STRUCTURAL ANALYSIS

Project **FAMILY HOUSE IN GREAT EXUMA, BAHAMAS.**

Date December 2019

MEMORY INDEX

APPENDIX INDEX

DESRIPTIVE REPORT

1 OBJECTIVE

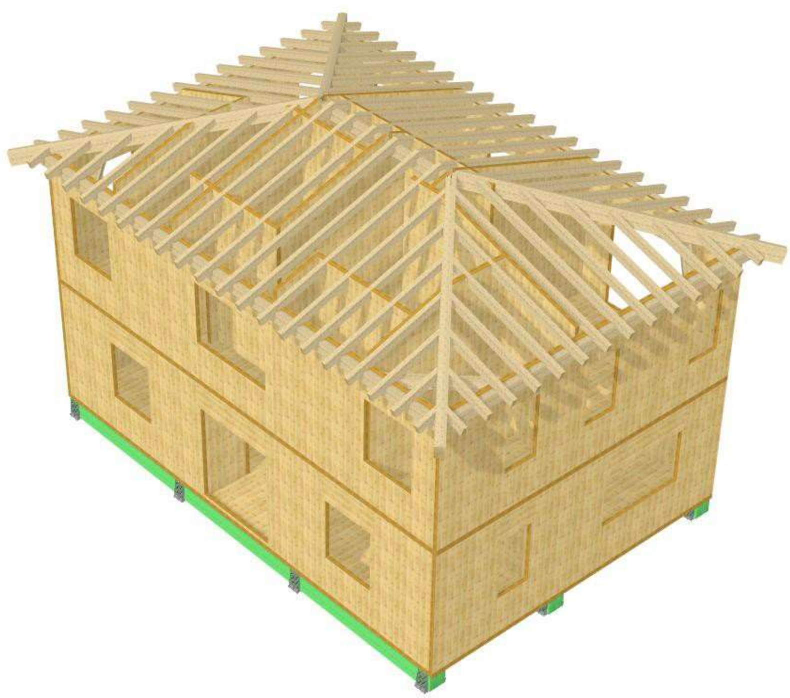
The purpose of this report is to document and justify the structural solution adopted for a Family House Project in Great Exuma, Bahamas. The characteristics of the materials, the verifications and all aspects that have been taken into account, in compliance with the applicable building regulations, are described in detail in this document.

2 DESCRIPTIVE REPORT OF THE PROJECT

The project consists of a building for residential use. It is a construction of two stories above ground level, with a built area of about 96 m² per floor. The house also has a two-story back porch of 46 m² per floor and a small covered entrance on the main facade.

The main building has a hip roof, with slopes of 18.43°. The roof in the back porch is practically flat, and the roof on the main entrance porche has a slope of 17.31º.

The dimensions of the house envelope are: 11.49m long and 7.83 m wide, with a height above ground level of 7.80 m. The back-porch dimensions are 11.49 m long and 4.17 m wide.

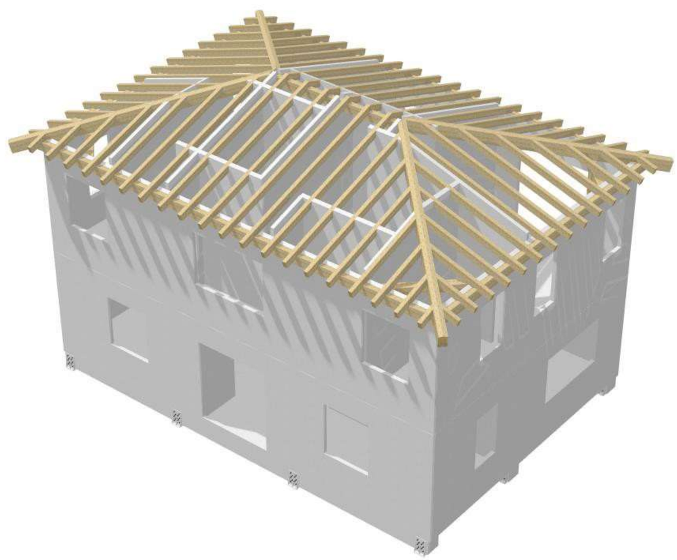


2.1 ROOF

2.1.1 GENERAL DESCRIPTION

The house has a hipped roof, with slopes of 18.43º. Glue laminated beams GL 24h are used for the structure, with the following structural elements:

- Hip Rafter of 200x315 mm section
- Ridge of 140x245 mm section
- Rafter of 100x175 mm section
- Corner Brace of 200x180 mm section
- Belt 140x240 mm section



2.1.2 STRUCTURAL BEHAVIOUR

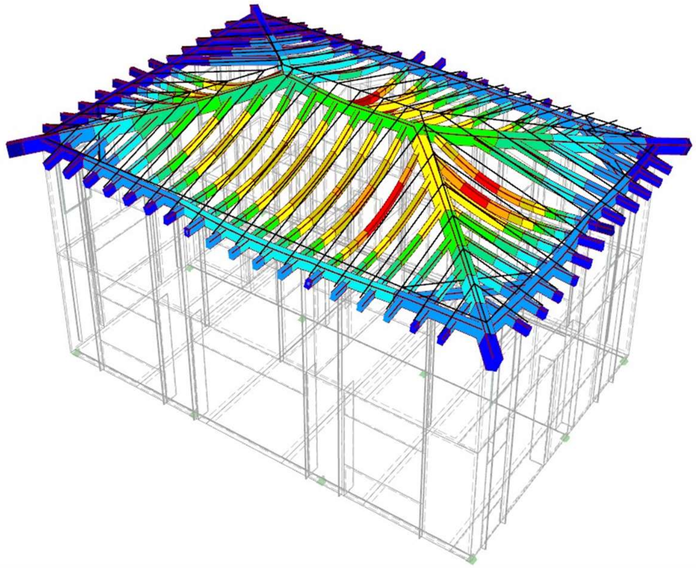
The hip rafters rest over the cross laminated timber walls, creating the hip roof. Two of these hip rafters are supported in two points, whereas the other two hip rafters count with additional support provided by the interior CLT walls.

The ridge rests over the walls on the second floor; the roof then works as an element supported in three points. On one hand it is supported by the hips and ridge, and on the other hand by the exterior walls, being the rafters placed every 590-610mm (23 1/4 - 24") from center to center.

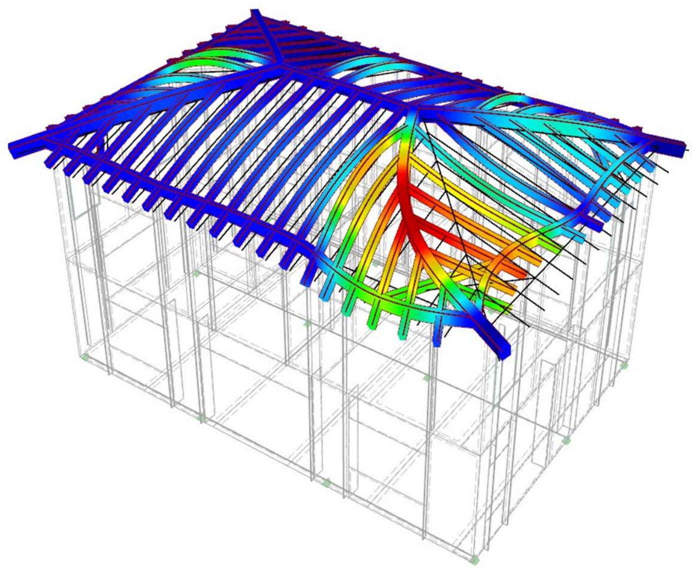
A belt beam is installed on the top edge of the exterior CLT walls for reinforcing the exterior wall. Its purpose is to minimize deformations on the top edge of the walls caused by the strong winds.

