DISASTER-RESISTANT MODERN BAHAY KUBO

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***Abstract*— Losses and destruction from floods and landslides increase in the Philippines as typhoons become more frequent and intense. A previous study conceptualizes a lightweight bamboo-based hybrid amphibious house with a buoyant basis of HDPE sewer pipes in a steel cage and easy base isolation. The main objective of this project was to design disaster-resistant Modern Bahay Kubo using Bamboo as the primary material data for wind loads, dead loads, and live loads have been obtained from the National Structural Code of the Philippines 2015 and the results of the forces applied are enough to endure the disaster-resistant Modern Bahay Kubo. Since no standard code is available for Bamboo, the Steel code of the NSCP 2015 has been adapted wherever necessary. The STAAD analysis findings indicate different maximum displacement values from different loading and load combinations specified by NSCP. In terms of wind load, it shows that the most significant displacement is roughly 0.099mm at 320 kph, indicating that the design for Bahay Kubo is durable and strong enough to endure wind speeds ranging from 240 to 320 kilometers per hour.**

***Keywords*— bamboo, disaster-resistant, Bahay Kubo, typhoon, structure, construction**

I. INTRODUCTION

The Philippines is one of the most vulnerable countries to natural disasters like typhoons. Every year, the Philippines is hit by a slew of typhoons, each of which poses a menace to livelihoods, shelter, and, in some cases, life. Flooding generated by such occurrences causes enormous damage to land and buildings, with devastating consequences for rural populations [1]. Typhoon Rolly damaged 80 to 90 percent of the houses in Virac [2], while Typhoon Yolanda destroyed and damaged 1.14 million houses [3]. Typhoon Ulysses left 88,713 houses damaged in the wake of its onslaught, with 9,763 destroyed [4]. Typhoon Ulysses wreaked havoc on the country's infrastructure costing the government ₱11.9 billion, as per the NDRRMC. Cagayan Valley was the most brutal hit, with 126,786 damaged houses, of which 17,200 were classified as "totally damaged" and 109,586 were classified as "partially damaged." [5]. These typhoons were so strong that they destroyed houses made of light materials and those built with concrete.

Some researchers have developed resilient housing structures as a solution to this problem. One of which is the schematic prototype house that can endure the effects of several risks in northeast India's Brahmaputra. The majority of the people living below the poverty line have yet to benefit from improved construction methods. This research aims to comprehensively record the hazard reactions of traditional Assamese buildings and enhance them with the intelligent incorporation of an amphibious foundation for modern but economic bamboo-based hybrid facilities [6]. Another study suggests a lifelong typhoon shelter that is inexpensive and easily upgradeable. Coco lumber, which is locally abundant in the Philippines, is the primary structural material utilized in the shelter. For ease of construction by local laborers, the suggested unit has a simple rectangular building design with a hip roof. The minimal overhang design efficiently reduces the effects of the prevailing wind, which is the primary source of roof structure damage during a typhoon. This housing will ideally be a starting point for a positive future in search of a better quality of life, particularly following the devastating consequences of a natural disaster [7]. Another idea from a group of researchers for disaster-resilient housing is amphibious foundations. It is a cost-effective, resident-friendly alternative to permanent static elevation for housing in areas where high flow speeds do not accompany rising floodwaters. Ordinarily, amphibious foundation systems preserve a home's proximity to the soil and relationship to the street by supporting the structure at a slightly high elevation. When flooding happens, the home floats to the appropriate height to be securely above water and then settles back into place when the water recedes [8].

The Bahay Kubo is one of the Philippines' most illustrative and well-known symbols. The names of the early Nipa huts were derived from the Spanish phrases "cube," which means cube due to its rectangular shape, and "Bahay," which is the Filipino word for house. The construction of a Bahay Kubo is entirely dependent on the demands and conditions of the community. The wall is constructed of nipa leaves or bamboo slats, and the floor is built of finely split, resilient Bamboo. The walls are made of ever-dependable Bamboo or kawayan and are banded together by tree strings with dried coconut leaves or cogon grass, and the floor is composed of finely split, resilient Bamboo. Bamboo is a sturdy, lightweight, and flexible material with many practical and traditional applications. It reflects much of Philippine culture and is used in various events, beliefs, and traditions [9]. Using Bamboo as a building material, it has a firm fiber. The compressive strength of Bamboo is two times higher than that of concrete, while the tensile strength is close to that of steel. Bamboo is considered one of the very strong building materials, with a tensile strength of more than 28,000 N per inch, compared to steel, which is 23,000 N per square inch [10].

