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Flash Flood-Resilient House Design: A Step towards Climate Adaptation

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Abstract. Traditional and amphibious houses situate their foundation on the ground or at a certain height and commonly do not anticipate the rapid increase in water level during flash floods, which can damage the structure. The study aims to design a flash flood-resilient house and estimate the construction cost. Archimedes' buoyancy principle is applied to allow the structure to float in times of flash flood. The buoyant component, EPS Geofoam, is attached to each of the structure's columns, encased by a retaining wall and lightweight materials such as bamboo panels are used for the structural parts carried by the buoyant component. With this, the flash flood-resilient house design can elevate from its stationary position, 1.5 m above the ground up to 3 m, making it a credible design based on the National Structural Code of the Philippines (NSCP) 2015 and the Federal Emergency Management Agency (FEMA). Moreover, the flash flood-resilient house design is 47% more expensive than the traditional housing cost, although the future expense from house reconstruction after flash floods makes it an economical approach. Thus, implementing the flash flood-resilient house design advances climate adaptation as it caters to the threat of flash floods and ensures safety.

Keywords: flash flood, house design, climate adaptation structures, amphibious house

Introduction

Flash floods are prevalent in different parts of the world, especially in densely populated and low-lying areas. These floods are known due to the sudden rise of water levels and the destructive surge of water. It occurs after excessive rainfall that lasts for minutes or hours caused by typhoons and hurricanes or may be due to a sudden water release from levee or dam failures. There are usually no signs when such an event happens, where the water level immediately increases, destroying and dragging debris along its path, causing property damage and loss of livelihoods and lives. From 1960 to 2020, over 360,000 people were killed due to flash floods, and millions were affected and left homeless worldwide (Salas, 2023). Its aftermath can critically affect a country's economy due to infrastructure, industrial, and agricultural damage, hindering economic growth and development for a significant time.

Anti-flood houses such as the Amphibious House and Floating House are developed to cope with flooding. Amphibious houses are constructed higher than the water level, designed to rise along the flood water and fall back to their original position once flooding is over. Similarly, floating houses can adapt to flooding because they can easily float and are initially built in a body of water (Ricardo-AEA, 2013). The amphibious and floating house concept mitigates the risk of water from entering the house if the water increase is slow, as the slab or base of the structure can float. However, it is unsafe during flash floods when there is a sudden rise and if the flood current drags trees, rocks, and other debris. On average, flash floods have a channel velocity of 2.7 meters per second, which is strong enough to move objects weighing 41 kg (Clements et al., 2016).

Through the application of structural engineering, hydraulics, and modern methods to cope with flooding, the study aims to design a flash flood-resilient house and estimate the construction cost. A flash flood-resilient house comprises a durable structural and nonstructural component capable of resisting flash flood hazards, flood forces, and floodwater deterioration (Southern Tier Central Regional Planning and Development Board, 2020).

Literature Review

Amphibious House

Anjali et al. (2020) conceptualized the utilization of amphibious houses to prevent economic damages caused by flooding in urban and lowland areas by facing the flood instead of fighting it. An amphibious design idealized the concept of a flood-resistant house capable of providing a secure living space. The design utilizes the buoyancy principle, which permits the water to flow past the house as it floats on top of the water rather than blocking the water's path and absorbing the full force of the flow. This design eliminates the risk of occasional and seasonal flooding, paving the way to recognize the beneficial aspects of such a concept, where people can live with water and adapt to its natural hazards.

Geofoam

Srivastava et al. (2019) research in the construction field showed that EPS-geofoam is a cost-effective and time-saving material. It is easy to handle during construction and requires no specialized equipment. Moreover, it is not affected by weather conditions. EPS-geofoam can also be conveniently cut and shaped on the construction site, which reduces job site challenges. Additionally, there are various types of EPS-geofoam materials available that can be chosen by the designer based on the project's specific requirements. When considering maintenance, protecting EPS-geofoam from ultraviolet rays, buoyancy issues, termite and chemical attacks, heat, and concentrated loads is essential. If the environment and loading conditions are favorable, EPS-geofoam can last up to 100 years. This material has several advantages in civil engineering, including its lightweight design, predictable performance, and ability to be installed in various weather conditions. It also maximizes installation efficiency and is available in different densities to meet strength requirements, providing a cost-effective solution.