On the four corners of the building a square is located, an element creating a 45-degree angle with the exterior walls. This square works as a brace, supporting traction and compression efforts and ensuring the building will remain squared at all times.

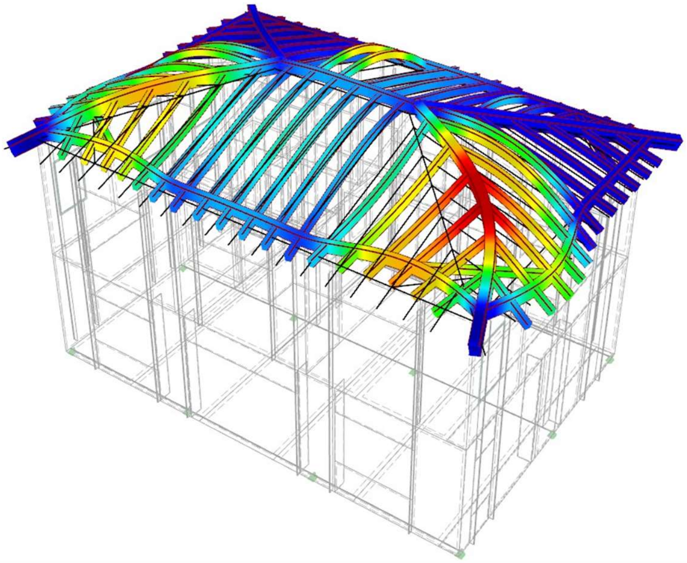
Deformations caused by vertical loads.



Deformations caused by wind force in longitudinal direction



Deformations caused by wind force on cross direction

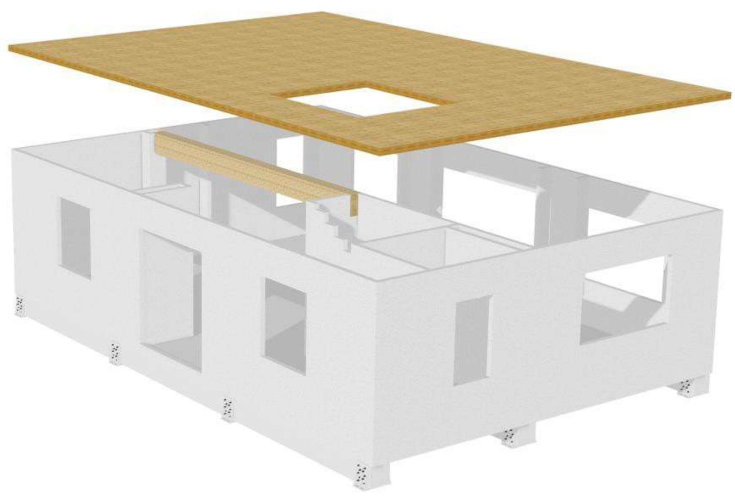


2.2 FLOOR L1

2.2.1 GENERAL DESCRIPTION

The following structural elements are proposed for the first level floor:

- Cross laminated timber panels of 120 mm of width with a layer composition of 40-40-40, being layers 1 and 3 with longitudinal orientation and layer 2 with cross orientation.
- 2 glue laminated beams GL24 with a section of 140x42mm to provide additional support in the area where there are no interior walls (living / dining room).



2.2.2 STRUCTURAL BEHAVIOUR

All panels have at least three supports on the ground floor walls or the beams. This way the floor slab shows a good behavior against deformations.

The floor structure was solved with a panel of low thickness, adapting to the requirements of the architectural design.

Deformations caused by vertical loads

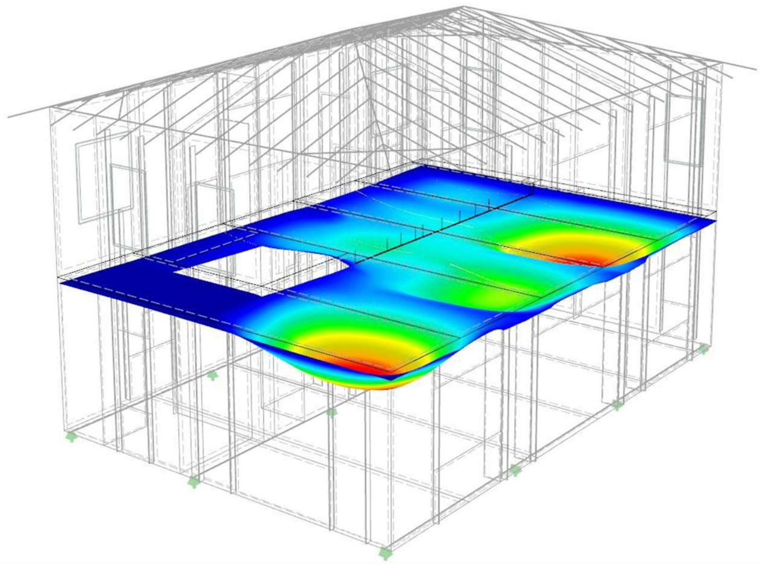
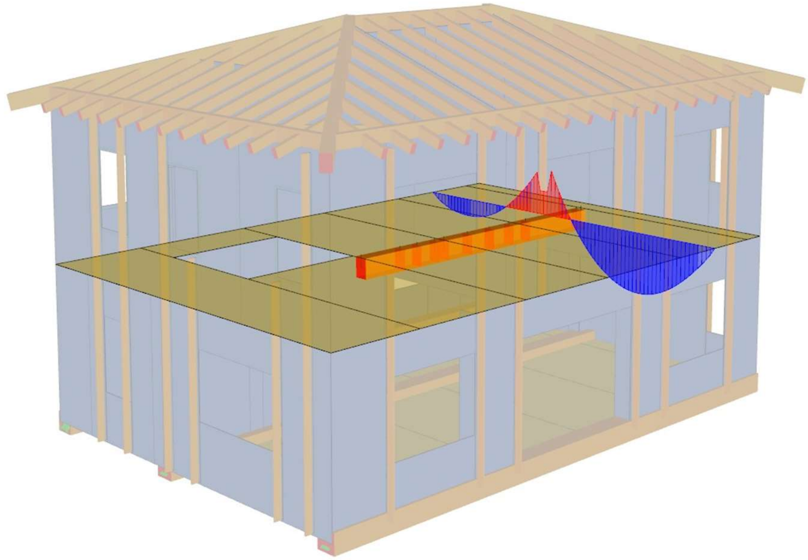


Diagram of moments caused by vertical loads on the floor slab panels



Note: The discontinuity in the maximum moments respond to an area of smoothness on the support of the floor slab panels over the beam which follows the width of the beam and this way to avoid the appearance of singular peak

2.3 STRUCTURAL WALLS

2.3.1 GENERAL DESCRIPTION

All bearing walls have the following structural elements:

- CLT of 100mm thickness, made of three layers 30-40-30. Layers 1 and 3 have a vertical orientation, and layer 2 a horizontal orientation.
- Exterior glue laminated structural ribs with a section of 30x140mm reinforcing the exterior walls against deformations on its plane.
- Interior glue laminated structural ribs with a section of 80x120mm reinforcing the perimeter on the door openings on the bedrooms on the second level

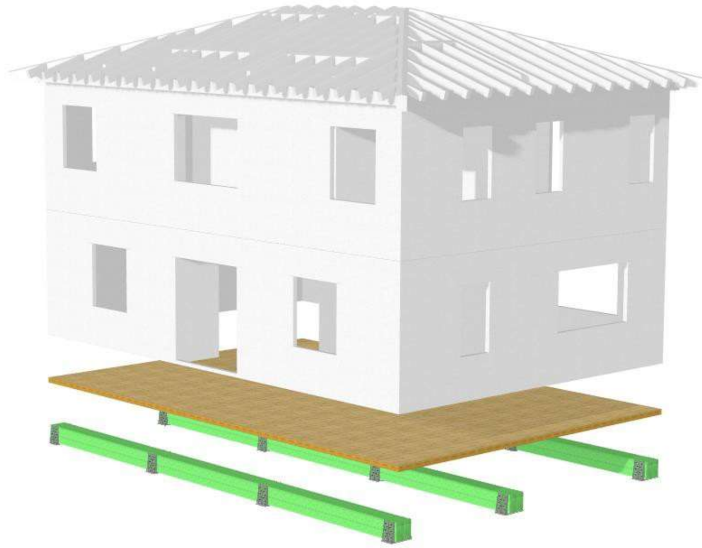
The cross laminated timber panels of 100 mm thickness are used on the exterior bearing walls and on the interior bearing walls. These panels allow the vertical loads to be transferred to the foundation and guarantee the lateral stability of the building caused by horizontal wind stress.

2.4 FLOOR SLAB GROUND FLOOR

2.4.1 GENERAL DESCRIPTION

The floor slab on the ground floor has the following structural elements

- Cross Laminated Timber panels of 120 mm thickness made up of 40-40-40 mm layers. Layers 1 and 3 have longitudinal orientation and layer 2, cross orientation
- Glue laminated wooden beams with a resistant category of GL24 h treated for risk category IV and a support section of 200x385 mm for the floor slab panel

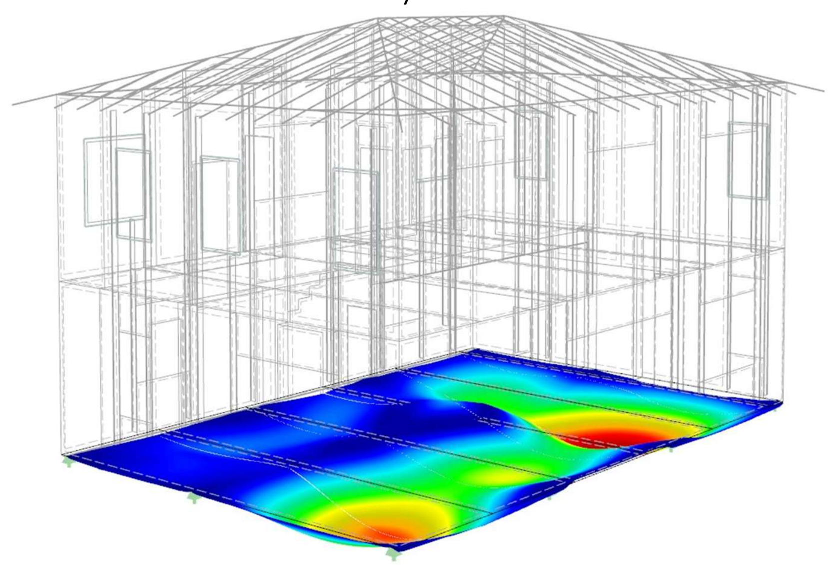


2.4.2 STRUCTURAL BEHAVIOUR

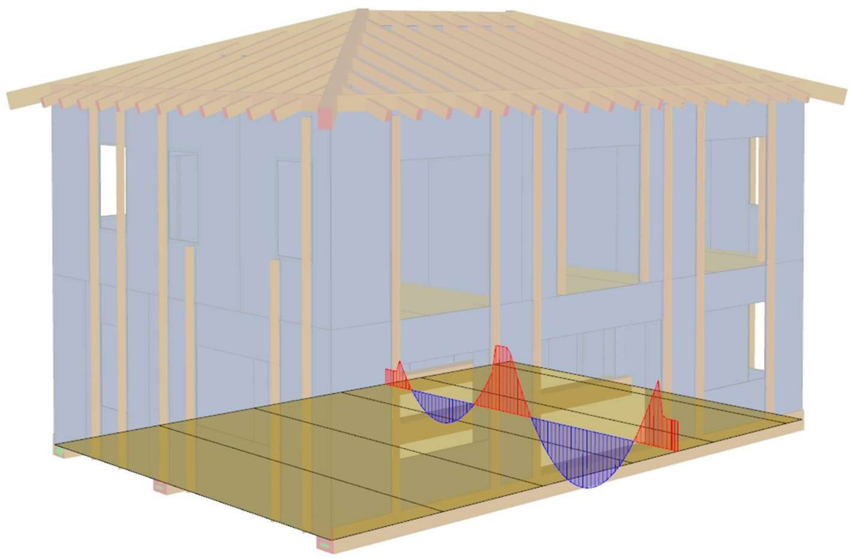
All of the panels have at least 3 supports over a couple of treated glued laminated beams. This way the floor slab shows good behavior against the deformations.

The beams, at the same time, transmit the loads to the foundations. They are dimensioned to rest over at least 4 supports.

Deformations caused by vertical loads



Bending moment caused by vertical loads over the floor slab panels



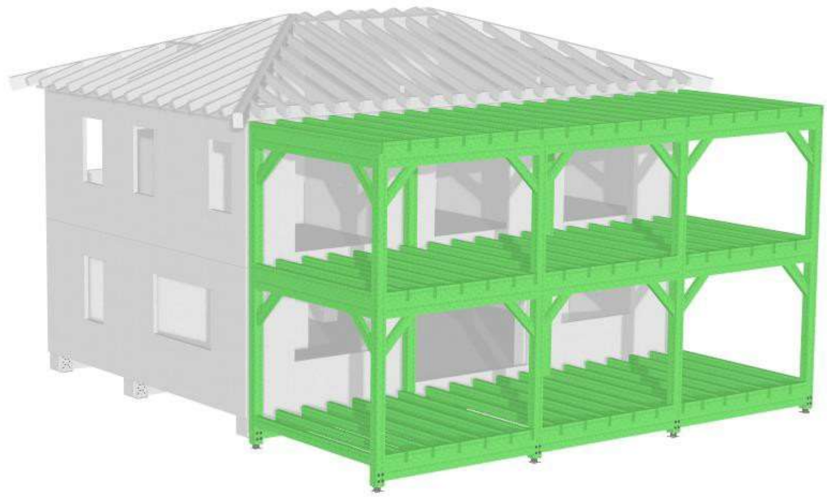
Note: The discontinuity in the maximum moments respond to an area of smoothness which have been included on the supports over the beams to avoid the appearance of singular peak forces.