Due to the billions of losses in infrastructure caused by the typhoon's wrath, the researchers have decided to construct a modern Nipa Hut (locally known as Bahay Kubo) to mitigate future wind-related disasters and create safer and sustainable societies.

II. Related Works

In 2020 the Philippines hit at least 20 typhoons due to its geographical location. Typhoons impact people's lives because they frequently deliver torrential rain, floods, and powerful winds over large areas, resulting in significant casualties and agricultural and property destruction. There are two destructive typhoons struck the Philippines consecutively, typhoons Rolly and Ulysses. On October 29, 2020, typhoon Rolly, entered the Philippine Area of Responsibility (PAR), which intensified as a super typhoon. There are four areas in Southern Luzon where its landfall. It made its initial landfall over Bato, Catanduanes, and then Tiwi, Albay. On November 1, 2020, typhoon Rolly made its third landfall in San Narciso, Quezon, and its fourth landfall in Lobo, Batangas. Typhoon Rolly left the Philippine Area of Responsibility (PAR) on November 3, 2020

The death toll has grown to 22, with damage to infrastructure and agriculture estimated at Php14.1 billion. Under the authority of the NDRRMC, infrastructure damage in Bicol province and Mimorapa totaled P10.81 billion infrastructure damage, and 56,747 houses were destroyed or damaged [11]. November 11, typhoon Vamco, locally known as Ulysses, made its landfall in Quezon Province, in the Calabarzon portion of the Luzon Island group. Typhoon Ulysses destroyed eight different areas in the Luzon Island group. The Department of Social Welfare and Development-Field Office 1 (DSWD-1) recorded a total of 173 wrecked residences, 167 in Pangasinan, five in Luna, La Union, and one in Pagudpud, Ilocos Norte. The infrastructure damages in Ilocos Norte are estimated at Php 326 million. [12]. Cagayan Region also suffered Php 4.9 billion in damages to infrastructure, followed by Bicol, which is still rebuilding after Super Typhoon "Rolly" (international name Goni) wreaked havoc earlier this month, at P1.8 billion. Ulysses' surge had damaged 88,713 structures, with 9,763 wholly demolished [13]. On November 8, Eastern Visayas also suffered Super Typhoon "Yolanda" with the international name "Haiyan" hit with sustained winds of 195 miles (314 km) /hour. Haiyan was the most intense tropical storm ever recorded [4]. Due to the extensive destruction and damage caused by the super typhoon, P1.1 million houses were either destroyed or damaged, and the total cost of damage caused was P95.48 billion [14].

Advanced development innovations are to be introduced to the vast majority of people living below the poverty line. A schematic model house is proposed that can withstand the impact of different risks if the region beneath thinks about it [6]. The Philippines is known as locally abundant in coco lumber, coco lumber is the primary structural material being utilized for a lifelong typhoon shelter that is both inexpensive and upgradable. A rectangular building with a hip roof design will reduce the effects of wind, which is the primary cause of roof structure damage during typhoons. Its slanted wall design will make the shelter appear more prominent, and the rainwater collected can be used in toilets and gardening systems by the occupants. This type of shelter can be a starting point for a better future, especially after the devastation of natural disasters [8].

When a new structure is proposed to be built in a Special Flood Hazard Area (SFHA) represented on the corresponding FIRM flood map, mitigating measures must be integrated into the design to ensure that the building will not drown. In this instance, a structure may be designed to stand on piles or have thick foundation walls so that the lowest floor level is higher than the indicated Base Flood Elevation (BFE). Because of the energy contained in coastal waves striking buildings, flood damage from coastal flooding is often more severe than flood damage from riverine flooding. Riverine flooding in an A Zone (without waves and high velocity) can submerge a structure without causing damage, whereas in the coastal V Zone, a wave crest elevation flood depth of 3 to 4 feet (1m to 1.3m) beyond the bottom of the floor beam, or around 1 to 2 feet (30 – 60cm) over the top of the floor, is enough to cause significant (more than 50%) damage to a building. If the BFE is not considered to be correct, it is advised to elevate the floor level at least 3 feet (1m) above the BFE; if the BFE is recognized to be precise, it may be sufficient to elevate the floor level 1 to 2 feet (30 to 60cm) above the BFE. Elevation on Fill in the process of raising a building by a bit of amount. It is only economical up to 2 to 3 feet (60 – 90cm), but due to wave action, it is not a permissible type of building height in coastal Zones. Elevation on the extended concrete foundation is a typical method of elevating a structure up to four feet (1.2

