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A Proposed Additional Two-Storey ACI Code-Based GFRP Reinforced Institutional Building for Tarik Suliman High School in Sagrada Familia, Masantol, Pampanga

Alexis Mark D. Landayan[1], Bridget Kelly V. Lambid[2], Ericka Lai G. Lapid[3], Jessica S. Ibe[4], Regine Diane L. Jurado[5],John Robert D. Gabriel[6], Inla Diana C. Salonga[7]
[1-5 Student], Don Honorio Ventura State University/College of Engineering and Architecture/Department of Civil Engineering, Cabambangan, Bacolor, Pampanga, Philippines, 2001
2020100211@dhvsu.edu.ph[1], 2020100210@dhvsu.edu.ph[2], 2020100212@dhvsu.edu.ph[3], 2020100197@dhvsu.edu.ph[4], 2020101015@dhvsu.edu.ph[5]
[6-7 Faculty], Don Honorio Ventura State University/College of Engineering and Architecture/Department of Civil Engineering, Cabambangan, Bacolor, Pampanga, Philippines, 2001
jrdgabriel@dhvsu.edu.ph[6], icsalonga@dhvsu.edu.ph[7]

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Abstract:
The study, "A Proposed Additional Two-Storey ACI Code-Based GFRP Reinforced Institutional Building for Tarik Suliman High School in Sagrada Familia, Masantol, Pampanga," is aligned with Sustainable Development Goals (SDG) 9, 'Industry, Innovation, and Infrastructure,' and SDG 11, 'Sustainable Cities and Communities.' It aimed to address challenges in the engineering field by proposing the use of Glass Fiber-Reinforced Polymer (GFRP) rebars as an alternative to conventional steel bars. This change significantly improves structural integrity and longevity, particularly in combating corrosion, a common issue for steel bars, especially in coastal areas. The research considered the facility needs of Tarik Suliman High School, taking into account its geographical location, population, geotechnical data, and vulnerability to floods. Information was gathered through interviews and document reviews. The architectural design adhered to DepEd Order No. 64, Series of 2017. The structural design of the GFRP building was based on ACI CODE 440.11-22 and the National Structural Code of the Philippines (NSCP) 2015. Structural Design and Analysis (STAAD) Pro V8i Select Series 6 was utilized for analysis and designing the main structural members and simulating the most critical beam. Additionally, the study provided a cost comparison between GFRP bars and steel bars for pricing reference.

Keywords **—GFRP bars, Corrosion, School Building, ACI CODE 440.11-22, STAAD.Pro V8i SS6**

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I. INTRODUCTION

Global urbanization is progressively moving at outstanding rates due to several economic and demographical factors, which have far-reaching effects on the industrial and civil construction sectors. At the same time, this surge in urbanization is leading to ethical obligations and a pressing necessity for protecting the natural environment, conserving other resources not derived from renewable energy, or maintaining ecological balance [1]. Also, many infrastructures gradually or suddenly deteriorate and may become vulnerable to occupancy due to alteration for intended use, loading conditions, structural or architectural design, substandard materials, or environmental effects on the materials and buildings [2]. In light of these challenges, it becomes imperative to address the urbanization-induced strains on infrastructure with a holistic approach that ensures structural integrity and aligns with global sustainability goals. There were 17 Sustainable Development Goals (SDGs) of the United Nations that outline the possible ways to solve the challenges of the nations in terms of rapid urbanization, conservation of the environment, and promotion of a more resilient community. Goal 9, ''Industry, Innovation, and Infrastructure' focuses on the production and improvement of resilient structures to advance every nation's economy and care for human well-being [3]. This SDG 9 emphasizes the demand for a more sustainable and inclusive industrialization.

Moreover, Goal 11, 'Sustainable Cities and Communities,' is focused on the rising conflicts brought on by rapid urbanization. SDG 11 aims to promote the building of safer, more inclusive, resilient, and sustainable cities [3]. Urban planning should incorporate construction policies and practices to decrease cities' environmental impact. The connection between Goal 11 and the challenges of infrastructure deterioration in urban areas is evident, as sustainable cities require resilient infrastructure to thrive amid the complexities of urban development. These civil infrastructures, particularly buildings, local and national roads, highways, bridges, and dams, are mostly reinforced concrete, known to be the most widely used material. The structures that use reinforced concrete are experiencing several negative impacts, particularly the internal reinforcing steel bars that are corroding and require repairs, maintenance, or retrofitting [4].

Fig. 1.1.a (left) shows exposed corroded internal steel reinforcing bars in a beam and Fig. 1.1.b (right) shows a totally exposed steel bars in the slab of the structure. (Source: left – Ju-Seong et. al., 2022; right – Corrosionpedia, 2019)

Many structures experience significant environmental pressures, and the resulting corrosion threatens the integrity of individual structural components and entire buildings. This corrosive damage accelerates material deterioration, particularly in coastal and industrial areas, potentially leading to structural failure. Steel corrosion is fundamentally an electrochemical process arising from diverse metals, irregularities in steel composition, or variations in the chemical and physical conditions of the surrounding concrete [5]. The effectiveness of steel structures is significantly influenced by the environmental conditions they are exposed to, specifically the presence of substances like chlorides, carbonates, sulfates, and other ionic materials. The existence of these elements has adverse effects, notably diminishing the structural performance as corrosion sets in [6]. Deterioration and internal and external damages to these structures are highly expensive to repair and to keep in suitable condition to maintain serviceability. As a result, engineers and researchers were motivated to find substitute materials for traditional reinforced concrete and its conventional reinforcement [4].

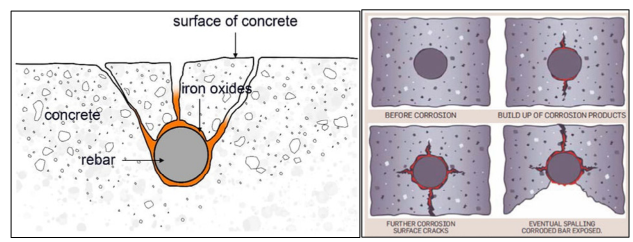


Fig. 1.1.c (left) show the formation of oxides in the steel surface that causes tensile stresses in surrounding concrete and Fig. 1.1.d (right) shows the process of the deterioration of concrete due to corrosion. (Source: Konstantinos et. al., 2020)

When iron oxides accumulate on steel reinforcement, the steel gradually returns to its original state and rusts. Because the concrete cover first shields the steel bars, this rusting process usually proceeds slowly. Because of its high alkalinity, the concrete aids by coating the steel with a thin oxide layer. Chloride ions, however, can permeate concrete in abrasive conditions and compromise these barrier layers. The protective layers disintegrate, and electrochemical corrosion starts when the chloride concentration reaches excessive. The developing rust eats up two to six times the original steel's volume, leading to cracks and eventual collapse of the surrounding concrete [7].

Fiber-reinforced polymer (FRP), or fiber-reinforced plastic, is a composite material where fibers like glass, basalt, carbon, or aramid are embedded in a polymer matrix. Although phenol-formaldehyde resins are still used in some applications, thermosetting polymers like epoxy, vinyl ester, or polyester are usually used to create this matrix. Numerous sectors, including aerospace, automotive, marine, and construction, use FRPs. Advanced engineering constructions like vehicles, boats, ships, aircraft, spaceships, and civic infrastructure like bridges and buildings depend on them. The usage of FRP composites is growing in both established industries and new ones, such as civil engineering structures and biomedical devices. Their application has increased due to advancements in high-performance resins and the creation of fresh reinforcement methods, such as the application of nanoparticles and carbon nanotubes.

The use of FRP materials in various sectors is growing as new and improved materials are created [8]. GFRP rebar materials are often used in civil engineering projects to prolong these buildings' life and improve their strength, corrosion resistance, and durability [4]. Reinforcements using FRPs as an alternative to steel are further investigated to solve corrosion issues and ensure electromagnetic compatibility within different components of load-bearing structures [9]. There are various characteristics that GFRP bars possess, such as high mechanical properties higher than steel, lightweight, low density, oxidation, and corrosion resistance, and being flexible [10].

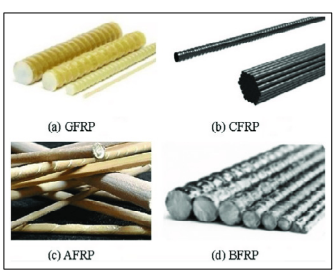


Fig. 1.1.e (left) shows four of the most common FRPs particularly: (a) Glass Fiber-Reinforced Polymer (GFRP), (b) Carbon Fiber-Reinforced Polymer (CFRP), (c) Aramid Fiber-Reinforced Polymer (AFRP), (d) Basalt Fiber-Reinforced Polymer (BFRP) and Fig. 1.1.f (right) shows the traditional or conventional steel reinforcing bars. (Source: Imad et. al., 2021)

The Mahanaim Consulting and Development Inc. (MCDI), operating under Armastek Philippines, pioneered the manufacturing and distribution of GFRP rebars in the country starting in the year 2020 and constantly emerging in the market as the best alternative to steel rebars. This introduction to the structural and construction field is a revolutionary mark of shifting into a more sustainable infrastructure utilizing fibers as the alternative composition of reinforcement bars. Adopting alternative rebars like GRP paved the way for research and exploration of its implications and impact on the Philippine engineering and construction industry [11].

Fig. 1.1.g (left) shows on of the pioneer of the first distributors of GFRP bars in the Philippines and Fig. 1.1.h (right) shows the actual GFRP bars delivered in the construction site in Laguna. (Source: Armastek Philippines)

The National Structural Code of the Philippines (NSCP), first released in 1972, is the backbone of every structural design in the country, providing guidelines for planning, designing, and constructing infrastructures. Since then, it has served as the firsthand source of structural designers who ensure that all the buildings planned and constructed adhere to the code provisions for the safety and resilience of construction projects. One of the country's structural code references is the American Concrete Institute (ACI), one of the reputable international standards for building design and construction, contributing to global innovation and setting standards for best practices. Due to the increasing trend of GFRP rebars as reinforcement in structures, the latest code is deficient, the NSCP 2015, for code provisions in designing and constructing reinforced concrete buildings with GFRP rebars. This is important since GFRP production worldwide is expanding quickly, with a compound annual growth rate of 3.7%. In 2022, the ACI released code provisions for the usage of GFRP rebars in construction, the ACI CODE 440.11-22, which is comprehensive provisions with 27 chapters dedicated to the integration of these new alternative materials to steel rebars through a meticulous and protracted consensus process. By covering a broad range of components, connections, and structural systems, including precast, cast-in-place, composite construction methods, and non-prestressed, this new ACI code offers new opportunities for structural engineers. The ACI CODE 440.11-22 strongly emphasizes structures that adhere to ASTM D7957- 22 criteria and are reinforced using GFRP bars. The introduction of ACI CODE 440.11-22 and its possible incorporation into the NSCP represent a significant turning point for the Philippine construction sector in the rapidly developing field of construction technology. This integration might improve the nation's structural design standards with international best practices and technology breakthroughs by keeping them current [13-15].

The structural design of any building ensures and contributes to integrity, strength, and serviceability, making it the most important component of civil engineering. The design process involves formulating, creating, and analyzing diverse types of structures like tall skyscrapers, towers in the city, bridges, and tunnels, essential buildings, and residential and commercial infrastructures. Structural engineering is a comprehensive industry that emphasizes the building’s strength and stability. Providing accurate structural analysis design aims to ensure that the structure will withstand all the loads applied without failing in its entire designed serviceability and comply with all national and international safety standards, specifications, and provisions [16].

The STAAD engineering software is highly regarded around the world and is best known for its compatibility, adaptability, efficiency, and more accurate analysis skills. It is a software used to perform structural analysis and design of reinforced concrete and steel structures in three dimensions. This most widely used software belongs to Bentley Systems, which features modeling, simulation, seismic analysis, and design that ensures the best analytical accuracy. One of the versions of the software is STAAD.Pro V8i SS6 suits various engineering and professional tasks such as developing structural models and frames, structural research, building design, finite-element and dynamic analysis, and simulation. The software's GUI or graphical user interface is easy to navigate for the efficient generation and analysis of the constructed models [17,18].

Since structural design is treated with utmost importance in civil engineering, especially in essential buildings like school buildings, the main integral parts of the structure are important, like beams. Columns, slabs, and footings. The outline of the design process meticulously considered the intended use for the building, accurate applied loads acting on the structure, and strict compliance with the national and international structural codes and standards. The school building, which will be the avenue for the students for most of their basic education journey, must be designed accurately to be secure, functional, and durable in any circumstances. These factors should be considered efficient, conducive, and safe learning environments [19-21]. The importance of all the elements of the entire structural design process is emphasized in the Center for Development Institutions for Engineering and Architecture [22].

Structural engineers in the world use STAAD.Pro V8i SS6 to generate 3D structural rendered models, perform analyses, and design multi-material infrastructures. STAAD was created by experts in the field internationally and is compatible with all Windows versions on laptops and computers. It is constantly improving over the years to cope with ISO 9001 certification standards. It is also compatible with the building codes of most nations, making it a flexible and dependable tool for integrated structural analysis and design [23]. Proficient structural analysis and design application STAAD.Pro supports a number of international and American codes that structural, civil, and other engineers frequently utilize. It is well known for satisfying all structural engineering needs and is held in the highest respect globally. With its extensive finite element and dynamic analysis features, strong analysis and design capabilities, and modern user interface, the software offers much. STAAD.Pro use by professional for tasks including model generation, analysis, design, visualization, and result verification. With its insights into bending moments, axial forces, shear forces, and beam stresses, it is especially helpful for building analysis and practical design [23].

The STAAD.Pro structural analysis and design software was first created by California-based Research Engineers International for use in a range of civil engineering projects. Late in 2005, Research Engineers International was acquired by Bentley Systems. Iowa State University's civil and structural engineering programs utilize STAAD-III, an older version of Windows. The industry uses a lot of commercial versions, such as STAAD.Pro. It provides a range of analytical techniques, such as buckling analysis, geometric nonlinear analysis, second-order p-delta analysis, and first-order static analysis. The program supports multiple steel, concrete, and timber design codes. Additionally, it has dynamic analysis features like modal extraction, time history analysis, and response spectrum analysis [24].

Study Area

Structures situated in coastal regions often experience corrosion issues. The coastal environment, abundant in chloride ions, is a significant external factor leading to damage in reinforced concrete structures. This is primarily due to its impact on the steel's passivity, causing early onset of corrosion [25]. Certain concrete structures exhibit common corrosion damage resulting from exposure to harsh conditions like flooding or standing water [26].

Due to its geographical location, the Philippines faces an increased risk of flooding due to the impact of typhoons. The country falls under a moist tropical climatic region, characterized by high temperatures and consistent rainfall throughout the year. Tropical cyclones typically occur between July and November, peaking in August, but recent weather variations have led to storms as early as May. In 2009, the peak of the rainy season shifted to September-October, affecting some regions, particularly Luzon, with a higher frequency of tropical cyclones. The combination of these pre-existing problems with weather variability creates a "bullwhip effect," amplifying the country's vulnerability to disasters for every additional challenge posed by changing weather conditions. [27]. Numerous regions across the Philippines have suffered extensive damage from natural disasters, including Central Luzon, recognized as the country's rice granary due to its fertile farmlands. The lives, properties, and livelihoods of many families in this region have been profoundly impacted by successive typhoons such as Ompong, Domeng, and Rosita. Among the provinces in Central Luzon, Pampanga has particularly borne the brunt of these natural calamities [28].

Fig. 1.1.1.a shows the provincial map of Pampanga. (Source: Alviera – Ayala Land)

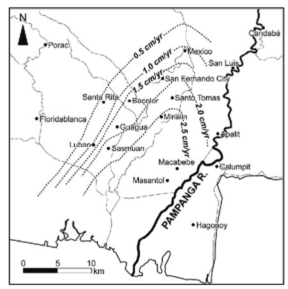


Fig. 1.1.1.b shows the whole course of Pampanga River through the provinces in Central Luzon. (Source: ChigakuZasshi, 2016)

Pampanga's lower elevation makes it more susceptible to flooding. Because of their proximity to the Pampanga River, the towns of Apalit, San Simon, Candaba, and San Luis are at a moderate to extreme risk of flooding. Similarly, the province's southern region, which includes the municipalities of Masantol, Sasmuan, Minalin, and Macabebe, is situated on the Pacific coast and faces a moderate to high risk of flooding. Bulacan, Nueva Ecija, Pampanga, and Tarlac are all crossed by the Pampanga River, the second-largest river in Luzon Island and an important tributary of the province. It provides water for these provinces, and if this river experiences extreme flooding, it can destroy and submerge not only the Province of Pampanga but also the surrounding territories [28].

The Pampanga River Basin is the Philippines' fourth largest basin, with a total size of 10,540 square kilometers. This vast watershed includes parts of seven provinces: Tarlac, Nueva Ecija, and

Pampanga; tiny portions of Nueva Vizcaya, Aurora, and Zambales; and most of Bulacan. With primary tributaries originating from the northern to northeastern region, the watershed receives an average of 1900 mm of rainfall annually [29].