2.5 BACK PORCH

2.5.1 GENERAL DESCRIPTION

The porch shall have a glue-laminated structure, made of GL 24H beams suitable for Risk Category IV buildings. It consists of the following structural elements:

- Columns of 200x200 mm section
- Beams of 200x280 mm section
- Joists of 100x210 mm section
- Diagonals of 160x175 mm section
- Struts of 100x175 mm section



2.5.2 GENERAL BEHAVIOUR

In accordance with the design recommendations for buildings exposed to high winds, the annexed elements (back porch and entrance porch) are independent structures from the main house, they are designed independently.

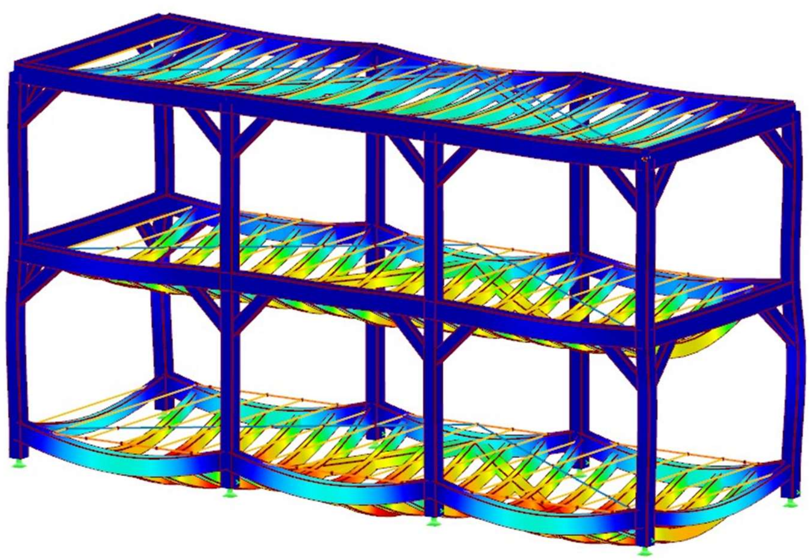
As it is likely that no person will use the porch areas as shelter in any hurricane situation, the annexed elements are designed in such way that their collapse does not affect the main structure or endanger the integrity of the home.

The pillars are sized as continuous pieces from the foundation to the roof and transmit the loads of the two floors and from the roof to the foundation. They are fixed to the footings through costume pillar metal supports, sized to withstand the suction efforts caused by the wind and grant a certain degree of embedment at the moment.

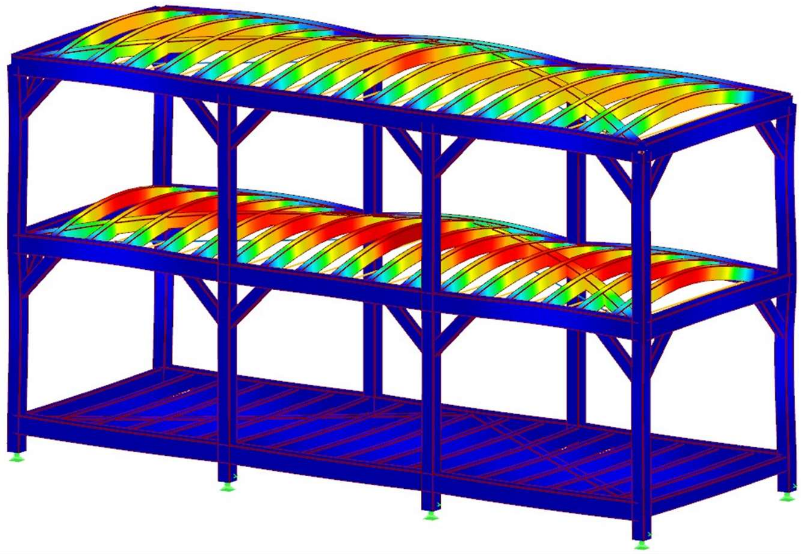
The main beams are situated between the pillars working as dual supported elements. The joists rest over the beams, working with a dual support and constitute the structure of both floor slabs and the roof.

In order to provide the structure with stability against horizontal stresses, it is necessary to place diagonals on the floor slabs and roof planes, and struts in the four vertical planes.

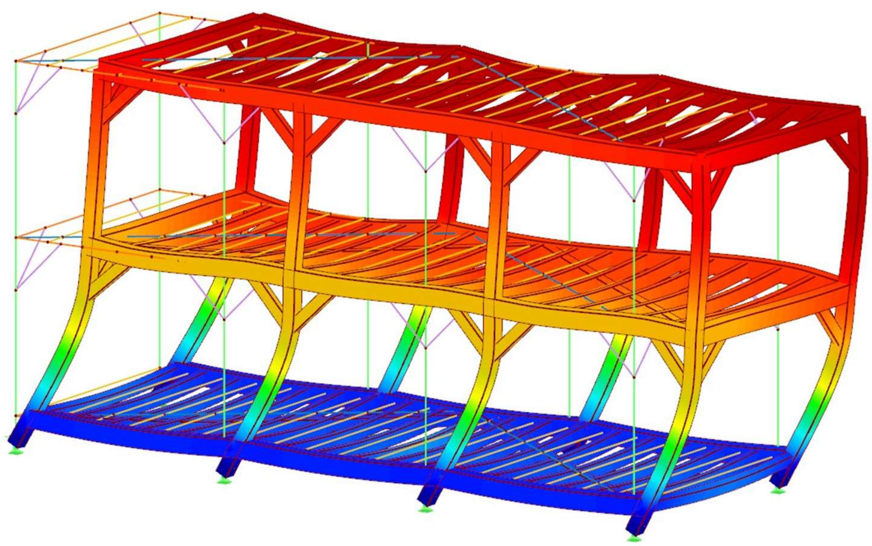
Deformation caused by vertical loads.



Deformation caused by wind suction forces.



Deformations caused by cross wind forces

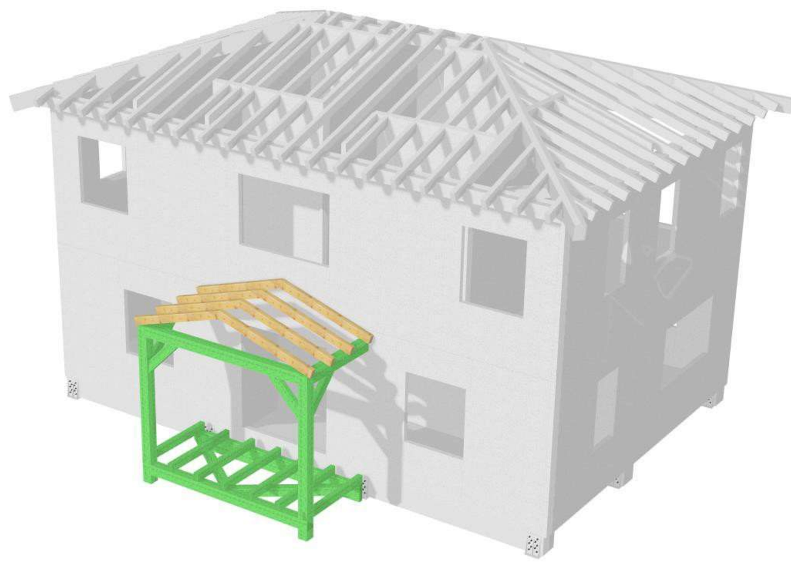


2.6 FRONT PORCH

2.6.1 GENERAL DESCRIPTION

The front porch shall have a structure made of glue laminated timber beams, suitable for risk category IV. It shall have the following structural elements:

- Columns of 200x200 mm of section
- Beams of200x210 mm of section
- Forged Joists of 100x175 mm of section
- Struts of 100x175 mm of section
- Diagonals of 160x175 mm of section
- Rafters of 100x160 mm of section



2.6.2 STRUCTURAL BEHAVIOUR

In accordance with the design recommendations for buildings exposed to high winds, the annexed elements (back porch and entrance porch) are independent structures from the main house, they are designed independently.

