Schematic Design and Peer Review of

Gayaza Medical Center and Walk-In Clinic

Kampala, Uganda

For:
HIINGA, Uganda
and
Pyramid Technical Services, LTD

Submitted by:
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Fall 2022

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1. INTRODUCTION

The Gayaza Medical Center project aims to provide reliable full-service medical care to the region of northeast Kampala. The site for this construction is an empty 2.75 acre lot approximately 8 kilometers north of the city center, set in a largely residential area. The complex will serve as both an in-patient hospital with several operating rooms and as a walk-in clinic providing more minor or preventative medical attention. In addition to the utility of the final hospital, the project will also contribute to the local economy by employing and training local workers.

The project is funded by HIINGA, an impact fund that specializes in creating jobs and small businesses in the fields of healthcare, education, and agriculture in Eastern Africa. The Cal Poly students were initially brought on by the design team in Uganda to work on the preliminary architectural and structural design. Biweekly coordination meetings between the students and the Ugandan team ensured that the various project constraints were met.

This first design phase involved several major considerations that differed significantly than those that would apply to a similar structure in the United States. The design of the structure needed to be such that hospital services could remain largely uninterrupted, even in the event of a power outage or prolonged period of intense rain. The structural design also needed to maintain a level of simplicity that would make construction feasible for workers without previous extensive training. Finally, the material for both the architectural and structural components of the building were to be sourced locally as much as possible, decreasing the overall carbon footprint of the construction process and significantly reducing the cost of the project. In the United States, labor costs typically make up 40%-50% of the overall cost of construction, while in this area of Uganda that figure is typically half that (around 20%-30%). This discrepancy is due in part to relatively high wages in the United States, and in part to the notably high price of importing materials to Uganda. Utilizing as many locally-produced materials as possible, therefore, was the best way to keep the cost of the building as low as possible.

After the students' initial design was sent to the team in Uganda in the summer of 2022, the team working out of Uganda had changed, and the design of the medical complex evolved significantly. After consulting with the new engineer on the project, it was determined that the most useful work for the last several months of Cal Poly's involvement on the project would be to conduct a peer review of the structural design. This would consist of a computational analysis model of the structure, and an updated material take-off to be used for bidding purposes during construction.

While much of the work of this project was done in close coordination with the architecture and construction management students on the team, this report describes only the work of the structural engineering students through both phases of the design and peer review.

1.1 Project Information

Project	HIINGA Gayaza Medical Center
Location	Kampala, Uganda [0° 25’ 11.72” N 32° 36’ 2.06” E]
Owner	HIINGA, Uganda
Primary Architect	Joseph Kasimbi
Student Architect	Annebel van der Meulen
Engineer of Record	Pyramid Technical Services LTD.
Building Codes	2018 International Building Code ASCE 7-16 AISC 15th Edition TMS 402/602-16

Structural System Overview [Walk-In Clinic]

Gravity	Roof trusses Exterior masonry walls
Lateral	Reinforced masonry shear walls
Foundation	Slab-on-grade Shallow concrete foundations

Structural System Overview [Gayaza Medical Center]

Gravity	Steel beams Steel columns Concrete over metal deck roof and floor system
Lateral	Steel moment frames Concrete shear walls
Foundation	Slab-on-grade Shallow concrete foundations

1.2 Discussion of Structural Materials

Steel After a preliminary cost analysis of steel types and quantities was completed early in the project, it was determined that using large wide-flange steel members would be unnecessarily costly for a small building in Uganda, where labor is much less costly than in the United States. Instead, purchasing smaller tube members to construct trusses on-site would be far less expensive and would additionally further the goal of contributing to the local economy by providing a set of construction jobs for people in the community around the hospital.

In the updated medical center design, the size of the project had increased so significantly that the cost of larger members was outweighed by the design efficiency they brought.

Masonry To the same ends of reducing cost and utilizing local labor and materials, the initial plan for the construction of the walk-in clinic was to manufacture masonry units on site using a brick making machine from ZCJK Machinery Group (Fig. 01), and sand from local areas. The design strength of the bricks was not readily discernible, due in part to the high variability of sand that could be used for the bricks. An extra conservative strength design value of 10.2MPa (1500psi) was therefore used. The standard block dimensions are 390x190x190mm.

***Figure 01**. Proprietary Block Making Machine*

Concrete While commercial concrete will tend to have less variability in strength, international quality control standards may vary slightly. To account for this, and since this project is only in the preliminary design stages, a conservative estimate of 2500psi concrete was used wherever concrete elements were designed.

2. WALK-IN CLINIC

When the ARCE students joined the project Annebel van der Muelen, fourth year Architecture student, had begun the preliminary architectural design of the medical center (Figure 02) based on the community's needs and constraints. Such considerations as the use of local materials, design for frequent power outages, and design for heavy humidity and rainfall were incorporated into the design, to ensure the facility's operational success.

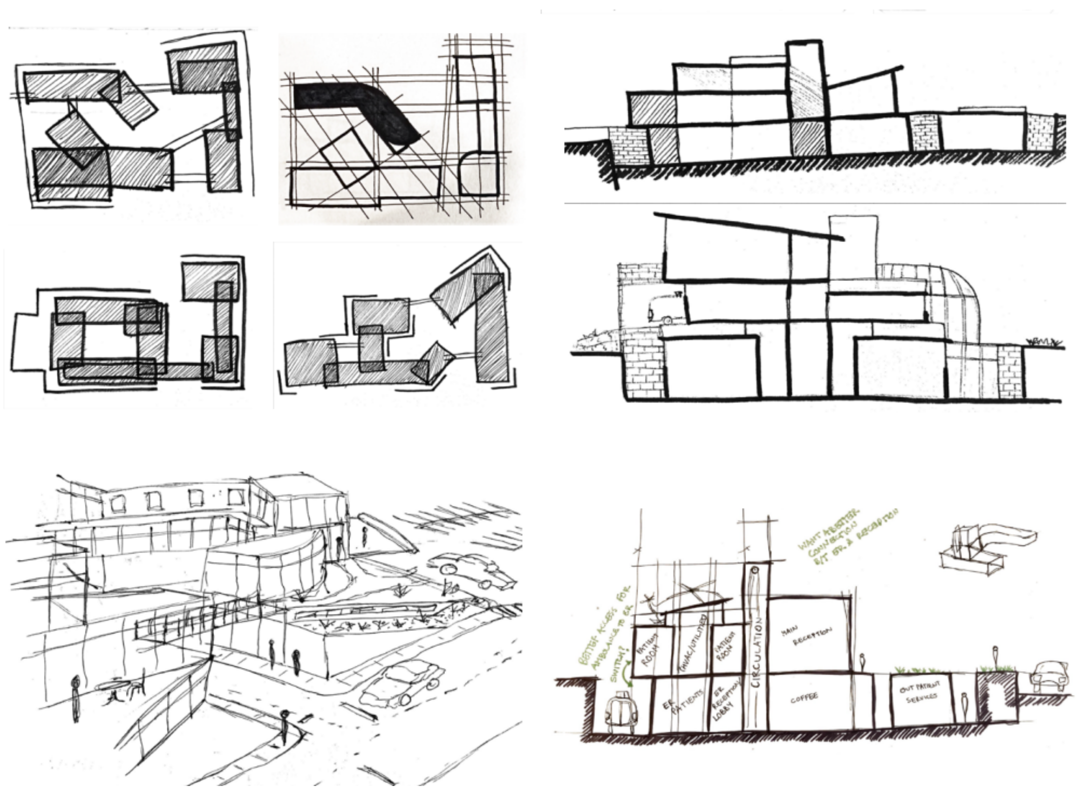


Figure 02. *Preliminary Designs by Architecture Student*

2.1 Design Process

Based on the community needs for a medical center and the complexity of the overall project, it was determined that a small walk-in clinic would be designed and built first (Fig 03). This building would then be operational as the rest of the medical center was constructed. The structural scope of the first phase of this project therefore consisted of the gravity and lateral systems of this building.

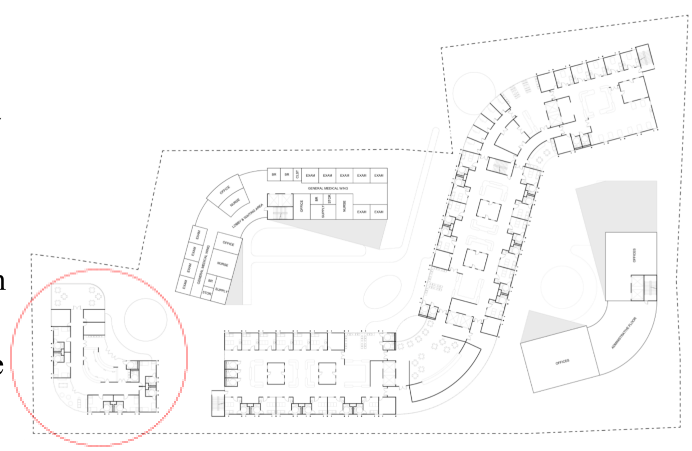


Figure 03. *Walk-In Clinic Located on Site Plan*

After further collaboration with the HIINGA team, the clinic took the L-shape design shown in Figure 04. While this is a relatively small, single-story structure, its design presented several unique coordination and structural challenges.

The most significant of these was the provisional program of the building. The temporary walk-in clinic had different code and design requirements from the eventual design of the psychiatric unit, as it pertained to room sizes, egresses, natural light, and layout. While the initial design goal was to create a space that would work for both of these facilities, it proved nearly impossible to do so without noticeable sacrifice in at least one of the architectural designs. Eventually, every interior structure was designed to be temporary and adaptable, so that the layout could evolve with the needs of the medical practitioners over time.

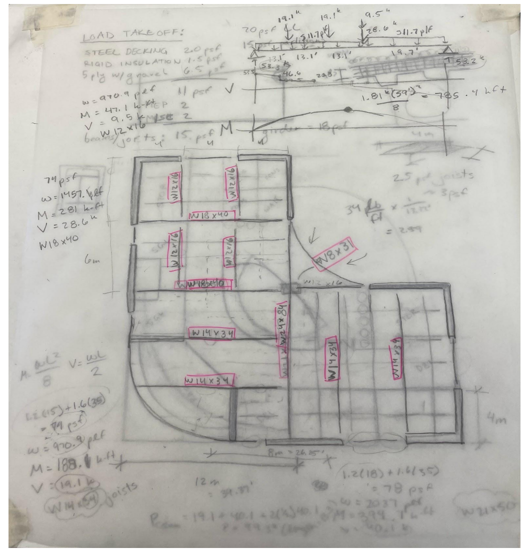


***Figure 04**. Initial Roof Framing*

To this end, only the exterior masonry walls and the roof system were to be used structurally. The initial gravity system was designed as a steel beam/girder system with shallow concrete foundations. Preliminary member sizes were developed by hand and initial coordination with the architect about shear wall placement began.

Shear wall placement, as is fairly common in industry, quickly became a nuanced coordination issue. Selecting locations that made the most sense structurally, while ensuring that the architectural requirements for natural light and egress were met, proved to be an involved process. The final placements, shown in red in Figure 05, kept the center of mass of the structure close to the center of rigidity, and allowed plenty of space for wall openings. The relative smallness of this structure, and the proportionally low forces facilitated this flexibility.

As coordination continued with both the architecture student on this project and the team in Uganda, a preliminary cost investigation concluded that a roof system consisting of long-span trusses made from smaller tube members would be less expensive than heavy wide-flange steel beams. Given that HIINGA focuses not only on the construction of new infrastructure in Africa, but also the development of local economies and workers, the on-site fabrication of roof trusses would also help to further the goal of providing jobs and training in the community.

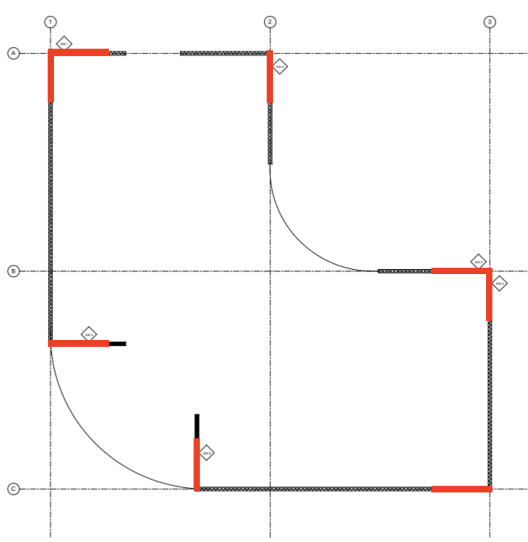


***Figure 05**. Final Shear Wall Placement*

2.2 Design Loads

The design loads for this building were determined based on ASCE 7-16, which is at least as conservative as the building code in effect at the site (IBC). For site-specific design values, equivalent sites in the United States (where more seismic and wind data is available) were used to derive approximate design values for this project.