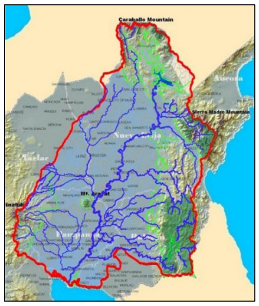


Fig. 1.1.1.c shows the major tributaries of the Pampanga River Basin. (Source: Department of Interior and Local Government, 2012)

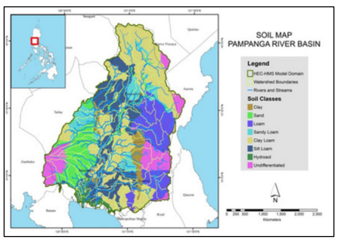


Fig. 1.1.1.d shows the Pampanga River Basin Soil Map. (Source: University of the Philippines and Department of Science and Technology – DREAM Program, 2015)

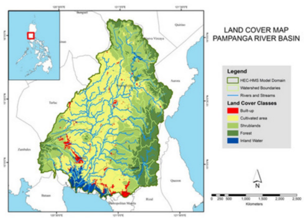


Fig. 1.1.1.e shows the Pampanga River Basin Land Cover Map. (Source: University of the Philippines and Department of Science and Technology – DREAM Program, 2015)

Four of the seven provinces in the Pampanga River Basin—Pampanga, Nueva Ecija, Tarlac, and Bulacan—are among the nation's top 10 most flood-prone provinces. One thing these provinces have in common is that they have large tributaries from the Sierra Madre Mountains, which have been cleared of trees. Specifically, Pampanga has the highest danger of flooding, with about 79.54% of its geographical area at risk. The Pampanga River's eastern portion is more prone to flooding, which substantially affects eight towns: Apalit, Arayat, Candaba, Macabebe, Masantol, San Luis, San Simon, and Santa Ana [28].

Located in the Philippine province of Pampanga lies the second-class municipality, the Municipality of Masantol. It covers 4,825 hectares of land in total. 57,990 people are living in the municipality, according to the results of the Philippine Statistics Authority's (PSA) 2020 census. Originally known as the San Miguel de Masantol community, it was then part of the municipality of Macabebe. As a result, on May 1, 1878, the new Spanish village of San Miguel was officially established. General Domingo Moriones y Murillo, the Spanish governor, gave it the go-ahead. A Royal Decree dated November 30, 1893, officially recognized the Catholic Parish of San Miguel. It was known as San Miguel Masantol for a short while but finally returned to its previous name. Masantol was reincorporated into Macabebe on July 26, 1904. However, it reclaimed its standing as a distinct, autonomous municipality in 1907 and still does [30].

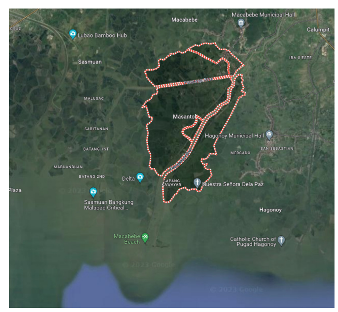


Fig. 1.1.1.f shows the Map of the Municipality of Masantol. (Source: Google Maps)

Masantol is the southernmost town in the province of Pampanga since the municipality of Macabebe almost completely encloses it. Its borders are with Macabebe to the north, with sections of Macabebe and Manila Bay to the south, with Calumpit and Hagonoy in Bulacan to the east, and with Macabebe to the west. Alauli, Bagang, Balibago, Bebe Anac, Bebe Matua, Bulacus, San Agustin (Caingin), Santa Monica (Caingin), Cambasi, Malauli, Nigui, Palimpe, Puti, Sagrada (Tibagin), San Isidro Anac, San Isidro Matua (Poblacion), San Nicolas (Poblacion), San Pedro, Santa Cruz, Santa Lucia Matua, Santa Lucia Paguiaba, Santa Lucia Wakas, Santa Lucia Anac

(Poblacion), SapangKawayan, Sua, and Santo Niño are among the 26 barangays that make up Masantol [30].

Masantol, a coastal municipality in Pampanga's southernmost region, is well-known for serving as a catchment area for floodwater during the rainy season. In contrast to previous years when flooding was limited to the rainy season, the majority of barangays in Masantol town are currently facing up to two feet of floodwater during the dry season due to high tides. [31]. Apart from floods brought on by storms and typhoons, some of the high tides, which may reach heights of up to five feet, also contribute to the rise in water levels in Masantol's area covered in water. Shaped by its physical attributes and communal traits, Masantol, Pampanga's left bank of the Pampanga River is a distinct and dynamic place. The barangays of Sagrada Familia, Nigui, Bagang, Balibago, and Alauli are on the left bank.

Barangay Sagrada occupies an area of roughly 234.77 hectares. Because to high tides, constant sea level rise, and a land elevation of 23.3 feet, the majority of the land area—156.51 hectares, or almost two-thirds of the total land area—is made up of inland waterways. There are just thirty hectares set aside for residential areas, leaving forty-eight hectares for agricultural use. About 5.5 kilometers separate the barangay Sagrada from Consuelo Beach's shore. In 2022, the barangay carried out an internal census to collect data on the overall population of the barangay. The results reported 535 families and 490 houses, adding up to a total population of 1843.

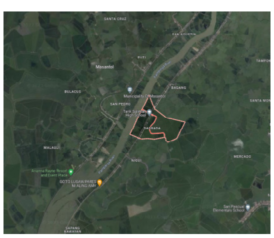


Fig. 1.1.1.g (left) and Fig. 1.1.1.h (right) show the Map of Barangay Sagrada Familia, Masantol. (Source: Google Maps)

In addition to being a vital component of the riverside, Sagrada Familia is unique in that it is the only an area with Tarik Sulman High School, the only high school located inside its limits. Having been the only high school in the area for 21 years, Tarik Suliman High School is an important facility for meeting the educational needs of the community. The school's importance is belied by its vulnerability due to its proximity to the Pampanga River and frequent flooding, which could compromise the structural integrity of its buildings, particularly because of the rusting of steel reinforcing bars.

Fig. 1.1.1.i shows the Tarik Suliman High School that is 273.35 meters away from the Pampanga River. (Source: Google Maps)

Fig. 1.1.1.j shows the Site of Tarik Suliman High School. (Source: Google Maps)

Tarik Suliman High School was formed in 2002 to meet the educational needs of the rural Masantol coastline barangay population. Recognizing the difficulties caused by the lack of a bridge connecting the town center to the coastal area, the community decided to take the initiative and provide secondary education for their children headed by Hon. According to Sagrada Familia resident and vice mayor Marcelo Bajun I. Lacap, Jr. The community chose not to rely exclusively on the government to develop a secondary school. TSHS is located in this community. It was renamed Tarik Suliman High School in 2005 after being known as Masantol High School-Annex, an extension of the town's lone secondary school. The school pays homage to Rajah Tarik Suliman, considered the first Kapampangan hero who valiantly fought against the Spaniards. It is believed that Tarik Suliman, the true hero of the Battle of Bangkusay, stayed at Batung Dalig in Sagrada Familia, Masantol— the very location of the school. The renaming was done to honor his heroism and nationalism and to raise awareness about his significant role among Kapampangans and Filipinos nationwide [32].

Review of Related Literature

Structural Applications of Fiber-Reinforced Polymer (FRP) Composites in the Philippines

Compared to conventional materials, fiber-reinforced polymer (FRP) composites have many benefits, including being lightweight, highly durable, corrosion-resistant, and requiring little upkeep. They have been extensively employed in the world's civil infrastructure, with applications as diverse as composite pile systems, maritime constructions, bridges in Australia, and the reinforcement of bridges and buildings in the Philippines. This article analyzes the difficulties associated with deploying this novel material to increase the use of FRP composites in the Philippines' civil infrastructure. It highlights recent advancements in its use in both countries [33].

Design of Concrete Beam Reinforced with GFRP Bars as Per ACI Codal Provisions

The study described the ACI 440.1R-15 regulation's design guidelines for concrete beams reinforced with glass fiber-reinforced polymer (GFRP) bars. GFRP has several advantages, two of which are that it is lightweight and more resistant to corrosion than the traditional steel used in construction. However, the linear elasticity of the GFRP bars and their limited elongation at break cause GFRP-reinforced concrete beams to typically exhibit a brittle failure mode [34].

Finite Element Analysis of Glass Fiber-Reinforced Polymer-(GFRP) Reinforced Continuous Concrete Beams

The study focused on exploring the moment redistribution of the continuous concrete beams subjected to the flexural and shear loads reinforced with GFRP. In order to forecast shear capacity, the research required building and testing a finite element model that used modified compression field theory as specified by the Canadian Standards Association (CSA) S806, as well as current experimental data. The finite element model agreed well with experimental results, with the beams experiencing shear failure following a large moment redistribution from hogging to sagging moments, according to an analytical model, comparison of the model, and the available data [35].

Comparison of Mechanical Behavior of Circular Stepped Beam using FEM & STAAD.Pro

Stepped beams are primarily used in the modern environment to meet the increasing need for lightweight, structurally efficient constructions with much higher strength-to-weight ratios. Usually made of steel or aluminum, these structural components are distinguished by distinct beam elements placed at predetermined intervals in one or both directions to support applied stresses. The structural behavior of beams under static, homogeneous loads is the main topic of this investigation. The study first examines the geometrically nonlinear behavior of linear elastic material beams, considering substantial deflections under transverse loads over the lengths of the beams. The beam deflects into an elastic curve when subjected to external loads. Using STAAD.Pro software, the study seeks to determine the link between beam deflection and applied loads. The results will then be extrapolated to do additional beam analyses. A numerical system analysis is conducted as part of the simulation analysis using STAAD.Pro is a complete finite element software that can solve nonlinear differential equations. Advanced graphics features provided by STAAD.Pro makes it easier to visualize analysis results on a high-resolution graphics workstation [36].

Research Gap

The application of glass fiber-reinforced polymers (GFRP) in construction has been thoroughly studied, especially in relation to ACI-compliant concrete beams reinforced with GFRP bars. Nevertheless, a significant research vacuum exists concerning the building industry in the Philippines' coastal regions. GFRP bars are essential because of their ability to withstand corrosion—especially when following the new ACI CODE 440.11- 22 criteria—the use of GFRP rebars in structures and Bentley Systems' STAAD.Pro software for the thorough design and analysis of such buildings' structural integrity, stress distribution, and deformation under varied loading conditions has also been the subject of a few small studies. It is essential to fill these research gaps, practical application, and performance of GFRP-reinforced structures in the Philippines, particularly in coastal regions prone to corrosion-related challenges. This research aims to fill this gap by investigating the feasibility and effectiveness of utilizing GFRP bars in construction projects in coastal areas, focusing on adherence to the latest ACI standards by utilizing the structural engineering software STAAD.Pro V8i SS6, this research sought to analyze the structure's behavior under different loading combinations generated in the software. This study would help civil engineers and future researchers in designing structures with GFRP rebars that are corrosion-resistant, especially those structures that will be situated in coastal areas and earthquake-prone areas.

Objectives

General Objectives

The research is focused on promoting the advancement of civil engineering design, practice, and construction in the Philippines through the proposed architectural plans and structural design for the additional two-storey school building for the Tarik Suliman High School in the coastal community of Sagrada Familia, Masantol, Pampanga. Focusing on the main structural components – slabs, columns, beams, and footings, the design used Glass Fiber Reinforced Polymer (GFRP) rebars in compliance with ACI Code 440.11-22 and the National Structural Code of the Philippines (NSCP) 2015. This study aimed to promote safer and more sustainable construction practices in coastal locations by evaluating the performance of GFRP-reinforced structural members through analysis using STAAD.Pro.

Specific Objectives

The research distinctively intended:

- To assess the facility needs of the Tarik Suliman High School from a Civil Engineering perspective, especially the students, teaching, and non-teaching staff.
- To gather the site data in terms of the soil profile and seismic conditions of the proposed construction of a two-storey GFRP-reinforced institutional building in Sagrada Familia, Masantol, Pampanga,
- To provide an architectural and structural design for the two-storey GFRP reinforced institutional building based on the DepEd School Building Standards, National Building, and Structural codes and integrate international code provisions for utilizing GFRP reinforcement bars.
- To analyze the structural members of a two-storey GFRP-reinforced institutional building and to simulate the maximum principal stress of the most critical member using Structural Analysis and Design Software.
- To provide cost analysis for the construction of a two-storey GFRP-reinforced institutional building.

Significance of the Study

The study results provide a structural and architectural design for the proposed GFRP institutional building that benefits the Sagrada Familia, Masantol Pampanga community. This research aimed to provide designs for the structural members based on code provisions and analyze the institutional building through structural analysis and design software. Moreover, the findings were intended to benefit the following:

Civil Engineering Field. The study's objective was to considerably progress the field of civil engineering by increasing understanding and using GFRP in structural design. This study would contribute to more resilient, safer, longevity, and environmentally friendly construction practices and design.

Association of Structural Engineers of the Philippines (ASEP). The study would contribute useful information to the association's experts for their further advancement of the structural code.

Civil Engineers. The findings would give the civil engineers ideas and an outline for designing buildings reinforced by GFP rebars in their main structural members.

Academe. The study's addition to the body of knowledge regarding GFRP in structural engineering would benefit academic communities and civil engineering institutes. It would help create training programs and curricula that incorporate cutting-edge tools and materials, readying upcoming civil engineers to fulfill industry expectations.

Community. The study's main contribution to the community was the potential advancement of safer and more environmentally friendly construction methods. GFRP's promotion as a practical reinforcing material would make buildings more robust and resilient, lowering community members' risks during natural catastrophes and enhancing general living conditions.

Tarik Suliman High School. By integrating GFRP rebars as the main reinforcement, this research would advance civil engineering practices that would guarantee the structural integrity and safety of the additional building that is proposed. This research would benefit the school's students, instructors, and non-teaching staff.

Local Government. This research would result in adopting updated building rules and construction standards based on international standards, which would benefit local government agencies. This would improve local infrastructure's resilience to environmental problems and public safety.

Future Researchers. Future researchers anticipating to study GFRP rebars and its applications in structural engineering might find the study useful. It would serve as the starting point for additional research and analysis in this area, promoting the ongoing development and innovation in civil engineering practices, especially for new materials in the market.

Scope and Delimitations

The assessment, design, and analysis of a two-story institutional building with GFRP (glass fiber reinforced polymer) reinforcements were the main objectives of this comprehensive research. By using the ACI Code 440.11-22 standards and assessing GFRP's suitability for institutional building construction—especially in the context of the Philippines—the study aimed to make a contribution to the area of structural engineering. The Philippines was the main geographic focus of the study. The National Structural Code of the Philippines (NSCP) 2015 was the focus of the assessment and evaluation of the code's provisions. The review sought to recognize these provisions' deficiencies, gaps, challenges, and potential areas for development. A significant portion of the research involved the integration and application of the American Concrete Institute (ACI) 440.11-22 code provisions for GFRP. This code served as an alternative or supplementary reference for the structural design and analysis, and its specific provisions will be applied to the study. The researchers engaged in the structural design and computation of key structural members, for the proposed two-storey institutional building. The design and computation adhered to the principles and guidelines outlined in ACI Code 440.11-22.

The research locale concentrated in Tarik Suliman High School, the only high school situated on the left bank of the Pampanga River located at Barangay Sagrada Familia, Masantol, Pampanga, one of the coastal municipalities in the province. This locale is prone to standing water and frequent flooding, presenting potential challenges to the durability of structures due to the corrosion of steel reinforcing bars. The assessment and evaluation of code provisions specifically tailored to address conditions prevalent in this locality, ensuring the findings are contextually relevant.

The study utilized industry-standard software tools, STAAD.Pro by Bentley Systems, in analyzing, designing and simulating the structural behavior of the proposed two-storey institutional building. The research focused on a specific architectural configuration—a two-storey institutional building. The structural design and analysis centered on this particular building type, and the findings may not be directly applicable to other types of structures or building heights. The primary material of interest in this research was GFRP. The assessment, design, and analysis revolved around the use of GFRP as a primary reinforcement material for the structural members of the institutional building. The main structural members designed in this study were beams, columns, slabs, and foundations. Due to the utilization of GFRP and centering the provisions on ACI CODE 440.11-22, there were limitations in the ACI Code and no provisions on wall reinforcement provided, thus, the researchers focused on the available provisions for main structural members only. The Armastek Philippines by MCDI, a GFRP pioneer manufacturing and distributing company based on Sta. Rosa, Laguna, was recently venturing on the usage of GFRP as shear reinforcement and did not formally run series of testing through DPWH accredited laboratory. With this limitation, the study adopted steel bars acting as shear reinforcements. The ACI CODE 440.11-22 allowed the hybrid design of reinforced concrete as stated in "Chapter 1: R1.1 - Scope of ACI CODE 440.11-22."

Conceptual Framework

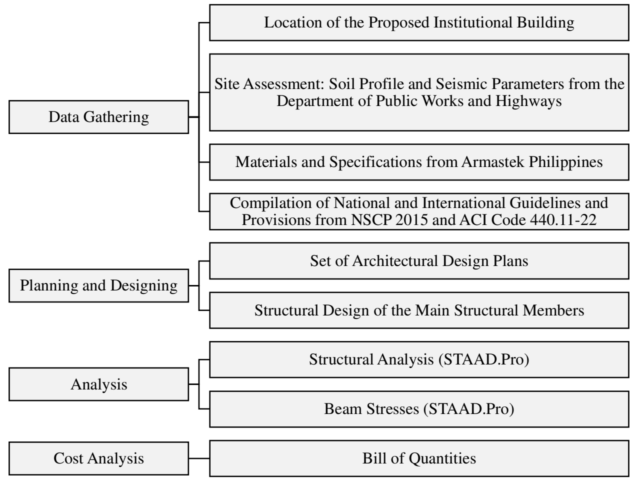


Fig. 1.6.1 shows the conceptual framework of the study.

The research process began with data gathering from the School Principal of Tarik Suliman High School, Planning and Design Section Chief of Pampanga 1st District Engineering Office of the Department of Public Works and Highways, and the representative of Armastek Philippines through MCDI, a GFRP bars pioneer manufacturer and distributor based from Sta. Rosa Laguna, where information about the proposed two-storey institutional building's location is collected. This included the comprehensive assessment of the geotechnical data executed by the TERMS Concrete & Materials Testing Laboratory Inc., a DPWH-BRS Accredited Laboratory, focused on understanding the soil profile and seismic parameters and the recommended type of foundation to be used. Additionally, details about material specifications and design parameters were gathered, and national and international guidelines and provisions related to construction are compiled. Moving on to the planning and designing phase, a set of architectural design plans was developed along with the structural design of the building. The next step involved analysis and simulation, utilizing STAAD.Pro. This phase ensured the structural integrity and safety of the proposed building. Finally, the research concluded with a cost analysis, a cost comparison between the distributor's pricing on GFRP bars and the market price of steel rebars to estimate the financial aspect of the project. This comprehensive approach established a systematic and well-informed process for proposing an additional two-storey institutional building for Tarik Suliman High School in the Coastal Barangay Sagrada Familia, Masantol, Pampanga, adhering to ACI code standards and reinforced with Glass Fiber Reinforced Polymer (GFRP).