As it is likely that no person will use the porch areas as shelter in any hurricane situation, the annexed elements are designed in such way that their collapse does not affect the main structure or endanger the integrity of the home.

The dual-supported joists of the slab are supported on their two ends over the beams which transfer the loads to the columns. The front columns, in addition to transferring the slab loads to the foundation, support the main roof beams on which the roof rafters rest.

To provide stability to the structure of the front porch against horizontal stresses, it is necessary to place diagonals in the plane of the slab and struts on the upper part of the pillars, in both directions.

2.7 UNIONS

Below is a list of the unions used on the different parts of the structure. See structural drawings for union details.

2.7.1 ROOF

UNION	DESCRIPTION
Belt beam to exterior walls	Partial Threaded screw Ø8-L220 w/ 200
Belt beams strapping pieces between each other	Mechanized half wood + Bolt M16-L240
Hips to interior walls	Hardware to size + Bolt M10 + Self drilling Ø7
Hips to exterior walls	Boxing + Fully threaded screw Ø7-L340
Rafters to Hips	4x Fully threaded screw Ø7-L220
rafters to ridge	2x Fully threaded screw Ø7-L221
rafters over walls	2x Fully threaded screw Ø7-L340
Braces to walls	8x Partial Threaded and disc head Ø10-L200

2.7.2 FLOOR SLAB GROUND FLOOR

UNION	DESCRIPTION
Beam to foundation	Hardware to size + 8x Bolt M16 + 4x Threaded Bar M16

2.7.3 LINEAR UNIONS BETWEEN CLT PANELS

UNION	DESCRIPTION
Panels over beams	Partial Threaded screw Ø8-L220 w/ 150
between floor panels GF	Partial Threaded screw Ø8-L140 w/ 500
wall panels GF with floor panels GF	Angled Bracket w/ring threaded nails c/900
between floor panels 2F	Partial Threaded screw Ø8-L140 w/ 150
floor panels 2F with wall panels GF	Partial Threaded screw Ø10-L200 c/100
wall panels GF with floor panels 2F	Angled Bracket w/ring threaded nails c/1000
Between panels exterior walls	Partial Threaded screw Ø8-L120 w/ 100
Between panels interior walls	Partial Threaded screw Ø8-L120 w/ 300
Encounters on “L” or “T” between vertical walls	Partial Threaded screw Ø8-L120 w/ 200
Traction connections	Perforated plate 120x600x2 + 72x Slotted Nails
Exterior wall panels with reinforcement ribs	Partial Threaded screw L220 w/ 200 (with pre-drill de Ø4)

2.7.4 PORCH

UNION	DESCRIPTION
columns to foundation	Hardware to size + 4x Bolt M16 + 4x Bar M12
front beams to columns	4x Fully threaded screw Ø9-L360
Struts to columns and beams	Boxing + 3x Fully threaded screw Ø8-L180
Inferior Diagonals to beams	2x Fully threaded screw Ø9-L240
Floor slab Beams on frontal beams	Fully threaded screw Ø7-L220

3 CALCULATION BASIS

3.1 REFERENCE NORM

The following regulations were taken into account when creating this document:

- Norm EN 1990 Eurocode: Basis of structural design.

- Norm EN 1991 Eurocode 1: Actions on structures.
    - EN 1991-1-1:2002 Part 1-1: General actions. Densities, self-weight, imposed loads for buildings
    - EN 1991-1-2:2002 Part 1-2: General actions - Actions on structures exposed to fire
    - EN 1991-1-3:2003 Part 1-3: General actions - Snow loads
    - EN 1991-1-4:2005 Part 1-4: General actions - Wind actions

- Norm EN 1995 Eurocode 5: Design of timber structures.
    - EN 1995-1-1:2004 Part 1-1: General - Common rules and rules for buildings
    - EN 1995-1-2:2004 Part 1-2: General - Structural fire design

- Bahamas Building Code. Third edition. 2003. Part V, Engineering and Construction Regulations.

- ASCE/SEI 7-16. American Society of Engineers. Minimum Design Loads and Associated Criteria for Buildings and Other Structures.

- Consultation document: *Country Risk Profile: Bahamas*. CCRIF: Caribbean Catastrophe Risk Insurance Facility. Agosto de 2013.

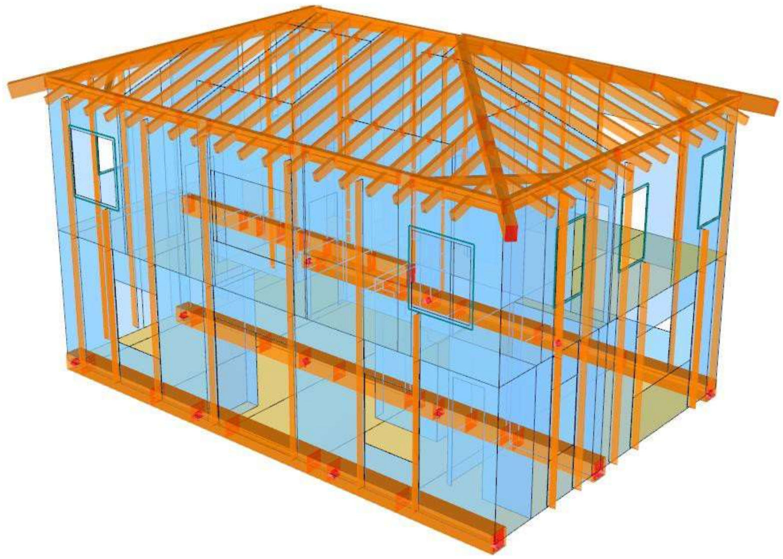
- Consultation document: GAPS Guidelines GAP 15.2.3.3. *Earthquake hazard zones – Caribbean, Central America and South America.*

3.2 CALCULATION METHODS & MODELS

3.2.1 HOUSE STRUCTURE

The finite element analysis program RFEM from Dlubal was used for modeling and designing the whole building model and for calculating and designing the cross laminated timber panels.

The panels have been introduced as laminated surfaces considering the mechanical properties of the materials, their stratigraphy and orientation of the layers. The unions between the panels bending moment and shear movement have been considered and addressed with the use of threaded screws.



This model has been used in the following calculation phases

- dimensioning of the cross laminated timber, floor slab laminated beams, and the roof structure
- obtaining the reactions over the supports in order to generate the load plane to the foundation
- Obtaining efforts between the panels and on the supports of the bars for the design and calculation of the joints

3.2.2 TRACTION CONNECTIONS

On the basis of the complete model in RFEM, a second model has been generated, replacing the supports of the vertical panels of the ground floor with supports with failure if they receive traction efforts. This model includes some specific supports in any necessary area, simulating that all the traction efforts produced by wind action is concentrated on traction brackets.