Moreover, Gonzalez-Placito (2021) coined in his study regarding Aabøe (2018) research results that foam blocks have multiple uses, such as reducing loads, absorbing energy, and mitigating seismic activity. EPS blocks come in a range of densities and sizes. The density of the foam affects its buoyancy properties. When submerged, EPS foam has excellent flotation capabilities. In infrastructure projects with unexpected flooding, foam without proper drainage can unintentionally damage the bridge or road structure. The buoyant force per unit of volume can be determined using the difference in unit densities of the EPS foam selected and the unit density of water. Additionally, Gonzalez-Placito (2021) stated that the main application of EPS Geofoam is to provide buoyancy. The lower the density of the foam, the greater the buoyancy it can generate. Therefore, instead of hindering it, pieces of expanded polystyrene are expected to contribute to the buoyant force. Air comprises a significant portion of an EPS block's volume, making it both cost-effective and highly buoyant.

Research Methods

General Concept

Buoyancy Principle

Archimedes' principle of buoyancy subjects an upward force acting on a submerged body. It considers the volume of the body submerged in relation to the density of the liquid. Since flash floods involve water, buoyancy is applicable in designing a flood-resilient structure using buoyant materials. These buoyant materials are determined through their density, which can be solved by dividing the total mass of the material by its volume and relating it to the density of the liquid. A lower material density than the liquid results in the material to float, while a higher material density will cause the material to sink. Water has a density of 1000 kg/m^3, entailing that for a material to float, the density must be less than 1000 kg/m^3.

Properties of EPS Geofoam

EPS Geofoam blocks are used for reducing loads, absorbing energy, and mitigating seismic activity. EPS blocks come in a range of densities and sizes. The density of foam affects its buoyancy properties. When submerged, EPS foam has excellent flotation capabilities. The main application of EPS Geofoam is to provide buoyancy. The lower the density of the foam, the greater the buoyancy it can generate. Pieces of expanded polystyrene are expected to contribute to the buoyant force. Air comprises a significant portion of an EPS block's volume, making it both cost-effective and highly buoyant (Gonzales-Placito, 2021).

EPS29 Geofoam was chosen for the research study as the buoyant component. This type of geofoam has a compressive resistance of 75 kPa at 1% strain, 170 kPa at 5% strain, and 200 kPa at 10% strain, flexural strength of 345 kPa, and a buoyant force of 9.53 Kn/m^3 when dry. The EPS29 Geofoam also exhibited thermal resistance properties, with an R-value of 4.8 at 25 °F, 4.6 at 40 °F, and 4.27 at 75 °F. The R-value signifies 1'' thick (ft^2)(hr)(°F), denoting a higher R-value means greater insulating power.

Structure Design Considerations

Prior to the design load calculations, the structure design factored in the required building codes, general house lot area for the schematic plans, mechanisms involved, and selection of materials. In addition, the base flood elevation of the selected area must be determined using the Flood Hazard Map provided by DOST-PAGASA or LiDAR Portal for Archiving and Distribution.

The flash flood-resilient house design adapted an area of 34.56 sqm based on the survey conducted by the Statista Research Department (2023), showing half of the Filipino households lived on a lot of area varying from 10 sqm to 49 sqm. The residential structure comprises a living room, dining room, bathroom, kitchen, and bedroom, sufficient for single-family occupancy. The plan aligns the economic capability of the people to ensure proper utilization of the design and long-term economic significance.

Material selection utilized lightweight, sustainable, and economical materials that are highly durable and can be easily implemented in the structure. These materials are designated for the buoyancy, interior and exterior walls, floor and roof coverings, steel wall framing, and steel floor framing. Since the structure is elevated from the ground, alternative construction procedures are implemented for the different parts, securing the structure's stability and optimal utilization of materials.

Based on the 25-Year Flood Hazard Map provided by LiDAR Portal for Archiving and Distribution, Belison and Sibalom, Antique, Philippines have varying flood hazard levels. The majority of Belison and Sibalom, Antique is classified as Medium to High Hazardous with a flood height of 0.5 to more than 1.5m (LiPAD, 2017).

Flash flood debris is associated with population density, as it is the primary factor contributing to the number of debris carried by flood water. Belison has a population density of 714 people/km^2, and Sibalom has a population density of 317 people/km^2. The population density classification is as follows: less than 314 people/km^2, very low, 341 to 500 people/km^2, low, 510 to 1000 people/$km^{2,}$ medium, 1001 to 5000 people/km^2, high, and more than 5001 people/km^2 is very high (Widyarsana et al., 2020). Belison population density falls in the range of medium population density, and Sibalom falls in the range of low population density.

Design Approach

The construction of the flash flood-resilient house is based on the National Structural Code of the Philippines 2015. This encompasses the applicable load factors, load calculations, and load combinations.