II. METHODOLOGY

Framework

By detailing this methodology for the proposed additional two-storey institutional building at Tarik Suliman High School in Coastal Barangay Sagrada Familia, Masantol, Pampanga, the research aimed to encourage the usage of Glass Fiber-Reinforced Polymer (GFRP) in the Philippines. The process followed a structured one to ensure a thorough and informed approach. The first stage comprised the methodical gathering of information, primarily concerning the planned site of the building. This included a thorough evaluation of the site, with a focus on comprehending the seismic properties and composition of the soil. The next step was to formulate and design the structure, wherein the set of plans was created, followed by the structural design. After the design phase, the structural analysis was performed using STAAD.Pro V8i SS6 was also used to model and frame the structure. The study also provided a cost analysis for the proposed building with a complete bill of quantities.

Data Gathering

Mechanical Properties of Glass Fiber Reinforced Polymer (GFRP) Rebar

The mechanical properties of the reinforcement are crucial for the entire structural design of a structure because it determines the accurate parameters, precision, and integrity of the rebar itself. These properties, as defined by the manufacturer, Armastek Philippines, are directly correlational to the structural integrity of the reinforced concrete. In comparison with the traditional steel reinforcement bars, Armastek Philippines introduced the edge of GFRP rebar's properties like higher tensile strength of 3 times than the steel bars have, lower modulus of elasticity, significant value of flexural strength, weight, corrosion resistance, and has a thermal and electrical insulation, which are advantageous than steel. There are several advantages in utilizing the GFRP bars, including a longer life span accumulating to 80 years and more for the reinforced concrete with GFRP rebars, can endure extreme fatigue, and is resistant to impacts compared to the A-III carbon steel. It is also quick to install, deliver, and layout on the construction site from the manufacturer. The GFRP rebar is also bacterial growth resistant, chemical attack resistant, chloride ions resistant, non-magnetic, and nonconductive compared to steel.

The mechanical properties of the Glass Fiber-Reinforced Polymer (GFRP) and Steel A-III are compared in the following ways based on the brochure of Armastek Philippines [7]:

TABLE 2.2.1.A:
CHARACTERISTICS COMPARISON OF STEEL A-III AND GLASS FIBER-REINFORCED POLYMER

CHARACTERISTICS	Reinforcing Bar	
	Steel A-III Rebar	GFRP Rebar
Material	***Steel***	***Glass Fiber-Reinforced Polymer***
Ultimate Tensile Strength (MPa)	390	1200
Modulus of Elasticity (MPa)	200000	55000
Elongation (%)	25	2.2
Density (kg/m^3)	25	2.2
Thermal Conductivity (W/m-K)	48-58	0.25
Diameter Variations (mm)	6-80	4-40
Length per Cut (m)	6-12	Any length required
Longevity (years)	In accordance with building standards	80 years and beyond

(Source: Armastek Philippines - MCDI)

In replacing the traditional steel reinforcement, the following are the equivalent in diameter in utilizing GFRP rebars [7]:

TABLE 2.2.1.B:

DIAMETER EQUIVALENTS FROM STEEL REBAR TO GFRP REBAR

GFRP Equivalents for Replacing Steel Reinforcing Bar	
Steel A-III	***GFRP***
6 mm	4 mm
8 mm	6 mm
10 mm	7 mm
12 mm	8 mm
14 mm	10 mm
16 mm	12 mm
18 mm	14 mm
20 mm	16 mm

(Source: Armastek Philippines - MCDI)

National Structural Code of the Philippines (NSCP 2015)

The compilation of the requirements, codes, provisions, and guidelines for structural engineering and construction design in the Philippines is the National Structural Code of the Philippines (NSCP) 2015. The NSCP 2015 is a set of provisions provided by the ASEP covering the aspects of structural engineering design and construction that ensure security, stability, and welfare [10]. The NSCP 2015's provision for reinforced concrete found in chapter 4 of the code does not include a chapter for GFRP rebars.

ACI CODE-440.11-22: Building Code Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars—Code and Commentary

GFRP reinforced the structural design process, its properties, and construction procedures, which are based on ACI CODE-440.11-22. The procedure entails a careful reading of the code, with an emphasis on the areas that are directly related to the application of GFRP in structural concrete. Design factors are examined to understand the recommended recommendations for GFRP applications. These parameters include load capacities, structural configurations, and performance standards.

Research Locale

The locale of this study was one of the coastal areas in the province situated on the left bank of the Pampanga River, in the vicinity of Tarik Suliman High School in Sagrada Familia, Masantol, Pampanga. Within Masantol, Barangay Sagrada Familia stood out as a coastal community and contributed unique environmental characteristics that necessitated careful consideration in constructing the proposed two-storey institutional building. The proximity to the coastline brought forth challenges related to saltwater exposure, standing inland water, and surging high tides, which may have implications for the durability of building materials. Being part of the Pampanga River Basin, the locale also contributed to the town's high vulnerability to flooding and other hazards.

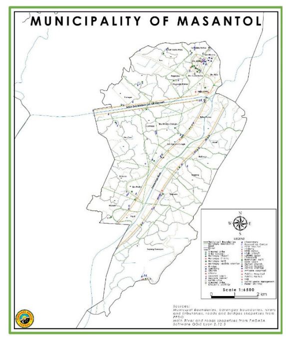


Fig. 2.3.a show the Municipality Map of Masantol. (Source Masantol MDRRMC)

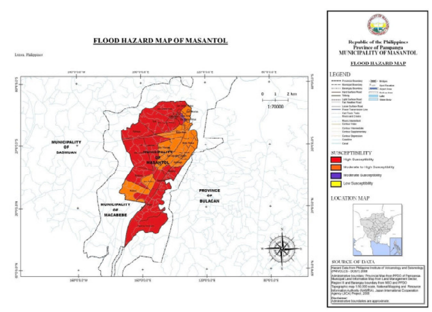


Fig. 2.3.b show the Flood Hazard Map of Masantol. (Source Masantol MDRRMC)

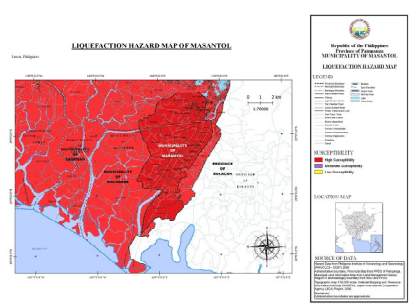


Fig. 2.3.c show the Liquefaction Hazard Map of Masantol. (Source Masantol MDRRMC)

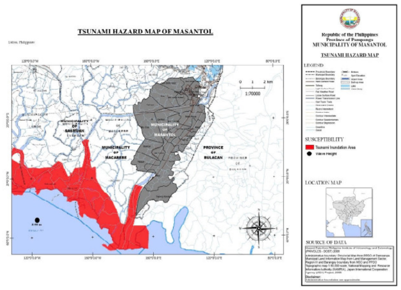


Fig. 2.3.d show the Tsunami Hazard Map of Masantol. (Source Masantol MDRRMC)

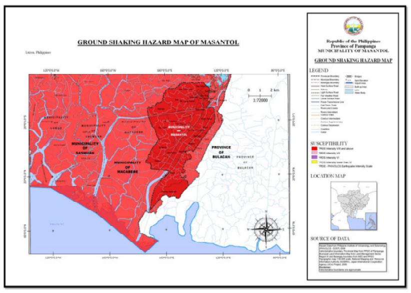


Fig. 2.3.e show the Ground Shaking Hazard Map of Masantol. (Source Masantol MDRRMC)

Tarik Suliman High School provides secondary education for the entire population on the left bank. It was established with a commitment to academic excellence and community development and has served as a beacon of learning for the local residents for 21 years and counting. The following is the population of Tarik Suliman High School's students, teachers, and non-teacher staff.

The Junior High School Population in Tarik Suliman High School has 503 students based on annual enrolment in the School Year 2023 – 2024. The four sections in grade 7 have a male population of 66 students while 63 are female, summing up 129 students for the year level. The grade 8 students have a total of 134 students, 76 of whom are male and 58 are female, all from the four sections in the year level. Grade 9 students have the lowest population among junior high schools, with 108 students, 56 students, and 52 students, male and female, respectively. The grade 10 students garnered 132 enrollees for the school year, having 74 male students and 58 female students.

The Senior High School Population in Tarik Suliman High School has 224 students based on annual enrolment in the School Year 2023 – 2024. The three sections in grade 11 have a male population of 60 students, while 45 are female, for a total of 105 students for the year level. The grade 12 students have a total of 119 students, 54 of whom are male and 65 are female, all from the three sections in the year level.

Overall, Tarik Suliman High School serves 727 students who need secondary education from the left bank of the Pampanga River. There are 22 teachers with an assigned advisory class, and 19 have other assigned tasks or positions in the school. This sums up to a population of 768 for both students and teaching and non-teaching staff.

Fig. 2.3.f show the Entrance Banner of Tarik Suliman High School. (Source Tarik Suliman High School Official Facebook Page)

Tarik Suliman High School faces persistent challenges from environmental factors that significantly impact the student's learning ability. The locality is susceptible to frequent storms, typhoons, and elevated high tides, creating adverse conditions for the educational infrastructure. Unfortunately, the elevated alkalinity in this coastal barangay is primarily caused by stagnant waters and seawater penetration, which negatively impacts the school's infrastructure. The primary problem is the deterioration of concrete buildings and the rusting of the steel reinforcing bars in these establishments. The decrease in structural integrity of the structural members is due to the effects of the high salinity of seawaters and stagnant rainwaters. As a result, three of Tarik Suliman High School's seven buildings, or reinforced concrete structures, are currently non-operational, which impairs the school's overall functionality.

Figure 2.3.j. Portion of Tarik Suliman High School infiltrated with inland waters

(Source: Tarik Suliman High School Official FB Page)

Fig. 2.3.g show the portion of Tarik Suliman High School infiltrated with inland waters. (Source Tarik Suliman High School Official Facebook Page)

Site Investigation

A structural designer needs to know and investigate the soil characteristics and properties to contribute to the safety and rigidity of the structure. The proposed two-storey institutional building for Tarik Suliman High School in Barangay Sagrada Familia, Masantol, has no exemption; the soil profile and seismic data of the vicinity are gathered through the Department of Public Works and Highways Region III. It is crucial to know the soil profile of the structure's location to know the soil bearing capacity of the soil and if it is capable of supporting the entire weight of the building. The soil bearing capacity is important for the plan of the construction foundation to know the type of foundation to use to be safe. Also, seismic parameters are important for structural analysis and design software. Through these considerations, the building will be designed to reduce susceptibility to earthquakes, become rigid, and not fail.

Formulation of Plans

Several important documents laying the groundwork were involved in the first phase of a construction project. The project site's layout was described comprehensively in the Site Development Plan, which acted as a detailed overview. Layouts, elevations, and structural elements were depicted in architectural drawings that emphasized the project's visual appeal. The designs and specifications of the building's structural components were described in detail in the structural plans, which were crucial construction papers. While floor plans depicted the placement of structural elements on each level, the foundation plan described the design and proportions of the necessary kind of footing. Section drawings and elevations provide views from the inside and outside, respectively. In-depth information includes manual beams, columns, pile footing, one-way and two-way slabs, and STAAD.Pro calculation knowledge is applied to assess the forces and moments of the structures based on material specifications and governing load combinations. Stability and safety were guaranteed by the details of the connections and reinforcements, and additional structural aspects met particular needs. The Soil Profile report's insights about the composition and properties of the soil helped to avert future problems like settling, which was crucial for directing foundation design. Loadings, which include the forces structures have to bear, direct the design process and guarantee that the structures are safe and strong enough to endure various forces. Following building and structural codes was required to ensure structural integrity and safety.

Preparation of Plans

The utilization of AutoDesk's AutoCAD for the creation of the architectural plans was the researchers' main tool in the planning of the proposed two-storey GFRP reinforced institutional building at Tarik Suliman High School in Sagrada Familia, Masantol, Pampanga. The plans formulated in AutoCAD are the ground-floor plan, second-floor plan, and front, rear, left-side, and right-side elevations. Also, the rendered version of the front elevation was provided.

Codes and Specifications

The set of principles and parameters used in the architectural and structural design of the proposed two-storey reinforced institutional building for Tarik Suliman High School in Sagrada Familia Masantol Pampanga is the following:

DepEd Order No. 64, Series of 2017 entitled, "Establishing the Minimum Performance Standards and Specifications for DepEd School Buildings"

Relying on the DepEd Order No. 64, Series of 2017, educational facility feasibility, utilization, and safety were guaranteed, exhibiting performance standards and demands for DepEd school establishments. To emphasize the significance of reinforcing student-friendly learning environments, site selection, architectural design, structural design, and environmental sustainability were sorted out. Providing high-quality educational infrastructure, DepEd's ordinance remains steadfast in its guidelines for the planning, designing, constructing, and conserving school facilities.

Presidential Decree 1096 or National Building Code of the Philippines 2005

The NBC mandates a set of rulings for building safety and construction in the Philippines, applying oneself to a number of topics such as structural, mechanical, electrical, and architectural quandaries. Fire safety, accessibility, and other crucial areas of building construction were adhered to meet a point of reference.

The National Structural Code of the Philippines 2015

The set of rules and stipulations for planning and building sturdy and safe structures were presided over by the NSCP in the Philippines, with the national code's minimum safety demands and precautions to which the structural integrity was adhered.

ACI Code 440.11-22 (American Concrete Institute - Building Code Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars—Code and Commentary)

ACI Code 440.11-12 comprehensively provided guidelines for using Glass Fiber-Reinforced Polymer (FRP) materials to reinforce and restore concrete buildings. In line with that, ACI outlined instructions on using GFRP materials in the design, analysis, and building process, ensuring that the structural components were safe and durable.

Structural Design

The prominence of the structural design of the proposed two-storey institutional building for Tarik Suliman High School that is reinforced with GFRP is to do a good turn for constructing slabs, beams, columns and foundations following the ACI Code's provisions.

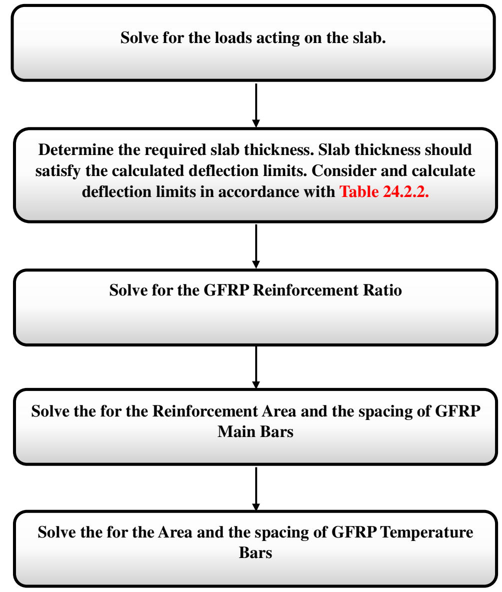


Fig. 2.8.1 shows the procedure for designing the slabs.

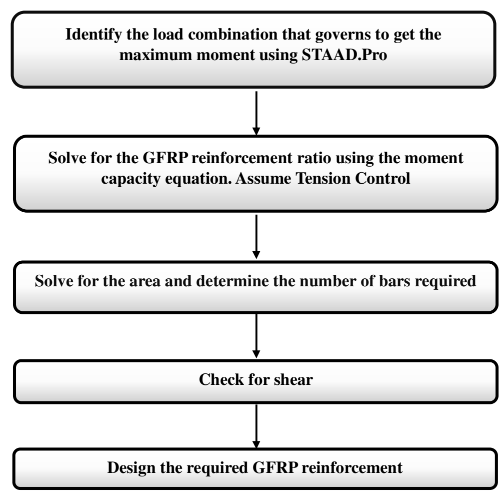


Fig. 2.8.2 shows the procedure for designing the beams.

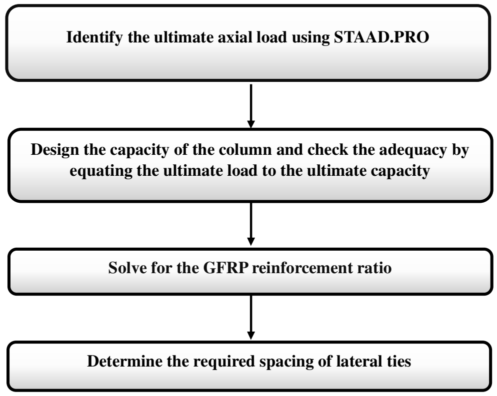


Fig. 2.8.3 shows the procedure for designing the columns.

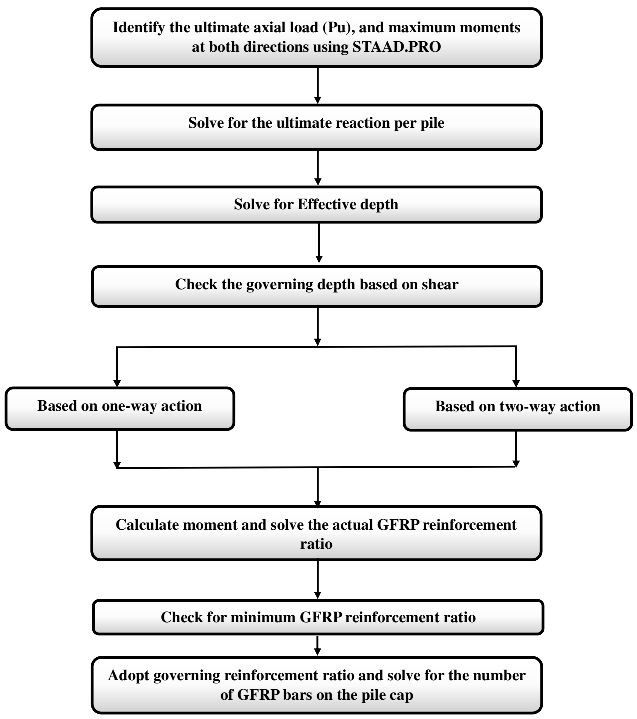


Fig. 2.8.4 shows the procedure for designing the footings.