2.2.1 Superimposed Gravity Loads [Per ASCE 7-16]

<u>Dead Load Take-Off</u>

Steel Deck	114.9 N/m^2
Rigid Insulation	71.8 N/m^2
Subtotal to Trusses	186.7 N/m^2
Trusses	129.3 N/m^2
Subtotal to Walls	**316.0 N/m^2**

<u>Live Load</u>

Roof Live Load = **957.6 N/m^2** [ASCE T. 4.3-1]

2.2.2 Seismic Design Values and Forces

Seismic design values were not readily available for Uganda using USGS maps, so a city in the U.S. with comparable distances to nearby earthquake faults was used to estimate these values. Gallup, Arizona was found to have had the most similar fault geography to Kampala.

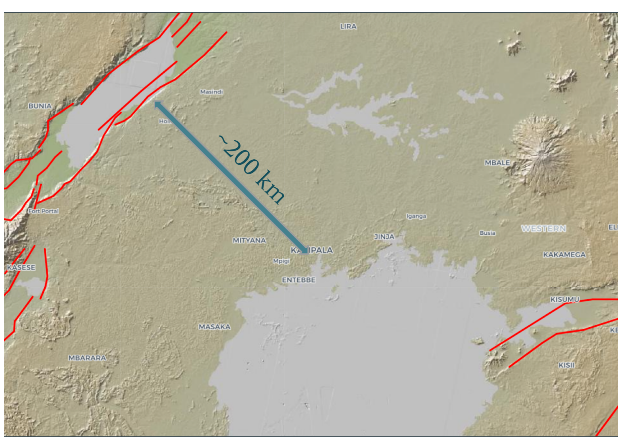


Figure 06*. Faults near Kampala, Uganda*

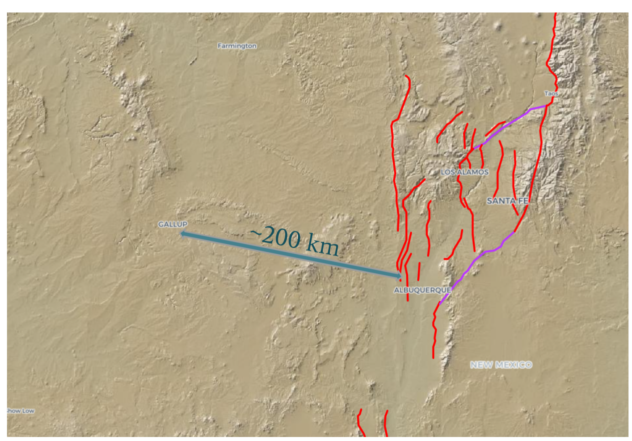


Figure 07*. Faults near Gallup, AZ*

Building Weight

The building weight calculation uses the values from the load take off in Section 2.2.1, and assumes a typical CMU weight of 23.6N/m^3 (150 pcf):

<u>Roof Weight</u>
432m^2 x 316 N/m^2 = 136.5 kN [§ 2.2.1]

<u>Wall Weight</u>
88m x 0.2034m x 3.5m x 23.6kN/m^3 = 1478.5 kN

Total Building Weight (W) = 1614.9 kN

Base Shear Calculation

The preliminary design base shear for the clinic was calculated using the requirements from ASCE Chapters 11 & 12. For seismic design category B [from Tables 11.6-1 & 11.6-2], it was determined that the ordinary masonry shear wall lateral system preferred by the architect was permitted [Table 12.2-1]. The structure had a reentrant corner irregularity as defined in Table 12.3-1, but no additional seismic detailing requirements were needed for a building with SDC B. Therefore, the derivation of the design base shear could continue according to the ELF procedure in ASCE Section 12.8.

<u>Seismic Load - Equivalent Lateral Force Procedure</u>

S_{DS} = 0.164 [USGS Seismic Maps, Appendix A]
S_{D1} = 0.083 [USGS Seismic Maps, Appendix A]
Ie = 1.25 [§ 11.5.1]
R = 2 [Table 12.2-1]
$C_s = S_{DS}\frac{Ie}{R} = 0.168\frac{1.25}{2} = 0.105$ [Eq. 12.8-2]

$V = C_s W$ = 0.105 (1614.9kN) = **169.6 kN** [Eq. 12.8-1]

The governing seismic design force on this structure was **169.6kN**, to be compared with the wind force calculated below in Section 2.2.3. The governing lateral load would then be used in the design of the lateral forces resisting system of the building.

2.2.3 Wind Design Forces

The team used the global wind atlas to determine that the wind conditions at this site are comparable to Monterey County, CA. The directional procedure from ASCE 7-16 Chapter 27 was used to determine the governing wind pressure.

<u>MWFRS Wind Loads for Buildings of All Heights - Directional Procedure</u>

Risk Category: III [T. 1.5-1]
Basic Wind Speed, V: 42.9 m/s^2 [Fig. 26.5-1]
Wind Load Parameters [Sec. 26.6 - 26.13]
$K_d = 0.85$
Exposure Category: B
$K_{zt} = 1.0$
$K_e = 0.86$
$G = 0.85$
Enclosure = Enclosed
$GCpi$ = +/- 0.18
Velocity Pressure Exposure Coefficient, $K_h = 0.57$ [T. 26.10-1]

Velocity Pressure, $q_h = 0.613\ K_z\ K_{zt}\ K_d\ K_e\ V^2$ [Eq. 26.10-1]
$= 0.631(0.57)(1.0)(0.85)(0.86)(42.9^2)$
$= 483.88$ N/m^2

External Pressure Coefficient, $C_N = 1.2$ [Fig. 27.3-4]

Wind Pressure, $p = qh\ G\ C_N$ [Eq. 27.3-1]
$p = 483.88$ N/m^2 (0.85) (1.2)
$\boldsymbol{p = 493.56}$ **N/m^2**

Governing Wind Force [Largest Wall Area]

Wall Area = 3m x 12m = 36m^2
Total Wind Pressure = 36m^2 x 493.56N/m^2 = **17.77 kN**

2.2.4 Governing Lateral Force

Based on the above analyses, the wind force would control the lateral system design for this building. The unfactored lateral design force was **169.6kN**.

2.3 Gravity System Design

As discussed in the design process overview, the main gravity system of this building was to consist of the roof truss system shown below. Since local labor was to be used in the construction of this process, and the goal was to employ even workers without extensive training, simplicity of constructability became key to design in this phase of the process. To facilitate this, the longest truss was designed, and the rest of the roof trusses would follow the same design.

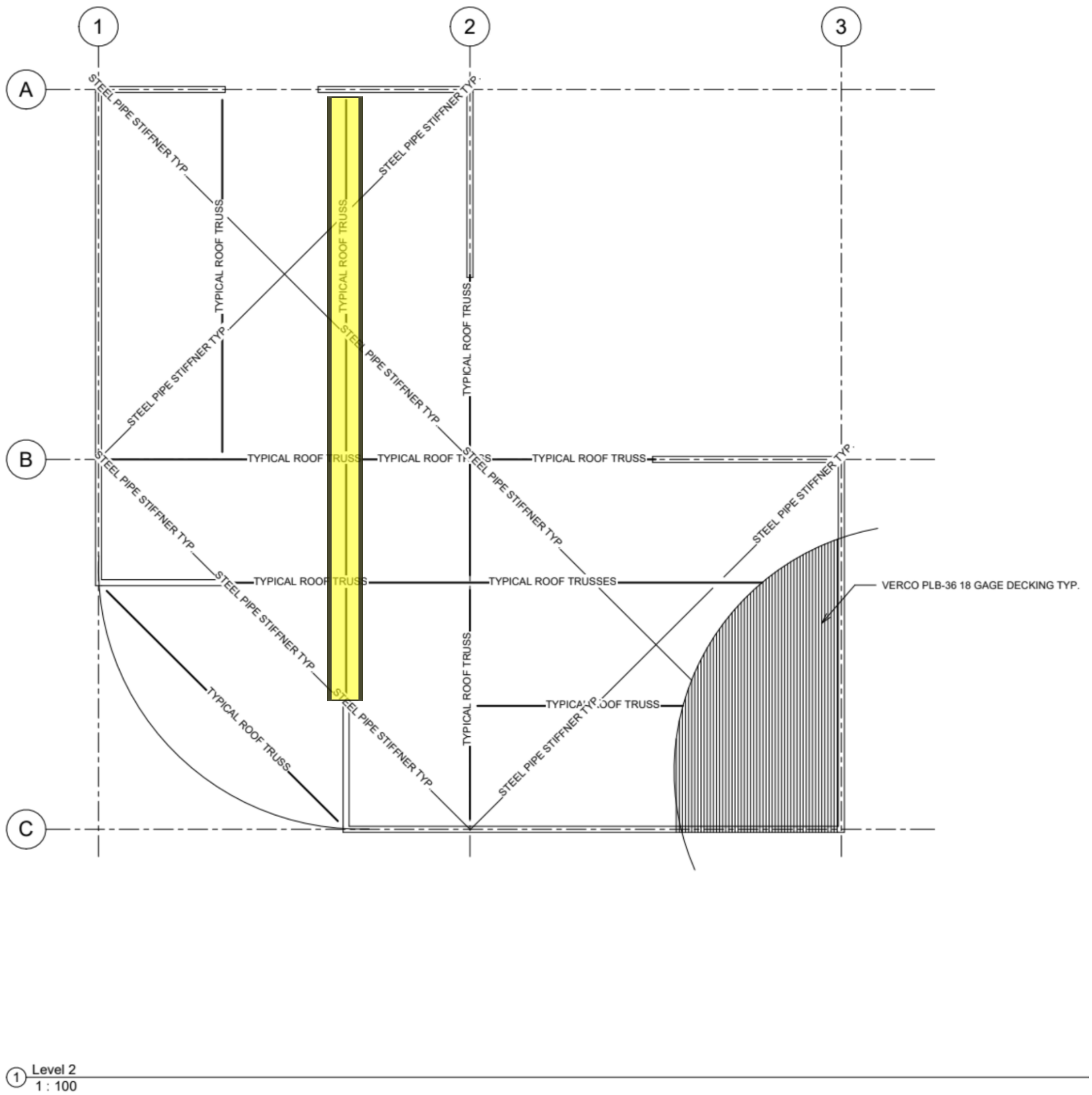


***Figure 08.**. Roof Framing Plan, Walk-In Clinic*

2.3.1 Roof Truss Design

The longest roof truss (highlighted in Figure 08) spans 20m. SAP2000 was used to design the truss members given the following load and geometry conditions. A simple Pratt truss design (Figure 09) was used to minimize construction error.

Unfactored Load Summary

Superimposed Dead Load = 186.7 N/m^2
Roof Live Load = 957.6 N/m^2

Factored Design Load [Controlling Load Combination]

$w_u = 1.2D + 1.6L_r$
$w_u = 1.2\ (186.7\ \text{N/m}^2)\ (3\text{m}) + 1.6\ (957.6\text{N/m}^2)\ (3\text{m})$
$w_u = 672.1\ \text{N/m} + 4596.6\ \text{N/m}$
$\boldsymbol{w_u = 5.27\ \textbf{kN/m}}$

Truss Analysis

After preliminary hand calculations proved the feasibility of this truss design, given the factored design loads, a more detailed analysis model in SAP2000 (Figure 10) was used to ensure the adequacy of the members, and to find the stresses in the connections that were to be designed. The Eurocode steel tube members sized below were determined to be small enough to handle without special equipment, and the finalized truss design is shown in Figure 09.

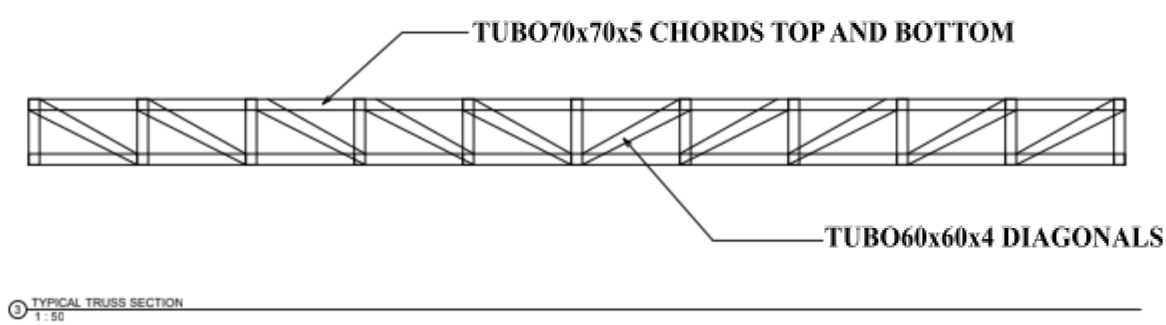
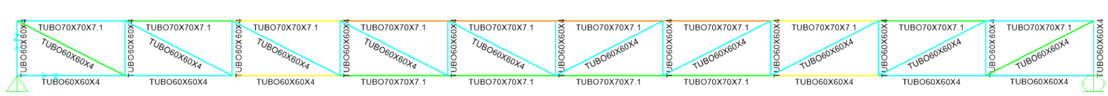


Figure 09. *Truss Geometry*



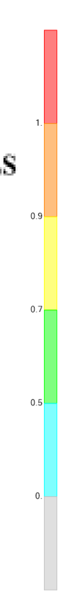


Figure 10. *Truss SAP2000 Analysis Model*

2.4 Lateral System Design

The main lateral force resisting system in this structure was 4 single-story masonry shear walls, shown in blue in Figure ZZ. The diaphragm consisted of roof trusses, with steel tube stiffeners on the diagonals.