For the calculation of flood-related loads, Federal Emergency Management Agency (FEMA) equations were used as certain combinations were not covered by the NSCP and the National Building Code of the Philippines. Figure 1 shows the design front elevation plan. The flash flood-resilient house is elevated at a height of 1.5m from the natural ground line. The elevation height of 1.5m is adapted based on the flood level hazard provided, which ensures that the structure can cope and float with the rising flood water before it reaches the floor line.

Figure 1. Design front elevation plan

Figure 2 shows the traditional house design with buoyant foundation. The elevated structure concept tackles the main concern for traditional amphibious house design, which situates their foundation on the natural ground line or to a certain height, with a protruding foundation that occupies the whole floor area. This makes the design prone to flash flood debris that can damage the perimeter, if not destroy the structure during intense flooding. Submerge structures require the walls or the foundation to resist the hydrostatic and hydrodynamic forces. Lateral Hydrostatic forces may not affect the whole structure, given that each side is subjected to the same force. However, the columns and walls of the side where the water level is higher will experience greater lateral stress (Carden et al., 2015).

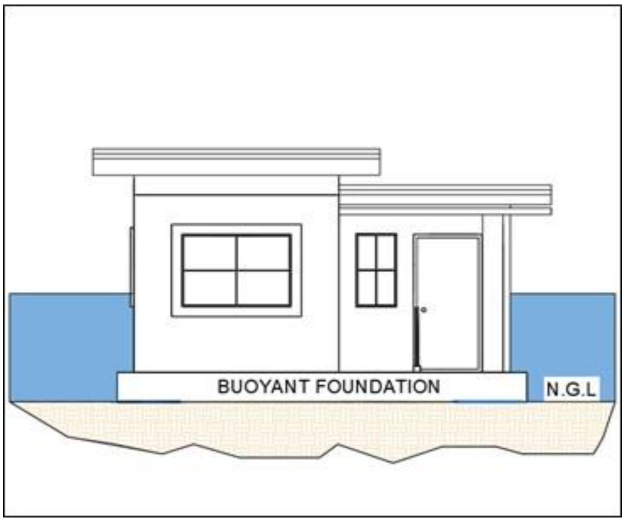

Figure 2. Traditional house design with buoyant foundation

Figure 3 shows the flood drain layout plan. The flash flood-resilient design incorporated a flood drain system that ensures equal water distribution in all parts of the buoyant component. This will cause a simultaneous upward mechanism when the water level reaches the required depth. The flood drain system ensures the stability of the structure, as water is equally distributed through a piping system embedded at the ground surface and is connected to all the buoyant components.

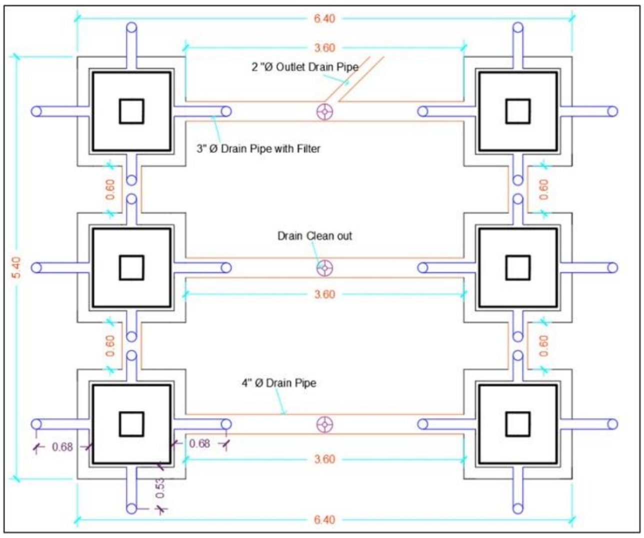

Figure 3. Flood drain layout plan

The retaining wall casing designated along the perimeter of the column covers the buoyant component. It is integrated to trap the drained water, allowing the buoyant component to elevate before a higher water level envelops the residential area. The casing has a drainpipe on each side to cope with higher flood velocities and abrupt water level rise. This drainpipe ensures water can fill the casing and allow the buoyant component to float.

The flood drain system comprised four (4) – 3'' diameter pipes on the ground and aligned at each center of the retaining wall side. Each of the six columns has ground flood drains, adding to 24 ground flood drains. The flood drain opening and exit have filters for large constituents, with a 1'' drain pipe attached at the entrance of the retaining wall intended to wash out filtered particles. An additional four (4) – 3'' diameter pipe on each side is also added at an elevation of 0.20 m, 0.60 m, and 1.00 m to cope with the rapid rise of flood water. This equates to 16 pipe drainage for each column, with 96 drainage pipes for the entire structure. A 4'' diameter drainpipe connects the buoyant components and allows flood water distribution. This 4'' diameter drainpipe is situated below ground level at a depth aligned at the top of the footing. The 4'' diameter drainpipe with a length of 3.60 m has a drain clean-out located in its center for maintenance and clogging. After flooding, a 2'' diameter outlet drainpipe is situated at the structure's rear side, allowing the buoyant component's steady descent.