Structural Analysis

In this study, the STAAD.Pro's navigation was valued by examining the building's resistance to various forces. It better illustrated how various components, such as beams and columns, would react in the face of the weight of outside tensions like wind and seismic forces. Making sure of the structure's endurance was decisive without going through excessive stress or deformation. In order to validate that the suggested building is reinforced by glass fiber-reinforced polymer (GFRP), certain provisions for durability and safety must be made. With safety provisions, STAAD.Pro substantiates that the design satisfies the standards inaugurated by the American Concrete Institute (ACI). The software analyzes the response of the proposed building under different loadings and conditions. The STAAD.Pro V8i SS6 is important in designing buildings, especially those in the earthquake-prone regions.

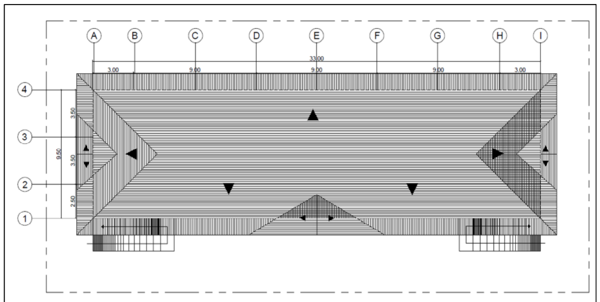
Cost Analysis

The cost analysis for the proposed additional two-storey ACI Code-based GFRP reinforced institutional building for Tarik Suliman High School at Sagrada Familia, Masantol, Pampanga, remained vitally important.

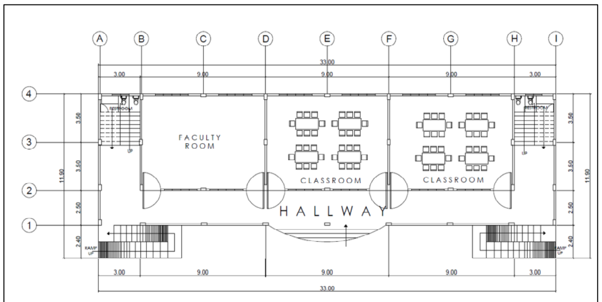
III. RESULTS AND DISCUSSIONS

This chapter presented the examination and analysis of data gathered from the usage of code provisions for the main structural members of the building from the ACI CODE 440.11-22, as well as the results of the structural analysis software from STAAD.ProV8i SS6 and manual design computations. This chapter also presented the architectural plans formulated for the proposed building. The data collected was methodically examined and evaluated to identify noteworthy findings. This chapter also included the data from interviews and document review provided by the Administration of Tarik Suliman High School and the Planning and Design Section of the Department of Public Works and Highways – 1stDistrict Engineering Office, and the costing for the required GFRP reinforcement based on the distributor's pricing, MCDI Armastek Philippines.

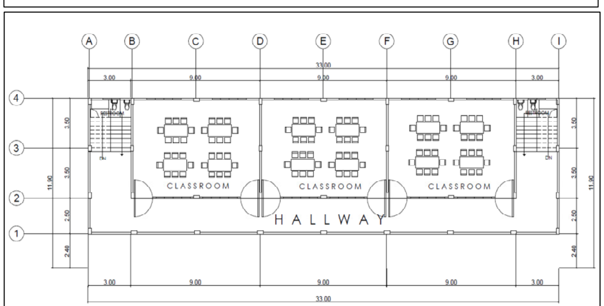
Fig. 3.1.1 shows the vicinity map of the proposed GFRP building.



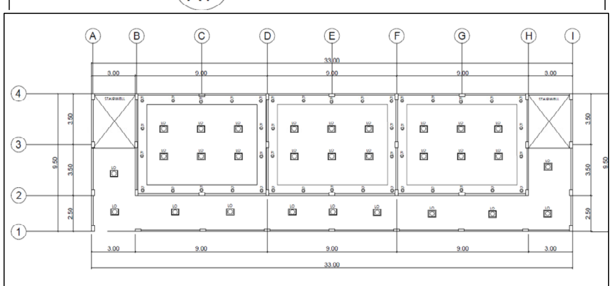
1 SITE DEVELOPMENT PLAN
A1 SCALE: 1:100



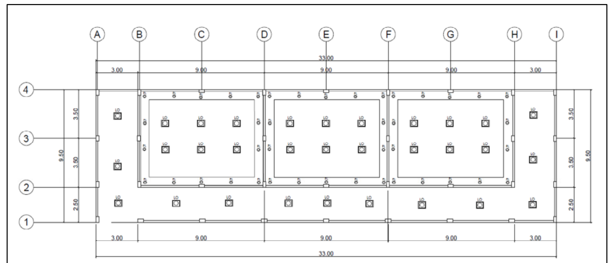
2 GROUND FLOOR PLAN
A1 SCALE: 1:100



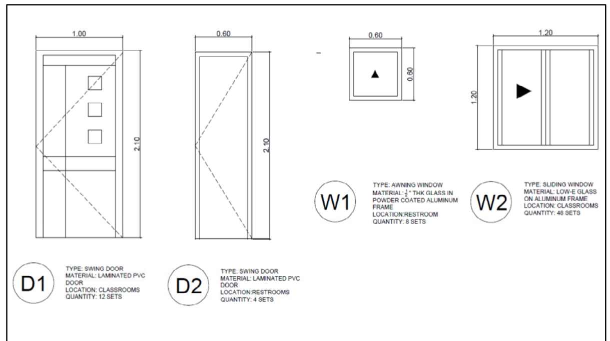
3 SECOND FLOOR PLAN
A1 SCALE: 1:100



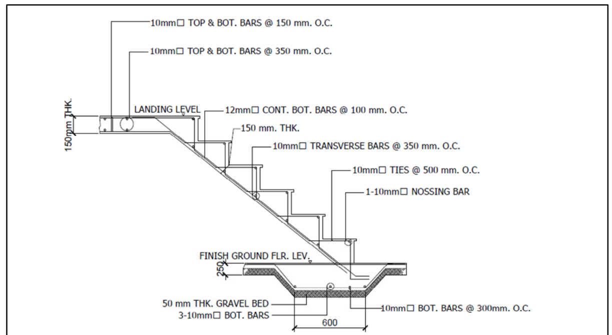
4 GF REFLECTED CEILING PLAN
A1 SCALE: 1:100



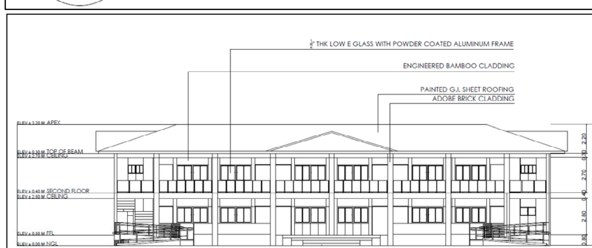
5 SF REFLECTED CEILING PLAN
A1 SCALE: 1:100



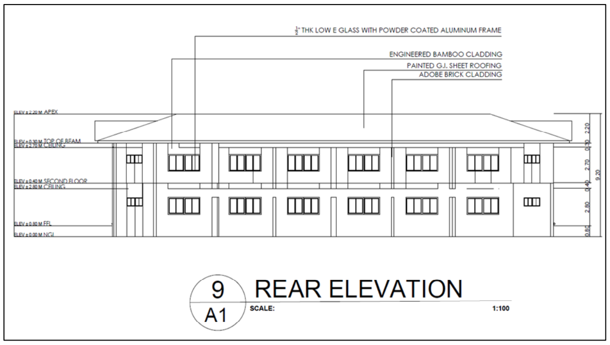
6 SCHEDULE OF DOORS AND WINDOWS
A1 SCALE: 1:10



7 CONCRETE STAIR DETAIL
A1 SCALE: 1:15



8 FRONT ELEVATION
A1 SCALE: 1:100



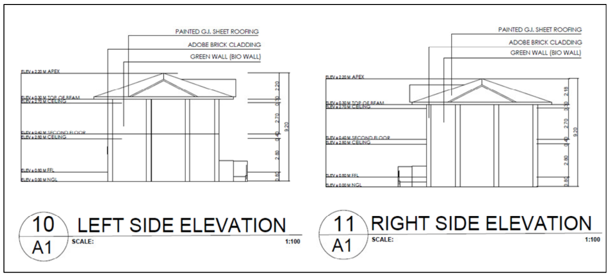


Fig. 3.1.12 shows the 3D rendered view of the front exterior perspective of the proposed GFRP building.

Architectural plans were shown above, which include the following: site development plan, second-floor plan, ground floor plan, ground floor reflected ceiling plan, reflected ceiling plan, second-floor schedule of doors and windows, rear elevation, front elevation, right-side elevation, and left-side elevation. The GFRP-reinforced building design for Tarik Suliman High School in Sagrada Familia, Masantol, Pampanga, was inclusive and had basic student facilities based on the school's needs. The School Principal, Sir Lindon Q. Batayola, mentioned the need for four to five classrooms to cater to the opening of Science, Technology, Engineering, and Mathematics (STEM), an academic senior high school program for the entire Pampanga River Left Bank community. Additionally, the classroom setup is based upon the observations of the educators that having an interactive arrangement of chairs and tables would positively impact the students' learning engagement. The proposed two-storey GFRP-reinforced building had five Senior High School Department classrooms, one room that could serve as a faculty room or storage room, two comfort rooms on opposite sides of the buildings, and ramps on the façade.

Structural Design Criteria

This study should deliberate the source design for the Structural Engineering aspect of the additional two-storey ACI Code-based GFRP reinforced institutional building for Tarik Suliman High School in Sagrada Familia, Masantol, Pampanga.

Applied Codes, Standards and References

Engineering design works were performed based on the latest Codes, Standards, and References editions.

A.ACI CODE 440.11-22: Building Code Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars—Code and Commentary, American Concrete Institute, ACI, (2022), ISBN: 978-1-64195-193-7

B. National Structural Code of the Philippines 2015 Volume 1, 7th Edition, Association of Structural Engineers of the Philippines, ASEP, (2010)

C. ASCE/SEI 7-10, American Society of Civil Engineers, Minimum Design Loads for Buildings and Other Structures

D. DepEd Order No. 64, Series of 2017: Establishing the Minimum Performance Standards and Specifications (MPSS) for DepEd School Buildings, Department of Education, (2017)

E. Final Report on Geotechnical Investigation of Tarik Suliman High School, Sagrada Familia, Masantol, Pampanga, Office of the District Engineer, Pampanga 1st District Engineering Office (Region III), Department of Public Works and Highways, (2019)

Design Dead Loads

The following forces and basic loads shall be measured in the design with various arrangements of loads shall be used in design calculations provided by NSCP 2015 table 204- 1 Minimum

Densities for Design Loads from Materials in kN/m^3, Table 204-2 Minimum Design Loads in kPa, and Table 205-1 Minimum Uniform and Concentrated Live Loads. The ACI Code 440.11-22 adopted the same load combinations from ACI 318, thus the load combinations provided by the NSCP 2015 was utilized. These were the considered dead loads upon designing:

1. 50 mm Floor Fill (Lightweight Concrete per mm = 0.015 kPa) = 0.75 kPa
2. 20mm Floor Finish (concrete fill finish per mm thk = 0.023 kPa) = 0.46 kPa
3. MEPFPS (Mechanical Electrical Planning Fire Protection System) = 0.1 kPa
4. Slab (150mm thk) = 3.54 kPa
5. Roof (purlins, rafter, and roofing sheet) = 0.3 kPa

Design Live Loads

According to the specifications, "live loads" encompass the combined weight of movable objects, including equipment, tools, office staff, and other items. This section was also based on DepEd Order No. 64, S. 2017. The applied live loads were the following:

1. Classroom = 1.9 kPa
2. Corridors Above Ground Floor = 4.8 kPa

Seismic Loads

Seismic load is the force applied to a structure by seismic vibrations, equivalent in design effect to the horizontal and vertical forces caused by ground movement during an earthquake. This load is defined by the National Structural Code of the Philippines (NSCP) 2015, based on the Uniform Building Code 1997 (UBC 97). According to NSCP 2015 Figure 208-1, which depicts the "Seismic Zone Map of the Philippines," Sagrada Familia Masantol, Pampanga, falls under Zone 4 and is located 47.4 km from the West Valley Fault.

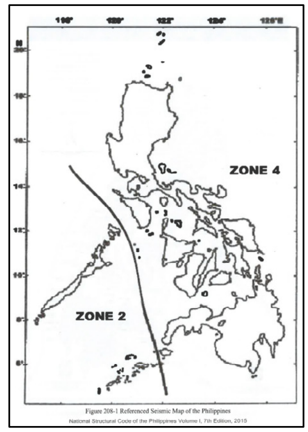


Fig. 3.2.4.a shows the Referenced Seismic Map of the Philippines. (Source: NSCP Fig. 208-1, National Structural Code of the Philippines, 2015)

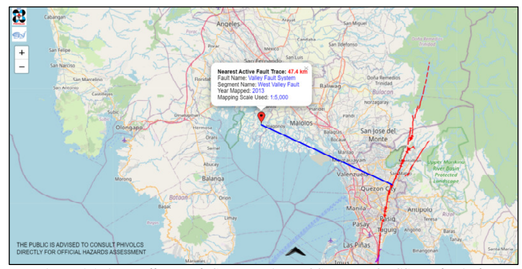


Figure 3.2.4.B: Valley Fault System using DOST-PHIVOLCS Fault Finder

Fig. 3.2.4.b shows the proximity of the site location from Sagrada Familia, Masantol, Pampanga to the nearest active fault in the Philippines, West Valley Fault. (Source: DOST-PHIVOLCS Fault Finder)

Seismic Parameters

- Seismic Source Type: A (Table 208-4 Seismic Source Type)
- Soil Profile Type: SE, Soft Soil Profile (208.4.3 Site Geology and Soil Structure)
- Seismic Zone: 0.40 (Table 208-3 Seismic Zone Factor)
- Occupancy Category: I, Essential Facility (Table 103-1 Occupancy Category)

Numerical Coefficient

- Base shear coefficient shall be derived using the following formula stipulated in NSCP
- Earthquake Load Provisions for Building Structures
- Total seismic dead load (W), (Soil Parameters not available)
- Nv = 1.0 (Table 208-5 Near-Source Factor)
- Na = 1.0 (Table 208-4 Near-Source Factor)
- Ca: acceleration- controlled coefficient (Table 208-8 Seismic Coefficient)
- Ca = 0.44(Na) = 0.44(1) = 0.44

- Cv: velocity-controlled coefficient (Table 208-7 Seismic Coefficient)
- Cv = 0.96 (Na) = 0.96(1.00) = 0.96
- I (Importance Factor) = 1.5 (Table 208-1 Seismic Importance Factor)
- Moment Resisting Frame Systems (R) = 8.5
- Ct = 0.0731 (Reinforced Concrete Structure)

Seismic Analysis

Earthquake Base Shear Result, Storey Drift Result, Soft Storey Check ASCE7 were performed through the utilization of STAAD.Pro V8i Select Series 6.

- Allowable Story Drift: Table 12.12-1 NSCP
- Structures other than masonry, shearwall,4 stories or less with interior wall, partitions,ceiling exterior walls. Occupancy category I = 0.025H: OR L/238 = 0.0042 FACTOR = 0.0042

Base Shear Result

- Base Shear at X- Direction = 1079.35 kN
- Base Shear at Z- Direction = 1079.35 kN

Storey Drift Check

STORY	HEIGHT (METE)	LOAD	AVG. DISP (CM) X	AVG. DISP (CM) Z	DRIFT (CM) X	DRIFT (CM) Z	RATIO	STATUS
BASE=	0.00						ALLOW. DRIFT = L / 238	
1	0.00	5	0.0000	0.0000	0.0000	0.0000	L /999999	PASS
		6	0.0000	0.0000	0.0000	0.0000	L /999999	PASS
		7	0.0000	0.0000	0.0000	0.0000	L /999999	PASS
		8	0.0000	0.0000	0.0000	0.0000	L /999999	PASS
		9	0.0000	0.0000	0.0000	0.0000	L /999999	PASS
		10	0.0000	0.0000	0.0000	0.0000	L /999999	PASS
2	2.31	5	0.0000	-0.0011	0.0000	0.0011	L /999999	PASS
		6	0.0000	-0.0014	0.0000	0.0014	L /159647	PASS
		7	0.2164	-0.0011	0.2164	0.0011	L / 1067	PASS
		8	-0.0005	0.2157	0.0005	0.2157	L / 1071	PASS
		9	0.1545	-0.0008	0.1545	0.0008	L / 1495	PASS
		10	-0.0003	0.1540	0.0003	0.1540	L / 1500	PASS
3	5.91	5	0.0000	0.0110	0.0000	0.0121	L / 29801	PASS
		6	0.0000	0.0138	0.0000	0.0153	L / 23586	PASS
		7	0.8667	0.0121	0.6502	0.0132	L / 553	PASS
		8	-0.0030	0.8711	0.0025	0.6554	L / 549	PASS
		9	0.6188	0.0094	0.4643	0.0102	L / 775	PASS
		10	-0.0022	0.6227	0.0018	0.4687	L / 768	PASS
4	9.31	5	0.0000	0.0223	0.0000	0.0113	L / 29978	PASS
		6	0.0000	0.0291	0.0000	0.0153	L / 22180	PASS
		7	1.1615	0.0227	0.2948	0.0106	L / 1153	PASS
		8	-0.0028	1.1651	0.0003	0.2941	L / 1156	PASS
		9	0.8293	0.0164	0.2105	0.0070	L / 1615	PASS
		10	-0.0020	0.8322	0.0002	0.2094	L / 1623	PASS

Soft Storey Check

VERTICAL STRUCTURAL IRREGULARITIES : SOFT STORY CHECK - ASCE/SEI 7-05

STORY	FL. LEVEL IN METE	STATUS X	STATUS Z
1	2.31	OK	OK
2	5.91	OK	OK
3	9.31	OK	OK

NOTE : NO SOFT STOREY IS DETECTED.

