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A Proposed Design of Disaster-Resilient Dome Multi-Purpose Building

Asher Antonio M. Mercado[1], Jazzy Andrea S. Dabu[2], Lawrence Daryl R. Batac[3], Charles D. Manalansan[4], Kian Dane V. Miguel[5], Rhommel U. Sarmiento[6], Ariel G. Pabalate[7], John Robert D. Gabriel[8]

[1]Student, Department of Civil Engineering, College of Engineering and Architecture, Don Honorio Ventura State University, Bacolor, Pampanga, Philippines.
Email: asherantoniomercado@gmail.com

[2]Student, Department of Civil Engineering, College of Engineering and Architecture, Don Honorio Ventura State University, Bacolor, Pampanga, Philippines.
Email: jazzyandrea.s.dabu@gmail.com

[3]Student, Department of Civil Engineering, College of Engineering and Architecture, Don Honorio Ventura State University, Bacolor, Pampanga, Philippines.
Email: lawrencedaryl.rodriguez.batac@gmail.com

[4]Student, Department of Civil Engineering, College of Engineering and Architecture, Don Honorio Ventura State University, Bacolor, Pampanga, Philippines.
Email: charlesmanalansan003@gmail.com

[5]Student, Department of Civil Engineering, College of Engineering and Architecture, Don Honorio Ventura State University, Bacolor, Pampanga, Philippines.
Email:danekianmiguel@gmail.com

[6]Student, Department of Civil Engineering, College of Engineering and Architecture, Don Honorio Ventura State University, Bacolor, Pampanga, Philippines.
Email: rhommelsarmiento19@gmail.com

[7]Instructor, Department of Civil Engineering, College of Engineering and Architecture, Don Honorio Ventura State University, Bacolor, Pampanga, Philippines.
Email: agpabalate@dhvsu.edu.ph

[8]Instructor, Department of Civil Engineering, College of Engineering and Architecture, Don Honorio Ventura State University, Bacolor, Pampanga, Philippines.
Email:jrdgabriel@dhvsu.edu.ph

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Abstract:

In the Philippines, where natural disasters frequently occur, there is a critical need for disaster-resilient evacuation infrastructure. This study addresses the limitations of existing facilities by proposing an innovative solution: the Disaster-Resilient Dome Multi-Purpose Building. Through a systematic approach involving capacity design, structural analysis, and cost-effectiveness evaluations, the research aims to provide a comprehensive solution. The methodology includes precise data collection, compliance with the National Structural Code of the Philippines (NSCP) 2015, architectural planning using AutoCAD, and structural analysis with STAAD.Pro and CSI SAFE software. The structure is designed to withstand seismic and wind loads, and the foundation is tailored to the prevailing soil conditions. Cost-analysis highlights the project's feasibility, demonstrating its capacity to accommodate 130 families of four. With reinforced structural elements such as W-shaped steel beams and columns, the proposed dome evacuation center is a practical and resilient solution for safeguarding communities in disaster-prone regions of the Philippines. This innovative approach not only addresses the immediate need for safer evacuation infrastructure but also establishes a precedent for sustainable disaster preparedness strategies. The multi-purpose functionality of the building allows it to fulfill various community needs during non-disaster periods, enhancing its utility and value. The proposed design aims to not only withstand disasters but also serve as a model of resilience for vulnerable areas throughout the Philippines by incorporating meticulous planning. This approach ensures the long-term sustainability and effectiveness of the evacuation infrastructure, providing a prototype that can be replicated in other disaster-prone regions.

Keywords **—Disaster-Resilient, National Structural Code of the Philippines (NSCP) 2015,AutoCAD, STAAD.Pro, CSI SAFE software, Cost-analysis.**

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I. THE PROBLEM AND REVIEW OF RELATED LITERATURES AND STUDIES

1.1 Introduction

The Philippines is located in a region prone to natural disasters, making it one of the most disaster-prone countries in the world. About 60% of its land and 74% of its population are exposed to hazards such as floods, typhoons, earthquakes, landslides, and tsunamis. An estimated 565 disasters have occurred since 1990, resulting in 70,000 fatalities and \$23 billion in damages. The country experiences approximately 20 cyclones annually, with eight of them making landfall. Typhoon Haiyan, the most powerful recorded typhoon in 2013, caused ₱44.48 billion in damages and claimed 6,000 lives. With 22 active volcanoes and significant tectonic activity, the Philippines is situated in an area prone to natural disasters [1].

Recent calamities have caused significant damage to structures, leading to physical damage, flooding, and fire damage, leaving many families homeless. Consequently, the government has established evacuation centers nationwide to provide shelter to those affected. Local Government Units (LGUs) and Municipality Disaster Risk Reduction and Management Offices (MDRRMOs) are responsible for identifying available evacuation centers within their respective barangays [1], [2].

Unfortunately, not all barangays have designated evacuation centers, and some public schools, covered courts, gymnasiums, and even churches are often used as alternatives. However, these buildings face various challenges such as overcrowding, limited resources, health and sanitation issues, and security concerns, making them unsuitable for this purpose and vulnerable to natural disasters.

To address this issue, researchers propose a dome structure design as an evacuation center. Domes have been proven to be highly resistant to earthquakes and strong winds because of their natural ability to distribute forces evenly in all directions. This unique design allows for optimal energy dissipation, reducing the risk of collapse. Furthermore, the dome's mass is situated low, which helps to lower its center of gravity, thus adding to its stability [3]. A study conducted by Dey and Deka (2012) compared the effectiveness of flat roofs and dome roofs. The results revealed that dome roofs are better equipped to handle transverse loads, making them an ideal choice for ensuring seismic stability. On average, there was a reduction of 30%, 34.5%, and 35% in deformation, maximum bending moment, and maximum shear force, respectively [4]. Additionally, the aerodynamic design of dome roofs makes them highly effective against explosions, and their larger vertical plane area allows them to generate remarkable force [5]

This study aligns with the objectives of "Sustainable Development Goal (SDG) 11" of the United Nations Sustainable Development Goals, as well as with "AmBisyon Natin 2040" of the National Economic and Development Authority (NEDA). The aim is to build a stronger and more resilient infrastructure that enhances community safety, comfort, and reduces anxiety during emergencies [6], [7].

1.2 Review of Related Literature

1.2.1 Evacuation Centers as Disaster Resilient Structures Globally and in the Philippines

Disaster-resilient infrastructures are known to be effective in saving lives, protecting infrastructure, livelihoods, and the environment as well as being both more cost-effective and sustainable. It is neither an alternative to intervention nor a new paradigm that can minimize the impact of natural disasters on their vulnerability [8]. The National Structural Code of the Philippines (NSCP 2015) is a guide that must be followed when designing structures in the country. It requires that vertical structures be designed to withstand various types of loads, including dead load, live load, wind load, earthquake load, and special loads. The code mandates that these loads must be considered in combination to ensure the safety and stability of the infrastructure [9], [10].

When constructing a building, it is crucial to take into account various important factors. These factors include site conditions, building configuration, openings, material selection, connections of structural members, and roofing. Site conditions comprise of natural disaster risks and slope steepness, which should be considered while selecting the site. Building configuration should involve the use of shear walls and properly aligned openings to ensure better structural integrity. It is important to select high-quality building materials and ensure proper connections of structural members. For roofing, a durable design with appropriate pitch and eaves is essential to ensure longevity and weather resistance.

Evacuation centers are facilities that are expected to be disaster-resilient as they serve as temporary shelters and are designed to provide essential needs like food and water to individuals who have been displaced by calamities [11]. Evacuation centers must have sleeping quarters, toilets and bathrooms for men and women, amenities for the disabled, emergency exit doors, and firefighting equipment such as fire extinguishers [12].

In Japan, the Great East Japan Earthquake in 2011 caused a devastating tsunami that resulted in significant damage to the country. As a result, the Ministry of Land, Infrastructure, Transport, and Tourism adopted a proposal and issued new guidelines in 2011 known as the Interim Guidelines for the Structural Design of Tsunami Evacuation Buildings. The primary objective of these guidelines is to ensure that tsunami evacuation structures are capable of withstanding expected tsunami loads, without collapsing, overturning, or moving laterally, to ensure the safety of evacuees. During the development process, individual members are classified as breakaway or non-breakaway components, while structural components are designed to be non-breakaway to resist and transfer the pressures acting upon them. Figures 1 and 2 show a sample of a tsunami evacuation tower in Japan [13].

Figure 1. Tsunami Evacuation Tower in Hamamachi Ward Kuroshio Town, Japan

Figure 2. Tsunami Evacuation Tower Sendai City, Miyagi Prefecture

The Nishiki Tower is a vertical evacuation center located in the town of Kise, Japan is designed specifically as a tsunami shelter but is also used as public toilets, storage for fire equipment, a meeting room, and an archival library for natural disasters during normal days [14]. The structure is an impressive five-story, 22-m-tall reinforced concrete structure resembling a lighthouse. Founded on a 4-m-deep layer of sand and gravel, the tower is supported on concrete piles extending 6 m below grade. It was designed to withstand the impact of a 10-ton ship at a velocity of 10 m/sec. For day-to-day use, it features public restrooms, a meeting room, firefighting equipment storage space, and 73 square meters of refuge space for evacuees [15].