Figure 4 shows the 3-layer casing section. The three (3) layer casing, implemented on the six sides of the structure. Each casing has its specific purpose and is designed under the building codes to withstand various factors. The outermost casing is the retaining wall, a reinforced concrete wall designed to cope against soil surcharge due to residential load, hydrostatic force, hydrodynamic force, and flood debris impact forces. The primary purpose of the retaining wall casing is to hold the floor frame of the structure since the floor frame is not permanently attached to the column to allow upward movement during a flood. The retaining wall's base is aligned with the foundation to limit sliding and ensure sturdiness and design compatibility. It forms a rectangular container that houses the buoyant component and composite column 1.5 m above the natural ground line. This casing also protects against external factors that may affect the buoyant component. Despite the buoyant component having properties to resist degradation and high compressive resistance, the retaining wall ensured it is safe from natural or anthropogenic damage.

The second casing is the composite column steel casing. It is a structural component that supports the upward movement of the buoyant component. The thickness of the steel plate is designed to be greater than that of the composite column, enough for it to move when force is applied at the base. The floor frame is welded on the side of the steel casing, carrying the total floor loads. A steel plate is welded at the base of the steel casing to lessen the pressure from the casing during load transfer to the retaining wall. The welded steel plate also acts as a vertical restraint that limits the downward movement of the floor frame, given that the steel plate is situated along the proximity of the retaining wall. For the buoyant component to stay intact, it is bolted at the bottom of the steel plate and attached to a 10 mm tendon bar inserted in the buoyant component.

The innermost casing is the composite column, a reinforced concrete column covered with a steel casing, which helps ensure the structure's overall stability and stiffness. The composite column allows the smooth movement of the casing forced by the buoyant component without damaging the concrete core.

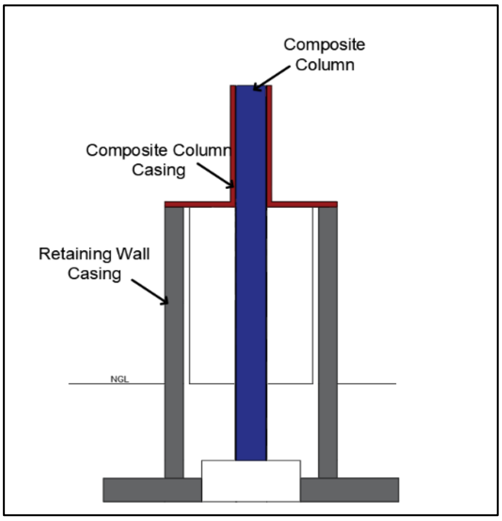

Figure 4. 3-Layer Casing Section

Loads Equations

Flood loads are categorized into four (4) types in general based on the equivalent equations for flood load calculations: buoyancy, lateral hydrostatic loads, hydrodynamic loads, and debris impact loads. Given that the National Structural Code of the Philippines does not consider an amphibious house concept for flash flood prevention, the equations will be based on the modified equation provided by the Federal Emergency Management Agency (FEMA) for preventing distress and structural failure due to lateral flood loads. The modified FEMA P-55 equations are utilized to ensure controlled floatation of the structure (Hughes, 2020).

$$d_b = \frac{Ws + (\rho g)(n)(Vg - Vc)}{(\rho)(n)(Ag - Ac)} \text{ - } \textit{Eq. 1 (Submerge Depth)}$$

where:
Ws = Mass of Structure (kg)
Wg = Mass of Buoyant Component (EPS Geofoam) (kg)
ρg = Density of Buoyant Component (kg/m^3)
ρ = Density of Water (1000 kg/m^3)
Vg = Volume of Buoyant Component (m^3)
Vc = Volume of Column (m^3)
Ag = Area of Buoyant Component (m^2)
Ac = Area of Column (m^2)

$$F_{stat} = (0.5)(Y_w)(d_b)^2 \text{ – } \textit{Eq. 2 (Lateral Hydrostatic Force)}$$
$$F_p = (0.5)(f_{stat})(d_b) \text{ – } \textit{Eq. 3 (Equivalent Point Load)}$$