This model has been used in the following calculation phases:

- Obtaining vertical reactions for the design of traction plates

3.2.3 FIRE SITUATION

On the basis of on the complete model in RFEM, a second model was generated by modifying the composition of the panels. It was adjusted considering they were exposed to fire during 30 minutes, based on the reduced cross-section method

This model has been used in the following calculation phases

- Verification of compliance with the ultimate limit state in a fire situation.

3.3 MECHANICAL PROPERTIES OF THE MATERIALS

3.3.1 CROSS LAMINATED TIMBER PANELS

The design and calculation of the cross laminated timber panels has been carried out based on the properties of the EGO_CLT material included in ETA-11/0464 from manufacturer EGOIN

C24 graded sawn timber, a premium structural and resistant timber, is used in the manufacturing of the panels.

Accorfing to the Norm"UNE-EN 338:2016 Structural Timber. Strenght classes" presents the following characteristic resistance values

Resistant properties	C24		
Flexion	$f_{m,k}$	24.00	N/mm²
Parallel traction	$f_{t,0,k}$	14.00	N/mm²
Perpendicular traction	$f_{t,90,k}$	0.40	N/mm²
Parallel compression	$f_{c,0,k}$	21.00	N/mm²
Perpendicular compression	$f_{c,90,k}$	2.50	N/mm²
Shear (Shear & twist)	$f_{v,k}$	4.00	N/mm²
Shear by rolling	$f_{r,k}$	0.65	N/mm²
Rigidity			
Average Elasticity module parallel	$E_{0,mean}$	11600	N/mm²
Average Elasticity module perpendicular	$E_{90, mean}$	370	N/mm²
Average shear module	G_{mean}	690	N/mm²
Module shearing by rolling	Gr_{mean}	50	N/mm²
Density			
Characteristic density	pk	350	Kg/m³
Average density	pmean	420	Kg/m³

3.3.2 GLUE LAMINATED TIMBER

According to standard "UNE-EN 14080 Timber structures. Glued laminated wood and glued solid wood. Requirements", GL 24h glued laminated timber has the following characteristic strength and stiffness values:

Resistant properties	GL24h		
Flexion	$f_{m,k}$	24.00	N/mm²
Parallel traction	$f_{t,0,k}$	19.20	N/mm²
Perpendicular traction	$f_{t,90,k}$	0.50	N/mm²
Parallel compression	$f_{c,0,k}$	24.00	N/mm²
Perpendicular compression	$f_{c,90,k}$	2.50	N/mm²
Shear (Shear & twist)	$f_{v,k}$	3.50	N/mm²
Shear by rolling	$f_{r,k}$	1.20	N/mm²
Rigidity			
Average Elasticity module parallel	$E_{0,mean}$	11500	N/mm²
Elasticity module parallel 5%	$E_{0,05}$	9600	N/mm²
Average Elasticity module perpendicular	$E_{90, mean}$	300	N/mm²
Elasticity module parallel 5%	$E_{90,05}$	250	N/mm²
Average shear module	G_{mean}	3650	N/mm²
Module shearing by rolling characteristic	G_{05}	540	N/mm²

Average Shear Module by Rolling	$G_{r,mean}$	65	N/mm²
Module shearing by rolling characteristic	$G_{r,05}$	54	N/mm²
Density			
Characteristic density	ρ_k	385	N/mm²
Average density	ρ_{mean}	420	N/mm²

3.4 CALCULATION HYPOTHESIS

3.4.1 SERVICE CATEGORY

The elements for the structure are classified according to the environmental conditions to which they are exposed according to Eurocode 5.

Structural Component	Exposure	Service category
cross laminated timber walls and floor slabs	Interior, under roof	1
roof and floor slab beams on 2F	Interior, under roof	1
floor slab beams on GF	Exterior, protected	2
Porch structural elements	Exterior, exposed	3

3.4.2 LOAD DURATION

The load duration significantly affects timber resistance, and it is defined by each load, as stated in the Eurocode.

Action	Load Duration
Own weight of structural materials	Permanent
Own Weight of roof and finishes	Permanent
Overload of used in floors Type A: Residential	Medium
Overload of used in floors Type G: Accessible decks only for maintenance	Short
Wind	Instant

3.4.3 COEFFICIENTS OF THE MATERIALS AND ACTIONS

Partial Safety coefficient of materials:

	Ordinary situation	Extraordinary situation
Cross laminated timber	1.25	1.00
Glue laminated wood	1.25	1.00
Steel plugs or pegs	1.25	1.00
Unions	1.30	1.00

Kmod values for materials, service category and load duration:

Material	Norm	Service categories	Load duration category				
			Permanent	**Long**	**Mediu**	**Short**	Permanent
CLT and MLE	EN 14080	1	0.60	0.70	0.8	0.9	1.10
		2					
		3	0.50	0.55	0.65	0.70	0.90

Partial Safety coefficient of actions:

To assess the Ultimate Limit State (ULS) and Service Limit State (SLS) the following partial coefficients of action safety are considered in accordance with the recommendations shown in table A.1.2 (B), Eurocode O, structure calculation bases:

Load type	Negative effect	Positive effect
Permanent actions	1.35	1.00
Variable actions	1.50	0.00

Simultaneity coefficient:

The numerical values of simultaneity coefficients for structures used in the calculation are shown in table A.1.1, Eurocode O, structure calculation basis:

:

Load type	Ψ_0	Ψ_1	Ψ_2
Use load (A, residential)	0.7	0.5	0.3
Use load (G, roof access only for maintenance)	0	0	0
Wind	0.6	0.2	0

Creep or Stress Factor

The Creep of Stress factor is applied to permanent loads or to the permanent aspect of the variable loads. The values K_{def} used for calculations are shown in the following table:

Material	Standard	Service category		
		1	2	3
CLT and MLE	UNE-EN 14080	0.60	0.80	2.00

3.4.4 CALCULATION SITUATIONS

The following verifications have been carried out, corresponding to the Ultimate Limit State and Service Limit State:

- Verification of roof and main building walls in the ULS and SLS
- Verification of roof and main building walls in the ULS in a fire situation
- Verification of roof porch structures in the ULS and SLS

All the details regarding the verifications are stated in calculation exhibit.

3.4.5 DEFLECTION LIMIT CRITERIA

The Eurocode considers the following criteria deflections:

Immediate deflection – characteristic situation

$$w_{in\text{��}} = \sum G + Q_{k,1} + \sum \Psi_{0,i} \cdot Q_{k,i}$$

Permanent deflection – quasi-permanent characteristic

$$w_{\text{�}in} = \sum G \cdot (1 + k_{\text{���}}) + Q_{k,1} \cdot (1 + \Psi_{2,1} \cdot k_{\text{���}}) + \sum Q_{k,i} \cdot (\Psi_{0,i} + \Psi_{2,i} \cdot k_{\text{���}})$$

According to the applicable regulation, the following deflection limit has been set for ELS verification in the structural elements (according to table 7.2, Eurocode 5, Timber Structural Projects).