Figure 3. Nishiki Tower

The Philippines is known to be prone to natural disasters due to its geographical location so as per the Mandatory Evacuation Center Act of 2019, it is required for every city, province, and municipality in the Philippines to construct evacuation centers that can withstand the impact of earthquakes, super typhoons, floods, and high tide storm surges, necessitating that they be raised above ground level. These centers must comply with the safety protocols established by the National Building Code [12].

The Department of Environment and Natural Resources (DENR) has been entrusted with the task of identifying suitable locations for these centers. of evacuation centers must be near residential areas, on higher ground, with adequate capacity and proper routes for rescuing [12].

The government has built evacuation centers such as the Llorente Center in Eastern Samar worth PHP20M. This facility can house over 300 families, has basic amenities, and serves as an office, storage area, and venue for training [16]. UNICEF opened the first typhoon-resilient evacuation center in Guiuan, Samar. The structure is designed to withstand extreme weather conditions such as category 5 winds and magnitude 8 earthquakes. It incorporates both local construction techniques and globally recognized disaster-resilient design practices for mass evacuation centers. This approach will enable the construction to be replicated at multiple locations across the Philippines. The evacuation center can comfortably accommodate up to 350 people during emergencies and also serve as a community gathering place during normal times [17].

However, due to a shortage of designated evacuation structures in some parts of the country, public schools have been used as alternative evacuation centers [18]. In Metro Manila, the majority of the list of evacuation centers available during Typhoon Ulysses are public schools both elementary and secondary schools, some are barangay-covered courts and chapels [19]. As of 2019, there were 28,083 evacuation centers recorded, out of which 63% were schools, ranging from daycare centers to full universities. However, only 822 centers were designated as evacuation centers [20].

Figure 4. Llorente Evacuation Center

Figure 5. Multi-purpose Evacuation Center in Guiuan, Samar

While school buildings are effective as evacuation facilities, their use as long-term shelters can disrupt children's education due to the uncertainty of how long they will be used by several families before moving back to their homes. In September 2022, during the budget deliberation of the Department of Education in the Senate, Vice President Sara Duterte, who is also the education secretary, stated that classrooms should not be used as long-term shelters. According to guidelines that she released last September, they can only be used as evacuation centers for up to 15 days [20].

1.2.2. Dome Structures and Its Different Types

Building earthquake-resistant structures is a critical endeavor in regions prone to seismic activity. While no building can be entirely immune to the devastating impact of strong earthquakes, several key techniques can significantly enhance their resilience. Among these techniques is the use of dome-shaped structures, which possess inherent characteristics that align with earthquake-resistant principles [21].

Domes have been used in construction since ancient times due to their unique ability to provide maximum space with minimal surface area [22]. These are self-supporting structures with a distinctive half-spherical form that boasts a generous floor plan without the need for interior support. They distribute loads evenly along the sides, and down to the foundations. Gravity tightly compresses them, and any external loads are carried by the internal compressive forces that develop [23].

Domes offer unique advantages in earthquake-prone areas. Their curved, spherical shapes are naturally resilient, efficiently distributing forces that lateral movements during an earthquake generate. Moreover, dome structures can incorporate innovations derived from skyscraper technology. These include shock-absorbing systems that mitigate the destructive force of seismic events, further enhancing their earthquake resistance [21].

Natural disasters in Sri Lanka have led to the creation of many post-disaster resettlement communities. Resettlement, either voluntary or involuntary, is complex and influenced by many factors. Housing for disaster-affected communities in Sri Lanka requires careful planning. The Government of Sri Lanka has introduced various resettlement housing projects, such as single-story and two-story houses, twin houses, and multi-story walk-up apartments, in response to the rising frequency of natural disasters. The dome housing project, from a technical perspective, is well-suited for flat terrains as it offers time-efficient and robust shelter for homeless communities. The circular design of the dome housing provides strong structural resilience against floods, high winds, and tsunamis. Additionally, it minimizes the risk of fire through ferrocement shell construction [24].

Figure 6. Dome House in Sri Lanka

The Philippine Arena stands as an awe-inspiring testament to the power of earthquake-resistant design in the realm of large domed structures. As the world's largest domed arena, it takes pride in being not only a remarkable architectural feat but also an earthquake-proof marvel. The arena's grandeur extends to its vast stadium roof, which spans an impressive 165 meters in the shortest direction. What makes this engineering marvel even more astounding is its resilience to extreme transient loads, including earthquakes, strong winds, and typhoons. It's a structure designed to endure the fiercest of nature's challenges. During an earthquake, the Philippine Arena showcases its earthquake-resistant features by withstanding significant lateral loads. These loads, which can amount to as much as 40% of the structure's mass, demonstrate the effectiveness of the design in ensuring the arena's stability even when the ground trembles [21].

Figure 7. Philippine Arena

In Tupelo, Mississippi dome shelter are constructed to serve as temporary shelter to provide safety for the residents during calamities [23]. The first monolithic dome in the Philippines is the Climate-smart monolithic dome located in Cagayan Valley. It is a P10 million facility run by the Department of Agriculture for the storage of agricultural products like seeds and other farm supplies [19].

Figure 8. Climate-smart monolithic dome for seed storage rising in Cagayan Valley

Engineering plays a vital role in constructing earthquake-resistant domes. Skilled professionals employ advanced techniques to design these structures, taking into account materials, geometry, and reinforcement. Using high-quality building materials is essential, ensuring the dome's ability to withstand seismic forces. Domes inherently feature structural continuity, reducing vulnerable joints and corners, and contributing to earthquake resilience. Efficient load distribution is another advantage, as the weight is evenly spread across the structure. Additional reinforcement techniques can be employed to fortify the dome's base, enhancing its stability during seismic events [21]. The cost-effectiveness, environmental friendliness, sturdiness, and ease of maintenance of these dome structures are their common advantages [25]. These types of structures are more durable than traditional buildings due to their stronger materials and shape. They are resistant to time, weather changes, and natural disasters, making them ideal for communities in prone areas.

1.2.2.1 Types of Dome Structures

(a) Geodesic Dome - its skeleton is made up of a variety of uneven and straight structural members that come together to form the many stable triangle components that offer resistance to gravitational, wind, and seismic loads. A huge span can be achieved using the geodesic dome without the use of interior supports, load-bearing walls, or deep beams. The load is dispersed uniformly throughout the dome's surface via trusses or other structures. It offers a strength-to-weight ratio with which many others are incomparable. Domes are suitable for many agricultural and commercial purposes because of their quick construction, low cost of materials, and durability in natural disasters [26].

(b) Ribbed Dome - composed of sturdy metallic trusses joined together by robust belts and braces, making them highly durable and versatile. The ribs at the bottom rest on a continuous foundation, while at the top they are joined by an octagonal ring, which also serves as a window. These structures can be employed for a wide range of purposes, including but not limited to museums, shopping centers, galleries, and pools [27].

(c) Cable Dome - A cable dome system is a network of cables and struts that are joined by pins. The system's forces are balanced by a perimeter ring beam and supporting walls or columns [28].

(d) Monolithic Dome - is one type of dome structure that can function effectively in every environment even in extreme cold or heat. Monolithic domes can reduce electricity consumption by up to one-third, which can save 60–70% of overall energy expenses [25]. A monolithic dome residence provides enhanced protection against fire, strong winds, tornadoes, and earthquakes. Presently, there are multiple compelling reasons to construct monolithic dome structures. The most cost-effective solution for safeguarding against tornadoes and hurricane-force winds is the use of concrete monolithic domes, typically at no additional construction cost. No other architectural design has demonstrated the capability to withstand EF5 tornadoes effectively. Many regions globally feature concrete homes and dome communities. Private-sector collaboration presents an alternative route if government incentives are not available. Monolithic domes offer a safer and more durable housing option compared to mobile homes and traditional stick-framed houses. Lower utility costs are particularly appealing for retirees on fixed incomes. Such dome homes are widely used worldwide, including in Japan's Aso Village, where approximately 480 Styrofoam domes are used for lodging, recreation, and retail. These domes, constructed with 7-inch-thick expanded polystyrene foam modules, require minimal maintenance and demonstrate high resistance to earthquakes, fires, and typhoons. [29].

