being in touch.

Best Wishes,

Nicholas

Nicholas Socrates
BA (Hons), BA (Hons), MA, MArch

w. www.nicholassocrates.com - architecture & urban design
p. www.nicholassocrates.com/portfolio
w. www.nicksocrates.com - art
l. uk.linkedin.com/in/nicksocrates/
t. @nick_socrates
e. nicholassocrates@live.com
m. 07842825312 / 07821646183

SENT:

From: Evan Myers [mailto:emyers89@gmail.com]
Sent: 10 July 2013 05:23
To: UNIDO-OFFICIAL-MAILBOX
Subject: Cottage Industry Manuals

UNIDO,

My name is Evan Myers, and I am a graduate student in Architectural Engineering at Kansas State University. I am currently researching for my master's report on *Structural Bamboo Design in East Africa*.

Through my research, I have found some of your work that I would like to include in my report. I am seeking your permission to use your work directly or as a reference for the original composition of my report. I would like to include the following materials:

1. Text and images from *Cottage Industry Manuals: Raw materials and tools for bamboo applications*. Joint venture with CFC and INBAR. (Copyright 2008).

Additionally, I welcome any other information you would like to provide on bamboo as a structural material. I appreciate your consideration and assistance, and look forward to your reply. Thank you.

Evan Myers

emyers89@gmail.com
(785)819-3106

REPLY:

Dear Evan Myers,

Good day!

You are welcome to use the information with due credit to UNIDO.

Best wishes

Ravindra Wickremasinghe (Mr.)
Advocacy and External Relations Assistant
Room D2116
Vienna International Centre
Wagramerstrasse. 5
A-1400, Vienna
Austria
www.unido.org

SENT:

On Jul 10, 2013, at 4:14 AM, "Evan Myers" <emyers89@gmail.com> wrote:

Dr. Bhavna Sharma,

My name is Evan Myers, and I am a graduate student in Architectural Engineering at Kansas State University. I am currently researching for my master's report on *Structural Bamboo Design in East Africa*.

Through my research, I have found some of your work that I would like to include in my report. I am seeking your permission to use your work directly or as a reference for the original composition of my report. I would like to include the following materials:

1. Text and images from your 2010 University of Pittsburgh Dissertation: *Seismic Performance of Bamboo Structures*.

Additionally, I welcome any other information you would like to provide on bamboo as a structural material. I appreciate your consideration and assistance, and look forward to your reply. Thank you.

Evan Myers

emyers89@gmail.com
(785)819-3106

REPLY:

Evan,

Thank you for your email. If I understand correctly, you would like to reference my dissertation? It is fine to reference the dissertation using the appropriate citations. I suggest you speak with your reasearch or academic advisor regarding this.

Bhavna

SENT:

From: Evan Myers [mailto:emyers89@gmail.com]
Sent: Friday, July 12, 2013 9:21 AM
To: Chung, Kwok-fai [CEE]
Subject: Citing Source

Professor Chung,

My name is Evan Myers, and I am a graduate student in Architectural Engineering at Kansas State University in the United States. I am currently working on my master's report on *Structural Bamboo Design in East Africa*.

Through my research, I have found some of your work that I would like to include in my report. I am seeking your permission to use your work directly or as a reference for the original composition of my report. Any sources authorized will be cited in the report based on APA formatting. I would like to include the following materials:

1. Text and images from your work with W.K. Yu in *Mechanical properties of structural bamboo for bamboo scaffoldings (2001).*

Additionally, I welcome any other information you would like to provide on bamboo as a structural material. I appreciate your consideration and assistance, and look forward to your reply. Thank you.

Evan Myers

emyers89@gmail.com
(785)819-3106

REPLY:

Thanks for your e-mail, and I have no objection to your request. I have copied your e-mail to r H C Ho, and he will provide your further information shortly.

Regards.

SENT:

-------- Original Message --------
Subject: Citing Source
From: Evan Myers <emyers89@gmail.com>
Date: Wed, July 10, 2013 4:47 am
To: info@kitilfarm.com

Hi,

My name is Evan Myers, and I am a graduate student in Architectural Engineering at Kansas State University. I am currently researching for my master's report on *Structural Bamboo Design in East Africa*.

Through my research, I have found some of your work that I would like to include in my report. I am seeking your permission to use your work directly or as a reference for the original composition of my report. I would like to include the following materials:

1. Text and images from your brochure, *Oxytenanthera Abyssinica (Solid Bamboo).*
2. Text and images from *Bamboo as an alternative source of energy*.

Additionally, I welcome any other information you would like to provide on bamboo as a structural material. I appreciate your consideration and assistance, and look forward to your reply. Thank you.