meters) above grade. Way of raising a structure to 4 feet (1.2m) above grade; much higher and abandoning lower enclosed parts may be more cost-effective. This approach is likewise not permitted in V Zones along the coast. The consequence is that the lower floor level is 'abandoned' as a habitable area, and the higher floor level is replaced with the new lowest floor level. This may be less expensive than attempting to raise the entire structure by more than 4 feet (1.2m). In part, the bottom floor might still be used for vehicle storage [15].

Bahay-Kubo is a very functional home given the limited material choices in the provinces. But with the right choice of materials and the proper construction methodology, the Bahay-Kubo can withstand strong storms. Its elements are sustainable, and its design principles are still being extracted, studied, and translated into modern-day thinking [16]. As a construction material, bamboo has a powerful fiber in this study. The compressive strength of bamboo is two times higher than that of concrete, while the tensile strength is close to steel. Bamboo is considered one of the very strong building materials, with a tensile strength of more than 28,000 N per inch, compared to steel, which is 23,000 N per square inch [11]. Bamboo has been used for its natural strength and flexibility since ancient times, and one of the most prominent uses of bamboo in construction. It has been reinvigorated not only as a cheap but also as a durable building material since the 1980s, thanks to a renewed interest in it as a construction material. Many bamboo-based building materials that are more suitable for modern construction needs have also been developed. It can also be used to reduce soil erosion, which helps avoid disasters such as landslides and flooding.

Studies have shown that using bamboo in construction promotes sustainable construction because it has numerous environmental benefits that can encourage people to use it to enhance their socioeconomic status [17]. This study examines the social/cultural, physical, and economic factors that influence the usage of bamboo as an indigenous building material in low-income housing in developing nations. Post-occupancy research was conducted in Costa Rica using a pilot housing project for low-income Indian families. The interior and exterior design features were subjected to participant-observer analysis based on cultural, social, physical, and economic aspects. The results were utilized to propose design and philosophy enhancements that may be applied to bamboo housing projects for low-income families. According to qualitative and quantitative findings, bamboo is an appropriate, low-cost, locally accessible, renewable material that lends itself to self-construction methods. Bamboo is a valuable material in creating appropriate, cheap, and culturally acceptable housing in developing nations if housing project administrators properly examine residents' requirements, values, and perspectives [18].

Bamboo is a natural fiber source and one of the world's fastest-growing large plants with enormous economic potential. Each bamboo cane's strong strands give it tremendous flexibility, allowing it to bend without snapping [19]. Bamboo has attracted the attention of scientists and engineers for use as reinforcement in concrete in the construction sector due to its exceptional qualities such as low weight-to-strength ratio, high tensile strength, and factors such as low cost, easy availability, and environmental friendliness during service. In comparison to unreinforced concrete, the use of bamboo strips as reinforcement in concrete columns enhanced the weight-bearing capacity of the column. Bamboo is a feasible alternative to steel, concrete, and masonry as a stand-alone building material. The primary component of bamboo is cellulose, which is the source of bamboo's mechanical qualities [20]. Bamboo has a powerful fiber that makes it an excellent building material. It doubles the compressive strength of concrete and has a tensile strength comparable to steel. Bamboo fiber has more excellent shear and a longer lifespan than wood. Bamboo may also be bent without breaking. Bamboo is often recognized as one of the most long-lasting construction materials, with tensile strengths greater than and less than 28,000 N per inch, as opposed to steel, which has a tensile strength of 23,000 N per square inch [21].

III. Methods

A. Structural Parameters for STAAD Pro

Since STAAD Pro has only concrete, aluminum, steel, and timber as material, the researchers searched the characteristics and composition of bamboo, precisely the characteristics of Bambusa Blumeana, a variety of bamboo that is rampant in the Philippines. The researcher searched its density, Young's Modulus, and the like to be incorporated in and analyze the structure in STAAD Pro. These different properties are shown in Table I.