where:
f_{stat} = Lateral Hydrostatic Force per unit width (Kn/m)
Y_w = Unit weight of water (9.81 kN/m^3)
d_b = Submerged Depth t of Buoyant Component (m)

$$Vf = \frac{ds}{t} \text{ - } \textit{Eq. 4 (Lower Bound Hydrodynamic Force)}$$

where:
Vf = Design Flood Velocity (m/s)
d_s = Design Stillwater Flood Depth (m)
t = time (1 second)

$$F_d = \tfrac{1}{2}(C_d)(Y_w)(Vf^2)(A) \text{- } \textit{Eq. 5 (Horizontal Drag Force)}$$

where:
F_d= Horizontal drag force (kN)
C_d = Drag coefficient
A = Surface area of the obstruction normal to flow (m/s)

$$F_I = (W)(Vf)(C_D)(C_B)(C_{Str}) \text{ – } \textit{Eq. 6 (Flood Debris Impact)}$$

where:
CB = Blockage Coefficient
CStr = Building structure coefficient

Results and Discussion

Table 1 shows the estimated weight summary which amounts to 3048.38 kg. To ensure a safety factor, 200 kg is added, resulting in a weight total of 3248.38 kg. This value considers additional people in times of flash flood that will take shelter on the structure.

Table 1. Estimated Weight Summary

Materials	Weight Total (kg)
C-Channel	114.4
1-ply Solid Bamboo Panel	411.1
Angle Bar	179.82
Metal Stud	242.35
Vinyl Windows	140.52
Hollow Flush Doors	90
Roof Purlins	14.79
Gypsum Board Ceiling	132
Corrugated Galvanized Roofings	96
Steel Hollow Tube Casing	954
Resident Weight (Filipino Average)	173.4
Furniture Weight	500
TOTAL	**3048.38**

Submerged Depth

Height of buoyant component = 1.5m

$Ag = (1\ m)\ (1\ m) = 1m^2$

$Ac = (0.256\ m)\ (0.256\ mm) = 0.065536\ m^2$

$$d_b: \frac{3248.38\ kg + (28.8\ \frac{kg}{m^3})(6)((1m)(1m)(1.5m) - (0.256m)(0.256m)(1.5m))}{(1000\ \frac{kg}{m^3})(6)(1\ m^2 - 0.065536\ m^2)}$$

$d_b = 0.6225$ m

$d_r = h - d_b$ *(Remaining height)*

$d_r = 1.5m - 0.6225m = 0.8775$ m

Adding the buoyant component allowed the structure to elevate above flood water. Based on the calculation, which considered the weight of the structure and weight of the EPS Geofoam, the submerged depth of the buoyant component is 0.6225 m. Upon reaching this height, the vertical hydrostatic force pushes the buoyant component to carry the structure upwards. The remaining height not submerged in water is 0.8775 m.

Lateral Hydrostatic Force

(a) Buoyant Component

$F_{stat} = (0.5)(9.81\ kN/m^3)(0.6225\ m) = 1.9\ kN/m$

$F_p = (0.5)(1.9\ kN/m)(0.6225\ m) = 0.59\ kN$

(b) Retaining Wall Casing

$F_{stat} = (0.5)(9.81\ kN/m^3)(1.5\ m)^2 = 11.036\ kN/m$

$F_p = (0.5)(11.036\ kN/m)(1.5\ m) = 8.277\ kN$

The hydrostatic force subjected to the buoyant component at a submerged depth of 0.6225 m is 0.59 kN. In contrast, the retaining wall casing submerged at a depth of 1.5 m received 8.277 kN of hydrostatic force.

Hydrodynamic Force

Retaining Wall Casing – Surface Area (1.4 m x 1.5 m)

Flood water depth = 0.5 m

$Vf = \frac{0.5\text{ m}}{1\text{ s}} = 0.5$ m/s

Fd = ½ (1.5)(9.81 Kn/m^3)(0.5 m/s)^2(1.4 m)(1.5 m)

Fd = 3.86 kN

Buoyant Component – Surface Area (1 m x 1.5 m)

Flood water depth = 0.5 m

$Vf = \frac{0.5\text{ m}}{1\text{ s}} = 0.5$ m/s

Fd = ½ (1.5)(9.81 Kn/m^3)(0.5 m/s)^2(1 m)(1.5 m)

Fd = 2.76 kN

Results indicated that for the retaining wall casing, the hydrodynamic force for a flood depth of 0.5 m and design flood velocity of 0.5 m/s. In addition, a flood depth of 0.5 m and design flood velocity of 0.5 m/s has a hydrodynamic force of 2.76 Kn. The maximum hydrodynamic force for the retaining wall casing and buoyant component is used to test the capacity of each part.