	Immediate deflection	Permanent deflection
Elements on two supporting members	l/300 to l/500	l/150 to l/300
Cantilevered / Overhang	l/150 to l/250	l/75 to l/150

3.4.6 FIRE EXPOSURE SITUATION

The resistance of the building structure was checked in a fire duration of 30 minutes so as to ensure the evacuation of the building in such situation.

Should the Construction Management Board consider building resitance be reinforced, an intumescent product must be applied to the panels. Otherwise they be coated with protective panels (laminated plaster or similar) until the required fire time is reached. The geometry of the structural elements is then collected after 30 minutes of fire according to the reduced section method

3.4.6.1 Floor Panels

Section loss in 30 min	$d_{char,0}=\beta_0 \cdot t+k_0 \cdot d_0=0.65 \cdot 30+1 \cdot 7=$**26.5 mm**
Panel composition after 30 min	40-40-13.5

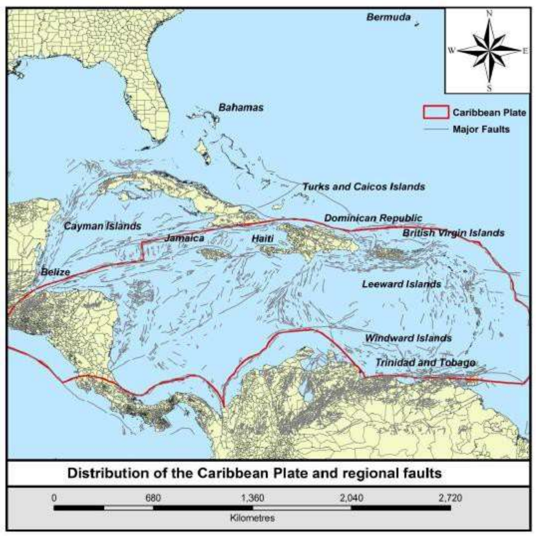
3.4.6.2 Wall panels

Section loss in 30 min	$d_{char,0}=\beta_0 \cdot t+k_0 \cdot d_0=0.65 \cdot 30+1 \cdot 7=$**26.5 mm**
Panel composition after 30 min	30-40-3.5

3.4.7 EARTHQUAKE SITUATION

The Bahamas is located close to the Caribbean plate. In order to determine the seismic activity and to assess how it affects Great Exuma, Country Risk Profile: Bahamas by CCRIF, Caribbean Catastrophe Risk Insurance Facility, August 2013 has been referred to.

The following map made by USGS Earthquake Hazards Program of the U.S. Geological Survey (USGS) shows how close the Bahamas is to the Caribbean plate.



In Great Exuma, the seismic acceleration value for a return period of 475 years (equivalent to 10% probability of overcoming 50 years) is between **0.01 and 0.02 g** according to the map herein below [Bahamas Country Risk Profile].

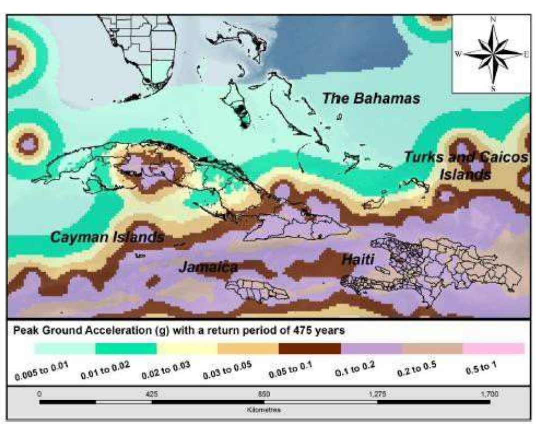


Figure 2.5: Sub-regional map for peak ground acceleration with return period of 475 years.

For the same area, the seismic acceleration value for a return period of 2475 years (equivalent to 2% probability of overcoming 50 years) is between **0.01 and 0.02 g** according to the map herein below [Bahamas Country Risk Profile].

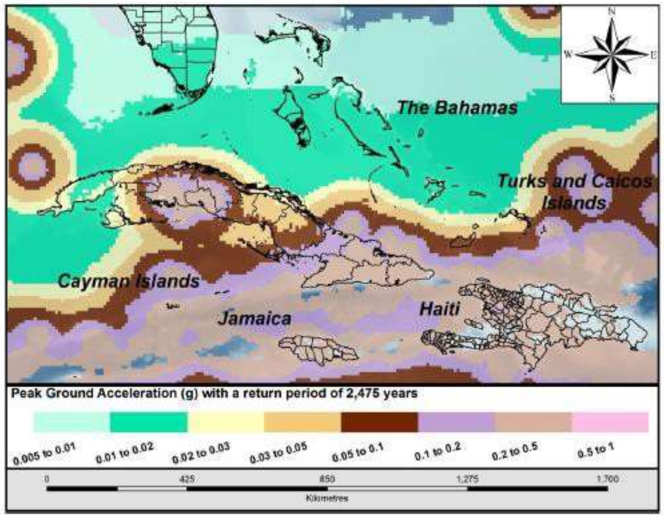


Figure 2.6: Peak Ground Acceleration with return period of 2,475 years (equivalent to 2% probability of exceedance in 50 years).

According to the data published by Global Asset Protection Services LLC in GAPS Guidelines GAP 15.2.3.3 "Earthquakes hazard zones – Caribbean, Central America and South America", the Bahamas can be deemed almost an earthquake free zone and has been categorized as zone 1, similar to Florida.

The Bahamas are considered to consist of: Grand Bahama, Andros Island, Great Abaco, Little Abaco, Eleuthera, Cat Island, Long Island, Crooked Island, Acklins Island, Mayaguana and Great Inagua (Among others).

Aruba
Hazard Zone 4

Bahamas*
Hazard Zone 1

Barbados
Hazard Zone 5

Barbuda
Hazard Zone 5

* The Bahamas may be considered virtually Earthquake free and have been indicated as Zone 1, similar to Florida. The Bahamas are considered consisting of: Grand Bahama, Andros Island, Great Abaco, Little Abaco, Eleuthera, Cat Island, Long Island, Crooked Island, Acklins Island, Mayaguana and Great Inagua.

GAPS Guidelines

2 A Publication of Global Asset Protection Services LLC

According to the previous data, the earthquake risk in Great Exuma, Bahamas, is classified as very low since the seismic acceleration is within the threshold corresponding to cases of very low seismicity, where the ground acceleration does not exceed 0, 04g. Due to this, the verification of the structure under the effects of the seismic action has not been considered.