2.4.1 Horizontal Lateral Force Distribution

Since the metal decking and truss system diaphragm could be idealized as flexible in accordance with ASCE Section 12.3.1.1, the horizontal lateral force distribution was simply found in accordance with relative lateral stiffness of the resisting elements [ASCE Section 12.8.4]. In this case, with all shear walls having equivalent stiffnesses, and the center of mass and center of rigidity being geometrically very close, the force to each shear wall could be closely approximated based on their tributary area, as in Figure 11. The relatively low forces on the building allowed that the shear wall reinforcement be utilize only a single rebar size, which again facilitates construction for workers without extensive experience.

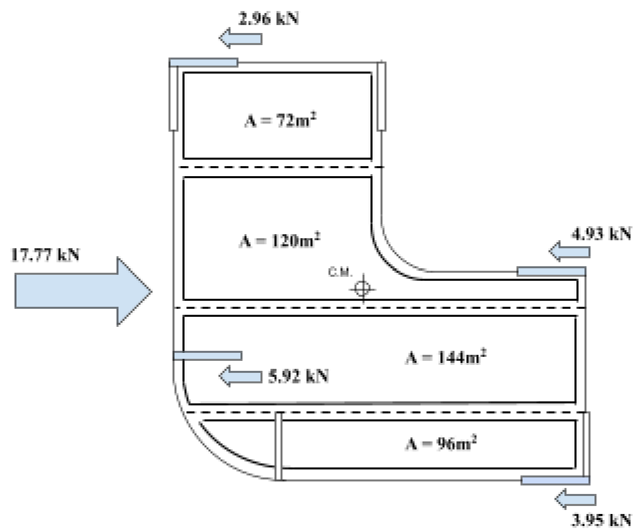


Figure 11. *Horizontal Lateral Force Distribution*

2.4.2 Ordinary Reinforced Shear Wall Design

<u>Design Assumptions</u>

Typical CMU Dimensions = 390mm x 190mm x 190mm
Typical CMU Strength, *f'm* = 10.2 MPa

<u>Unfactored Design Loads</u>

Distributed Dead Load, D = 186.7 N/m^2 x 4m = **0.747 kN/m**
Distributed Live Load, L_r = 957.6N/m^2 x 4m = **3.83 kN/m**
Governing Lateral Load, Wind, W = **17.77 kN**

Controlling Load Combinations

$w_u = 1.2D + 1.6L_r + 0.5W$
$w_u = 1.2(0.747) + 1.6(3.83)$
$\boldsymbol{w_u} \mathbf{= 7.02\ kN/m}$

$F_u = 0.9D + 1.0W$
$F_u = 1.0(17.77\text{kN})$
$\boldsymbol{F_u} \mathbf{= 17.77\ kN}$

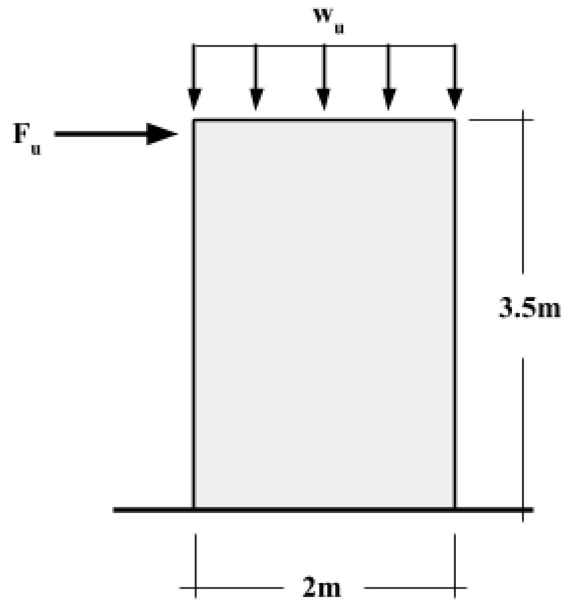


Figure 12. *Shear Wall Loading Diagram*

Design Loads

$\phi P_n = P_u$
$P_n = P_u / \phi = 7.02$ kN/m (2m) / 0.9
$\mathbf{P_n = 16\ kN}$

$V_n = V_u / \phi = 17.77 / 0.9$
$\mathbf{V_n = 19.74\ kN}$

$M_{OT} = V_n (l_u) = 19.74$ kN (3.5m)
$\mathbf{M_{OT} = 69.1\ kN\text{-}m}$

Minimum Rebar Requirements

$$A_{s,req} = \frac{0.8\, f'm\, b\, a - (Pu/\phi)}{fy}$$

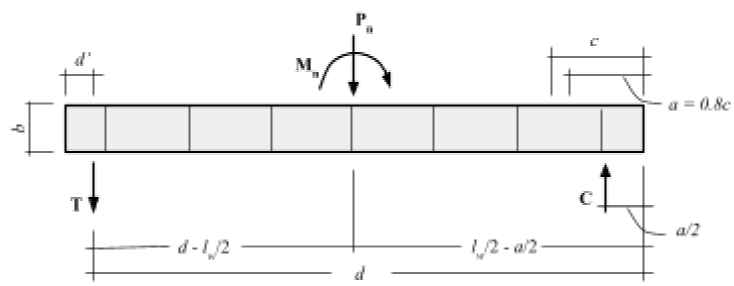


Figure 13. *Shear Wall Internal Force Diagram*

$f'm = 10.2$ MPa
$b = 203$ m
$Pu = 14.04$ kN
$Mu = 56$ kN-m
$fy = 413.7$ MPa
$d = 2\text{m} - 203\text{mm} = 1.797\text{m}$

$$a = d - \sqrt{d^2 - \frac{2(Pu(d-t/2)+Mu)}{\phi(0.8f'm)(b)}}$$

$$a = 1797mm - \sqrt{(1797mm)^2 - \frac{2(14040N(1797-203/2)+56x10^6}{\phi(0.8(10.2)(203)}}$$

$$a = 1797mm - 1763.5mm$$

$$a = 33.5mm$$

$$A_{s,req} = \frac{0.8\,(10.2\ MPa)(203mm)(33.5mm) - (19{,}740N)}{413.7\ MPa}$$

$$A_{s,req} = 86.4\ mm^2$$

Try (2) 16,0 bars at each end of wall.

Moment Capacity

$C - T = P_n = 0.8\, f'm\, b\, a - A_s f_y$

$a = \frac{Pn+Asfy}{0..8f'm\, b} = \frac{19.74kN+308mm2(413.8MPa)}{0.8(13.8MPa)(203mm)}$

$a = 65.7mm \Rightarrow c = 80.1mm$

$C = 0.8\,(13.8MPa)\,(203mm)\,(65.7mm) - (308mm2)\,(413.8MPa)$

$C = 19.79kN$

$M_n = T\,(d - l_w/2) + C\,(l_w/2 - a/2)$

$M_n = (308mm2)(413.8MPa)(1797 - 2000/2) + (19790N)(2000/2 - 65.7/2)$

M_n = 120,717.9 N-m

$\phi M_n = 0.9\,(120,717.9Nm) = 108.65\,kNm > M_u = 69.1kNm$ **O.K.**

Nominal Axial Strength

$r = \frac{1}{\sqrt{12}} t = \frac{1}{\sqrt{12}}(190mm) = 54.8mm$

$\frac{h}{r} = \frac{3.5m}{54.8mm} = 63.9$

$P_n = 0.8[0.8(f'm)(A_n - A_{st}) + f_y A_{st}](70\frac{r}{h})^2$

$P_n = 0.8[0.8(13.8MPa)(2000(190) - 308) + 413.8MPa(308)](70\frac{54.8}{3500})^2$

$P_n = 4146.5kN$

$\phi P_n = 3,731.8kN > P_u = 14.04kN$ **O.K.**

Nominal Shear Strength

$\frac{Mu}{Vdv} = \frac{56kNm}{17.77kN(2m)} = 1.58 > 1.0$ **O.K.**

Additional Reinforcing Requirements

Minimum Horizontal Reinforcement = 0.0007(190mm)(1000mm) = 133mm^2/m

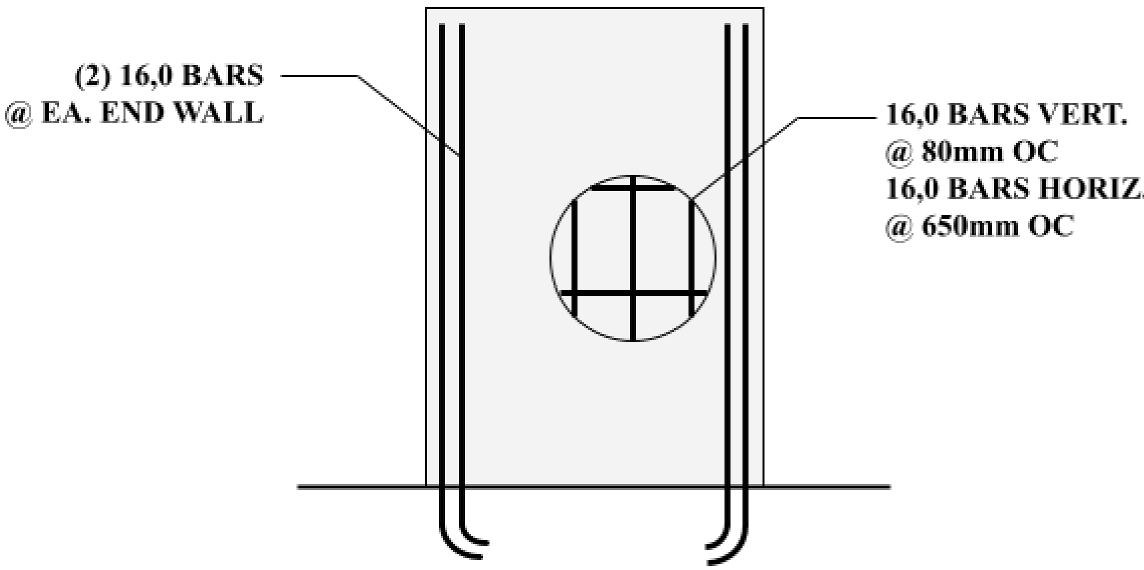
Maximum Spacing = $\frac{1}{3} l_w = \frac{1}{3}(2000mm)$ = 667mm ⇒ **Use 16,0 bars @ 650mm OC**

Minimum Vertical Reinforcement = 0.02(190mm)(1000mm) = 3800mm^2/m

Vertical Reinforcement Required = 3800mm^2 / 154mm^2 = **Use (25) 16,0 bars @ 80mm OC**

<u>Shear Wall Design Summary</u>

(2) 16,0 bars @ each end of wall
16,0 horizontal bars @ 650mm
16,0 vertical bars @ 80mm



2.5 Next Steps

Had this design scheme been taken all the way through construction, the subsequent steps for the structural team would have been to develop a complete diaphragm design, a more rigorous shear wall analysis and design, and a more detailed connection study of both the truss joints and their attachment to the masonry walls. The temporary partition walls would have also been designed, with the intent to facilitate their moving as the facility transitioned from the walk-in clinic to the psychiatric unit. A foundation system design was to have been completed, albeit in the absence of a detailed geotechnical report of the site conditions. As described in the following section, however, this design concept was suspended and work continued in a different direction.

3. GAYAZA MEDICAL CENTER

During the summer of 2022 several members of the team traveled to Uganda to visit the project site and meet the rest of the design team. At the time of the trip the design of the hospital remained largely consistent with the work done in the spring, but over the course of the next several months the design team in Uganda changed significantly. New budget constraints changed the scope and size of the project, and a new structural engineer was hired. The walk-in clinic was no longer to be a separate structure, and the whole complex would be constructed in a single phase. The new proposed design of the hospital is located on the site plan shown in Figure 14.