Flood Debris Impact

Debris Weight per Flood Velocity = $\frac{41\text{ kg x }9.81\frac{m}{s^2}}{(2.7\frac{\text{m}}{\text{s}})(1000\text{ N})}$

Debris Weight per Flood Velocity = $0.15\ \frac{\text{kN}}{\frac{\text{m}}{\text{s}}}$

Maximum F_I:

Debris Weight = (1.5 m/s)($0.15\ \frac{\text{Kn}}{\frac{\text{m}}{\text{s}}}$) = 0.225 kN

F_I = (0.225 kN) (1.5 m/s) (1.0)(0.6)(0.8)

F_I = 0.162 kN

Calculation results showed that the maximum flood-borne debris impact is 0.162 kN. The flood-borne debris impact data is essential to determine the capacity of the retaining wall casing and buoyant component.

Table 2 shows the structural design safety summary. The composite column has a required capacity of 52,640 N based on the transfer of loads. Adapting the design of 0.256 m x 0.256 m resulted in a column capacity of 655,494 N, which makes the design safe.

The footing's required wide beam shear depth is 33.77 mm, and the punching shear depth is 34.87 mm. It also accounted for a permissible bearing pressure of 52.64 kN. Adapting the footing dimension of 0.8 m x 0.8 m x 0.35 m gave the footing an effective depth of 257 mm and a bearing pressure capacity of 2102.35 kN, which is categorized as safe.

In designing the steel casing, the transfer of loads from the floor frame to each casing was observed. Transferring the tensile stress to the 0.27 m x 0.27 m x 0.0095 m steel casing required a capacity of 52.87 mPa. The steel casing used has a tensile capacity of 400 mPa, which is more than the required capacity. This makes the design safe.

For the retaining wall, the stem thickness was analyzed based on the standards set by the NSCP 2015. Calculations showed that the required effective depth after load considerations is 126 mm. The total depth of the retaining wall is 300 mm minus the effective covering of 75 mm, resulting in an adapted effective depth of 225 mm, which makes the design safe.

The buoyant component compressive capacity is also analyzed, considering it may elevate above the retaining wall casing during flooding. The hydrostatic, hydrodynamic, and flood-borne impact loads subjected to the buoyant component is 28.8 kPa. The EPS29 Geofoam 1 m x 1 m x 1.5 m in dimension has a compressive resistance of 75 kPa, which is more than the required value; therefore, the buoyant component is safe against flood loads.

Similar to the steel casing, load transfer is also considered for the floor frame c-channel to determine its flexural capacity. Analysis showed that the c-channel has a critical flexural requirement of 80.884 mPa. Compared to the flexural capacity of 148.8 mPa, the floor frame c-channels are safe.

For typhoon considerations, the roof purlins with a dimension of 2’’ x 3’’ x 1.5 mm spaced at 1.45 m were analyzed. Results indicated that for a windspeed of 300 kph, the bending stress is 30.43 mPa. This value is less than the bending capacity of 148.8 mPa, which makes the roof purlins safe against bending.

Overall, the structural design of the flash flood-resilient house is safe against the required values set by the NSCP 2015.

Table 2. Structural Design Safety Summary

Description	Required Value	Adapted Value	Status
Composite Column Capacity (0.256 m x 0.256 m)	52640 N	655494 N	Safe
Footing Wide Beam Shear Depth (0.8 m x 0.8 m x 0.35 m)	33.77 mm	257 mm	Safe
Footing Wide Punching Shear Depth (0.8 m x 0.8 m x 0.35 m)	34.87 mm	257 mm	Safe
Footing Bearing Pressure (0.8 m x 0.8 m x 0.35 m)	52.64 kN	2102.35 kN	Safe
Steel Casing Tensile Capacity (0.27 m x 0.27 m x 0.0095 m)	52.87 mPa	400 mPa	Safe
Retaining Wall Stem Thickness (1.4 m x 1.4 m)	126 mm	225 mm	Safe
Buoyant Component Compressive Capacity (1 m x 1 m x 1.5 m)	28.8 kPa	75 kPa	Safe
Floor Frame C-Channel Flexure (C3 x 3.5)	80.884 mPa	148.8 mPa	Safe
Roof Purlins Bending Stress (2 ‘’ x 3’’ x 1.5 mm)	30.43 mPa	148.8 mPa	Safe