VERTICAL STRUCTURAL IRREGULARITIES : SOFT STORY CHECK - ASCE/SEI 7-05

STORY	FL. LEVEL IN METE	STATUS X	STATUS Z
1	2.31	OK	OK
2	5.91	OK	OK
3	9.31	OK	OK

NOTE : NO SOFT STOREY IS DETECTED.

STAAD.Pro V8i SS6 Results

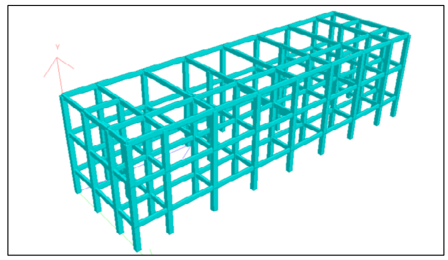


Figure 3.3A: STAAD.Pro's 3D Structural Model of the GFRP Building of Tarik Suliman High School

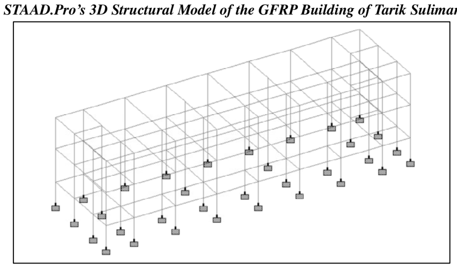


Figure 3.3B: Structural Frame of the GFRP Building of Tarik Suliman High School

The figures above (Figure 3.3A and Figure 3.3B) showed the three-dimensional isometric view of the structure as well as the structural frame of the proposed multifunctional building, created using Bentley Systems' Structural Analysis and Design software, STAAD.Pro V8i SS6.

Diagrams Due to Load Combinations

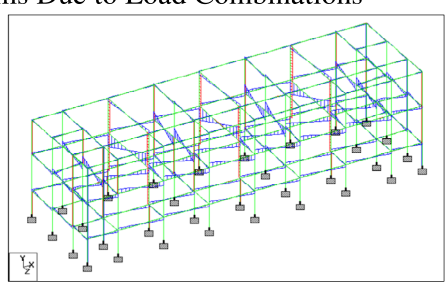


Figure 3.3.1.1A: Shear Diagram (Superstructure)

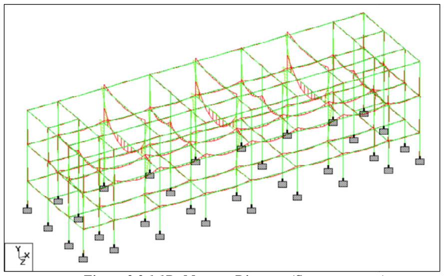


Figure 3.3.1.1B: Moment Diagram (Superstructure)

Fig. 3.3.1.a and Fig. 3.3.1.b show the shear and bending moment diagram of the superstructure of the proposed GFRP-reinforced building due to the load combination: 120% Dead Load +160% Live Load ((1.2DL + 1.6 LL).

These diagrams identified critical sections that might cause failure or deformation due to shear and bending stress. They also highlighted key areas with the highest or lowest shear and bending moment values, indicating where suitable reinforcing or cross-sections were needed.

Material Strength

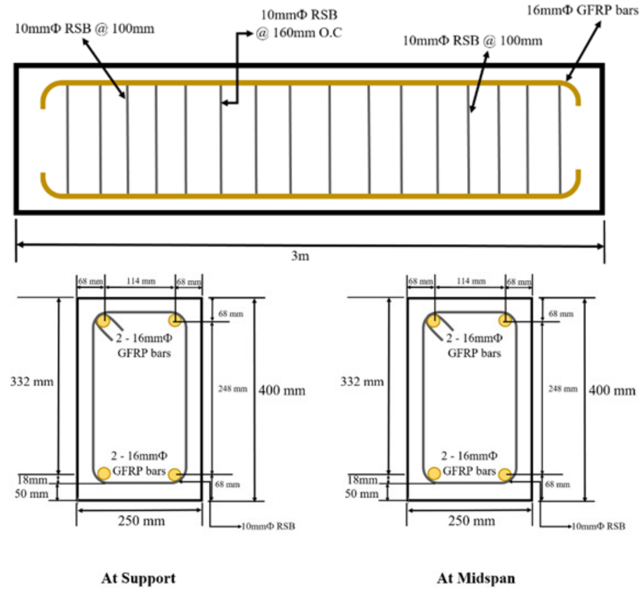
- Compressive Strength (fc') - 27.5 MPa
- Guaranteed Tensile Strength (ffu*) – 1200 MPa (16mm Ø)
- Design Tensile Strength (ffu) – 1020 MPa (16mm Ø)
- Modulus of Elasticity (Ef) – 55000 MPa
- Environmental Reduction Factor (CE) – 0.85
- Concrete Modulus of Elasticity (Ec) – 200000 MPa
- Structural Steel (fy) – 276 MPa (10mm Ø)

GB – 1

Beam Data:

- Span type = One end continuous
- Span Length = 3 m
- Width (b) = 0.250 m
- Height (h) = 0.4 m
- Main Bars = 16mm
- Stirrups = 10mm

Use 250 mm. x 400mm. section with 2 - 16mmΦ GFRP bars at support and 2 - 16mmΦ GFRP bars @ midspan. Stirrups with 10mmΦ RSB: 1 @ 50mm, 4@100 mm, REST are spaced 160mm O.C.

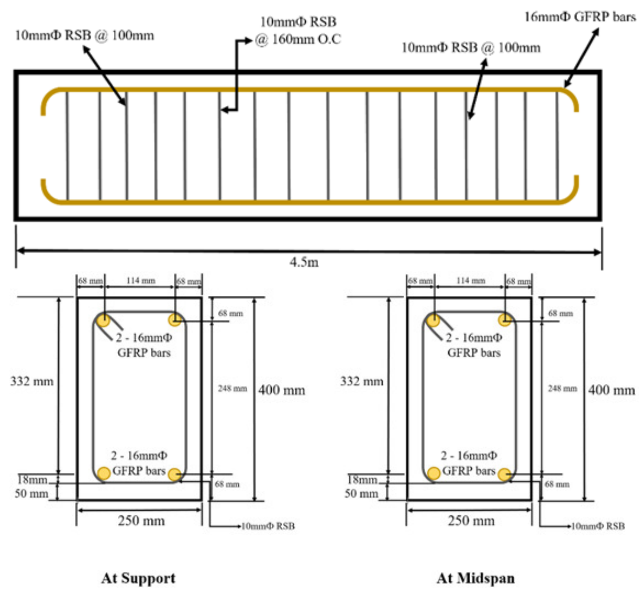


GB – 2

Beam Data:

- Span type = Both ends continuous
- Span Length = 4.5 m
- Width (b) = 0.250 m
- Height (h) = 0.4 m
- Main Bars = 16mm
- Stirrups = 10mm

Use 250 mm. x 400mm. section with 2 - 16mmΦ GFRP bars at support and 2 - 16mmΦ GFRP bars @ midspan. Stirrups with 10mmΦ RSB: 1 @ 50mm, 4@100 mm, REST are spaced 160mm O.C.

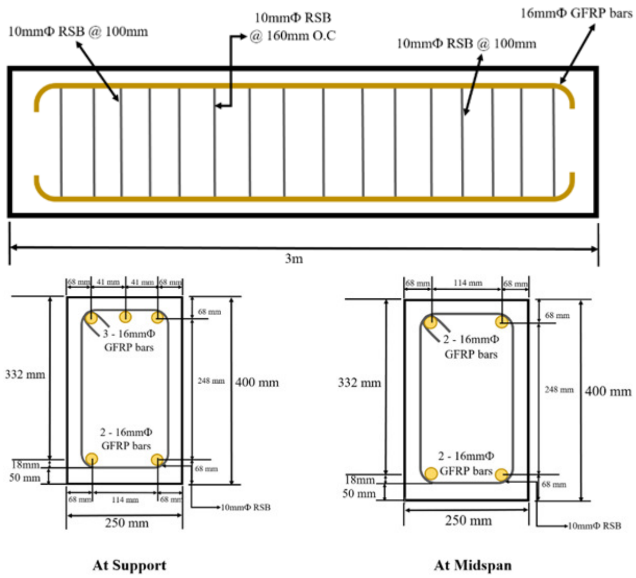


GB – 3

Beam Data:

- Span type = One end continuous
- Span Length = 3 m
- Width (b) = 0.250 m
- Height (h) = 0.4 m
- Main Bars = 16mm
- Stirrups = 10mm

Use 250 mm. x 400mm. section with 3 - 16mmΦ GFRP bars at support and 2 - 16mmΦ GFRP bars @ midspan. Stirrups with 10mmΦ RSB: 1 @ 50mm, 4@100 mm, REST are spaced 160mm O.C.

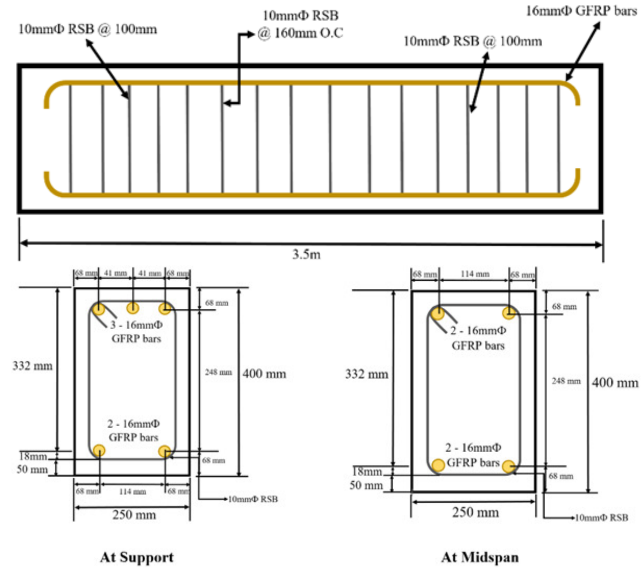


GB – 4

Beam Data:

- Span type = One end continuous
- Span Length = 3.5 m
- Width (b) = 0.250 m
- Height (h) = 0.4 m
- Main Bars = 16mm
- Stirrups = 10mm

Use 250 mm. x 400mm. section with 3 - 16mmΦ GFRP bars at support and 2 - 16mmΦ GFRP bars @ midspan. Stirrups with 10mmΦ RSB: 1 @ 50mm, 4@100 mm, REST are spaced 160mm O.C.

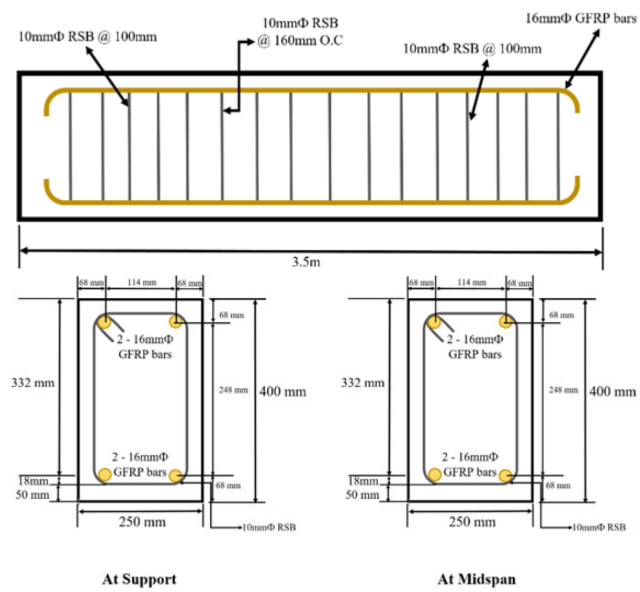


GB – 5

Beam Data:

- Span type = One end continuous
- Span Length = 3.5 m
- Width (b) = 0.250 m
- Height (h) = 0.4 m
- Main Bars = 16mm
- Stirrups = 10mm

Use 250 mm. x 400mm. section with 2 - 16mmΦ GFRP bars at support and 2 - 16mmΦ GFRP bars @ midspan. Stirrups with 10mmΦ RSB: 1 @ 50mm, 4@100 mm, REST are spaced 160mm O.C.

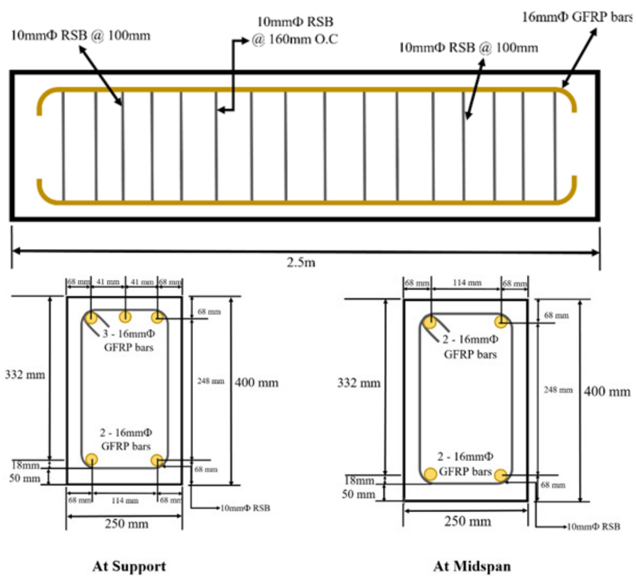


GB – 6

Beam Data:

- Span type = One end continuous
- Span Length = 2.5 m
- Width (b) = 0.250 m
- Height (h) = 0.4 m
- Main Bars = 16mm
- Stirrups = 10mm

Use 250 mm. x 400mm. section with 3 - 16mmΦ GFRP bars at support and 2 - 16mmΦ GFRP bars @ midspan. Stirrups with 10mmΦ RSB: 1 @ 50mm, 4@100 mm, REST are spaced 160mm O.C.

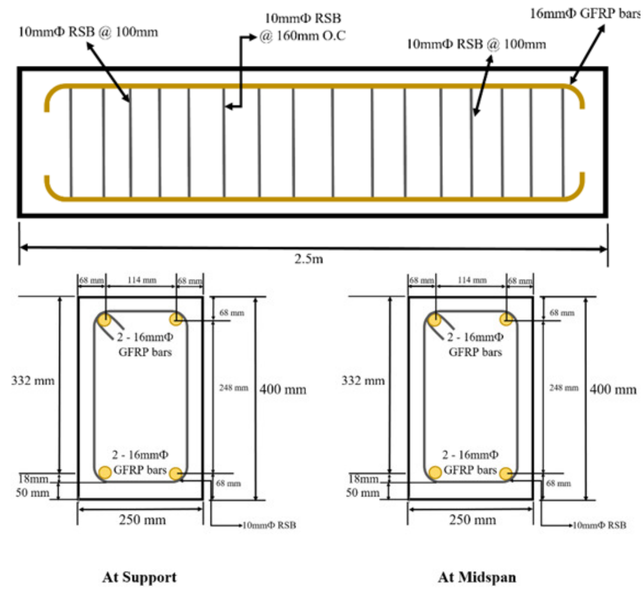


GB – 7

Beam Data:

- Span type = One end continuous
- Span Length = 2.5 m
- Width (b) = 0.250 m
- Height (h) = 0.4 m
- Main Bars = 16mm
- Stirrups = 10mm

Use 250 mm. x 400mm. section with 2 - 16mmΦ GFRP bars at support and 2 - 16mmΦ GFRP bars @ midspan. Stirrups with 10mmΦ RSB: 1 @ 50mm, 4@100 mm, REST are spaced 160mm O.C.

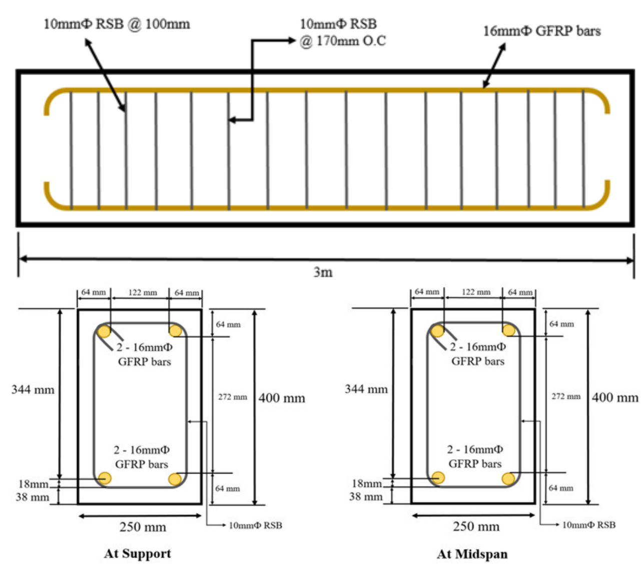


2FB – 1

Beam Data:

- Span type = One end continuous
- Span Length = 3.5 m
- Width (b) = 0.250 m
- Height (h) = 0.4 m
- Main Bars = 16mm
- Stirrups = 10mm

Use 250 mm. x 400mm. section with 2 - 16mmΦ GFRP bars at support and 2 - 16mmΦ GFRP bars @ midspan. Stirrups with 10mmΦ RSB: 1 @ 50mm, 4@100 mm, REST are spaced 170mm O.C.