Table II shows the different load combinations set by the National Structural Code of the Philippines. A load combination occurs when more than one form of load applies to a structure. Building codes often include several load combinations and load factors (weightings) for each load type to assure the structure's safety under various maximum predicted loading situations.

TABLE I. PROPERTIES OF BAMBUSA BLUMEANA

Properties	Values	Reference
Young's Modulus (E)	10034000kN/m2	[22]
Poisson's Ratio (nu)	0.013to0.278	[23]
Density	8.3552537487kN/m3	[24]
Thermal Coeff (a)	65x10-6	[25]
Critical Damping	0.00152	[26]
Shear Modulus (G)	2200kN/m2	[27]

TABLE II. LOAD COMBINATION

Number	Load Combinations
1	1.4 DL
2	1.2 DL + 1.6 LL
3	1.0 DL + 1.6 LL + 1.0W windward
4	1.0 DL + 1.6 LL + 1.0W leeward
5	1.0 DL + 1.6 LL + 1.0W sidewall

B. Locale of the Study

Tuguegarao City, located along the Cagayan River, the Philippines' longest river, is the most vulnerable locality to flooding in the whole Cagayan Valley region due to its physical location and sea-level rise. Fig. 1 depicts a flood danger map for Tuguegarao City. The majority of its communities along the Cagayan River are vulnerable to flood threats caused by constant rain. As a result, floods occur in some towns of Tuguegarao City every year.

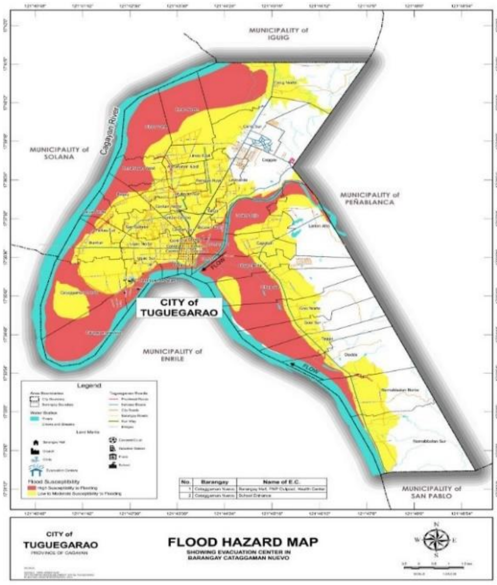

Fig. 1. Flood Hazard Map of the Locale.

C. Designing of Structure

In designing the structure, the researchers must first acquire information about Bahay Kubo, identify the factors to consider in making the structure resilient in terms of typhoons and floods, and then locate the possible location of the structure if it is in a typhoon or flood-prone area—knowing information about Bahay Kubo and its characteristics, such as how strong and disaster-sensitive the building materials used in it are and if it can withstand severe winds, can assist researchers in determining what strategies to employ to make it disaster resilient. Researchers should also collect information on developing disaster-resistant structures, such as their characteristics, what elements should be addressed, such as the design of the roof, and the appropriate materials to use.

After gathering the data needed for a particular location, the researcher can now sketch the structure's design by considering some techniques for building resilient houses. The researcher's first thing to consider in making disaster-resilient houses is the size of the columns. In this parameter, researchers should consider making the columns of the exterior structure more prominent than the interior structure. The stiffness of the roof is the second factor to consider, using vernacular techniques like knots and lashing. This method is a way to maximize the strength of the material. The third thing to consider in sketching the design of the resilient house is the foundation, which is the crucial part wherein the foundation bears the weight of the entire house, transferring the force through to the ground beneath. Therefore, in planning the structure's foundation, the researchers should make the foundation stable and firm to protect the structure from harm from natural forces.

D. Dead Load Simulation

After gathering the data needed for the structure's design, using the Philippine National Structural Code (NSCP) Provision, external forces would be determined by the researchers to calculate the loads of the system. In computing the unit dead load for a surface region, the researchers must identify the region of a roof plan, floor plan, or elevation where the unit load is needed. The weight of permanent components such as beams, floor slabs, columns, and walls contribute to a structure's dead load as shown in Fig. 2. The researchers can estimate an accurate dead load for each component by computing every member's volume and then multiplying it by the material's unit weight from which it is made. After that, STAAD is utilized to input the values, then assign property, and supports, assign loads, and analyze if the structure passed. Researchers consider dead load calculations as an important aspect of an engineer's structural calculations, as they ensure the safe construction of building structures [28].