Mechanism Response Time

Volume of Retaining Wall Casing = 1.1 m x 1.1 m x 2.30 m = 2.783 m^3

Volume of Buoyant Component = 1 m x 1 m x 1.5 m = 1.5m^3

Volume of Footing Above Retaining Wall Base = 0.8 m x 0.8 m x 0.15 m = 0.096 m^3

Volume of Column = 0.256m x 0.256m x 0.65 m = 0.0425 m^3

Hollow volume = (6) (2.783 m^3 – 1.5 m^3 – 0.096 m^3 – 0.0425 m^3)= 6.87 m^3

4’’ Drain Pipe Volume = (π)(0.0508 m)^2(0.90 m x 4 + 3.90 x 3) = 0.124 m^3

Total hollow volume = 0.124 m^3 + 6.87 m^3 = 6.994 m^3

Volume to reach the required depth of 0.6225 m above natural ground line
= 6.994 m^3 – (0.05 m)(0.05 m)(0.88 m)(6) = 6.98 m^3

Case 1
Affected Scope = All Direction
Flood Depth = 0.5 m
Design Flood Velocity = 0.5 m/s
Outlet Drainage = 1 – 2'' diameter drain pipe
Functional Drainage = 36 – 3'' diameter drain pipe

Inlet Discharge of each pipe $Q_I = (V_F)(A_{dp})$
Inlet Discharge of each pipe $Q_I = (0.5 \text{ m/s})(\ (\pi)(0.0381 \text{ m})^2$
Inlet Discharge of each pipe = 0.00228 m^3/s
Total Inlet Discharge = 0.00228 m^3/s (36) = 0.082 m^3/s

Outlet Discharge = $(0.5 \text{ m/s})(\ (\pi)(0.0254 \text{ m})^2$
Outlet Discharge = 0.001 m^3/s

Time for mechanism to rise = $\left(\frac{6.98 \text{ m}^3}{0.082\frac{\text{m}^3}{\text{s}} - 0.001\frac{\text{m}^3}{\text{s}}}\right)$

Time for mechanism to rise = 86.17 seconds

Case 2
Flood Depth = 1.0 m
Design Flood Velocity = 1.0 m/s
Functional Drainage = 96 – 3'' diameter drain pipe
Outlet Drainage = 1 – 2'' diameter drain pipe

Inlet Discharge of each pipe $Q_I = (V_F)(A_{dp})$
Inlet Discharge of each pipe $Q_I = (1 \text{ m/s})(\ (\pi)(0.0381 \text{ m})^2$
Inlet Discharge of each pipe = 0.00456 m^3/s
Total Inlet Discharge = 0.00456 m^3/s (96) = 0.44 m^3/s

Outlet Discharge = $(1.0 \text{ m/s})(\ (\pi)(0.0254 \text{ m})^2$
Outlet Discharge = 0.00202 m^3/s

Time for mechanism to rise = $\left(\frac{6.98 \text{ m}^3}{0.44\frac{\text{m}^3}{\text{s}} - 0.00202\frac{\text{m}^3}{\text{s}}}\right)$

Time for mechanism to rise = 15.936 seconds

Case 3
Flood Depth = 1.5 m
Design Flood Velocity = 1.5 m/s
Functional Drainage = 96 – 3'' diameter drain pie
Outlet Drainage = 1 – 2'' diameter drain pipe

Inlet Discharge of each pipe $Q_I = (V_F)(A_{dp})$
Inlet Discharge of each pipe $Q_I = (1.5 \text{ m/s})(\ (\pi)(0.0381 \text{ m})^2$
Inlet Discharge of each pipe = 0.00684 m^3/s
Total Inlet Discharge = 0.00684 m^3/s (96) = 0.66 m^3/s

Outlet Discharge = $(1.5 \text{ m/s})(\ (\pi)(0.0254 \text{ m})^2$
Outlet Discharge = 0.003 m^3/s

Time for mechanism to rise = $\left(\frac{6.98\ \mathrm{m}^3}{0.66\ \frac{\mathrm{m}^3}{\mathrm{s}} - 0.003\ \frac{\mathrm{m}^3}{\mathrm{s}}}\right)$

Time for mechanism to rise = 10.62 seconds

Table 3 shows the mechanism response time of the flash flood-resilient house design. It considered three (3) cases for computing the response time of the mechanism during floods. For Case 1, the flood depth is 0.5 m, and the design flood velocity is 0.5 m/s; 36 drain pipes are functional, resulting in a response time of 86.17 seconds. The second case has a flood depth of 1 m, a design flood velocity of 1 m/s, and 96 functional drain pipes, resulting in a time 15. 94 seconds. Lastly, the 3rd case has a flood depth of 1.5 m and a flood velocity of 1.5 m/s. It accounted for 96 functional drainpipes and can respond after 10.62 seconds of flood. Results indicated that the higher the flood level, the faster the mechanism to respond and begin its upward movement.