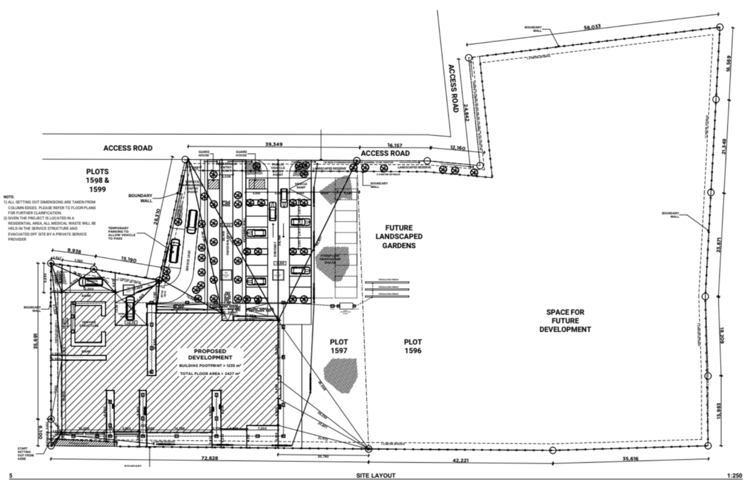


***Figure 14**. Updated Hospital Footprint Located on Site Plan*

3.1 Design Evolution

Given that much of the structural design decisions had already been made by the new team over the summer, it was proposed that the structural team from Cal Poly conduct a two-part peer review of the new building. The first piece was to build an ETABS model of the structure, and run it with preliminary design loads. This would give the engineering team a better sense of the structure's behavior, and indicate any areas in need of further structural development. The second was a material take-off of the initial design, which could be used for estimating the overall cost of the project, and later as a basis for bidding the job out to local contractors.

Over the course of fall quarter, the Cal Poly structural team were in regular contact with the architect and engineer in Uganda, and participated in the ongoing coordination meetings to stay apprised as the design evolved. Unfortunately, as the new hospital was to use exclusively steel construction and had changed so significantly in size and design, none of the work done previously was judged to be similar enough to be useful to the new design. Instead, the most current architectural model of the project (Figure 15) as well as the 50% permit set structural drawings were used as the basis for the peer review conducted by the Cal Poly team.

***Figure 15**. 3D View of Architectural Model*

3.2 Design Loads

This updated design was located at the same site as the previous clinic, so much of the seismic and wind design force calculations had already been completed using the same ASCE 7-16 procedures. Since the main purpose of this model was to act as a peer review, only a high-level estimate of the seismic and wind forces were calculated. The idea was that as the design advances the engineers in Uganda could use the model to run a more detailed dynamic analysis.

3.2.1 Superimposed Gravity Loads [Per ASCE 7-16]

Dead Load

Flooring, cladding, and other finishes was modeled in ETABS, instead of being added as superimposed loads.

Live Load

Roof Live Load = **957.6 N/m^2** [ASCE T. 4.3-1]
Worst-Case Hospital Floor Live Load = **3830.4 N/m^2** [ASCE T. 4.3-1]

3.2.2 Seismic Design Forces

All site-specific coefficients of seismic design were consistent from the previous structure's design. The differences affecting base shear on the building were the effective seismic weight of the structure, and any values that change with the ductility of a structure. The new design was far more flexible and much larger than the preliminary design, which resulted in new seismic design loads.

Building Weight

The building weight calculation in this case was done with ETABS. The model was run with only the self-weight of the members and no additional load cases to find the overall building weight to be used in design.

Total Building Weight, *W* = 789 tonf = 7861.6 kN

Base Shear Calculation

The same ELF procedure from Section 2.2.2 was used in this calculation, but since the main lateral force resisting system had changed from masonry shear walls to ordinary reinforced concrete shear walls, a new value for R was to be used. The checks for allowability as reported in Section 2.2.2 were run initially by the engineer in Uganda.

Ie = 1.25 [§ 11.5.1]
R = 4 [Table 12.2-1]
$C_s = S_{DS} \frac{Ie}{R} = 0.168 \frac{1.25}{4} = 0.0525$ [Eq. 12.8-2]

$V = C_s W$ = 0.0525 (7861.6kN) = **412.7 kN** [Eq. 12.8-1]

The governing seismic design force on this larger structure was **412.7kN**, to be compared with the wind force calculated below in Section 3.2.3. The governing lateral load was then compared to those derived by the engineering team in Uganda, and used in the design of the lateral forces resisting system of the building.

3.2.3 Wind Design Forces

As with the seismic design, much of the wind design force calculations remained the same from section 2.2.3, with only the increased surface area of the building affecting the overall wind design load.

Wind Pressure, ***p* = 493.56 N/m^2** [Section 2.2.3]

Governing Wind Force [Largest Wall Area N/S]

Wall Area = 49.5m x 10m = 495m^2
Total Wind Pressure = 495m^2 x 493.56N/m^2 = **244.3 kN**

3.2.4 Governing Lateral Force

Based on the above analyses, the seismic force controlled the lateral system design for this building. The unfactored lateral design force was **412.7kN**.

3.3 PEER REVIEW ETABS ANALYSIS

The purpose of constructing an analysis model for this structure was to provide both a check of the existing design, as well as a more detailed understanding of how the building will behave when loaded. Where weaknesses in the design were found, high-level solutions were proposed to the design team in Uganda.

3.3.1 ETABS Model

The structural drawings provided by the engineer of record showed a design that was fairly structurally irregular. The footprint of the building (Figure 16) had significant geometric torsion, and several locations where lateral force transfer was interrupted, such as on the south side of the building in Figure 16. This, along with the ramp in the northwest corner of the building, which was an architectural accommodation for transporting patients and equipment between floors in the event of a power outage, presented interesting modeling challenges.

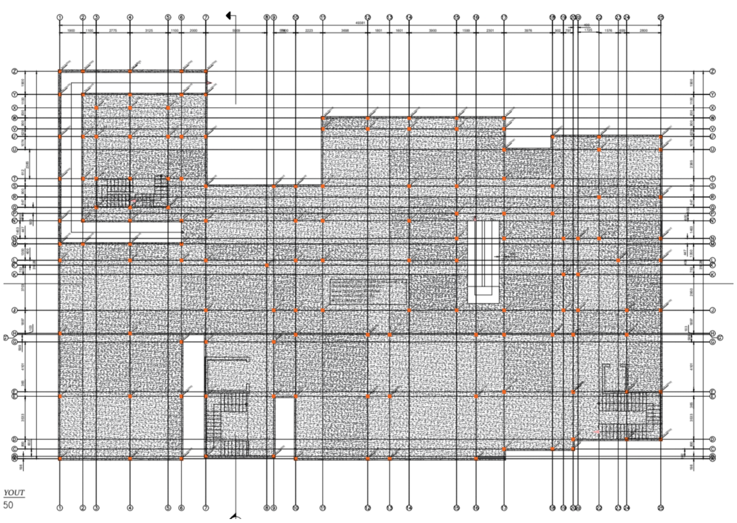


Figure 16. *Slab-On-Grade Plan*

As with all analysis software, ETABS requires a high level of precision and coordination in order to run effectively. For a building with such a complex shape as this one, any small imprecision in one location often gets proliferated throughout and can easily lead to a failure of the softwares ability to run.

After modeling the geometry of each level (see Appendix B for detailed ETABS inputs and results), each member and shell component was assigned their respective material and shape properties using ETABS' built-in European standard shapes and materials.

The seismic loads were vertically distributed between stories according to ASCE Section 12.8.3 (see Appendix B3), and at each level were idealized as a distributed load across the entire slab area of each floor. This loading would give a good preliminary understanding of the structure's behavior and adequacy, and after the team in Uganda finalized the design the model could be used to run a non-linear analysis of the structure. The model was loaded with unfactored gravity and lateral loads, and the controlling load combinations were determined from ETABS' steel design load combinations. These are built into the program directly from ASCE 7-16, and when checked against a hand-calculated estimate of the controlling load, the result given by ETABS was indeed within 5% of the expected.

3.3.2 Lateral System Failure and Proposed Solution

Upon running the model, it was determined that while the gravity system was adequate from a strength perspective, the lateral system was not sufficiently robust to sustain the design loads. The lateral force resisting system consisted entirely of two concrete elevator pits in the SE and SW corners of the building (shown in red in Figure 18). In the EQy (N/S) direction of loading, these two points of lateral system were relatively symmetrical, and therefore did not cause extreme torsion. The displacements in the N/S direction did exceeded the code-defined drift limits, however, and will need to be revised in a similar manner to the solution provided below for the E/W direction.

In the EQx direction, the model showed torsion that would be far worse than the structure could realistically handle. Displacements of up to several meters at various joints suggest a critical failure of the lateral system. As shown in Figure 19, the two points of lateral resistance fall along the same line when loaded in the E/W direction, leaving the geometric distance between the center of mass and the center of gravity relatively large, and resulting in significant torsion. The simplest solution to this is the addition of lateral resistance elements at the lines shown on the right hand side of Figure 19. The addition of steel braces at these locations would bring the center of stiffness much closer to the center of mass, thereby both reducing the torsion experienced by the structure and reinforcing the overall lateral strength of the structure.

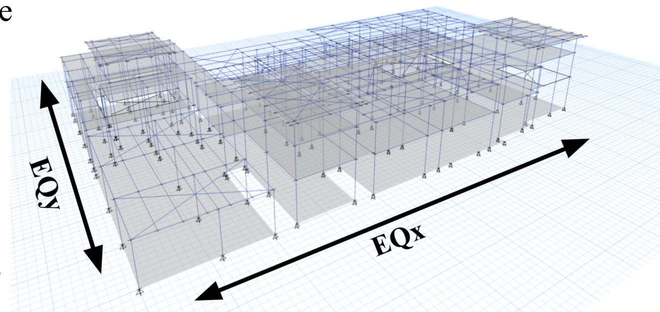


***Figure 17**. 3D View of ETABS Model*

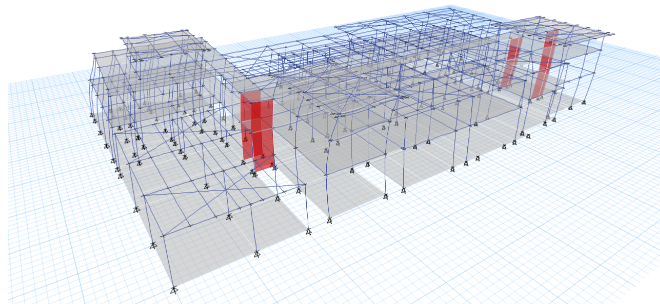


***Figure 18**. Deflection in the EQx Direction*

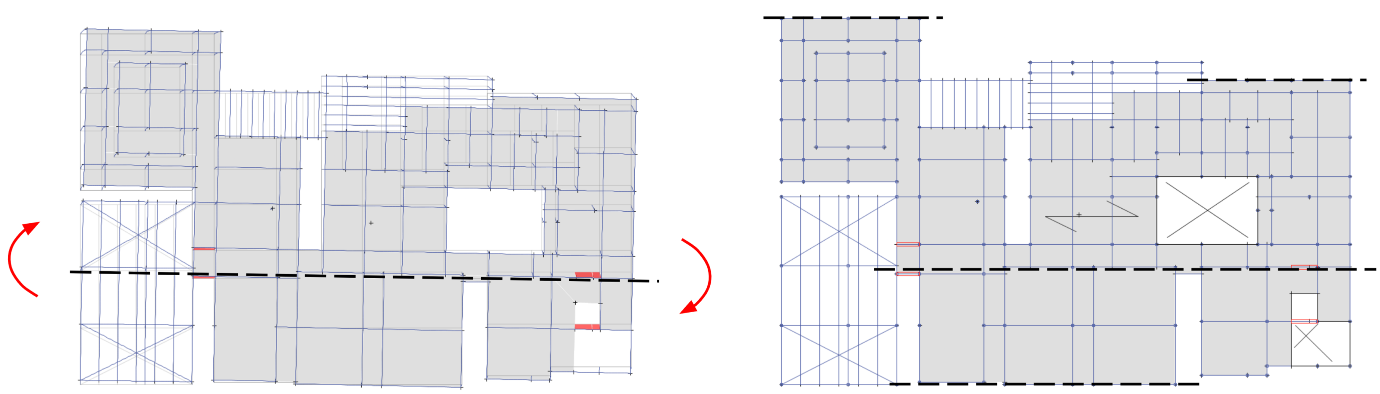


***Figure 19.** Second Floor Plan View Before and After Proposed Lateral Additions*

3.4 Material Estimate

As part of the peer review, a take-off of structural materials to be used for the new design was calculated. These totals are to be used for contracting and bidding purposes. The structural layouts and member sizes provided by the Ugandan engineers were used to calculate the quantities of steel and concrete; no members from the proposed additional structural solutions were included in this estimate. For steel members, member lengths were tallied and multiplied by the weight per linear foot for the given material. For concrete, the volume was calculated given the dimensions from the plans. The overall total quantities of the materials are provided below, and the full breakdown of the calculations are provided in Appendix D.