1.3 Statement of the Problem

The Philippines, situated in the Pacific Ring of Fire, is consistently exposed to natural disasters, such as typhoons, volcanic eruptions, and earthquakes. The current evacuation centers, often repurposed structures like schools, gymnasiums, community centers, and religious buildings, frequently prove inadequate in safeguarding the population due to their design limitations. To address this issue, this study proposes the design of a dome structure as a multi-purpose evacuation center. The aim is to create a structurally resilient and disaster-resistant facility capable of providing shelter during calamities. The study seeks answers to the following questions:

1. How many families can the dome design of a multi-purpose evacuation center accommodate during calamities based on the National Building Code of the Philippines General Requirements for Occupant Load?
2. How can the following structural components of the multi-purpose dome evacuation center be designed to withstand earthquake load and wind load?
   a. Roof Slab
   b. Beam
   c. Column
   d. Connections
   e. Base Plate
   f. Anchor Bolts
   g. Pedestal
   h. Tie Beam
   i. Foundation

3. Is the proposed design of the dome as an evacuation center cost-efficient?

1.4 Objectives

1.4.1 General Objectives

This study aims to design a disaster-resilient multi-purpose evacuation center using a dome structure.

1.4.2 Specific Objectives

1. To design an evacuation center capable of sheltering a large number of families in the midst of calamity.
2. To design the structural components of the dome evacuation center that can withstand environmental loads such as earthquake load and wind loads.
3. To design an evacuation center that is cost-efficient.

1.5 Scope and Limitations

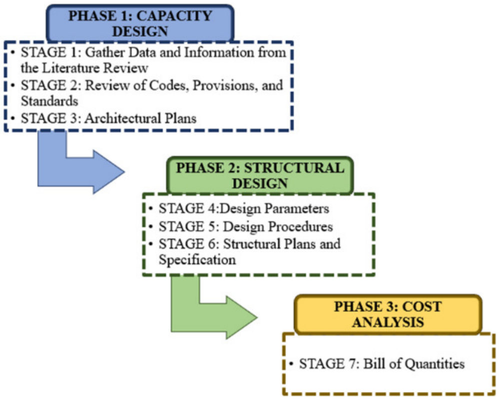
The focus of this study is to design a dome structure that can serve as an evacuation center in Mexico, Pampanga. The design will takeinto account the location's unique characteristics. Structural members will be designed using software such as STAAD.Pro v8i series 6 and CSI SAFE, along with manual computations based on the National Structural Code of the Philippines (NSCP 2015). The performance of the design will be analyzed against natural loads, and cost-efficiency will also be considered.

This study focuses on the use of a dome-shaped structure as the primary design for an evacuation center. However, it only covers the architectural and structural components of the design, excluding electrical, plumbing, and sanitary. Moreover, the costing will only consider the structural members such as concrete roof slabs, steel beams, steel columns, tie beams, pedestals, and pile footings.

II. METHODOLOGY

In this section, the research methodology that will be used to achieve the established goal will be discussed. The methodology consisting three phases: capacity design, structural design, and cost analysis. This process will be described in detail to ensure a clear understanding of the research methodology. Read already published work in the same field.

2.1 Methodological Framework



2.2 Phase 1: Capacity Design

2.2.1 Stage 1: Data Gathering

This is the process wherein the researchers gather data and information in a way that will support the problems of the project that need to be addressed. The information about the design, materials used, and parameters for this study is extracted from the related literature.

2.2.2 Stage 2: Review of Codes, Provisions, and Standards

The design of a Disaster-Resilient Multi-Purpose Dome Evacuation Center was quantitatively approached. The researchers followed the standards and specifications outlined in the National Structural Code of the Philippines (NSCP 2015), the National Building Code of the Philippines (NBCP), to ensure that the structure was not only resilient to disasters but also met all safety requirements.

2.2.3 Stage 3: Architectural Plans

AutoCAD, Autodesk's Computer-Aided Design software, is widely used by architects and designers in drafting and designing, providing them with a platform to create precise and detailed drawings that aid in the visualization and planning of different structures.

During the architectural design phase, the AutoCAD software will be utilized to meticulously detail the various architectural components such as the floor plan, and elevations of the structure ensuring that the evacuation center meets capacity requirements and provides necessary amenities.

2.3 Phase 2: Structural Design

2.3.1 Stage 3: Design Parameters

When designing a structure, it involves carefully considering key parameters to ensure safety and functionality. The following parameters used are the codes and standards from the NSCP 2015 as the researchers considered for designing the Disaster-Resilient Dome Multi-Purpose Evacuation Center.

2.3.1.1. Load Cases

2.3.1.1.1. Dead Load

Dead Load refers to the unchanging weight of a structure's fixed components, including materials such as concrete, steel, masonry, and wood, as well as the weight of walls, floors, roofs, and other structural elements. As these loads remain constant over time, it is essential to factor them in when designing structures, to ensure they can bear their weight and any additional loads they may encounter. Precise calculation of dead loads is critical to establish the stability and safety of a structure.

2.3.1.1.2. Live Load

Live loads are temporary and dynamic loads that vary in magnitude and location over time. These loads are caused by movable items like people, furniture, equipment, vehicles, etc. Designing structures that can withstand live loads is essential to ensure their safety and longevity. Building codes specify live loads based on occupancy type, building function, and local climate conditions.

2.3.1.1.3 Wind Load

Wind load is the term used to describe the amount of force exerted by wind on a structure. In the design of buildings, bridges, towers, and other structures, wind load is a critical factor to consider, as neglecting it can lead to significant stress and deformation. The magnitude of wind load varies depending on several factors such as wind speed, direction, duration, and the shape and size of the structure. Proper analysis and consideration of wind effects help engineers design structures that can withstand the forces imposed by the wind and maintain their integrity over time.

2.3.1.1.4 Earthquake Load

Earthquake loads are the result of seismic activity, including earthquakes and ground shaking. These loads are unpredictable and can lead to substantial stress, deformation, and harm to structures if not accounted for during the design phase. The Philippines is susceptible to earthquakes due to its geographical location, thus, designing for earthquake loads is important to ensure the safety and durability of structures during earthquakes, safeguarding both people and property. Complying with building codes and standards, such as NSCP 2015, which details specific earthquake-resistant design and construction practices, is essential to this goal.

2.3.1.2. Load Combination

The NSCP 2015 provides a guide on load combinations that structures must endure based on the principles of structural engineering, guaranteeing safety and stability. It considers various factors such as dead loads, live loads, wind loads, earthquake loads, and other pertinent loads to determine the maximum expected loads.

a. 1.4 DL
b. 1.2 DL + 1.6 LL
c. 1.2DL + 1.6 (Lr or R) + 0.5 (Lr or R)
d. 1.2DL + 1.0 WL + f1LL + 0.5 (Lr or R)
e. 1.2 DL + 1.0 EL + f1LL
f. 0.9DL + 1.0 WL
g. 0.9DL + 1.0 EL

2.3.2. Stage 5: Design Procedure

In this stage, the process of designing the structural steel member for various cross-sections and connection were analyzed and established by a comprehensive review of the design and criteria and specifications based on the NSCP 2015, and Load and Resistance Factor Design (LRFD).

2.3.3. Stage 6: Structural Design

The study will employ STAAD.Pro v8i series 6, a structural analysis software, simulates the behavior of the domes under various loads and environmental conditions by defining the geometry, and CSI SAFE software, an advanced software tool for designing concrete floor and foundation systems.

Incorporating supports, and applying loads within STAAD.Pro v8i series 6, the researchers can comprehensively assess the structural response. Stress distribution visuals will guide the researchers in identifying potential areas of concern, deformation data will inform necessary structural adjustments and understanding load reactions will contribute to ensuring stable foundations. Utilizing the CSI SAFE software helps the researchers to efficiently design the foundation of the dome evacuation center with ease.

2.4 Phase 3: Cost Analysis

2.4.1. Stage 7: Bill of Quantities

During this stage, the researchers will calculate the total expenses expected to be incurred at the dome evacuation center to determine whether the proposed design is cost-efficient. This process involves estimating the project’s direct costs, indirect costs, and other expenses. This will ensure an established budget that aligns with the financial resources necessary for a successful project [31]. The Bill of Quantities (BOQ) is an essential document that itemizes all the required materials and services, including their quantities, which helps contractors streamline pricing [33]. The researchers will utilize BOQ to list the total expenses on the proposed evacuation center.

III. RESULTS AND DISCUSSION

This section features a detailed presentation and discussion of the outcomes obtained from the methodology employed by the researchers. The results are relevant in fulfilling the objectives of the studies

PHASE 1: Capacity Design

Stage 1: Data Gathering

1.1 Site Setting

The picture below is the area where the dome evacuation center is about to be constructed.

Figure 9. Location of the Proposed Dome Multi-Purpose Building
Source: Google Earth

Figure 10. Location of the Proposed Dome Multi-Purpose Building
Source: Google Earth

The area is situated at the boundary of Barangay San Roque and Barangay Sta. Maria in Mexico, Pampanga. It is located beside the Pampanga PDRRMC Evacuation Center and was chosen due to its accessibility to the communities of two barangays during times of disaster.