Table 3. Mechanism Response Time

Case	Flood Depth (m)	Vf (m/s)	Functional Drainpipe	Response Time (s)
1	0.5	0.5	36	86.17
2	1	1	96	15.94
3	1.5	1.5	96	10.62

Table 4 shows the construction cost of flash flood-resilient house design, which considered the excavation, concrete works, reinforcement, framing, roofings, doors and windows, flood drain system, sewage, water system, stairs and other design components, is *Php 663,580.04***.** By adding the labor cost, which is 45% of the material cost, the total cost of construction is *Php 962,191.06 or approximately $17,200.*

Table 4. Flash flood-resilient house design cost

Item	Cost (Php)
Excavation	7,732.80
Concrete Works	67,620.04
Reinforcement	56,645.00
Framing	82,225.00
Roofings	36,032.00
Doors and Windows	52,500.00
Flood Drain System	11,150.00
Sewage	3,130.00
Water System	300.00
Stairs	8,620.00
Other Design Components	337,625.20
SUB TOTAL	663,580.04
TOTAL (+45% Labor Cost)	**962,191.06**

Figure 5. Flash flood-resilient design perspective

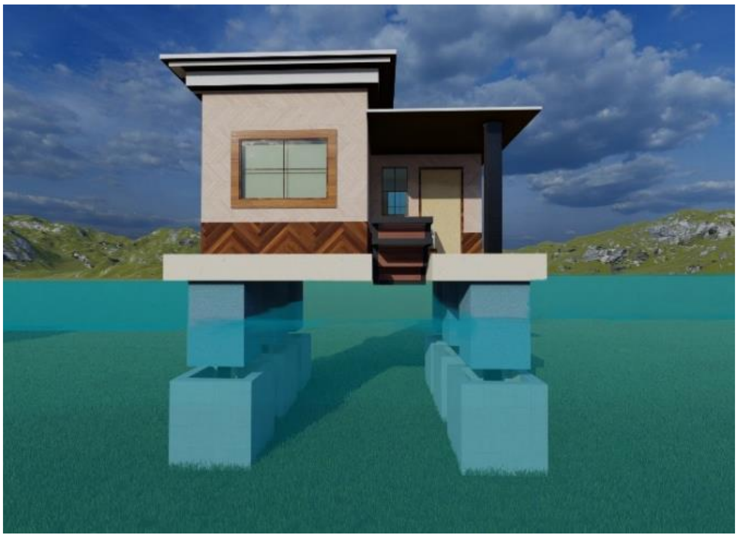

Figure 6. Elevated Flash Flood-Resilient House Design Perspective

Conclusion

The frequent occurrences of flash floods in the Philippines threaten the economic stability of the country, as they can affect a broad scope that comprises the economic system. The need for adaptive and mitigation measures to cater the effects of flash floods is essential, given that the intensity may further worsen in the years to come.

Through the creation of the flash flood-resilient house design, flash floods from a depth of 0.5 m to more than 1.5 m can be coped with, given that the design can elevate higher than the flood depth. The constant elevation above flood water through the buoyant component made the design reliable and safe, even if the flood depth continuously increased. It addressed the risk of debris and flood loads which may impact traditional amphibious designs that situate their structure's base directly on top of flood water. The elevated feature also tackled the risk of the sudden rise of flood level, where water can reach the floor area, if not at a higher depth, posing a threat to the residents and the structure itself, since the flash flood-resilient house design is already elevated at a height of 1.5 m, and it's response time to elevate is faster as the flood depth is higher.

The average residential construction cost in the Philippines for the first quarter of 2023 is 10.5 thousand per square meter. Compared with the flash flood-resilient house design, house construction ranging from the average floor area of 10 sqm to 49 sqm is cheaper. However, this construction cost still does not consider the potential incurring expense caused by flash floods. Reconstruction of these residential units may potentially double the expense, without the safety assurance from the impending natural calamity. Individuals affected by floods experience economic, health, and safety threats for the succeeding flood events, despite infrastructure improvements. Residents abandoned their houses due to flood damage, while others moved to a different location, without considering relocation as a temporary solution.

The acceptance and implementation of the flash flood-resilient house design as an alternative residential unit for Filipinos is an advancement for the economy as it caters to the economic threat of flash floods and ensures the safety of Filipinos in times of calamity.

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