Totals of Materials:

59,960 kg of steel

364.5m^3 of concrete

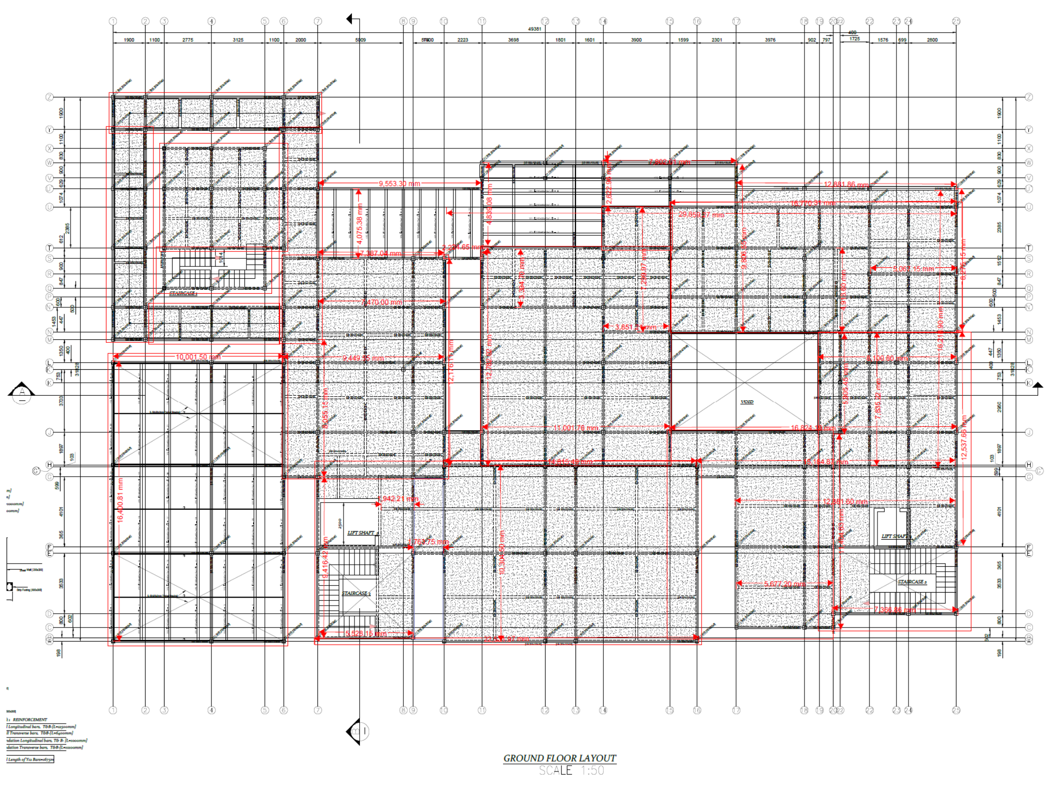


Figure 20. *Red Lined Structural Plans*

4. CONCLUSION & REFLECTION

Working on the Gayaza Medical Center gave us a sense of how a holistic, interdisciplinary design process happens in practice, and of some of the complexities that come with that. Throughout the project, the coordination between the architecture and engineering teams shaped not only the structures' design, but the materiality and the timeline of the construction. The project's dramatic evolutions required us to develop a level of adaptability that went far beyond what our undergraduate courses required of us.

During the first phase of the project, the most significant learning came from integrating the architectural design with our engineering intuition for maximizing structural efficiency. Considering building code requirements for windows and doors is rarely, if ever, part of the curriculum in our structural systems classes, synthesizing these new constraints with what we already knew about structural efficacy presented an interesting new kind of problem-solving.

Reducing the cost and complexity of the structural system also led to a set of constraints that were unfamiliar to us. Finding or estimating the strengths of locally sourced materials required independent research and communication with experts in Uganda. Doing this analysis with a set of units that were largely unfamiliar to us initially proved challenging, since we lacked any kind of baseline sense of material strengths or quantities in these units. Over the course of the project, we found that this skill developed significantly, to the point where in coordination meetings near the end of the project we were able to fluently discuss material properties and sizes with metric units and standard European sizes.

Creating a structural design using repetitive member sizes as much as possible served the dual purpose of reducing overall cost and facilitating construction for workers new to the construction process. Replacing heavy steel beams, for instance, with lighter steel tube sections meant that small teams of builders would be able to construct and install trusses by hand, without the use of expensive machinery which often requires certification. This philosophy also came into play in the design of the masonry shear walls, where the spacing of the rebar was adjusted so that bars of the same size could be used throughout.

From design coordination to strategizing how best to accomplish HIINGA's community goals, the architecture and engineering teams in Uganda were invaluable to our learning and success in this project. The process of developing the structural system for this hospital, while consistently maintaining the community needs at the forefront of our decision making, expanded our understanding of the work of structural engineering and illustrated to us the growth that can happen through close interdisciplinary work.

Appendix A

USGS Seismic Design Maps Results

Search for Address or Coordinates

Reference: ASCE 7-16 | Risk Category: III | Site Class: D - Default (See Section 11.4

Project Title (optional) | Address | Coords | Gallup, AZ | Go

Gallup, NM, USA

Latitude, Longitude: 35.5280783, -108.7425843

Print

Date	12/15/2022, 3:49:32 PM
Design Code Reference Document	ASCE7-16
Risk Category	III
Site Class	D - Default (See Section 11.4.3)

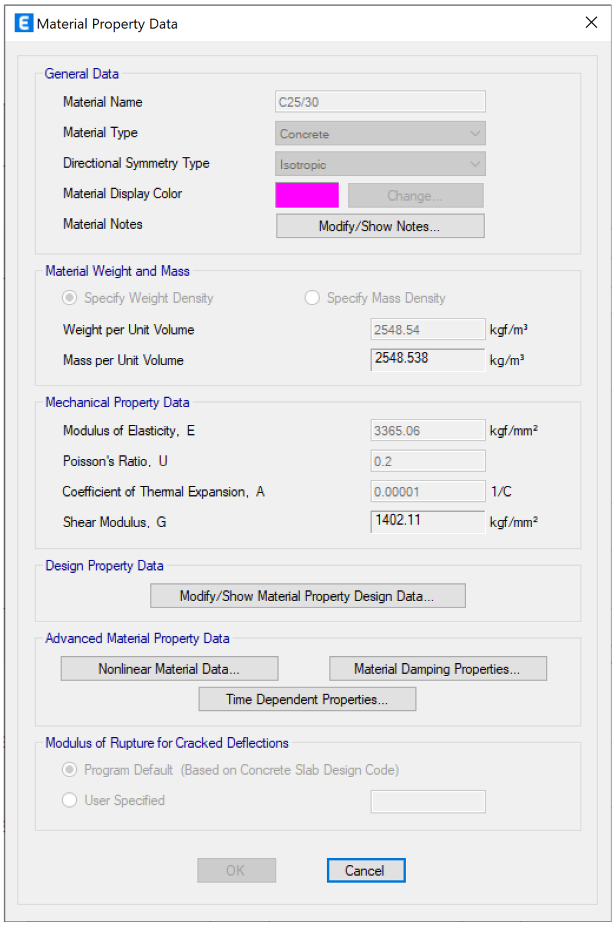
Type	Value	Description
S_S	0.153	MCE_R ground motion. (for 0.2 second period)
S_1	0.052	MCE_R ground motion. (for 1.0s period)
S_{MS}	0.245	Site-modified spectral acceleration value
S_{M1}	0.125	Site-modified spectral acceleration value
S_{DS}	0.163	Numeric seismic design value at 0.2 second SA
S_{D1}	0.083	Numeric seismic design value at 1.0 second SA

Appendix B

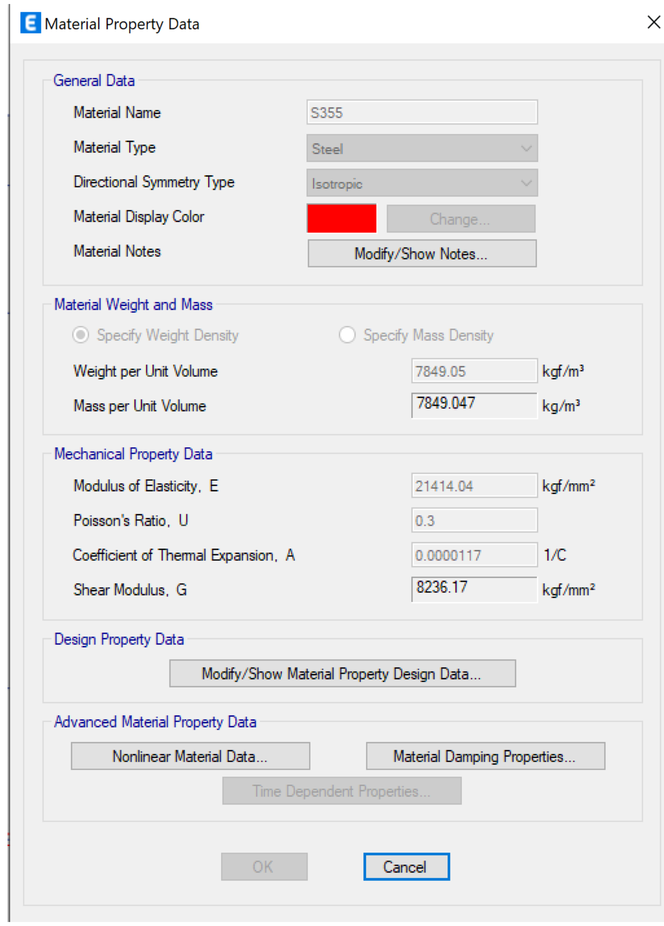
Detailed ETABS Inputs and Outputs

INPUTS

B1 - Material Properties

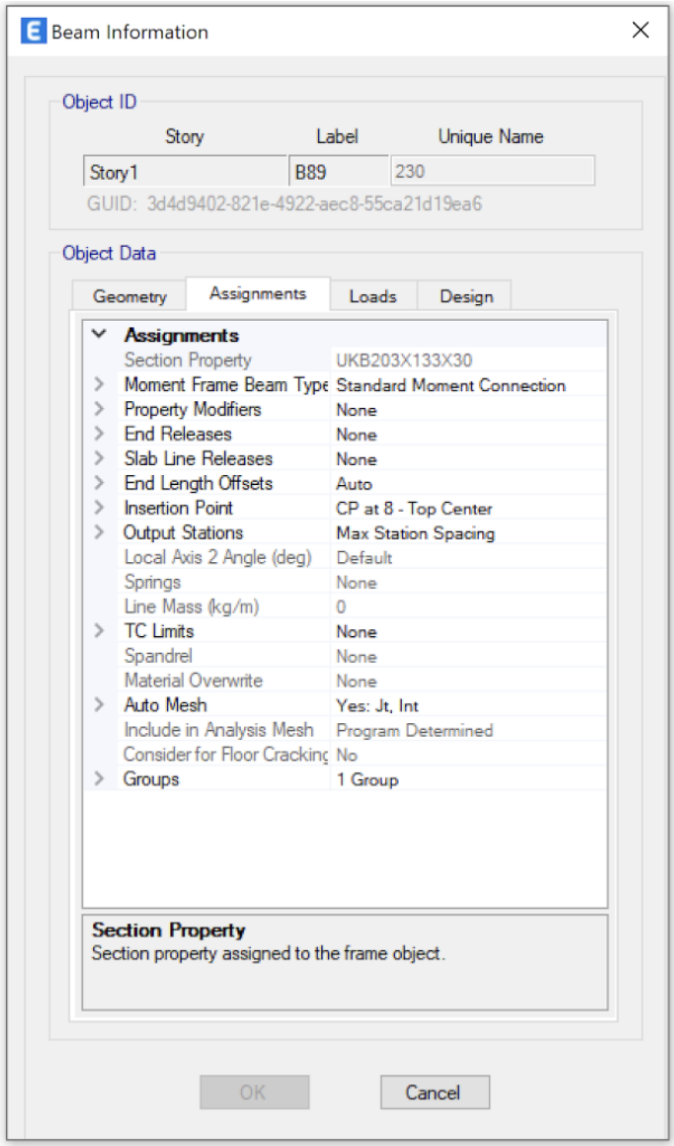


Concrete Material Property



Steel Material Property

B2 - Section Properties

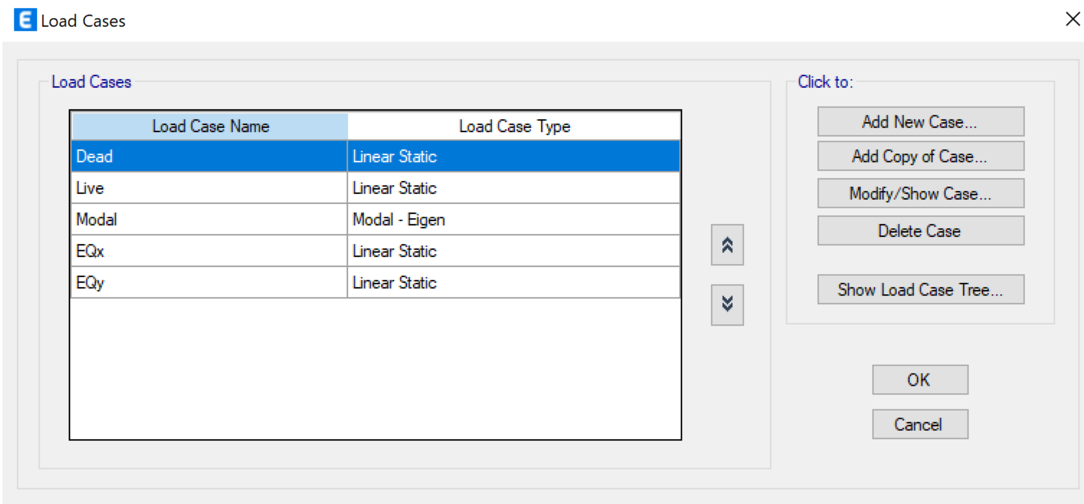


Most Common Beam Size Section Properties per ETABS Default

TABLE: Program Control											
ProgramName	Version	ProgLevel	LicenseNum	CurrUnits	StlFrmCode	CompBmCode	CompColCode	StlJstCode	ConcFrmCode	ConcSlbCode	ShrWallCode
ETABS	20.1.0	Ultimate	2008-*1SEBJE588B2UREH	N, mm, m	Eurocode 3-2005	Eurocode 4-2004	AISC 360-16	SJI-2010	Eurocode 2-2004	Eurocode 2-2004	Eurocode 2-2004