E. Live Load Simulation

Philippine National Structural Code (NSCP) Provision would be utilized as a basis for determining the live load of a structure. The researchers would identify the dynamic forces resulting from occupancy and intended use, referred to as live loads. Before any live loads are brought inside, the dead load of the structure must be determined. They are the transitory forces that can pass through a structure or act on a specific structural element. These loads, which are also measured in PSF, include the expected weight of people, furniture, and other items as shown in Fig. 3. After the researchers determine the factors needed for live loads, STAAD would analyze if there are errors and evaluate if there's no failure in it [29].

F. Wind Load Simulation

After gathering the data needed for the structure's design, using the Philippine National Structural Code (NSCP) provision, the researcher would determine the external forces required for calculating the loading applied to the structure as shown in Fig. 4. Using the Directional Procedure in calculating the wind pressure, the researcher must first determine the basic wind parameters: the occupancy category of the structure, the structure type, the exposure category, the topographic effects, the gust effect factor, and the enclosure classification found in NSCP 2015. After that, the researcher can now compute the wall pressure by setting the structure's leeward, sideward, and windward with the help of the Structural Analysis and Design application. After assessing the combination of loads in the structure, the STAAD would analyze the structure and assess if the structure can withstand the load on a different value.

G. Flood Vulnerability Assessment

Vulnerability is the most significant component in flood risk management. Establishing a clear relationship between theoretical flood vulnerability ideas and day-to-day administrative action is among the most important aims of flood vulnerability assessment [30]. In designing a flood-resilient structure, the researchers first consider some parameters in which the structure is being raised on stilts, one to two meters depending on the location where it is to be built if it is a flood-prone area. The shelter residents would be protected from flooding by raising the interior off the ground [31], and the water flow under the structure would move freely [32]. Considering this parameter, the structure can be flood-resilient.

IV. Results and Discussion

Fig. 2. Modern Bahay Kubo.

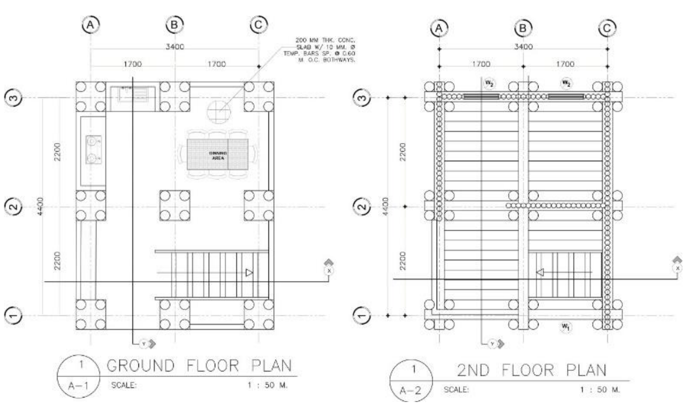

Fig. 3. Floor Plan.

Fig. 4. Column and Beam Connection.

The researchers utilized AutoCAD to design the frame system required to simulate various loads and their floor plans. SketchUp was another tool utilized by the researchers to create the 3D model of the structure, and it was rendered using V-Ray to depict its view in a real-world structure. The designed disaster-resistant Bahay Kubo is shown in Fig. 2 along with its floor plan in Fig. 3. The Bahay Kubo is built utilizing data and criteria acquired from several dissertations to construct a bamboo home that can withstand the high winds caused by typhoons and its height from the ground in terms of floods. In assessing the structure's vulnerability in terms of the flood, some dissertations suggest raising the structure's floor from the ground as a mitigating measure that must be integrated into the design to ensure that the building will not drown. Our designed modern Bahay Kubo adopted the dissertation to elevate the structure about 2 meters to ensure that the occupancy of the Bahay Kubo is safe from flooding. The joints for the bamboo construction should be carefully and effectively lashed to prevent future collapse or undesirable displacement in the structure. To further maintain the full strength of bamboo, the researchers utilized a lash for each connection rather than creating a hole to connect the bamboo, which may lead to an undesirable outcome. As shown in Fig. 4 and Fig. 5, the cut connection of the column and the beam are shown. In connecting the bamboo, a 3.5m of nylon monoline (Tansi) is lashed to the column and beam of the structure. For the column and foundation of the structure, the column is attached to the concrete floor as shown in Fig. 6.