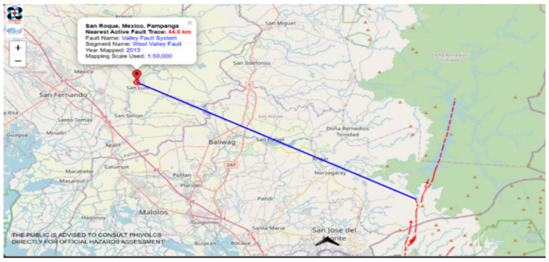
1.2.Soil Analysis

The researchers considered the closest structure where a soil analysis had been conducted to gather the preliminary data required for the structural analysis of the dome evacuation center. This is because there is no available information regarding the soil analysis in the specific area.

The nearest structure with available soil analysis is a Proposed Building in Sta. Maria, Mexico, Pampanga. The soil analysis was completed in 2016 and followed the guidelines established by the Department of Public Works and Highways (DPWH) and the American Society for Testing Materials (ASTM).

1.3.Nearest Active Fault in the Location

The location of the Evacuation center is 44km away from the nearest active fault which is the West Valley Fault



San Roque, Mexico, Pampanga
Nearest Active Fault Trace: 44.0 km
Fault Name: Valley Fault System
Segment Name: West Valley Fault
Year Mapped: 2013
Mapping Scale Used: 1:50,000

Figure 11. Nearest Active Fault in Mexico, Pampanga
Source: Fault Finder

1.4Multi-Hazard Map of Mexico, Pampanga

Based on the multi-hazard map of the municipality of Mexico, the dome evacuation center is situated in an area that is moderately susceptible to flooding and liquefaction.

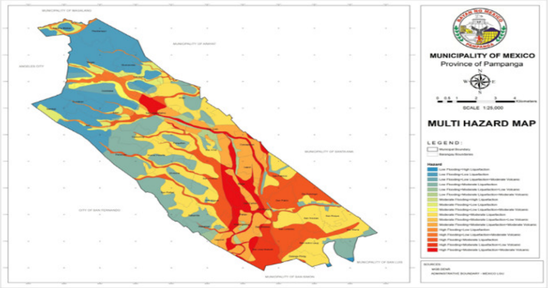


Figure 12. Multi-Hazard Map: Municipality of Mexico

Stage 2: Review of Codes, Provisions, and Standards

The Evacuation Center's structural engineering systems have been thoughtfully designed to ensure the safety and well-being of all occupants during times of crisis. To achieve this, the design process strictly adhered to the laws and regulations set by the Philippine government and utilized the NSCP 2015 edition. This document is the most current and relevant edition and was instrumental in ensuring that the center's engineering systems are up to code and meet all necessary standards for structural integrity.

Stage 3: Architectural Plans

The study was made possible with the assistance of a professional architect. The

AutoCAD software was used to create the architectural plans. The design for space requirements of the Dome evacuation center was based on the interview conducted with the MDRRMO Officer of the Municipality of Bacolor.

3.1 Perspective

Figure 13. Front View (Day)

Figure 14. Front View (Night)

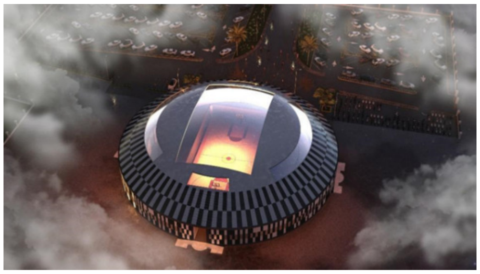


Figure 15. Aerial View (Day)

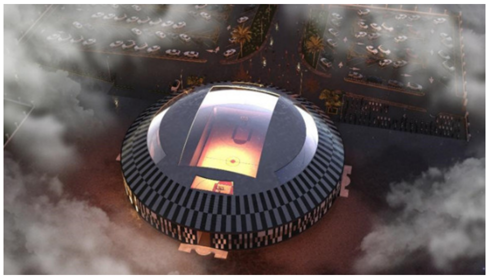


Figure 16. Aerial View (Night)

3.2 Elevation

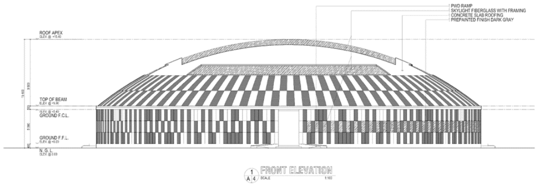


Figure 17. Front Elevation

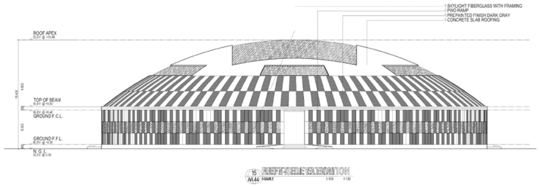


Figure 18. Left-Side Elevation

3.3 Floor Plan

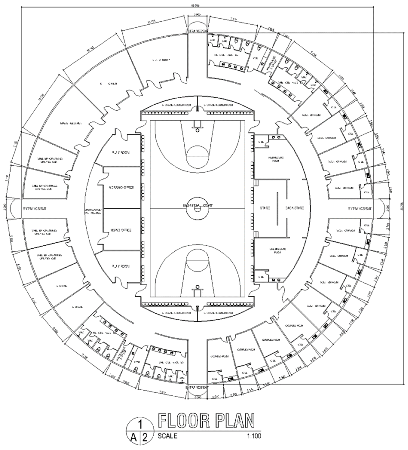


Figure 19. Floor Plan (A)

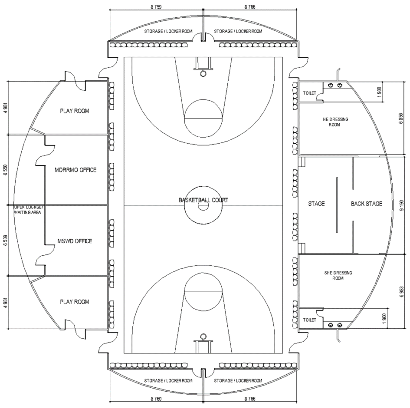


Figure 20. Floor Plan (B)

3.4 Total Number of Occupants

The number of occupants that the dome can accommodate has been calculated according to the National Building Code of the Philippines (NBCP), using the maximum floor allowance per occupant as specified in Table 29. Based on this calculation, the proposed dome evacuation center has a total area of 2,443 sq. m and can cater up to a total of 641 occupants. This number includes 518 individuals (excluding storage and kitchen facilities), which is equivalent to 130 families of four who can be sheltered during calamities.

PHASE 2: Structural Design Data and Consideration

Stage 4: Design Parameters

4.1 Dead Load

In NSCP2015, the dead load of a structure is calculated using specific densities and the minimum dead load. The following loads are from Table 204-2 (Minimum Design Dead Load)

Weight of 6” CHB = 2.75 kN/m

Wt. of Slab (150mm) = 3.532kPa

Materials

Concrete = 24.544 kN/m^3

Steel = 77.3 kN/m^3

Glass = 25.1 kN/m^3

Partition = 2.4 kPa

4.2 Live Load

The following Live Load was based on Table 205-1 – Minimum Uniform and Concrete Live Loads of NSCP 2015 LL = 7.2 kPA (Stages Areas), 2.4kPa (Office)

4.3 Roof Live Load

Using Table 205-3A of NSCP 2015, the computed value of the roof live load is 0.75kPa, to be applied in the design procedure of the structure.

4.3 Wind Load

The wind load used in the calculation is based on either NSCP 2015.

Location: Mexico, Pampanga

Structure: Enclosed Building

Occupancy Category: I (Essential)

Wind Speed= 270 kph

Wind Parameters:

Wind Directionality Kd = 0.85

Exposure Category: C

Surface Roughness: B

Topographical Factor Kzt = 1.0

Gust Effect Factor G = 0.85

Enclosed Classification: Enclosed

GCpi = +0.18, -0.18

Velocity Pressure Coefficient

Z = 6.1m

h = 10.85m

zg=365.76

$\propto$ =7.0

$Kz=2.01(z/zg)^{(2/\propto)}$; $Kh=2.01(h/zg)^{(2/\propto)}$

$$Kz = 2.01\left(\frac{6.1}{365.76}\right)^{\frac{2}{7.0}} \; ; \; Kh = 2.01\left(\frac{10.85}{365.76}\right)^{\frac{2}{7.0}}$$

$$Kz = 0.624 \quad ; Kh = 0.736$$

$$q_z = 0.613K_zK_{zt}K_dV^2$$

$$q_z = 0.613(0.624)(1.0)(0.85)(270)^2$$

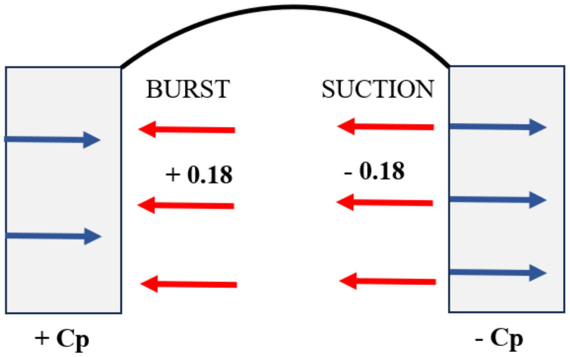
$$q_z = 1828.89$$

$$q_h = 0.613K_hK_{zt}K_dV^2$$

$$q_h = 0.613(0.736)(1.0)(0.85)(270)^2$$
$$q_h = 2157.147$$

Dome C_p using Figure 207B. 4-2 for Dome Roofs

$A_1 = +0.09$ $\quad\gamma = 55.797$
$B = -0.65$ $\quad f = 9.5$
$C = -0.101$



$p = qGC_p - q_i(GC_{pi})$; q = qz (Windward)/ qh (Leeward)

$$P_1 = 1828.89(0.85)(-0.07) - 2157.147\ (+0.18)$$
$$= -\frac{279.47N}{m^2} \approx -0.280\ kPa$$
$$P_2 = 2157.147(0.85)(-0.65)$$
$$- 2157.147\ (+0.18)$$
$$= -1589.11\frac{N}{m^2} \approx -1.40kPa$$
$$P_3 = 2157.147(0.85)(-0.101) - 2157.147\ (+0.18) = -573.48N/m^2$$