ETABS Code Settings

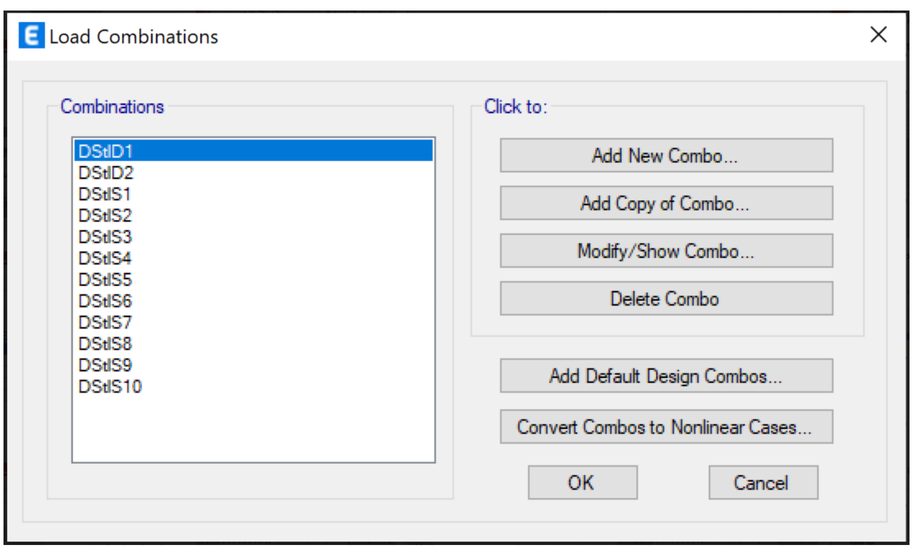
B3 - Loading



Load Cases

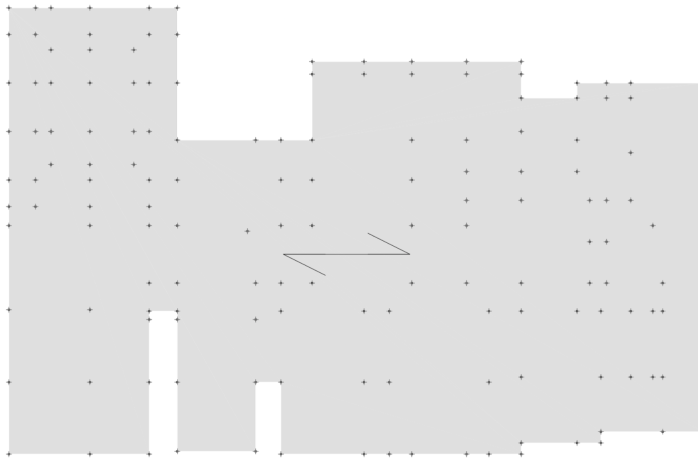
Floor	Height (m)	Weight (kN)	wx hx	Fx (kN)
Roof	10	628.9	6289	65.4
Second	7	2751.6	19261.2	200.2
First	4	3537.7	14150.8	147.1
		$\sum w_i h_i =$	39701	

Vertical Load Distribution of Seismic Forces

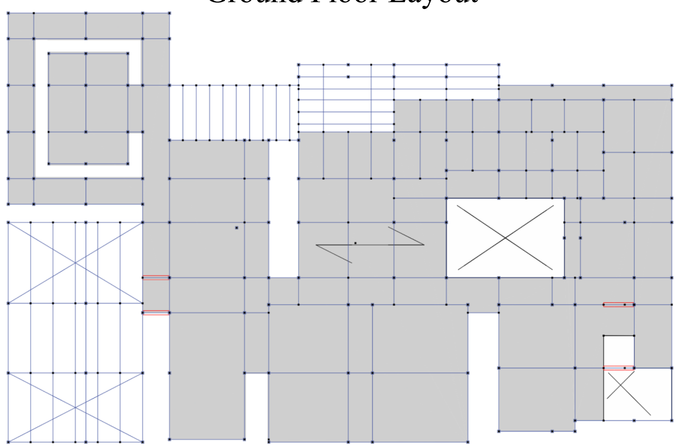


Steel Design Load Combinations from ETABS' Built-In Function

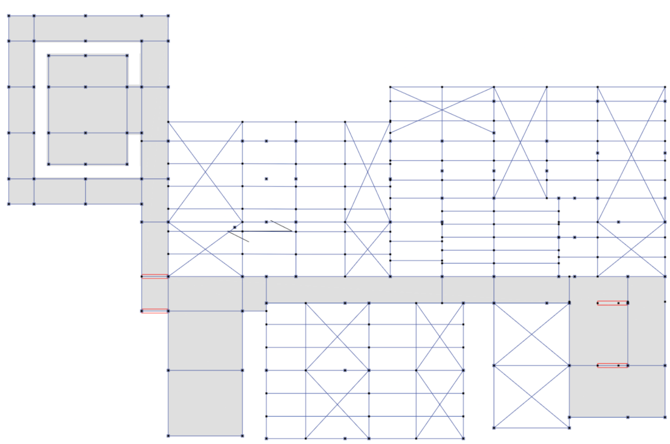
B4 - ETABS Structural Plan View



Ground Floor Layout



Second Floor Layout



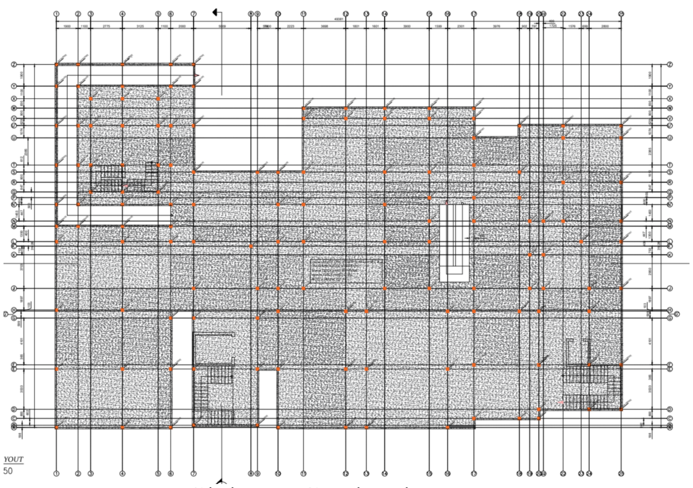
Third Floor Layout

B5 - Maximum Joint Deflection Values For Select Joints

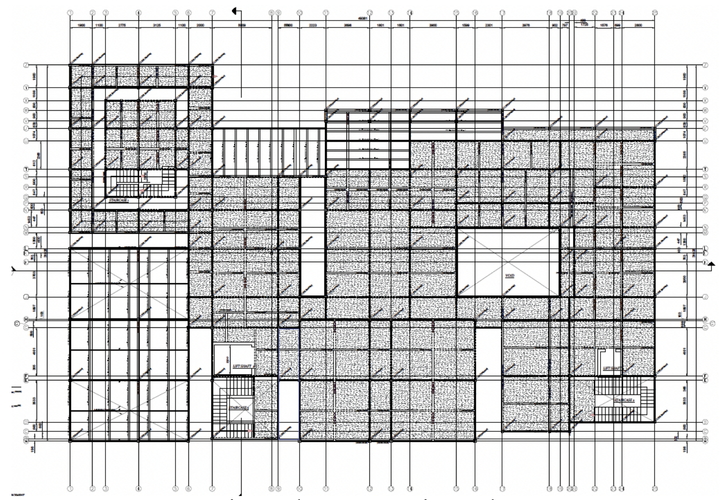
TABLE: Joint Displacements												
							mm	mm	mm	rad	rad	rad
Story	Label	Unique Name	Output Case	Case Type	Step Type	Step Number	Ux	Uy	Uz	Rx	Ry	Rz
Story2	63	498	DStlS2	Combination			-3.55E+03	8.21E+01	-0.439	0.000042	-0.012265	0.000005
Story2	63	498	DStlD2	Combination			-2.47E+03	5.71E+01	-0.306	0.00003	-0.008538	0.000003
Story3	409	699	DStlS4	Combination			-5.87E+03	-1.44E+02	1.741	0.003548	0.000016	0.000228
Story3	376	688	DStlS4	Combination			-5.86E+03	-1.83E+02	-0.481	-0.000614	-0.000361	0.000218
Story3	401	691	DStlS4	Combination			-5.86E+03	-1.95E+02	-0.168	0.0005	-0.000367	0.000213
Story3	411	701	DStlS4	Combination			-5.86E+03	-9.52E+01	1.948	0.004002	0.000164	0.000213
Story3	405	695	DStlS4	Combination			-5.86E+03	-5.70E+01	-0.409	-0.000636	-0.000396	0.00021
Story3	407	697	DStlS4	Combination			-5.86E+03	-4.64E+01	0.288	0.000445	-0.000391	0.00021
Story3	409	699	DStlS8	Combination			-5.85E+03	-1.57E+02	0.818	0.001785	0.000035	0.000224
Story3	376	688	DStlS8	Combination			-5.84E+03	-1.96E+02	-0.259	-0.000197	-0.00036	0.000214
Story3	411	701	DStlS8	Combination			-5.84E+03	-1.09E+02	0.992	0.002142	0.000141	0.000213
Story3	401	691	DStlS8	Combination			-5.84E+03	-2.07E+02	-0.246	0.000251	-0.000364	0.000209
Story3	405	695	DStlS8	Combination			-5.84E+03	-7.06E+01	-0.188	-0.000223	-0.000379	0.000211
Story3	407	697	DStlS8	Combination			-5.84E+03	-6.01E+01	0.213	0.000218	-0.000376	0.000209
Story3	12	641	DStlS4	Combination			-5.75E+03	-1.83E+02	-0.238	-0.000037	-0.000361	0.000211
Story3	374	686	DStlS4	Combination			-5.75E+03	-1.95E+02	-0.442	0.000662	-0.000367	0.000209
Story3	14	649	DStlS4	Combination			-5.75E+03	-5.70E+01	-0.155	-0.000061	-0.000396	0.000206
Story3	375	687	DStlS4	Combination			-5.75E+03	-4.64E+01	0.044	0.000597	-0.000391	0.000208
Story3	13	648	DStlS4	Combination			-5.75E+03	-1.23E+02	-0.101	0.000059	-0.000218	0.000218
Story3	12	641	DStlS8	Combination			-5.74E+03	-1.96E+02	-0.181	-0.000012	-0.00036	0.000208
Story3	14	649	DStlS8	Combination			-5.74E+03	-7.06E+01	-0.097	-0.000039	-0.000379	0.000205
Story3	374	686	DStlS8	Combination			-5.74E+03	-2.07E+02	-0.382	0.000321	-0.000364	0.000206
Story3	375	687	DStlS8	Combination			-5.74E+03	-6.01E+01	0.094	0.000286	-0.000376	0.000207
Story3	13	648	DStlS8	Combination			-5.73E+03	-1.36E+02	-0.07	0.000052	-0.000217	0.000215
Story3	17	642	DStlS8	Combination			-5.25E+03	-1.96E+02	-0.4	0.000001	-0.000257	0.000211
Story3	372	684	DStlS8	Combination			-5.25E+03	-2.07E+02	-0.546	0.00052	-0.000263	0.000202
Story2	6	419	DStlS4	Combination			-4.99E+03	1.02E+01	-0.144	0.000347	-0.000339	0.000205
Story2	5	418	DStlS4	Combination			-4.99E+03	-3.05E+01	-0.096	-0.000202	-0.00019	0.000202
Story2	3	417	DStlS4	Combination			-4.99E+03	-1.15E+02	-0.09	0.00001	-0.000344	0.000197
Story2	2	360	DStlS4	Combination			-4.99E+03	-1.91E+02	-0.178	0.000614	-0.000144	0.000196
Story2	1	355	DStlS4	Combination			-4.99E+03	-2.28E+02	-0.064	0.00024	-0.000297	0.000197
Story2	6	419	DStlS8	Combination			-4.99E+03	-3.70E+00	-0.096	0.000225	-0.000352	0.000201
Story2	5	418	DStlS8	Combination			-4.98E+03	-4.36E+01	-0.08	-0.00016	-0.0002	0.000198
Story2	2	360	DStlS8	Combination			-4.98E+03	-2.02E+02	-0.117	0.00047	-0.000155	0.000195
Story2	3	417	DStlS8	Combination			-4.98E+03	-1.27E+02	-0.068	0.000059	-0.000335	0.000195