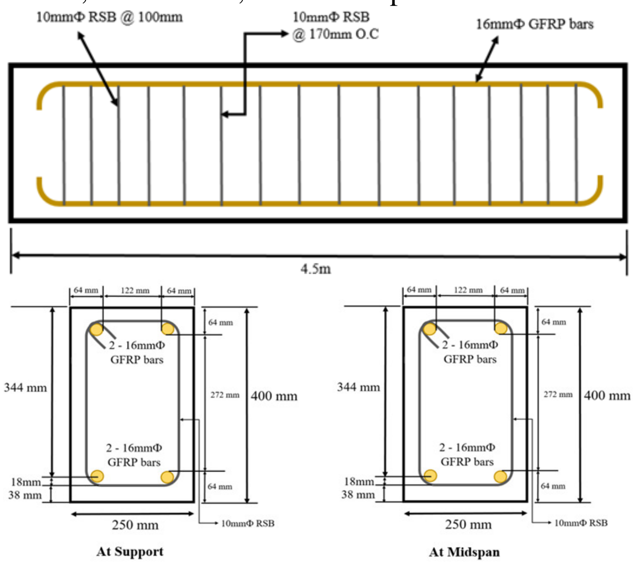


2FB – 2

Beam Data:

- Span type = Both ends continuous
- Span Length = 4.5 m
- Width (b) = 0.250 m
- Height (h) = 0.4 m
- Main Bars = 16mm
- Stirrups = 10mm

Use 250 mm. x 400mm. section with 2 - 16mmΦ GFRP bars at support and 2 - 16mmΦ GFRP bars @ midspan. Stirrups with 10mmΦ RSB: 1 @ 50mm, 4@100 mm, REST are spaced 170mm O.C.

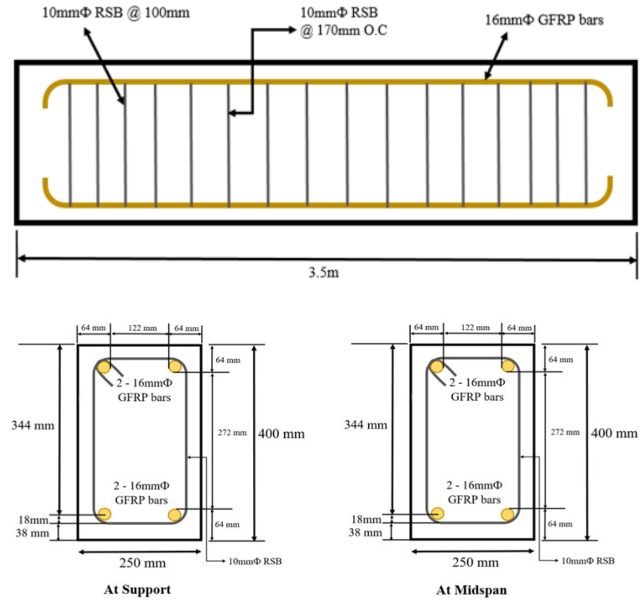


2FB – 3

Beam Data:

- Span type = One end continuous
- Span Length = 3.5 m
- Width (b) = 0.250 m
- Height (h) = 0.4 m
- Main Bars = 16mm
- Stirrups = 10mm

Use 250 mm. x 400mm. section with 2 - 16mmΦ GFRP bars at support and 2 - 16mmΦ GFRP bars @ midspan. Stirrups with 10mmΦ RSB: 1 @ 50mm, 4@100 mm, REST are spaced 170mm O.C.

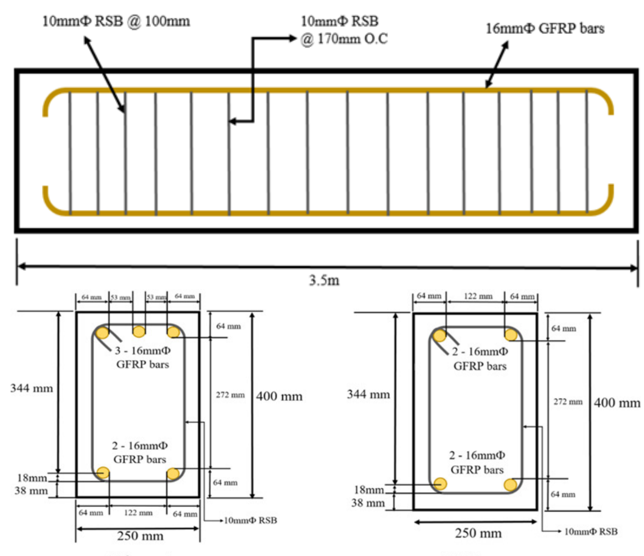


2FB – 4

Beam Data:

- Span type = One end continuous
- Span Length = 3.5 m
- Width (b) = 0.250 m
- Height (h) = 0.4 m
- Main Bars = 16mm
- Stirrups = 10mm

Use 250 mm. x 400mm. section with 3 - 16mmΦ GFRP bars at support and 2 - 16mmΦ GFRP bars @ midspan. Stirrups with 10mmΦ RSB: 1 @ 50mm, 4@100 mm, REST are spaced 170mm O.C.

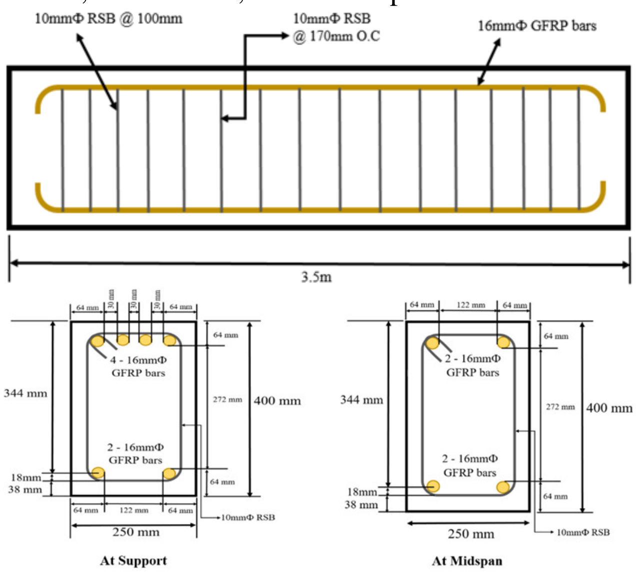


2FB – 5

Beam Data:

- Span type = One end continuous
- Span Length = 3.5 m
- Width (b) = 0.250 m
- Height (h) = 0.4 m
- Main Bars = 16mm
- Stirrups = 10mm

Use 250 mm. x 400mm. section with 4 - 16mmΦ GFRP bars at support and 2 - 16mmΦ GFRP bars @ midspan. Stirrups with 10mmΦ RSB: 1 @ 50mm, 4@100 mm, REST are spaced 170mm O.C.

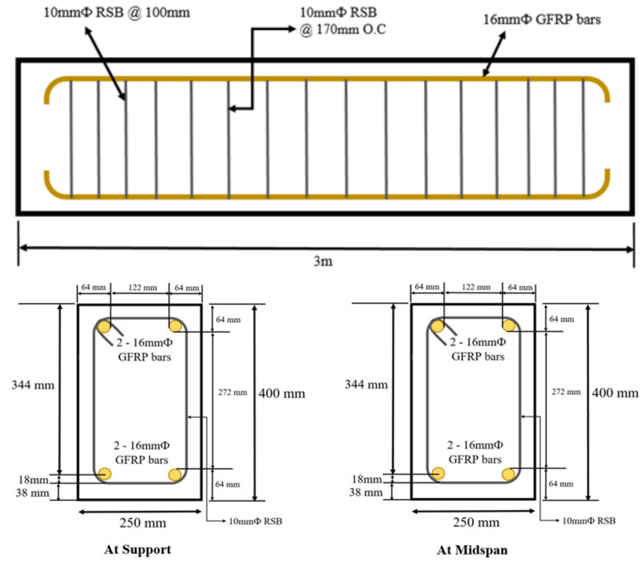


2FB – 6

Beam Data:

- Span type = Both ends continuous
- Span Length = 3 m
- Width (b) = 0.250 m
- Height (h) = 0.4 m
- Main Bars = 16mm
- Stirrups = 10mm

Use 250 mm. x 400mm. section with 2 - 16mmΦ GFRP bars at support and 2 - 16mmΦ GFRP bars @ midspan. Stirrups with 10mmΦ RSB: 1 @ 50mm, 4@100 mm, REST are spaced 170mm O.C.

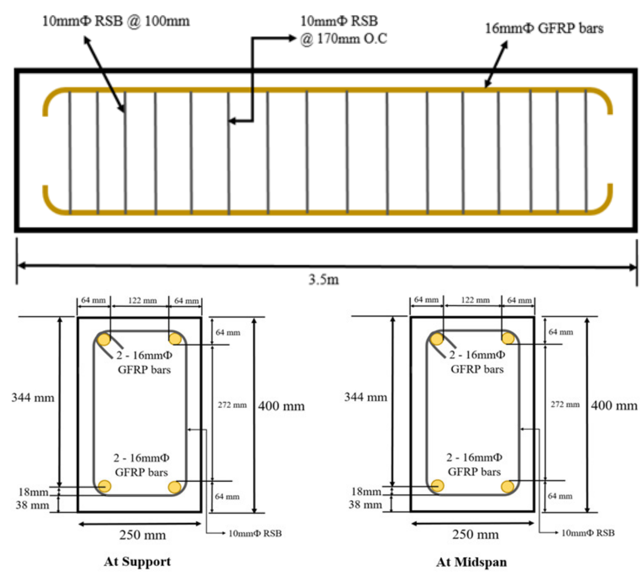


2FB – 7

Beam Data:

- Span type = Both ends continuous
- Span Length = 3.5 m
- Width (b) = 0.250 m
- Height (h) = 0.4 m
- Main Bars = 16mm
- Stirrups = 10mm

Use 250 mm. x 400mm. section with 2 - 16mmΦ GFRP bars at support and 2 - 16mmΦ GFRP bars @ midspan. Stirrups with 10mmΦ RSB: 1 @ 50mm, 4@100 mm, REST are spaced 170mm O.C.

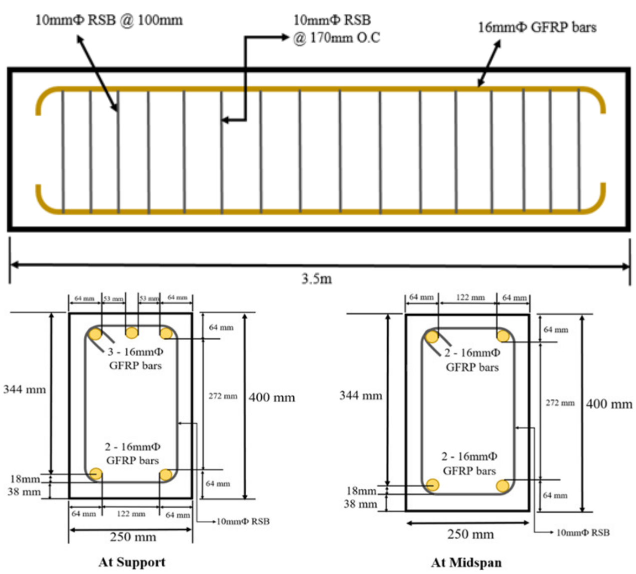


2FB – 8

Beam Data:

- Span type = Both ends continuous
- Span Length = 3.5 m
- Width (b) = 0.250 m
- Height (h) = 0.4 m
- Main Bars = 16mm
- Stirrups = 10mm

Use 250 mm. x 400mm. section with 3 - 16mmΦ GFRP bars at support and 2 - 16mmΦ GFRP bars @ midspan. Stirrups with 10mmΦ RSB: 1 @ 50mm, 4@100 mm, REST are spaced 170mm O.C.

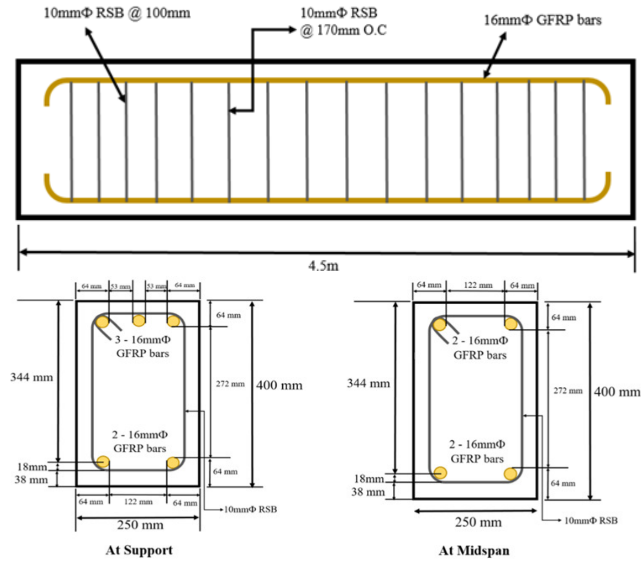


2FB – 9

Beam Data:

- Span type = Both ends continuous
- Span Length = 4.5 m
- Width (b) = 0.250 m
- Height (h) = 0.4 m
- Main Bars = 16mm
- Stirrups = 10mm

Use 250 mm. x 400mm. section with 3 - 16mmΦ GFRP bars at support and 2 - 16mmΦ GFRP bars @ midspan. Stirrups with 10mmΦ RSB: 1 @ 50mm, 4@100 mm, REST are spaced 170mm O.C.

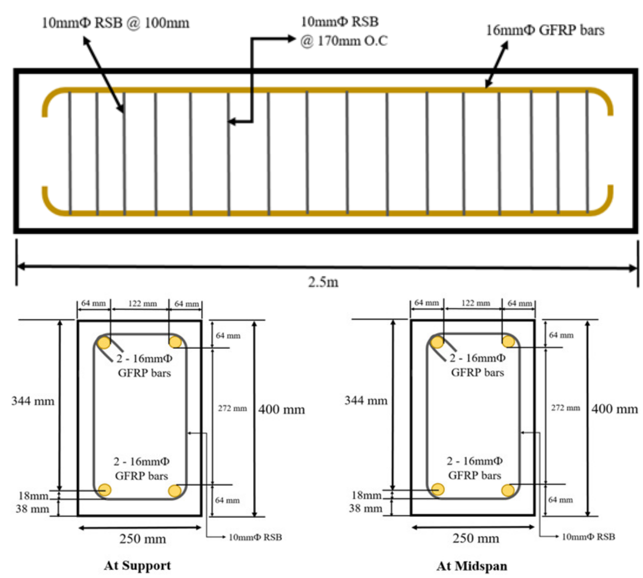


2FB – 10

Beam Data:

- Span type = One end continuous
- Span Length = 2.5 m
- Width (b) = 0.250 m
- Height (h) = 0.4 m
- Main Bars = 16mm
- Stirrups = 10mm

Use 250 mm. x 400mm. section with 2 - 16mmΦ GFRP bars at support and 2 - 16mmΦ GFRP bars @ midspan. Stirrups with 10mmΦ RSB: 1 @ 50mm, 4@100 mm, REST are spaced 170mm O.C.

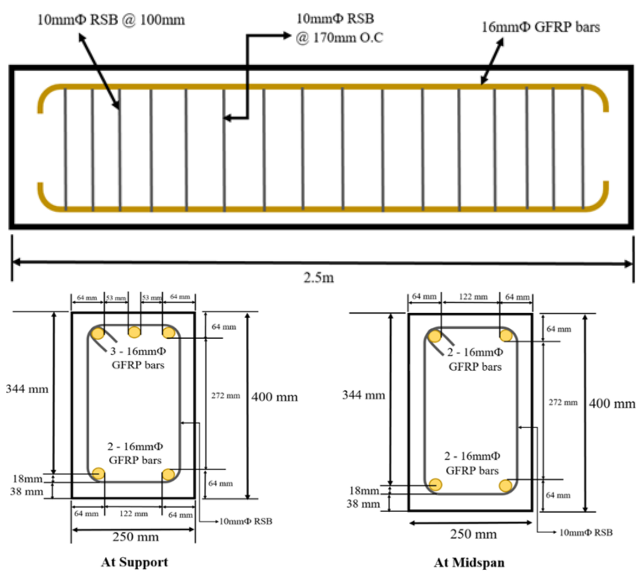


2FB – 11

Beam Data:

- Span type = One end continuous
- Span Length = 2.5 m
- Width (b) = 0.250 m
- Height (h) = 0.4 m
- Main Bars = 16mm
- Stirrups = 10mm

Use 250 mm. x 400mm. section with 3 - 16mmΦ GFRP bars at support and 2 - 16mmΦ GFRP bars @ midspan. Stirrups with 10mmΦ RSB: 1 @ 50mm, 4@100 mm, REST are spaced 170mm O.C.

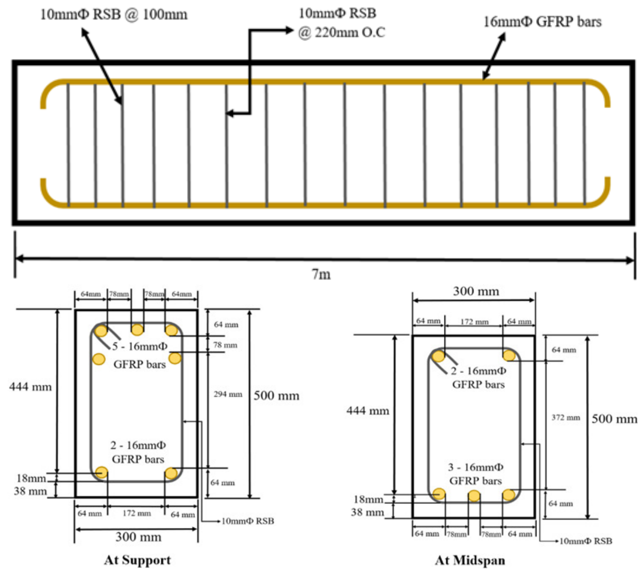


2FB – 12

Beam Data:

- Span type = One end continuous
- Span Length = 7 m
- Width (b) = 0.3 m
- Height (h) = 0.5 m
- Main Bars = 16mm
- Stirrups = 10mm

Use 300 mm. x 500mm. section with 5 - 16mmΦ GFRP bars at support and 3 - 16mmΦ GFRP bars @ midspan. Stirrups with 10mmΦ RSB: 1 @ 50mm, 4@100 mm, REST are spaced 220mm O.C.