∴Use Wind Load-0.280kPa for Windward,and-1.40 kPa for Leeward

4.4 Seismic Load

The computation of seismic load is based on NSCP 2015. The parameters used are based on specific seismic zone areas in the Philippines.

Seismic Parameters:

I = 1.5, Importance Factor (I) (Section 208.4.2, Table 208-1)

Soil Profile Type: E (Soft Soil Profile) (Table 208-2)

Z = 0.4 Seismic Zone Factor (Section 204.4.4.2, Table 208.3)

Seismic Source Type: A (Section 208.4.4.2, Table 208-4)Nv = 1.0 (Table 208-5 Near-Source Factor)

Na = 1.0 (Table 208-4 Near-Source Factor)

Ca = 0.44 (Table 208-8 Seismic Coefficient)

Cv = 0.96 (Table 208-7 Seismic Coefficient)

R = 8.0 (Steel) (Section 2.2.5.2, Table 2.2G)

Ct = 0.0853 (Steel Structure)

Self-Weight = 1375.82kN (STAAD)

Live Load = 7263.50 kN

Partition Deadload = 2562.24 kN

$$T = C_t h^{\frac{3}{4}} = 0.0853(6.1)^{\frac{3}{4}} = 0.331$$
$$W = \text{DL} + 0.25\ \text{LL} + (\text{Partition Deadload})$$
$$W = 1375.82 + 0.25(7263.50) + 2562.24 = 5753.93\ kN$$
$$V = \frac{C_v I}{RT}W = \frac{0.96(1.5)}{8.0\ (0.331)}(5753.93\ ) = 3129.03kN$$
$$V = \frac{2.5C_a I}{R}W = \frac{2.5(0.44)(1.5)}{8.0}(5753.93) = 1078.86kN$$
$$V = 0.11C_a IW = 0.11(0.44)(1.5)(5753.93\ ) = 417.74kN$$
$$V = \frac{0.8ZN_v I}{R}W = \frac{0.8(0.4)(1.0)(1.5)}{(8.0)}(5753.93\ ) = 345.24kN$$

∴Use Base Shear V=1078.86kN

Stage 6: Structural Plans and Specification

6.1 Structural Modeling

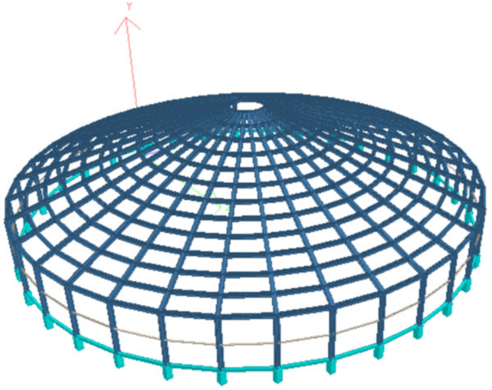
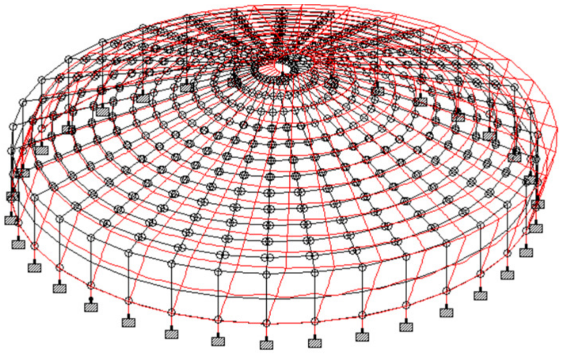


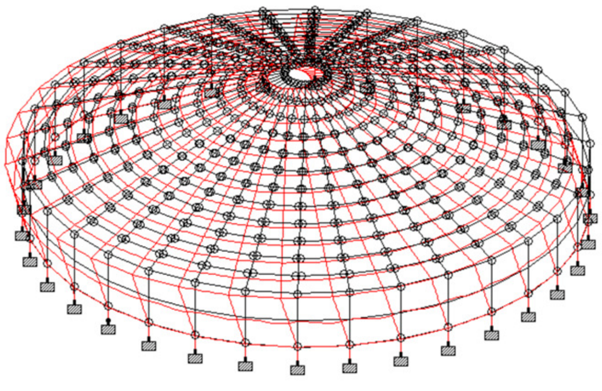
Figure 21. Framing System of The Dome Evacuation Center

6.2. Structural Analysis

6.2.1 Deflection Under Wind Load

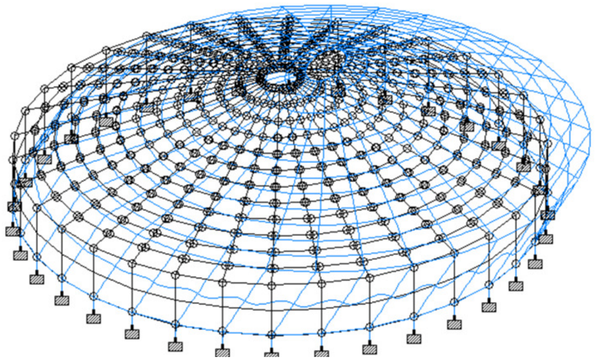


Windward

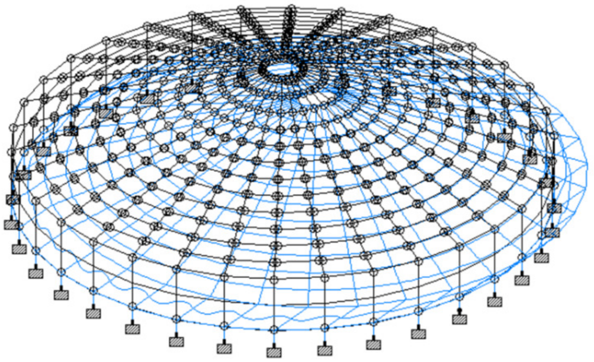


Leeward

6.2.2 Deflection Under Earthquake Load

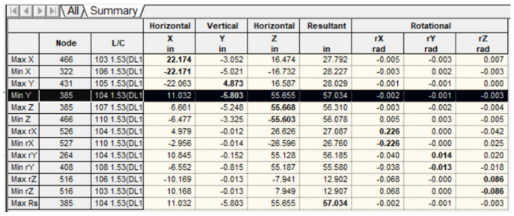


Earthquake Load at X-axis



Earthquake Load at Z-axis

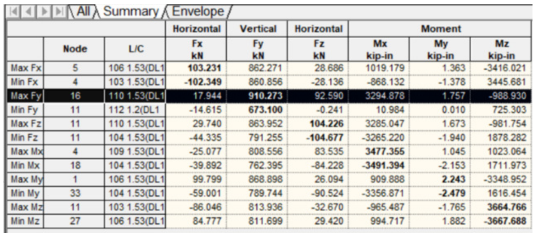
The Nodal Displacement Summary describes the maximum possible displacement at each node under different loading conditions. According to the results, node number 381 experienced the largest displacement due to the load combination 1.53 (DL1 + DL2) + 0.5LLR + 1.0EX – 0.3EZ. The computed resultant was -436.085 millimeters along the Y axis.