Appendix C

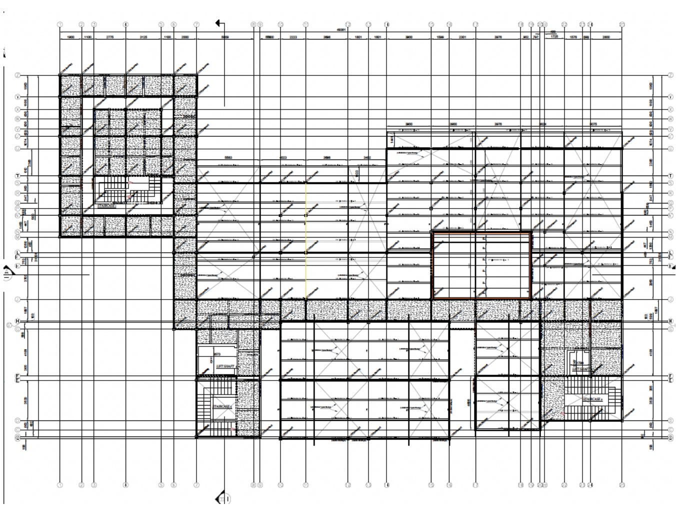
Structural Plans from Pyramid Technical Services LTD.



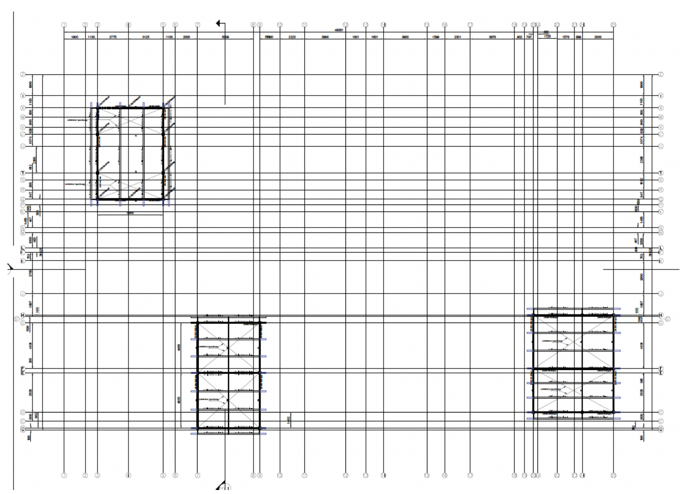
Slab-on-Grade Plan



First Floor Framing Plan



Second Floor Framing Plan



Roof Framing Plan

Appendix D

Structural Material Take-Off Full Calculations

Structural Cost Estimate

Steel Total									
Member		Dims	Quantity	Lenth (m)	Amount of Material (mm^3	Amount of Material (m^3)	Weight (kg)		
Columns	Steel	200x200x5x7498.08	145	1087.21	2690844750	2.69084475	21123.13129		
Beams									
Member	Length (mm)	Length (m)	Weight (kg)		Member	Length (mm)	Length (m)	Weight (kg/m)	Weight (kg)
203x133x30	12000	12	360		203x133x31	9460	9.46	30	283.8
203x133x30	12000	12	360		203x133x31	9460	9.46	30	283.8
203x133x30	1900	1.9	57		203x133x31	5705	5.705	30	171.15
203x133x30	1900	1.9	57		203x133x31	5705	5.705	30	171.15
203x133x30	1900	1.9	57		203x133x31	5705	5.705	30	171.15
203x133x30	1900	1.9	57		203x133x31	1790	1.79	30	53.7
203x133x30	1900	1.9	57		203x133x31	37710	37.71	30	1131.3
203x133x30	1900	1.9	57		203x133x31	37710	37.71	30	1131.3
203x133x30	1900	1.9	57		203x133x31	7430	7.43	30	222.9
203x133x30	3459	3.459	103.77		203x133x31	2610	2.61	30	78.3
203x133x30	3459	3.459	103.77		203x133x31	2610	2.61	30	78.3
203x133x30	1900	1.9	57		203x133x31	2610	2.61	30	78.3
203x133x30	1900	1.9	57		203x133x31	1925	1.925	30	57.75
203x133x30	3459	3.459	103.77		203x133x31	1925	1.925	30	57.75
203x133x30	3459	3.459	103.77		203x133x31	1925	1.925	30	57.75
203x133x30	1900	1.9	57		203x133x31	1925	1.925	30	57.75
203x133x30	1900	1.9	57		203x133x31	1925	1.925	30	57.75
203x133x30	1900	1.9	57		203x133x31	1925	1.925	30	57.75
203x133x30	1900	1.9	57		203x133x31	1925	1.925	30	57.75
203x133x30	1900	1.9	57		203x133x31	1925	1.925	30	57.75
203x133x30	3459	3.459	103.77		203x133x31	1925	1.925	30	57.75
203x133x30	3459	3.459	103.77		203x133x31	1925	1.925	30	57.75
203x133x30	1900	1.9	57		203x133x31	1925	1.925	30	57.75
203x133x30	1900	1.9	57		203x133x31	8685	8.685	30	260.55
203x133x30	12274	12.274	368.22		203x133x31	8685	8.685	30	260.55
203x133x30	12274	12.274	368.22		203x133x31	4680	4.68	30	140.4
203x133x30	1900	1.9	57		203x133x31	790	0.79	30	23.7
203x133x30	1900	1.9	57		203x133x31	7231	7.231	30	216.93
203x133x30	1900	1.9	57		203x133x31	7231	7.231	30	216.93
203x133x30	1900	1.9	57		203x133x31	7231	7.231	30	216.93
203x133x30	1900	1.9	57				0	30	0
203x133x30	1900	1.9	57		203x133x31	16775	16.775	30	503.25
203x133x30	1900	1.9	57		203x133x31	16775	16.775	30	503.25
203x133x30	1900	1.9	57		203x133x31	20710	20.71	30	621.3
203x133x30	1900	1.9	57		203x133x31	20710	20.71	30	621.3
203x133x30	1900	1.9	57		203x133x31	3915	3.915	30	117.45
203x133x30	8100	8.1	243		203x133x31	2955	2.955	30	88.65
203x133x30	8100	8.1	243		203x133x31	5075	5.075	30	152.25
203x133x30	5900	5.9	177		203x133x31	10510	10.51	30	315.3
203x133x30	7000	7	210		203x133x31	10510	10.51	30	315.3
203x133x30	7000	7	210		203x133x31	14985	14.985	30	449.55
203x133x30	7000	7	210		203x133x31	14985	14.985	30	449.55
203x133x30	5818	5.818	174.54		203x133x31	14985	14.985	30	449.55
203x133x30	5818	5.818	174.54		203x133x31	5765	5.765	30	172.95
203x133x30	5818	5.818	174.54		203x133x31	5765	5.765	30	172.95
203x133x30	5818	5.818	174.54		203x133x31	5765	5.765	30	172.95
203x133x30	5818	5.818	174.54		203x133x31	9480	9.48	30	284.4
203x133x30	2359	2.359	70.77		203x133x31	9480	9.48	30	284.4
203x133x30	2359	2.359	70.77		203x133x31	5990	5.99	30	179.7
203x133x30	5900	5.9	177		203x133x31	5990	5.99	30	179.7
		0	0		203x133x31	8150	8.15	30	244.5
203x133x30	7387	7.387	221.61		203x133x31	8150	8.15	30	244.5
203x133x30	7387	7.387	221.61		203x133x31	5610	5.61	30	168.3
203x133x30	7387	7.387	221.61		203x133x31	5610	5.61	30	168.3
203x133x30	9450	9.45	283.5		203x133x31	5610	5.61	30	168.3
203x133x30	9450	9.45	283.5		203x133x31	9340	9.34	30	280.2
203x133x30	9450	9.45	283.5		203x133x31	9340	9.34	30	280.2
203x133x30	9450	9.45	283.5		203x133x31	7232	7.232	30	216.96
203x133x30	12176	12.176	365.28		203x133x31	7232	7.232	30	216.96
203x133x30	12176	12.176	365.28		203x133x31	7232	7.232	30	216.96
203x133x30	12176	12.176	365.28		203x133x31	8775	8.775	30	263.25
203x133x30	8055	8.055	241.65		203x133x31	8775	8.775	30	263.25
203x133x30	8055	8.055	241.65			Total =	2422.414		72672.42