Fig. 5. Column and Roof Connection.

Fig. 6. Column and Foundation Connection.

The loadings gathered from the National Structural Code of the Philippines are applied to the structural bamboo frame and are validated by analyzing the frame using STAAD Pro. The frame dimension has been taken to be 4.31m in height and a span of 5 meters by 4 meters. The supports at the base of the column are pinned joints. The material specified for the analysis is the Bambusa Blumeana. Fig. 7, Fig. 8, and Fig. 9 show the simulation of STAAD Pro load in dead load, live load, and wind load, respectively.

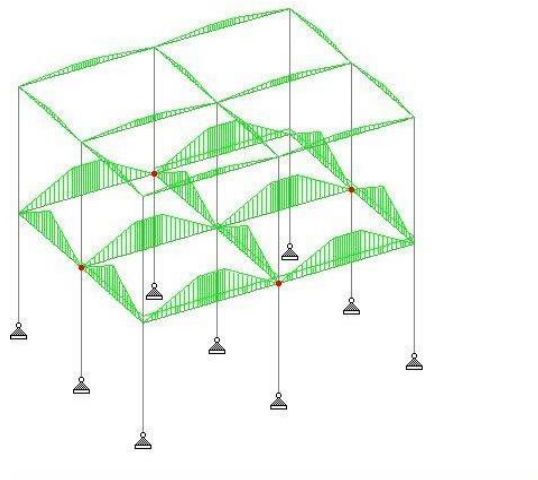

Fig. 7. Dead Load Simulation.

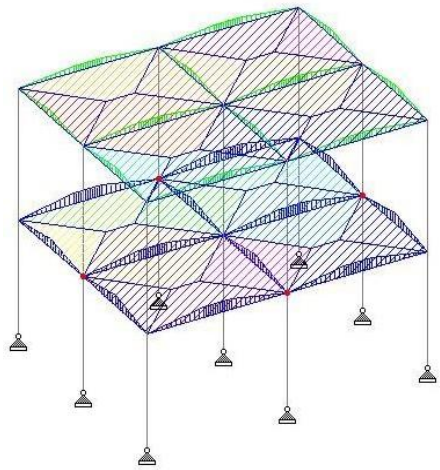

Fig. 8. Live Load Simulation.

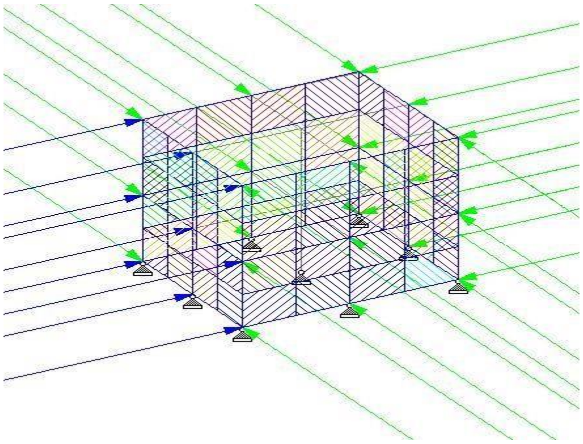

Fig. 9. Wind Load Simulation.

The results of the STAAD analysis show different values of maximum displacement from different loads and load combinations set by NSCP (see Table II for load combination).

In Table III, the tabulated data is from 240 kph, 280 kph, and 320 kph wind velocity for the standard occupancy category. The maximum node displacement is 0.284 millimeters in all wind velocity ranges. The highest node displacement is load combination two, the factored load of dead load and live load, followed by 0.256 millimeters as the second-highest maximum node displacement at 280 kph, which is then factored load of dead load, live load, and wind load. While dead load alone has a node displacement of 0.142mm in all wind velocity ranges, the live load alone has a 0.074-millimeter node displacement in all wind velocity ranges. Concerning wind load simulation, the maximum displacement is at the windward of 320 kph, having a node displacement of 0.099mm, while the minimum node displacement is at the leeward of 240 kph with 0.044mm node displacement.