			Horizontal	Vertical	Horizontal	Resultant	Rotational		
	Node	L/C	X in	Y in	Z in	in	rX rad	rY rad	rZ rad
Max X	466	103 1.53(DL1	**22.174**	-3.052	16.474	27.792	-0.005	-0.003	0.007
Min X	322	106 1.53(DL1	**-22.171**	-5.021	-16.732	28.227	-0.003	0.002	-0.003
Max Y	431	105 1.53(DL1	-22.063	**4.873**	16.587	28.029	-0.001	-0.001	0.000
Min Y	385	104 1.53(DL1	11.032	**-5.803**	55.655	57.034	-0.002	-0.001	-0.003
Max Z	385	107 1.53(DL1	6.661	-5.248	**55.668**	56.310	-0.003	-0.002	-0.004
Min Z	466	110 1.53(DL1	-6.477	-3.325	**-55.603**	56.078	0.005	0.003	-0.005
Max rX	526	104 1.53(DL1	4.979	-0.012	26.626	27.087	**0.226**	0.000	-0.042
Min rX	527	110 1.53(DL1	-2.956	-0.014	-26.596	26.760	**-0.226**	-0.000	0.025
Max rY	264	104 1.53(DL1	10.845	-0.152	55.128	56.185	-0.040	**0.014**	0.020
Min rY	408	108 1.53(DL1	-6.552	-0.815	55.187	55.580	-0.038	**-0.013**	-0.018
Max rZ	516	106 1.53(DL1	-10.169	-0.013	-7.941	12.902	-0.068	-0.000	**0.086**
Min rZ	516	103 1.53(DL1	10.168	-0.013	7.949	12.907	0.068	0.000	**-0.086**
Max Rs	385	104 1.53(DL1	11.032	-5.803	55.655	**57.034**	-0.002	-0.001	-0.003

Figure 22. Nodal Displacement Summary

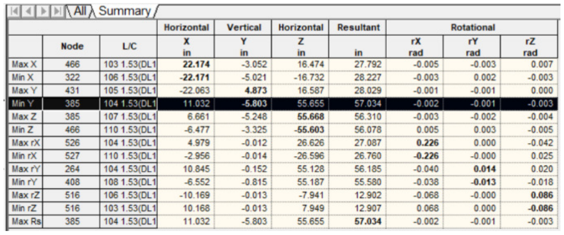
According to the Support Reaction Summary, the highest vertical force (Max Fy) was found at node 16 due to a combination of loads: 1.53(DL1 + DL2) + 0.5 LLR – 1,0EX – 0.3EZ. The value of Max Fy is 649.483kN.



			Horizontal	Vertical	Horizontal	Moment		
	Node	L/C	Fx kN	Fy kN	Fz kN	Mx kip-in	My kip-in	Mz kip-in
Max Fx	5	106 1.53(DL1	**103.231**	862.271	28.686	1019.179	1.363	-3416.021
Min Fx	4	103 1.53(DL1	**-102.349**	860.856	-28.136	-868.132	-1.378	3445.681
Max Fy	16	110 1.53(DL1	17.944	**910.273**	92.590	3294.878	1.757	-988.930
Min Fy	11	112 1.2(DL1	-14.615	**673.100**	-0.241	10.984	0.010	725.303
Max Fz	11	110 1.53(DL1	29.740	863.952	**104.226**	3285.047	1.673	-981.754
Min Fz	11	104 1.53(DL1	-44.335	791.255	**-104.677**	-3265.220	-1.940	1878.282
Max Mx	4	109 1.53(DL1	-25.077	808.556	83.535	**3477.355**	1.045	1023.064
Min Mx	18	104 1.53(DL1	-39.892	762.395	-84.228	**-3491.394**	-2.153	1711.973
Max My	1	106 1.53(DL1	99.799	868.898	26.094	909.888	**2.243**	-3348.952
Min My	33	104 1.53(DL1	-59.001	789.744	-90.524	-3356.871	**-2.479**	1616.454
Max Mz	11	103 1.53(DL1	-86.046	813.936	-32.670	-965.487	-1.765	**3664.766**
Min Mz	27	106 1.53(DL1	84.777	811.699	29.420	994.717	1.882	**-3667.688**

Figure 23. Support Reaction Summary

According to the data generated by STAAD software, the summary of distinct maximum and minimum values of stresses and their node position under various types of load combinations is as follows: The maximum Mz of 573.067kN-m is located at node 86, resulting from the load combination 1.53(DL1+DL2) + 0.5LLR +1.0EZ – 0.3EX. On the other hand, the minimum Mz of -572.030 is located at node 102, resulting from the load combination 1.53(DL1+DL2) + 0.5LLR +1.0EZ – 0.3EX.



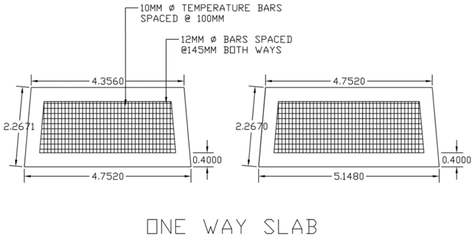
			Horizontal	Vertical	Horizontal	Resultant	Rotational		
	Node	L/C	X in	Y in	Z in	in	rX rad	rY rad	rZ rad
Max X	466	103 1.53(DL1	**22.174**	-3.052	16.474	27.792	-0.005	-0.003	0.007
Min X	322	106 1.53(DL1	**-22.171**	-5.021	-16.732	28.227	-0.003	0.002	-0.003
Max Y	431	105 1.53(DL1	-22.063	**4.873**	16.587	28.029	-0.001	-0.001	0.000
Min Y	385	104 1.53(DL1	11.032	**-5.803**	55.655	57.034	-0.002	-0.001	-0.003
Max Z	385	107 1.53(DL1	6.661	-5.248	**55.668**	56.310	-0.003	-0.002	-0.004
Min Z	466	110 1.53(DL1	-6.477	-3.325	**-55.603**	56.078	0.005	0.003	-0.005
Max rX	526	104 1.53(DL1	4.979	-0.012	26.626	27.087	**0.226**	0.000	-0.042
Min rX	527	110 1.53(DL1	-2.956	-0.014	-26.596	26.760	**-0.226**	-0.000	0.025
Max rY	264	104 1.53(DL1	10.845	-0.152	55.128	56.185	-0.040	**0.014**	0.020
Min rY	408	108 1.53(DL1	-6.552	-0.815	55.187	55.580	-0.038	**-0.013**	-0.018
Max rZ	516	106 1.53(DL1	-10.169	-0.013	-7.941	12.902	-0.068	-0.000	**0.086**
Min rZ	516	103 1.53(DL1	10.168	-0.013	7.949	12.907	0.068	0.000	**-0.086**
Max Rs	385	104 1.53(DL1	11.032	-5.803	55.655	**57.034**	-0.002	-0.001	-0.003

Figure 24. Beam End Force Summary

STAGE 7: Design Procedures

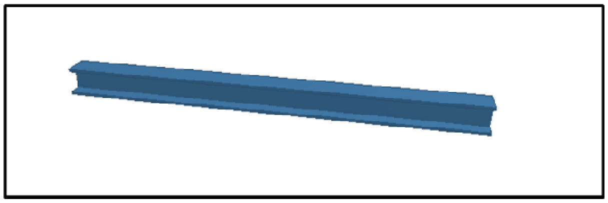
7.1 Design of Slab

7.1.1 One Way



7.2 Design of Beam

7.2.1 W 12X152



Properties:

$$Ax = 28839mm^2 D = 348.23mm$$

$tw = 22.10mm$ $bf = 316.99mm$

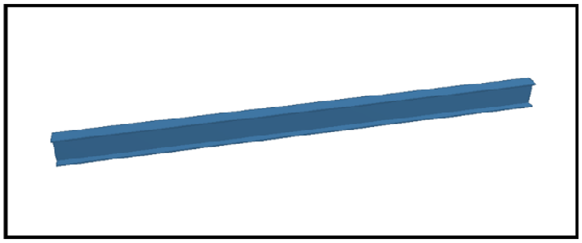
$tf = 35.56mm$ $T = 241.30mm$

$Ix = 595x10^6mm^3$ $rx = 143.76mm$

$Iy = 189x10^6mm^3$ $ry = 81.03mm$

$Sx = 3425x10^3mm^3$ $Zx = 3982x10^3mm^3$

7.2.2. W 12X170



Properties:

$$Ax = 32258mm^2 D = 356.36mm$$

$tw = 24.38mm$ $bf = 319.28mm$

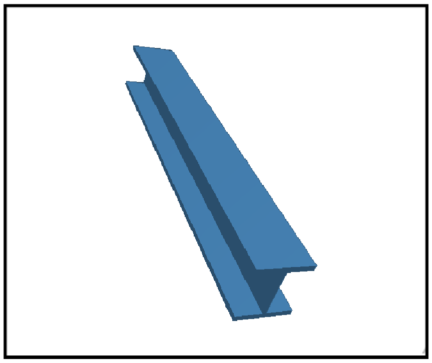
$tf = 39.62mm$ $T = 241.30mm$

$Ix = 687x10^6mm^3$ $rx = 145.80mm$

$Iy = 215x10^6mm^3$ $ry = 81.79mm$

$Sx = 3851x10^3mm^3$ $Zx = 4506x10^3mm^3$

7.2.3. W 12X336



Properties:

$Ax = 63742mm^2 D = 427.23mm$

$tw = 45.09mm \quad bf = 339.98mm$

$tf = 75.06mm \quad T = 241.3mm$

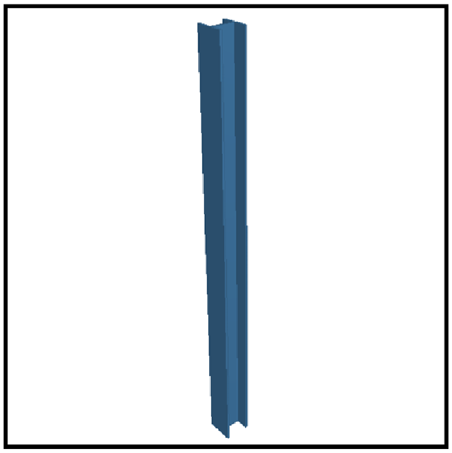
$Ix = 1690x10^6mm^3 \quad rx = 162.81mm$

$Iy = 495x10^6mm^3 \quad ry = 88.14mm$

$Sx = 7915x10^3mm^3 \quad Zx = 9881x10^3mm^3$

7.3 Design of Column

7.3.1 W 12X305



Properties:

$Ax = 57806mm^2 D = 414.53mm$

$tw = 41.28mm \quad bf = 336.17mm$

$tf = 68.71mm \quad T = 241.3mm$

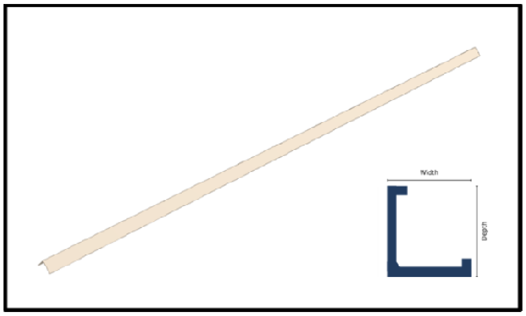
$Ix = 1478x10^6mm^3 \quad rx = 159.77mm$

$Iy = 437x10^6mm^3 \quad ry = 86.67mm$

$Sx = 7128x10^3mm^3 \quad Zx = 8800x10^3mm^3$

7.4 Lateral Bracing

7.4.1 4LS4 x 090



Properties:

$Depth = 101.6\ mm\ A = 490.3216\ mm^2$

$Bottom\ Width = 101.6mm \quad Iz = 578.56\ x10^3mm^4$

$Thickness = 2.286mm$

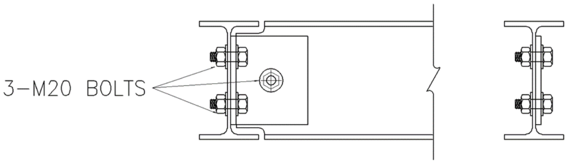
$Iy = 578.56\ x10^3mm^4$

$Fillet\ Radius = 4.7625\ mm \quad Iyp = 237.25\ x10^3mm^4$

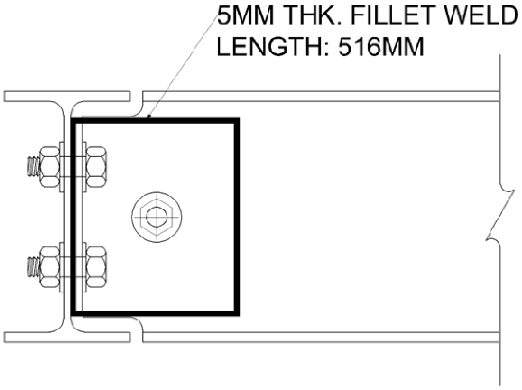
$Lip\ Depth = 12.7\ mm \quad Cz = Cy = 28.702\ mm$

7.5 Design of Connection

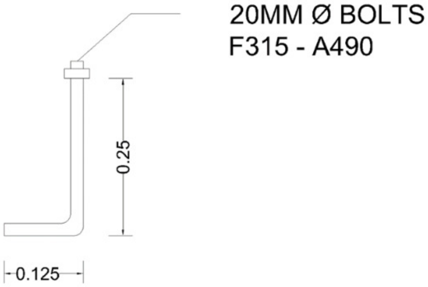
7.5.1 Bolt Connection



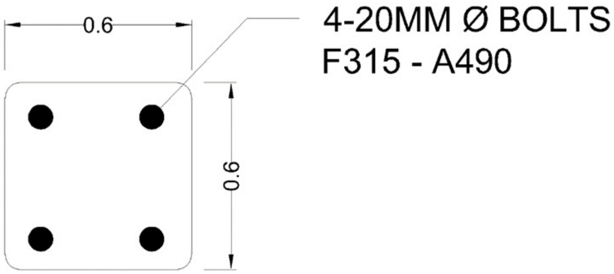
7.5.2 Welded Connection



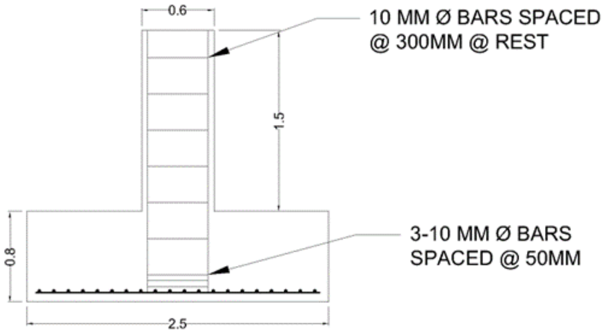
7.6 Design of Anchored Bolts

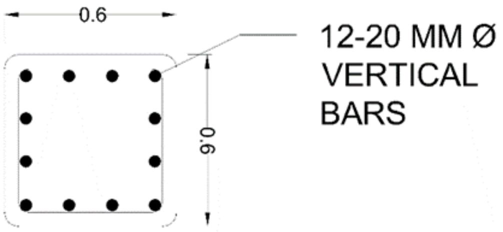


7.7 Design of Base Plate

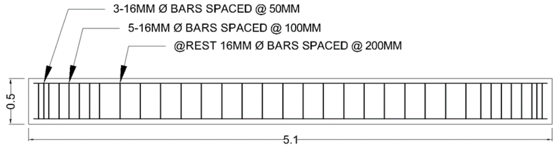


7.8 Design of Pedestal





7.9 Design of Tie Beam



7.10 Design of Footing

The researchers used pile footing for the foundation due to the location's soil characteristics. The design was produced using the CSI SAFE Software.

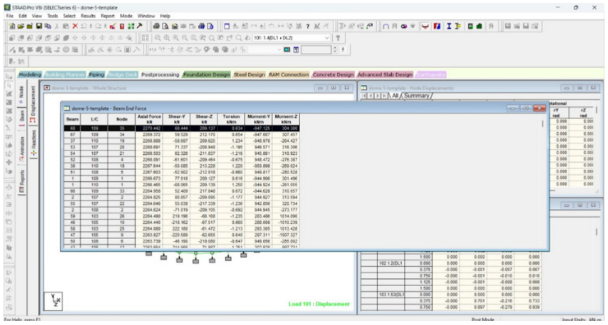


Figure 24. Beam End Forces

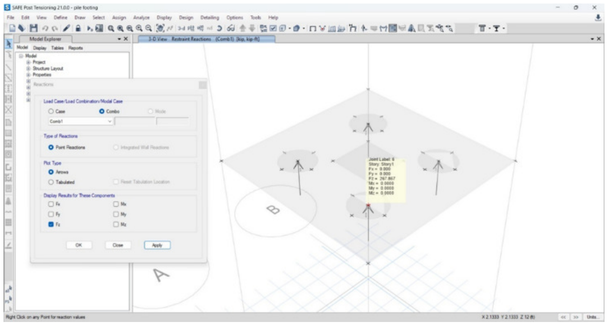


Figure 25. Load Capacity of Pile

The Load Capacity of the designed Pile is 267.867kN and is greater than the Actual Load of 68.44kN from STAAD.Pro CONNECT. Therefore, the design is considered Safe.