203x133x30	7387	7.387	221.61		Z160x60x15x1,2	16400	16.4	2.37	38.868
203x133x31	9416	9.416	282.48		Z160x60x15x1,2	16400	16.4	2.37	38.868
203x133x31	9416	9.416	282.48		Z160x60x15x1,2	16400	16.4	2.37	38.868
203x133x31	9416	9.416	282.48		Z160x60x15x1,2	16400	16.4	2.37	38.868
203x133x31	10300	10.3	309		Z160x60x15x1,2	16400	16.4	2.37	38.868
203x133x31	10300	10.3	309		Z160x60x15x1,2	16400	16.4	2.37	38.868
203x133x31	10300	10.3	309		Z160x60x15x1,2	16400	16.4	2.37	38.868
203x133x31	10300	10.3	309		Z160x60x15x1,2	4075	4.075	2.37	9.65775
203x133x31	10300	10.3	309		Z160x60x15x1,2	4075	4.075	2.37	9.65775
203x133x31	14815	14.815	444.45		Z160x60x15x1,2	4075	4.075	2.37	9.65775
203x133x31	14815	14.815	444.45		Z160x60x15x1,2	4075	4.075	2.37	9.65775
203x133x31	14815	14.815	444.45		Z160x60x15x1,2	4075	4.075	2.37	9.65775
203x133x31	14815	14.815	444.45		Z160x60x15x1,2	4075	4.075	2.37	9.65775
203x133x31	14815	14.815	444.45		Z160x60x15x1,2	4075	4.075	2.37	9.65775
203x133x31	5530	5.53	165.9		Z160x60x15x1,2	4075	4.075	2.37	9.65775
203x133x31	5530	5.53	165.9		Z160x60x15x1,2	4075	4.075	2.37	9.65775
203x133x31	1945	1.945	58.35		Z160x60x15x1,2	4075	4.075	2.37	9.65775
203x133x31	1765	1.765	52.95		Z160x60x15x1,2	7800	7.8	2.37	18.486
203x133x31	1765	1.765	52.95		Z160x60x15x1,2	7800	7.8	2.37	18.486
		0	0		Z160x60x15x1,2	7800	7.8	2.37	18.486
203x133x31	12780	12.78	383.4		Z160x60x15x1,2	12775	12.775	2.37	30.27675
203x133x31	12780	12.78	383.4		Z160x60x15x1,2	12775	12.775	2.37	30.27675
203x133x31	12780	12.78	383.4		Z160x60x15x1,2	12775	12.775	2.37	30.27675
203x133x31	7300	7.3	219		Z160x60x15x1,2	12775	12.775	2.37	30.27675
203x133x31	7300	7.3	219		Z160x60x15x1,2	12775	12.775	2.37	30.27675
203x133x31	3400	3.4	102		Z160x60x15x1,2	12775	12.775	2.37	30.27675
203x133x31	3400	3.4	102		Z160x60x15x1,2	12775	12.775	2.37	30.27675
203x133x31	1100	1.1	33		Z160x60x15x1,2	20710	20.71	2.37	49.0827
203x133x31	1100	1.1	33		Z160x60x15x1,2	20710	20.71	2.37	49.0827
203x133x31	1100	1.1	33		Z160x60x15x1,2	20710	20.71	2.37	49.0827
203x133x31	1100	1.1	33		Z160x60x15x1,2	20710	20.71	2.37	49.0827
203x133x31	1100	1.1	33		Z160x60x15x1,2	20710	20.71	2.37	49.0827
203x133x31	1100	1.1	33		Z160x60x15x1,2	20710	20.71	2.37	49.0827
203x133x31	3850	3.85	115.5		Z160x60x15x1,2	20710	20.71	2.37	49.0827
203x133x31	7300	7.3	219		Z160x60x15x1,2	20710	20.71	2.37	49.0827
203x133x31	9800	9.8	294		Z160x60x15x1,2	3915	3.915	2.37	9.27855
203x133x31	7300	7.3	219		Z160x60x15x1,2	3915	3.915	2.37	9.27855
203x133x31	7300	7.3	219		Z160x60x15x1,2	3915	3.915	2.37	9.27855
203x133x31	7300	7.3	219		Z160x60x15x1,2	2955	2.955	2.37	7.00335
203x133x31	7300	7.3	219		Z160x60x15x1,2	2955	2.955	2.37	7.00335
203x133x31	4910	4.91	147.3		Z160x60x15x1,2	2955	2.955	2.37	7.00335
203x133x31	8275	8.275	248.25		Z160x60x15x1,2	2955	2.955	2.37	7.00335
203x133x31	12880	12.88	386.4		Z160x60x15x1,2	5075	5.075	2.37	12.02775
203x133x31	16770	16.77	503.1		Z160x60x15x1,2	5075	5.075	2.37	12.02775
203x133x31	16770	16.77	503.1		Z160x60x15x1,2	5075	5.075	2.37	12.02775
203x133x31	16770	16.77	503.1		Z160x60x15x1,2	14985	14.985	2.37	35.51445
203x133x31	16770	16.77	503.1		Z160x60x15x1,2	14985	14.985	2.37	35.51445
203x133x31	5070	5.07	152.1		Z160x60x15x1,2	14985	14.985	2.37	35.51445
		0	0		Z160x60x15x1,2	14985	14.985	2.37	35.51445
203x133x31	8100	8.1	243		Z160x60x15x1,2	14985	14.985	2.37	35.51445
203x133x31	8100	8.1	243		Z160x60x15x1,2	14985	14.985	2.37	35.51445
203x133x31	16825	16.825	504.75		Z160x60x15x1,2	14985	14.985	2.37	35.51445
203x133x31	15185	15.185	455.55		Z160x60x15x1,2	14985	14.985	2.37	35.51445
203x133x31	12880	12.88	386.4		Z160x60x15x1,2	5765	5.765	2.37	13.66305
203x133x31	12880	12.88	386.4		Z160x60x15x1,2	5765	5.765	2.37	13.66305
203x133x31	12880	12.88	386.4		Z160x60x15x1,2	5765	5.765	2.37	13.66305
203x133x31	5675	5.675	170.25		Z160x60x15x1,2	5765	5.765	2.37	13.66305
203x133x31	12535	12.535	376.05		Z160x60x15x1,2	5765	5.765	2.37	13.66305
203x133x31	12535	12.535	376.05		Z160x60x15x1,2	5765	5.765	2.37	13.66305
203x133x31	7835	7.835	235.05		Z160x60x15x1,2	5765	5.765	2.37	13.66305
203x133x31	5900	5.9	177		Z160x60x15x1,2	8160	8.16	2.37	19.3392
203x133x31	11400	11.4	342		Z160x60x15x1,2	8160	8.16	2.37	19.3392
203x133x31	11400	11.4	342		Z160x60x15x1,2	8160	8.16	2.37	19.3392
203x133x31	11400	11.4	342		Z160x60x15x1,2	8160	8.16	2.37	19.3392
203x133x31	7366	7.366	220.98		Z160x60x15x1,2	5610	5.61	2.37	13.2957

Concrete Total				
Member		Dims (mm)	Volume (mm^3)	Volume (m^3)
Slabs	Over Site	47700x24600x100	1.17342E+11	117.342
	Ground Floor	37500x25500x100	95625000000	95.625
	First Floor	2700x39600x100	10692000000	10.692
		14000x12000x100	16800000000	16.8
		Total =	2.40459E+11	240.459
		Quamtity	Volume (mm^3)	Volume (m^3)
Pile Caps	200x200x3596.64	140	20141184000	20.141184
Footings		3750x13000x400	19500000000	19.5
		1500x13000x400	7800000000	7.8
		1300x3650x400	1898000000	1.898
		1200x1200x400	576000000	0.576
		1200x2000x400	960000000	0.96
		1200x1200x400	576000000	0.576
		1000x1000x400	400000000	0.4
		1000x1000x400	400000000	0.4
		1000x1000x400	400000000	0.4
		1000x1000x400	400000000	0.4
		1000x1000x400	400000000	0.4
		1200x1200x400	576000000	0.576
		1750x1200x400	840000000	0.84
		1200x1200x400	576000000	0.576
		1000x1000x400	400000000	0.4
		1000x1000x400	400000000	0.4
		1200x1200x400	576000000	0.576
		1200x1200x400	576000000	0.576
		1000x1200x400	480000000	0.48
		1200x1200x400	576000000	0.576
		1200x1200x400	576000000	0.576
		2000x2000x400	1600000000	1.6
		2700x1300x400	1404000000	1.404
		2700x1300x400	1404000000	1.404
		2700x1300x400	1404000000	1.404
		1000x1000x400	400000000	0.4
		1000x1000x400	400000000	0.4
		1000x1000x400	400000000	0.4
		4700x1000x400	1880000000	1.88
		2700x1300x400	1404000000	1.404
		2700x1300x400	1404000000	1.404
		1200x1200x400	576000000	0.576
		4700x1000x400	1880000000	1.88
		1200x1200x400	576000000	0.576
		1200x1200x400	576000000	0.576
		2700x1300x400	1404000000	1.404
		2700x1300x400	1404000000	1.404
		2000x1400x400	1120000000	1.12
		2000x1400x400	1120000000	1.12
		2000x1400x400	1120000000	1.12
		2100x2100x400	1764000000	1.764
		1600x1600x400	1024000000	1.024
		1600x1600x400	1024000000	1.024
		1600x1600x400	1024000000	1.024
		1600x1600x400	1024000000	1.024
		1200x1200x400	576000000	0.576
		1200x1200x400	576000000	0.576
		1200x1200x400	576000000	0.576
		1200x1200x400	576000000	0.576
		1200x1200x400	576000000	0.576
		1200x1200x400	576000000	0.576
		1200x1200x400	576000000	0.576
		1200x1200x400	576000000	0.576
		1200x1200x400	576000000	0.576
		1200x1200x400	576000000	0.576
		2700x1300x400	1404000000	1.404
		2700x1300x400	1404000000	1.404
		2700x1300x400	1404000000	1.404
		2700x1300x400	1404000000	1.404
		1200x1200x400	576000000	0.576
		1200x1200x400	576000000	0.576
		1200x1200x400	576000000	0.576
		1200x1200x400	576000000	0.576
		1200x1200x400	576000000	0.576
		2000x1000x400	800000000	0.8
		2000x1000x400	800000000	0.8
		1600x1600x400	1024000000	1.024
		1600x1600x400	1024000000	1.024
		1600x1600x400	1024000000	1.024
		1200x1200x400	576000000	0.576
		2700x1600x400	1728000000	1.728
		2700x1600x400	1728000000	1.728
		2700x1600x400	1728000000	1.728
		2000x1000x400	800000000	0.8
		1600x1600x400	1024000000	1.024
		1600x1600x400	1024000000	1.024
		2700x1600x400	1728000000	1.728
		2700x1600x400	1728000000	1.728
		1600x1600x400	1024000000	1.024
		1600x1600x400	1024000000	1.024
		1600x1600x400	1024000000	1.024
		1600x1600x400	1024000000	1.024
		1600x1600x400	1024000000	1.024
		1000x1000x400	400000000	0.4
		1000x1000x400	400000000	0.4
		2000x1000x400	800000000	0.8
		Total	1.03934E+11	103.934
		Concrete Total	**3.64534E+11**	**364.534184**

203x133x31	10000	10	300
203x133x31	10000	10	300
203x133x31	10000	10	300
203x133x31	10000	10	300
203x133x31	16400	16.4	492
203x133x31	16400	16.4	492
203x133x31	16400	16.4	492
203x133x31	9555	9.555	286.65
203x133x31	2225	2.225	66.75
203x133x31	4840	4.84	145.2
203x133x31	4840	4.84	145.2
203x133x31	4840	4.84	145.2
203x133x31	2620	2.62	78.6
203x133x31	2620	2.62	78.6
203x133x31	2620	2.62	78.6
		0	0
203x133x31	12050	12.05	361.5
203x133x31	12050	12.05	361.5
203x133x31	5925	5.925	177.75
203x133x31	7030	7.03	210.9
203x133x31	7030	7.03	210.9
203x133x31	7030	7.03	210.9
203x133x31	1900	1.9	57
203x133x31	1900	1.9	57
203x133x31	1900	1.9	57
203x133x31	1900	1.9	57
203x133x31	1900	1.9	57
203x133x31	2000	2	60
203x133x31	2000	2	60
203x133x31	2000	2	60
203x133x31	2000	2	60
203x133x31	2000	2	60
203x133x31	12050	12.05	361.5
203x133x31	12050	12.05	361.5
203x133x31	14245	14.245	427.35
203x133x31	14245	14.245	427.35
203x133x31	14245	14.245	427.35
203x133x31	14245	14.245	427.35
203x133x31	5900	5.9	177
203x133x31	5900	5.9	177
203x133x31	5900	5.9	177
203x133x31	5900	5.9	177
203x133x31	5900	5.9	177
203x133x31	2536	2.536	76.08
203x133x31	2536	2.536	76.08
203x133x31	8085	8.085	242.55
203x133x31	8085	8.085	242.55
203x133x31	1985	1.985	59.55
203x133x31	1985	1.985	59.55
203x133x31	1985	1.985	59.55
	Totals:	1211.207	36336.21

Z160x60x15x1,2	5610	5.61	2.37	13.2957
Z160x60x15x1,2	5610	5.61	2.37	13.2957
Z160x60x15x1,2	5610	5.61	2.37	13.2957
Z160x60x15x1,2	5610	5.61	2.37	13.2957
Z160x60x15x1,2	5610	5.61	2.37	13.2957
Z160x60x15x1,2	5610	5.61	2.37	13.2957
Z160x60x15x1,2	5610	5.61	2.37	13.2957
Z160x60x15x1,2	7230	7.23	2.37	17.1351
Z160x60x15x1,2	7230	7.23	2.37	17.1351
Z160x60x15x1,2	7230	7.23	2.37	17.1351
Z160x60x15x1,2	7230	7.23	2.37	17.1351
Z160x60x15x1,2	7230	7.23	2.37	17.1351
Z160x60x15x1,2	7230	7.23	2.37	17.1351
Z160x60x15x1,2	7230	7.23	2.37	17.1351
Z160x60x15x1,2	7230	7.23	2.37	17.1351
Z160x60x15x1,2	7230	7.23	2.37	17.1351
	Totals:	781.28		89115.8736
Diagonal Members				
L 50x50x3mm	11600	11.6	3	34.8
L 50x50x3mm	11600	11.6	3	34.8
L 50x50x3mm	11200	11.2	3	33.6
L 50x50x3mm	11200	11.2	3	33.6
L 50x50x3mm	7500	7.5	3	22.5
L 50x50x3mm	7500	7.5	3	22.5
L 50x50x3mm	10500	10.5	3	31.5
L 50x50x3mm	8100	8.1	3	24.3
L 50x50x3mm	9500	9.5	3	28.5
L 50x50x3mm	9500	9.5	3	28.5
L 50x50x3mm	7000	7	3	21
L 50x50x3mm	7000	7	3	21
L 50x50x3mm	8200	8.2	3	24.6
L 50x50x3mm	8200	8.2	3	24.6
L 50x50x3mm	5400	5.4	3	16.2
L 50x50x3mm	5400	5.4	3	16.2
L 50x50x3mm	8700	8.7	3	26.1
L 50x50x3mm	9600	9.6	3	28.8
L 50x50x3mm	10000	10	3	30
L 50x50x3mm	7800	7.8	3	23.4
L 50x50x3mm	7400	7.4	3	22.2
L 50x50x3mm	7400	7.4	3	22.2
L 50x50x3mm	7000	7	3	21
L 50x50x3mm	7000	7	3	21
L 50x50x3mm	6000	6	3	18
L 50x50x3mm	6200	6.2	3	18.6
	Totals:	216.5		649.5
	Steel Total	4507.404		219897.1

Material Take-Off Totals