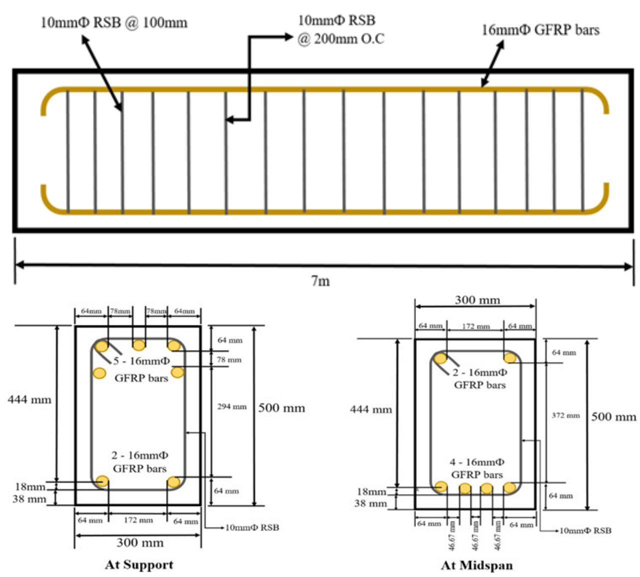


2FB – 13

Beam Data:

- Span type = One end continuous
- Span Length = 7 m
- Width (b) = 0.3 m
- Height (h) = 0.5 m
- Main Bars = 16mm
- Stirrups = 10mm

Use 300 mm. x 500mm. section with 5 - 16mmΦ GFRP bars at support and 4 - 16mmΦ GFRP bars @ midspan. Stirrups with 10mmΦ RSB: 1 @ 50mm, 4@100 mm, REST are spaced 200mm O.C.

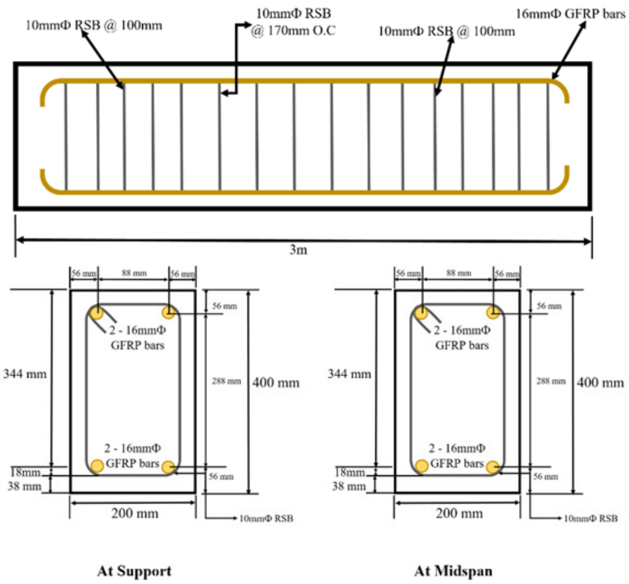


RB – 1

Beam Data:

- Span type = One end continuous
- Span Length = 3 m
- Width (b) = 0.2 m
- Height (h) = 0.4 m
- Main Bars = 16mm
- Stirrups = 10mm

Use 200 mm. x 400mm. section with 2 - 16mmΦ GFRP bars at support and 2 - 16mmΦ GFRP bars @ midspan. Stirrups with 10mmΦ RSB: 1 @ 50mm, 4@100 mm, REST are spaced 170mm O.C.

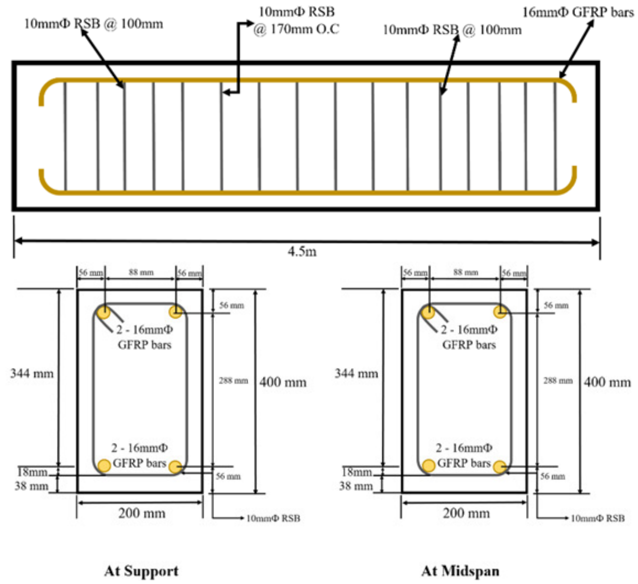


RB – 2

Beam Data:

- Span type = Both ends continuous
- Span Length = 4.5 m
- Width (b) = 0.2 m
- Height (h) = 0.4 m
- Main Bars = 16mm
- Stirrups = 10mm

Use 200 mm. x 400mm. section with 2 - 16mmΦ GFRP bars at support and 2 - 16mmΦ GFRP bars @ midspan. Stirrups with 10mmΦ RSB: 1 @ 50mm, 4@100 mm, REST are spaced 170mm O.C.

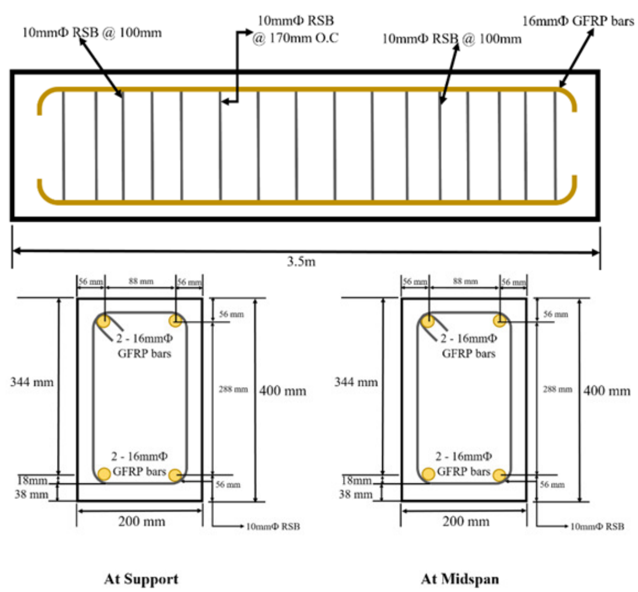


RB – 3

Beam Data:

- Span type = One end continuous
- Span Length = 3.5 m
- Width (b) = 0.2 m
- Height (h) = 0.4 m
- Main Bars = 16mm
- Stirrups = 10mm

Use 200 mm. x 400mm. section with 2 - 16mmΦ GFRP bars at support and 2 - 16mmΦ GFRP bars @ midspan. Stirrups with 10mmΦ RSB: 1 @ 50mm, 4@100 mm, REST are spaced 170mm O.C.

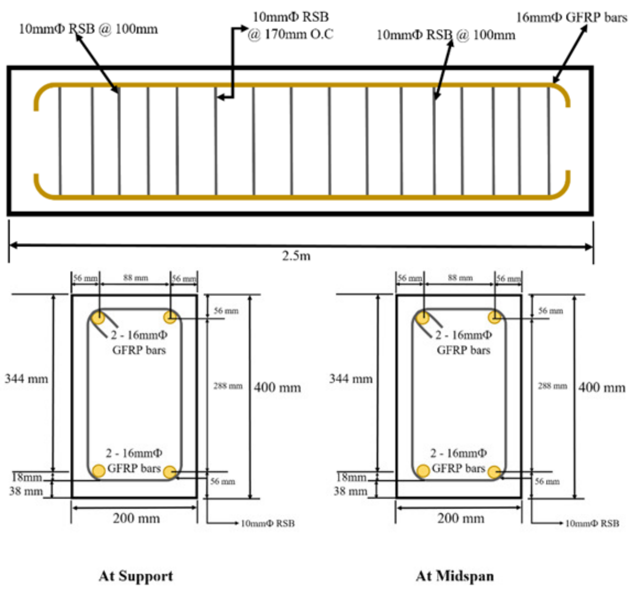


RB – 4

Beam Data:

- Span type = One end continuous
- Span Length = 2.5 m
- Width (b) = 0.2 m
- Height (h) = 0.4 m
- Main Bars = 16mm
- Stirrups = 10mm

Use 200 mm. x 400mm. section with 2 - 16mmΦ GFRP bars at support and 2 - 16mmΦ GFRP bars @ midspan. Stirrups with 10mmΦ RSB: 1 @ 50mm, 4@100 mm, REST are spaced 170mm O.C.

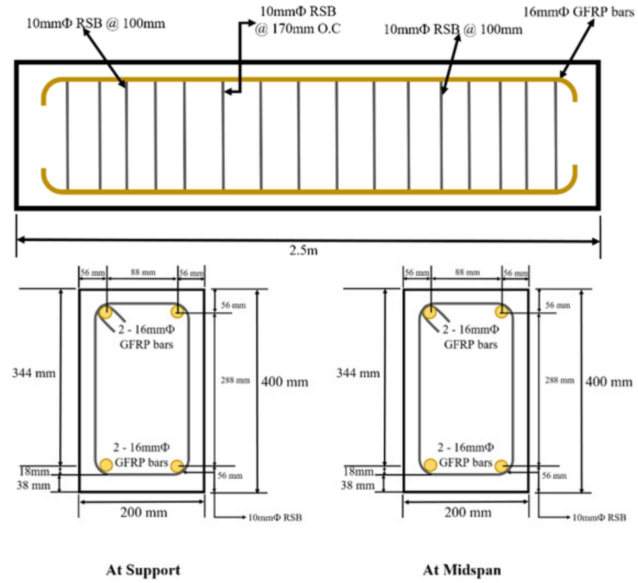


RB – 5

Beam Data:

- Span type = Both ends continuous
- Span Length = 3.5 m
- Width (b) = 0.2 m
- Height (h) = 0.4 m
- Main Bars = 16mm
- Stirrups = 10mm

Use 200 mm. x 400mm. section with 2 - 16mmΦ GFRP bars at support and 2 - 16mmΦ GFRP bars @ midspan. Stirrups with 10mmΦ RSB: 1 @ 50mm, 4@100 mm, REST are spaced 170mm O.C.

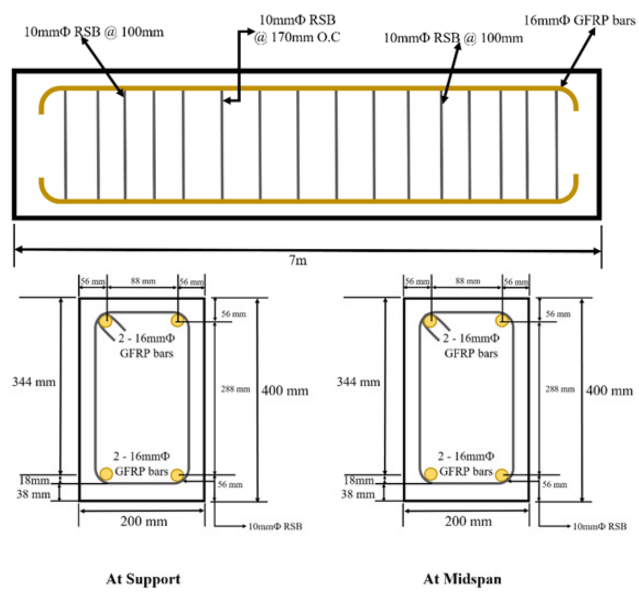


RB – 6

Beam Data:

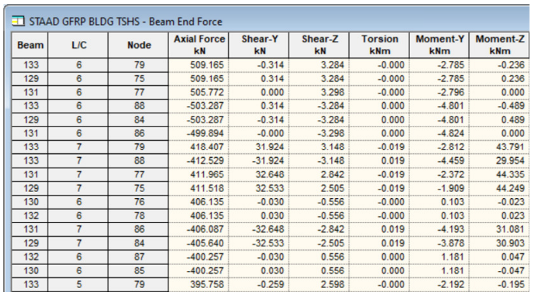
- Span type = One end continuous
- Span Length = 7 m
- Width (b) = 0.2 m
- Height (h) = 0.4 m
- Main Bars = 16mm
- Stirrups = 10mm

Use 200 mm. x 400mm. section with 2 - 16mmΦ GFRP bars at support and 2 - 16mmΦ GFRP bars @ midspan. Stirrups with 10mmΦ RSB: 1 @ 50mm, 4@100 mm, REST are spaced 170mm O.C.



Column Design

Critical Interior Column



STAAD GFRP BLDG TSHS - Beam End Force

Beam	L/C	Node	Axial Force kN	Shear-Y kN	Shear-Z kN	Torsion kNm	Moment-Y kNm	Moment-Z kNm
133	6	79	509.165	-0.314	3.284	-0.000	-2.785	-0.236
129	6	75	509.165	0.314	3.284	-0.000	-2.785	0.236
131	6	77	505.772	0.000	3.298	-0.000	-2.796	0.000
133	6	88	-503.287	0.314	-3.284	0.000	-4.801	-0.489
129	6	84	-503.287	-0.314	-3.284	0.000	-4.801	0.489
131	6	86	-499.894	-0.000	-3.298	0.000	-4.824	0.000
133	7	79	418.407	31.924	3.148	-0.019	-2.812	43.791
133	7	88	-412.529	-31.924	-3.148	0.019	-4.459	29.954
131	7	77	411.965	32.648	2.842	-0.019	-2.372	44.335
129	7	75	411.518	32.533	2.505	-0.019	-1.909	44.249
130	6	76	406.135	-0.030	-0.556	-0.000	0.103	-0.023
132	6	78	406.135	0.030	-0.556	-0.000	0.103	0.023
131	7	86	-406.087	-32.648	-2.842	0.019	-4.193	31.081
129	7	84	-405.640	-32.533	-2.505	0.019	-3.878	30.903
132	6	87	-400.257	-0.030	0.556	0.000	1.181	0.047
130	6	85	-400.257	0.030	0.556	0.000	1.181	-0.047
133	5	79	395.758	-0.259	2.598	-0.000	-2.192	-0.195

Fig. 3.6.1.a STAAD result for the maximum axial force in kN for interior columns.

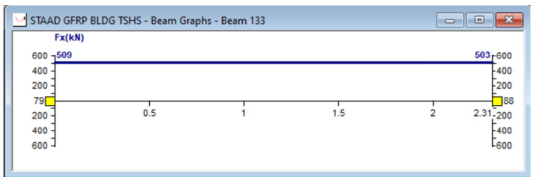


Fig. 3.6.1.b STAAD result beam graph for the maximum axial force in kN for interior columns.

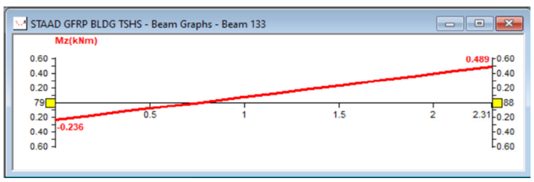


Fig. 3.6.1.c STAAD result beam graph for the maximum moment in kN-m for interior columns.

- Column # with Pu = 509.165 kN (Max Axial Force)
- Column # with Max Moment= 0.489 kN-m

Design Parameters

- Ag = 300mm x 300mm
- Span Length = 2.310m
- Compressive Strength, f'c = 27.5 MPa
- Main Bars = 16mmΦ
- Stirrups = 10mmΦ

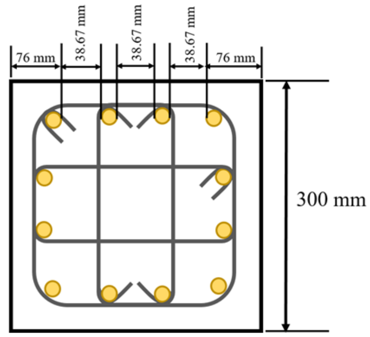
Check for Axial Load Capacity

$Pucap$ = 1093.95 kN > $\boldsymbol{Pu}$; t□erefore**SAFE**!

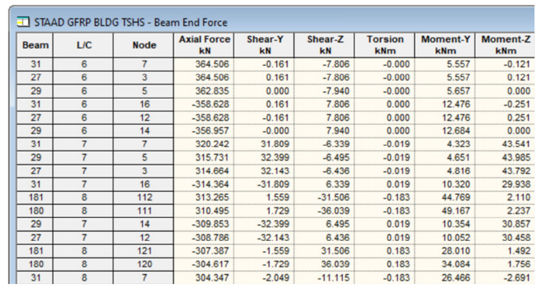
No. of GFRP Bars and Spacing of Lateral Ties

n = 12 – 16mmΦ
Use 190 mm O.C.

Therefore, use 300mm x 300mm. column section with 12-16 mmΦ GFRP Bars with 10mmΦRSB lateral ties spaced @ 190 mm O.C.



Critical Exterior Column



STAAD GFRP BLDG TSHS - Beam End Force

Beam	L/C	Node	Axial Force kN	Shear-Y kN	Shear-Z kN	Torsion kNm	Moment-Y kNm	Moment-Z kNm
31	6	7	364.506	-0.161	-7.806	-0.000	5.557	-0.121
27	6	3	364.506	0.161	-7.806	-0.000	5.557	0.121
29	6	5	362.835	0.000	-7.940	-0.000	5.657	0.000
31	6	16	-358.628	0.161	7.806	0.000	12.476	-0.251
27	6	12	-358.628	-0.161	7.806	0.000	12.476	0.251
29	6	14	-356.957	-0.000	7.940	0.000	12.684	0.000
31	7	7	320.242	31.809	-6.339	-0.019	4.323	43.541
29	7	5	315.731	32.399	-6.495	-0.019	4.651	43.985
27	7	3	314.664	32.143	-6.436	-0.019	4.816	43.792
31	7	16	-314.364	-31.809	6.339	0.019	10.320	29.938
181	8	112	313.265	1.559	-31.506	-0.183	44.769	2.110
180	8	111	310.495	1.729	-36.039	-0.183	49.167	2.237
29	7	14	-309.853	-32.399	6.495	0.019	10.354	30.857
27	7	12	-308.786	-32.143	6.436	0.019	10.052	30.458
181	8	121	-307.387	-1.559	31.506	0.183	28.010	1.492
180	8	120	-304.617	-1.729	36.039	0.183	34.084	1.756
31	8	7	304.347	-2.049	-11.115	-0.183	26.466	-2.691

Fig. 3.6.2.a STAAD result for the maximum axial force in kN for exterior columns.