Evan Myers

emyers89@gmail.com
(785)819-3106

REPLY:

Dear Evan,

Your request to use material in www.kitilfarm.com for research in a master's report on *Structural Bamboo Design in East Africa,* is approved.

Please provide us with a copy of the report or its location on the internet once finalised.

Regards,

J. M. Njuguna

CEO, Kitil farm.

A solid solution to a solid problem, with the SOLID BAMBOO!!

Please come and discuss with us your bamboo investment needs.

Kitil Farm HQ, Isinya, Kajiando District

P.O.Box 762 00606 Sarit Centre, Nairobi, Kenya

Tel: +254 787456156, +254 753683129, +254 722729630, Fax: +254 2 02701803

E-mail: info@kitilfarm.com;

We have over 2 million bamboo seedlings, 30-60 cm tall and planted on internationally accepted media. Ready for local, regional and international markets.

Facebook https://twitter.com/kitilfarm

SENT:

From: Evan Myers [mailto:emyers89@gmail.com]
Sent: Friday, August 16, 2013 10:40 AM
To: Megan Sappenfield
Subject: Fwd: Sources

Hi,

My name is Evan Myers, and I recently contacted you(August 1, my original email was sent to an incorrect address). I am a graduate student in Architectural Engineering at Kansas State University. I am currently working on my master's report on *Structural Bamboo Design in East Africa*.

Through my research, I have found some of INBAR's work that I would like to include in my report. I am seeking INBAR's permission to use the work directly or as a reference for the original composition of my report. Any sources authorized will be cited in the report based on APA formatting. I would like to include the following materials:

1. Text and images from the INBAR Technical Report 20 (Copyright 2000)
2. Text and images from *Bamboo as a building material for meeting East Africa's housing needs: a value chain study from Ethiopia* (2011).

Additionally, I welcome any other information you would like to provide on bamboo. I am also trying to contact Dr. Jules Janssen and Dr. Oscar Antonio Arce-Villalobos in order to receive their permission as sources if they have any affiliation with INBAR. I appreciate your consideration and assistance, and look forward to your reply.

Attached are the images I would like to include in my report from INBAR Technical Report 20 and *Bamboo as a building material for meeting East Africa's housing needs: a value chain study from Ethiopia* (2011). The images titled Cement Grout and Amhara-Traditional East African

House would be used in the body of the report, while the others would be placed in the appendices for reference. Thank you for your help and have a great day.

Evan Myers

emyers89@gmail.com
(785)819-3106

REPLY:

Hi Evan,

I spoke with Oliver Frith, one of our staff members who does bamboo construction, and he said he already told you to use any material necessary as long as you cite it properly. Please go ahead as planned.

Thanks,
Megan

SENT:

Hi,

My name is Evan Myers, and I am a graduate student in Architectural Engineering at Kansas State University. I am currently
finish
ing my master's report on *Structural Bamboo Design in East Africa*.

Through my research, I have found your work that I would like to include in my report. I am seeking your permission to use your work directly or as a reference for the original composition of my report. Any reference used will receive proper APA citation.

I would like to include the following materials:

1. Image from *Earthquake Risk in Africa: Modified Mercalli Scale*.

Additionally, I welcome any other information you would like to provide on bamboo as a structural material. I appreciate your consideration and assistance, and look forward to your reply. Thank you.

Evan Myers

emyers89@gmail.com
(785)819-3106

REPLY:

Dear Evan,

Thank you for your inquiry.

OCHA is hereby granted non-exclusive rights subject to the conditions below to republish in master report entitled *Structural Bamboo Design in East Africa* the following OCHA map:

Earthquake Risk in Africa: Modified Mercalli Scale, December 2007
http://reliefweb.int/map/ethiopia/earthquake-risk-africa-modified-mercalli-scale-december-2007

The following conditions apply:

1. OCHA maps must be republished in their original form and cannot be modified without the express permission of OCHA. Modification includes, without limitation, removing, resizing, or otherwise altering a map's title, contents, legend, symbology, acknowledgements, attributions, or disclaimers. An OCHA map may be reduced in size at the discretion of the Requestor provided the original spatial proportions are maintained.

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3. The following disclaimer ("Disclaimer") is clearly readable on each page where a ReliefWeb map appears: "The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations". Should the Requestor reduce the size of the map so that the Disclaimer appearing in the map is no longer clearly readable, the text of the Disclaimer must be reproduced and appear alongside the map.

If you have any questions, please do not hesitate to contact us at maps@reliefweb.int.

Kind regards,
Dita Anggraeni

ReliefWeb Map Centre
maps@reliefweb.int

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