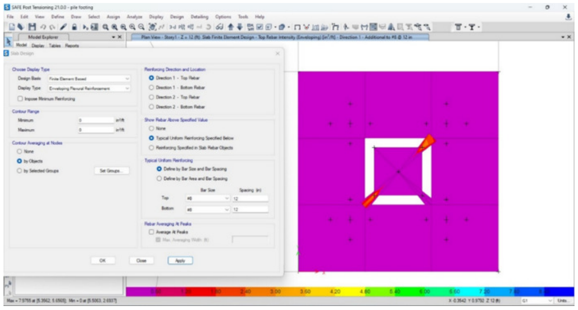


Figure 26. Design of Reinforcement of Footing (Bothways)

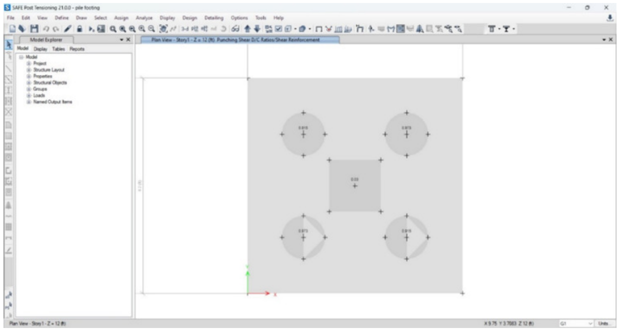
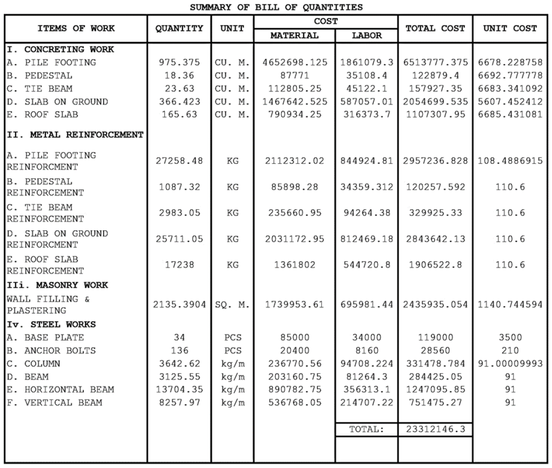


Figure 27. Punching Shear

Stage 8: Cost Analysis

8.1 Bill of Quantities

The table below shows the summary of the bill of quantities of the proposed evacuation center. It shows that the total cost of the project's structural members is 23,312,146.3 pesos or equivalent to 9,542.426 php/m^2



SUMMARY OF BILL OF QUANTITIES

ITEMS OF WORK	QUANTITY	UNIT	COST		TOTAL COST	UNIT COST
			MATERIAL	LABOR		
I. CONCRETING WORK						
A. PILE FOOTING	975.375	CU. M.	4652698.125	1861079.3	6513777.375	6678.228758
B. PEDESTAL	18.36	CU. M.	87771	35108.4	122879.4	6692.777778
C. TIE BEAM	23.63	CU. M.	112805.25	45122.1	157927.35	6683.341092
D. SLAB ON GROUND	366.423	CU. M.	1467642.525	587057.01	2054699.535	5607.452412
E. ROOF SLAB	165.63	CU. M.	790934.25	316373.7	1107307.95	6685.431081
II. METAL REINFORCEMENT						
A. PILE FOOTING REINFORCMENT	27258.48	KG	2112312.02	844924.81	2957236.828	108.4886915
B. PEDESTAL REINFORCEMENT	1087.32	KG	85898.28	34359.312	120257.592	110.6
C. TIE BEAM REINFORCEMENT	2983.05	KG	235660.95	94264.38	329925.33	110.6
D. SLAB ON GROUND REINFORCMENT	25711.05	KG	2031172.95	812469.18	2843642.13	110.6
E. ROOF SLAB REINFORCEMENT	17238	KG	1361802	544720.8	1906522.8	110.6
IIi. MASONRY WORK						
WALL FILLING & PLASTERING	2135.3904	SQ. M.	1739953.61	695981.44	2435935.054	1140.744594
Iv. STEEL WORKS						
A. BASE PLATE	34	PCS	85000	34000	119000	3500
B. ANCHOR BOLTS	136	PCS	20400	8160	28560	210
C. COLUMN	3642.62	kg/m	236770.56	94708.224	331478.784	91.00009993
D. BEAM	3125.55	kg/m	203160.75	81264.3	284425.05	91
E. HORIZONTAL BEAM	13704.35	kg/m	890782.75	356313.1	1247095.85	91
F. VERTICAL BEAM	8257.97	kg/m	536768.05	214707.22	751475.27	91
				TOTAL:	23312146.3	

Summary of Findings

The proposed design for the Dome Evacuation Center is to be located in Mexico, Pampanga. The soil classification in the area is soft clay, and the nearest active fault is the West Valley Fault which is 44km away. Based on the Multi-Hazard Map of Mexico, Pampanga, the location is expected to experience moderate flooding and moderate liquefaction during calamities.

The architectural plan covers an area of 2,443 sq. m. and can accommodate up to 518 people or 130 families of four. The design ensures the safety and comfort of evacuees in case of calamities.

In designing the structural members of the dome evacuation center, the researchers took into consideration the calculated earthquake load and wind load to ensure that the structural members are strong enough to withstand the natural load the location can experience. The structural members considered are slabs (roof), steel beams, steel columns, base plates, anchored bolts, pedestals, tie beams, and footings.bb

Slab

Slab	Reinforcement
One Way	12mmϕ Main Bars Spaced @145mm BOTH WAYS
	10mmϕ Temperature Bars @100mm O.C.

Beam

Types	Designation
STEEL - W Shape	W 12x159
STEEL - W Shape	W 12x170
STEEL - W Shape	W 12x336

Column

Types	Designation
STEEL - W Shape	W 12x305
Lateral Bracing (STEEL)	4LS4X090

Steel Connection

Type	Design
Bolt	3 – 20mmϕ
Weld (E60)	Thickness = 5mm Length = 516mm

Anchored Bolts

Classification	Design
F3125 – ϕA490 Anchor Bolts	4 – 20mmϕ
	250mm Embedment Length
	125 mm Hook (90°)

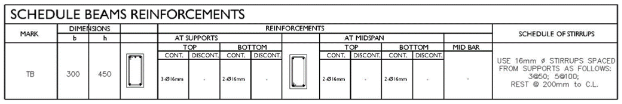
Base Plate

Classification	Design
Steel	600mm x 600mm x 150mm

Concrete Pedestal

Dimension	Reinforcement
600mm x 600mm	12 pcs – 12mmϕ Bars
	2 – 10mmϕ spaced @ 50mm
	Rest – 10mmϕ spaced @ 300mm

Tie Beam



SCHEDULE BEAMS REINFORCEMENTS

MARK	DIMENSIONS			REINFORCEMENTS										SCHEDULE OF STIRRUPS
	b	h		AT SUPPORTS					AT MIDSPAN					
				TOP		BOTTOM			TOP		BOTTOM		MID BAR	
				CONT.	DISCONT.	CONT.	DISCONT.		CONT.	DISCONT.	CONT.	DISCONT.		
TB	300	450		3-Ø16mm	-	2-Ø16mm	-		2-Ø16mm	-	2-Ø16mm	-	-	USE 16mm ø STIRRUPS SPACED FROM SUPPORTS AS FOLLOWS: 3@50; 5@100; REST @ 200mm to C.L.

Pile Footing

Details	Design
Dimension of Footing	2500mm x 2500mm x 750mm
Diameter of Pile	500mm
Length of Pile	12m
Number of Pile	4 pcs
Reinforcement (Top)	25mmϕ spaced @ 300mm OC
Reinforcement (Bottom)	25mmϕ spaced @ 300mm OC

According to the summary of the Bill of Quantities, the calculated total cost of the structural members of the proposed multi-purpose evacuation center is ₱23,312,146.3 or 9,542.426 php/m^2. The total price of the dome evacuation center is reasonable comparing to its design's functionality and rigidity.

IV. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusions

After analyzing the results of the study, the researcher came up with the following conclusions:

1. The Proposed Dome Evacuation Center can accommodate 130 families of four which is desirable for an evacuation center, especially during a sudden great calamity that affects large areas in the barangays near the evacuation center.
2. The structural design of the dome evacuation center has been fortified with the incorporation of W-shaped steel beams and columns and a pile foundation. This strategic implementation has significantly improved the structural strength of the facility, rendering it more resilient against natural disasters.
3. The design process of the dome evacuation center was influenced by the condition of the location. The soft clay soil near the site necessitated the use of a pile foundation. As a result, the cost of the dome evacuation center was reasonable, compromising the structure's strength and functionality.

4.2 Recommendations

The study focuses on the architectural and structural specifications of the Dome Evacuation Center. It examines how the center performs under seismic and wind loads, as well as the manual calculations used to design the structural members, cost analysis, and frame analysis using STAAD.Pro v8i series 6.

After completing the study, the researchers recommend several recommendations to enhance the design and improve the quality of the study.

- The researchers suggest conducting a soil investigation on the exact location where the structure will be built. This will result in a more precise design of the structure.
- It is also recommended to conduct an assessment in the location to ensure that the location is suitable for the project and if it is accepted by the community.
- The researchers recommend that future researchers who want to pursue this study to make an adjustment in the design of the dome evacuation center in consideration of the location where it will be situated.
- To accurately determine the cost efficiency, it is recommended to include the architectural, electrical, and plumbing properties of the project in the costing process.
- To enhance cost efficiency, the researchers recommend using an alternative design in the roofing system and using other materials to replace the wide beam flange that was used in the study while ensuring that the structure's performance is not compromised.
- Further, the researchers recommend employing other types of dome design, such as geodesic domes, monolithic domes, and ribbed domes.

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- The Researchers

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