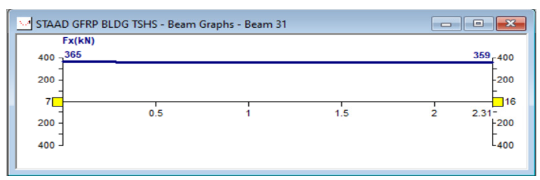


Fig. 3.6.2.b STAAD result beam graph for the maximum axial force in kN for exterior columns.

Dimensions	L = 4.5 m	S = 3.5 m
Compressive Strength (MPa)	fc'	27.5
Design Tensile Strength (MPa)	ffu^*	1200
Environmental Reduction Factor	CE	0.85
Design Tensile Strength (MPa)	ffu	1020
Modulus of Elasticity (MPa)	Ef	41000
Concrete Cover (mm)	Cc	20
Dead Load (KPa)	DL	5.834
Live Load (KPa)	LL	1.9
Unit weight of concrete (KN/m^3)	γc	23. 54
Thickness to Design	h	150 mm

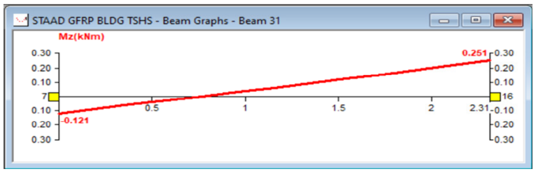


Fig. 3.6.1.c STAAD result beam graph for the maximum moment in kN-m for interior columns.

- Column # with Pu = 364.506 kN (Max Axial Force)
- Column # with Max Moment= 0.251 kN-m

Design Parameters

- Ag = 300mm x 300mm
- Span Length = 2.310m
- Compressive Strength, f'c = 27.5 MPa
- Main Bars = 16mmΦ
- Stirrups = 10mmΦ

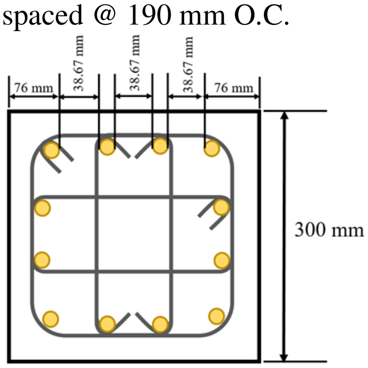
Check for Axial Load Capacity

$Pucap$ = 1093.95 kN $>\boldsymbol{Pu}$; $therefore\boldsymbol{SAFE}$!

No. of GFRP Bars and Spacing of Lateral Ties

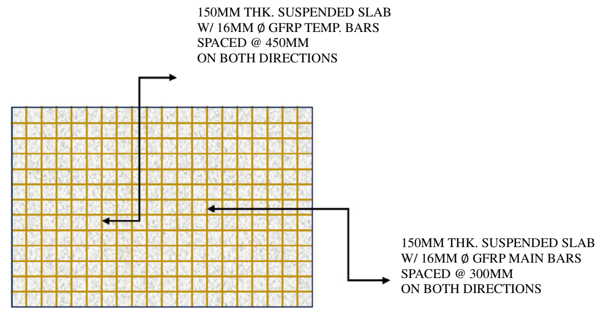
n = 12 – 16mmΦ
Use 190 mm o.c.

Therefore, use 300mm x 300mm. column section with 12 - 16mmΦ GFRP Bars with 10mmΦRSB lateral ties spaced @ 190 mm O.C.



Slab Design

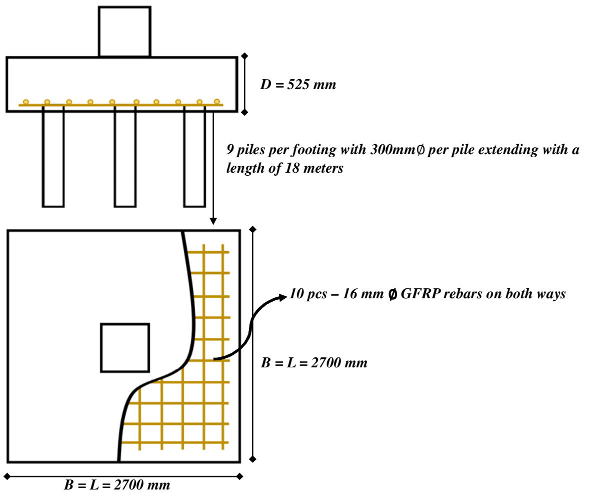
Slab – 1
Design Parameters:



Footing Design

The optimum type of footing for designing based on the geotechnical investigation should be any type of deep foundation. Given the character of the subsurface of the soil (Interbedded of Saturated Soft Clays Overlains by Loose Sands), the most economicaland practical type of footing to be used were deep foundations such as piles and drilled piers, which were suitable for school building up to 3 stories with 12 classrooms. In this design study, the GFRP Building of Tarik Suliman High School will only comprise two stories with three classrooms on each floor, utilizing a pile foundation as the main support of the building 2.31 m from the natural grade line.

For all pile caps of the pile footing, the area of the footing was designed to be 2.7 m x 2.7 m x 525 mm thick footing with an effective depth to top bars of 300 mm (total depth = 525 mm), with 10 pcs of 16-mm-diameter GFRP reinforcing bars on each side of the footing. The geotechnical report recommended the usage of piles 300 mm in diameter and a length of 18 meters to support the structure.



Stress Distribution on the Most Critical Member through STAAD.Pro V8i SS6

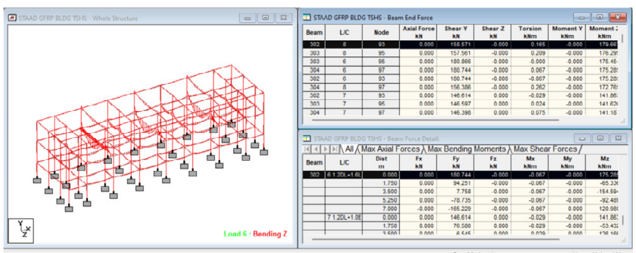


Fig. 3.9.a shows the most stressed beam in the structure.

The most critical member of the structure was the beam 302 or the beam at the second floor supporting the slab of the classroom. The beam was 7 meters in length with a cross section of 300 mm x 500 mm, reinforced with 5 – 16mm Ø GFRP bars at support and 3 - 16mm Ø GFRP bars at midspan.

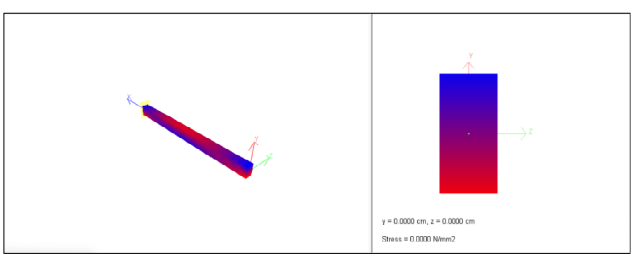


Fig. 3.9b: The stress distribution in the most critical component, the second-floor beam, was simulated using STAAD.Pro V8i SS6.

Cost Analysis

Republic of the Philippines
PROVINCE OF PAMPANGA
MUNICIPALITY OF MASANTOL
BRGY. SAGRADA FAMILIA

BILL OF QUANTITIES						
NAME OF PROJECT:	ADDITIONAL 2-STOREY ACI CODE BASED GFRP REINFORCED INSTITUTIONAL BUILDING					
LOCATION:	TARIK SULIMAN HIGH SCHOOL, BATUNG DALIG, SAGRADA FAMILIA, MASANTOL, PAMPANGA					
ITEM NO.	DESCRIPTION	% TOTAL	QUANTITY	UNIT	UNIT COST	TOTAL ESTIMATED COST
I	MOVING-IN	0.88%				150,000.00
II	EARTHWORKS, a.) Excavation	1.00%	297.43	cu.m	573.41	170,549.34
	b.) Embankment from Excavation	0.35%	297.43	cu.m	200.74	59,706.10
	Embankment from Borrow	0.62%	121.60	cu.m	868.81	105,647.30
	d.) Gravel Fill	1.03%	45.29	cu.m	3,892.99	176,313.52
III	STRUCTURAL CONCRETE	16.87%	246.19	cu.m	11,692.00	2,878,454.09
IV	GFRP REINFORCEMENT	11.90%	19,806.00	m	102.48	2,029,718.88
V	FALSEWORKS,(formworks and steel scaffoldings)	8.52%	860.44	sq.m	1,689.66	1,453,850.71
VI	MASONRY a.) 6" CHB	4.37%	538.64	sq.m	1,384.37	745,677.06
	b.) 4" CHB	0.49%	83.81	sq.m	1,001.97	83,975.11
VII	FINISHES A.) Plastering	2.80%	1,593.08	sq.m	299.51	477,143.39
	B.) Tileworks, a.) Ground Floor	3.71%	350.50	sq.m	1,803.83	632,242.42
	b.) Second Floor	3.38%	319.50	sq.m	1,803.83	576,323.69
	c.) Stone Works	0.78%	64.98	sq.m	2,044.03	132,820.80
VIII	CEILING WORKS, a.) Ground Floor	1.60%	350.50	sq.m	779.82	273,326.91
	b.) Second Floor	1.60%	350.50	sq.m	779.82	273,326.91
IX	FINISH CARPENTRY	0.42%	820.00	bdft.	86.78	71,155.77
X	DOORS & WINDOWS/GLASS GLAZING					
	a.) Door Manufactured	1.28%	28.80	sq.m	7,553.92	217,552.90
	b.) Windows Glass Exterior	0.62%	30.72	sq.m	3,439.58	105,664.01
	c.) Hardware	1.81%	356.00	units	867.30	308,758.80
XI	STEEL WORKS, a.) Roof Framing	5.48%	10,223.30	kls	91.40	934,451.82
	b.) Stair Railings	1.44%	95.04	m	2,586.14	245,786.75
	c.) Railings at Ramp	0.62%	41.02	m	2,586.10	106,081.97
XII	TINSMITHRY	4.20%	1,111.25	l.m	645.29	717,080.54
XIII	PLUMBING/SANITARY WORKS					
	a.) Septic Tank, Catch Basin, Manholes and Drainage	2.23%	1.00	lot	381,084.93	381,084.93
	b.) Downspout, Waste and Sewer	1.29%	154.00	lengths	1,434.35	220,889.37
	c.) G.I. Pipe & Polypropylene (PPR) Composite Pipe Water Line	1.81%	241.00	l.m	1,277.94	307,983.93
	d.) Fixtures	0.68%	86.00	sets	1,348.13	115,938.93
XIV	PAINTING WORKS a.) Steel	1.44%	750.96	sq.m	327.26	245,759.17
	b.) Ceiling Board and Finish Carpentry	0.21%	103.70	sq.m	353.51	36,658.99
	c.) Masonry	4.54%	2,489.85	sq.m	311.29	775,056.86
XV	ELECTRICAL WORKS	1.72%	436.00	sets	674.91	294,262.50
XVI	FIRE PROTECTION SYSTEM, a.) Pipes	0.42%	97.00	lengths	744.04	72,171.75
	b.) Standard Fittings	0.38%	1.00	lot	65,456.89	65,456.89
	c.) Switches and Gauges	1.16%	1.00	lot	197,930.25	197,930.25
XVIII	STRUCTURED CABLING	6.17%	1.00	lot	1,053,150.00	1,053,150.00
XIX	FIRE DETECTION AND ALARM SYSTEM	1.29%	1.00	lot	219,500.00	219,500.00
XXI	MOVING OUT	0.88%	1.00	ls	150,000.00	150,000.00
	TOTAL	100.00%				17,061,452.35
AMOUNT IN WORDS	:					

The total cost of the proposed building will be 17,061,452.35 million Pesos from moving-in, construction itself, the materials, and moving out costs. The cost of using GFRP rebars is more advantageous than using the conventional steel rebars.

IV.SUMMARY,CONCLUSIONS AND RECOMMENDATIONS

Summary

Due to the increasing student population and addition of the STEM Senior High School Program at Tarik Suliman High School in Sagrada Familia, Masantol, Pampanga, and its recurring problem of deterioration of facilities, there is a necessity to have an additional school building that can withstand coastal conditions, high salinity, and corrosive environment. The utilization of Glass Fiber-Reinforced Polymer (GFRP) rebars is aligned with the United Nations' SDG Goal 9, 'Industry, Innovation, and Infrastructure,' and 11, 'Sustainable Cities and Communities,' wherein SDG Goal 9 focuses on the development of resilient infrastructure to support economic growth and human well-being, highlighting the importance of sustainable industrialization, technological advancement, and innovation. SDG Goal 11 is closely related to the challenges posed by rapid urbanization, aiming to make cities inclusive, safe, resilient, and sustainable. There are several benefits to using glass fiber-reinforced polymer (GFRP) as the primary reinforcement material for structures close to the coast as opposed to more conventional materials like steel. Because GFRP is so corrosion-resistant, it is the perfect material to use in coastal areas where standard steel reinforcements are vulnerable to deterioration from exposure to humidity and seawater. Over the structure's lifetime, these corrosion-resistant qualities save money by lowering the need for regular repairs and maintenance.

Furthermore, GFRP is lightweight and has a high strength-to-weight ratio, making it easier to handle and transport than steel. This can result in faster construction times and lower construction costs. Additionally, GFRP is non-conductive, making it suitable for use in structures where electrical conductivity is a concern.

The proposed additional two-storey reinforced institutional building was anchored based on ACI CODE 440.11-22, National Structural Code of the Philippines 2015, ASCE/SEI 7-10, DepEd Order No. 64, Series of 2017, DPWH's Geotechnical Investigation of Tarik Suliman High School. The seismic analysis was accomplished through STAAD.Pro V8i SS6 specifically checks the base shear, story drift, and soft story. The forces and moments were also analyzed through the software and the simulation of the stress distribution from the most critical member. The main structural members designed were slabs, beams, columns, and pile foundations using GFRP rebars with a design tensile strength of 1020 MPa. The compressive strength of the concrete considered was 27.5 MPa to withstand the coastal environment of the school. Considering the safety and economic value of the structure, manual calculations were provided based on the code provisions. The architectural plan of the building was crafted in AutoCAD based on the DepEd Order No. 64, S. 2017.

Conclusion

Two-storey GFRP-reinforced institutional building design for the Tarik Suliman High School will ease the community's concern for the structural integrity of the building and its longevity and serviceability. It will greatly contribute to the field of civil engineering in the Philippines and promote the use of alternatives for sustainability. This study will serve as a guide for the design of reinforced concrete buildings with GFRP rebars. With the aid of STAAD.Pro V8i SS6, accurate calculations and analysis are done to ensure the structure's safety. The researcher aims to develop an innovative construction method that enhances school infrastructure and contributes positively to the environment, moving beyond mere maintenance. The safety of these structures will depend on proper construction practices, adherence to building standards, and rigorous testing to ensure structural integrity. The intention is for this study to serve as a model for future construction endeavors, promoting a gradual transition towards more sustainable building practices in the country. Drawing from their university education, both within and outside the academic sphere, the researchers have incorporated various theories and principles related to structural analysis, site investigation, cost analysis, and technical specifications. These efforts aim to lay a solid foundation for future research. Incorporating GFRP rebars into the design will further enhance the sustainability and durability of the proposed academic building. GFRP rebars offer advantages such as corrosion resistance, lightweight, and high strength, making them suitable for coastal areas and contributing to the structure's longevity. By integrating these rebars into the construction, the researchers are not only ensuring the safety and longevity of the building but also showcasing a forward-thinking approach to sustainable construction practices.

Recommendations

The following recommendations are offered after a thorough review of the outcomes, revelations, and conclusions:

- Adopt the architectural and structural design for the additional two-storey GFRP-reinforced school building for Tarik Suliman High School.
- Proper budget appropriations for public school buildings and sponsorship are crucial to supporting the entire construction project, especially in utilizing deep pile foundations.
- The incorporation of international standards as a basis for the design and the growing accredited distribution of FRPs, especially GFRP, in the country prove the need to update the existing national structural code.
- Explore other structural analysis and design software to further advance knowledge in structural design.
- Study and assess recent updates on the code provisions for GFRP and other FRPs, both national and international.
- Roofing Design and Shear Reinforcement Design can be explored from the ACI CODE 440.11-22 in the succeeding years of continuous development.
- Other construction plans, like plumbing plans and other architectural aspects, may be considered.
- Wind Load assessment using STAAD.Pro V8i SS6 may be conducted to evaluate the impact of wind on the proposed building. Wind load assessment is a critical component of building design, essential for determining the potential impact of wind forces during severe weather events like storms or hurricanes. This assessment allows researchers to pinpoint the building's design vulnerabilities and implement necessary modifications to enhance its resilience against high winds and other natural disasters.
- Future researchers may explore comparing the GFRP bars to high-tensile strength steel available in the market.

ACKNOWLEDGMENT

The proponents of this study would like to acknowledge and appreciate God for His divine guidance, the wisdom and strength He entrusted us with, which helped us accomplish the study. He is worthy of praise for providing the researchers with the capacity and eagerness to sustain the study from its start to its conclusion.

To Engr. John Robert D. Gabriel, the research adviser, the researchers acknowledge the unwavering support, incomparable expertise, and selfless guidance and effort he gave to the entire GFRP-ACI team. His mentorship and dedication were truly priceless, guiding them every step of the way. The collaboration with him in this study will forever be valued and honored.

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