TABLE III. NODES DISPLACEMENT

Loading	Wind Velocity		
	240 kph	280 kph	320 kph
DL	0.142mm	0.142mm	0.142mm
LL	0.074mm	0.074mm	0.074mm
WL Windward	0.056mm	0.076mm	0.099mm
WL Leeward	0.044mm	0.060mm	0.049mm
WL Sidewall	0.052mm	0.071mm	0.058mm
Load Combination 1	0.198mm	0.198mm	0.198mm
Load Combination 2	0.284mm	0.284mm	0.284mm
Load Combination 3	0.284mm	0.256mm	0.284mm
Load Combination 4	0.284mm	0.256mm	0.284mm
Load Combination 5	0.284mm	0.256mm	0.284mm

TABLE IV. NODES NUMBER

Loading	Node Number with Maximum Displacement		
	240 kph	280 kph	320 kph
DL	24	24	24
LL	24	24	24
WL Windward	11, 13, 16, 17	11, 13, 16, 17	11, 13, 16, 17
WL Leeward	11, 13, 16, 17	11, 13, 16, 17	11, 13, 16, 17
WL Sidewall	11, 13, 16, 17	11, 13, 16, 17	11, 13, 16, 17
Load Combination 1	24	24	24
Load Combination 2	24	24	24
Load Combination 3	24	24	24
Load Combination 4	24	24	24
Load Combination 5	24	24	24

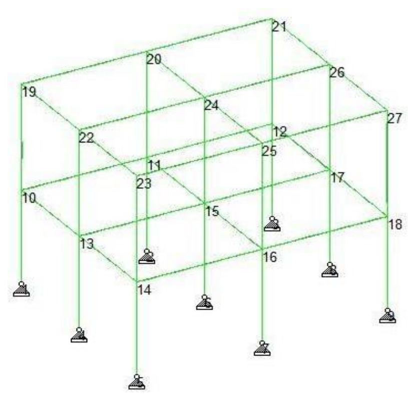

Fig. 10. Maximum Displacement.

When the structure induces dead load, live load, and load combinations, node number 24 exhibits the most significant displacement from its initial location, as tabulated in Table IV. Node number 24 is located in the middle of the roof, which carries the roofing structure of the Bahay Kubo. Node numbers 11, 13, 16, and 17 have the most significant node displacement in wind load. The tabulated displacement in all load and load combinations is not enough to displace the nodes of the structure, as shown in Fig. 10. Therefore, the modern Bahay Kubo design is sturdy and firm enough to withstand 240, 280, and 320 kilometers per hour wind velocity.

Table V shows the total number of materials needed in constructing the modern Bahay Kubo and it revealed that the estimated cost for a 5 x 4 m and 4.31 m height is worth ₱35,000. The structure gave a satisfactory result in the STAAD analysis, and it can withstand strong wind for the standard occupancy category which is a good characteristic of a resilient structure. The materials are environmentally friendly and easy to find in the locality.

TABLE V. COST ESTIMATION

Name Of Item	Quantity	Unit	Rate	Amount (Php)
chb	150	pcs	12	1800
cement	51	bags	230	11730
gravel	6	cu.m	715	4290
sand	3	cu.m	572	1716
steel bar (10mm)	20	pcs	165	3300
bamboo (sidewall)	196	pcs	12	3144
bamboo (flooring)	262	pcs	12	2352
nipa (roof)	234	pcs	5	1170
wood (stairs)	43	m²	179	7697
bamboo (0.25 m dia.)	36	pcs	12	432
bamboo (0.10 m dia.)	18	pcs	12	216
nylon (0.1)	60	pcs	35	2100
Total				40000

V. CONCLUSION

This project has covered the analysis and the conceptual design of a disaster-resistant Modern Bahay Kubo based on various loads and their combination. Wind loads have been considered based on Section 207 of NSCP 2015 and the structure was analyzed simply. The proposed structure aims to provide an alternative environment-friendly construction of disaster-resistant houses. The design developed for disaster-resistant Modern Bahay Kubo gives satisfactory results for the computation of forces like wind loads, dead loads, live loads, and load combinations. The structure shows a sturdy and firm connection between each component of the structure. Furthermore, no visible displacement is seen in the structure when it is subjected to the wind load and minimum displacement from different load combinations.

The calculation of disaster-resistant Modern Bahay Kubo should be carried out with the calculations and design of its foundation to make the Bahay Kubo more sturdy in terms of different loadings. Since no standard codes of practice are available for bamboo, the steel code (NSCP 2015) has been used wherever required, which might have led to some errors in the design.

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