3.5 ACTIONS TAKEN FOR CALCULATION

3.5.1 PERMANENT ACTIONS

3.5.1.1. Pitch Roof (Main Building)

The following table shows the weight of the pitch roof materials prescribed in the project, from exterior to interior:

Category	**Width (mm)**	**Density (kg/m³)**	**Weight (kN/m²**
Curved roof tile	-	-	0.500
Battens 50x50 c/300	50	-	0.042
Fiber insulation	60	110	0.066
Board OSB 3	32	550	0.176
Conifer Timber cladding	32	510	0.163
TOTAL ON ROOF PANELS			**0.947**

3.5.1.2. Second Floor (Building)

The following table shows the weight of the second-floor slab materials prescribed in the project, from top to bottom:

Category	**Width (mm)**	**Density (kg/m³)**	**Weight (kN/m²)**
Ceramic Tile Floor	16	2000	0.320
Thinset	32	1800	0.576
Fiber insulation	48	185	0.089
TOTAL ON FLOOR PANELS			**0.985**

3.5.1.3 Exterior walls

The following table shows the weight of the materials of the exterior walls prescribed in the project, from exterior to interior:

Category		**Width (m**	**Density (kg/**	**Weight (kN/m**
Timber fiber insulation		65	185	0.120
Trailed 50x70 c/300		70	-	0.064
Boarding of conifer timber cladding		32	510	0.163
	TOTAL			**0.347**

3.5.1.4 Floor (Porch)

The following table shows the weight of the exterior wall materials prescribed in the project, from top to bottom:

Category	**Width (mm)**	**Density (kg/m³)**	**Weight (kN/m²)**
Boarding of conifer timber flooring	50	510	0.255
TOTAL			**0.255**

3.5.1.5 Porch Roof

The following table shows the weight of the exterior floor materials prescribed in the project, from top to bottom:

Category	Width (mm)	Density (kg/m	Weight (kN/m²)
Concrete compression layer/slope	60	2400	1.440
Waterproof membrane	3.8	1250	0.048
TOTAL			**1.488**

3.5.2 VARIABLE ACTIONS

3.5.2.1 USE OVERLOAD

ROOF	Use overload on roof (building)	**0.4**	kN/m²
	The building roof is classified as load area category H, non-accessible roofs, except for normal maintenance and repair. The load value corresponds to that specified in Eurocode 1, table 6.10		

FLOORS	Overload of use on floors (building interior and terrace)	**2**	kN/m²
	Complies with "Bahamas Building Code" indications for Uniformly distributed live loads, Residential: one and two-family dwellings → 30 lbf / f t2 = 0.957 kN / m2		

3.5.2.2 SNOW LOAD

The American Standard ASCE 7-16 for South Florida, the closest and more similar area to Bahamas, considers a 0 lbf/ft2 load for snow loads.
Therefore, considering that the project is located in the isle of Great Exuma, at a 10-20 msnm from the sea level, it is not necessary to verify the structure for the snow loads.

3.5.2.3 WIND LOAD

Basic wind speed

In order to obtain the basic wind speed value the American Standard ASCE 7 is referred to, to which the Bahamas Building Code makes references. According to ASCE 7-16, table 1.5-1, the building structure is classified as **risk category II**.

Table 1.5-1 Risk Category of Buildings and Other Structures for Flood, Wind, Snow, Earthquake, and Ice Loads

Use or Occupancy of Buildings and Structures	Risk Category
Buildings and other structures that represent low risk to human life in the event of failure	I
All buildings and other structures except those listed in Risk Categories I, III, and IV	II
Buildings and other structures, the failure of which could pose a substantial risk to human life	III
Buildings and other structures, not included in Risk Category IV, with potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure	
Buildings and other structures not included in Risk Category IV (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives) containing toxic or explosive substances where the quantity of the material exceeds a threshold quantity established by the Authority Having Jurisdiction and is sufficient to pose a threat to the public if released[a]	
Buildings and other structures designated as essential facilities	IV
Buildings and other structures, the failure of which could pose a substantial hazard to the community Buildings and other structures (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, or hazardous waste) containing sufficient quantities of highly toxic substances where the quantity of the material exceeds a threshold quantity established by the Authority Having Jurisdiction and is sufficient to pose a threat to the public if released[a]	
Buildings and other structures required to maintain the functionality of other Risk Category IV structures	

According to the Bahamas Building Code recommendations, the basic wind speed shall be referred to in a 50 year period.

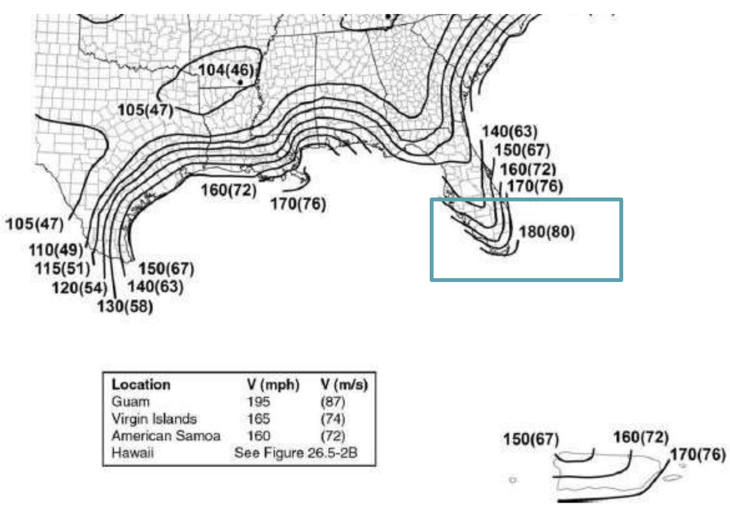
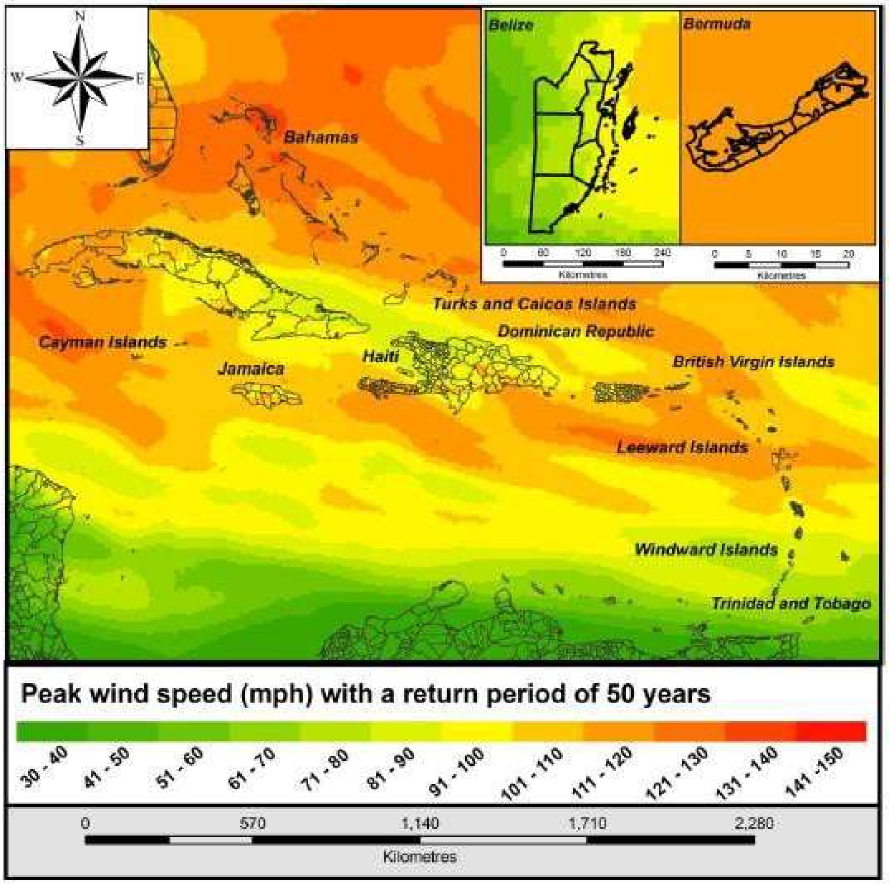


FIGURE 26.5-1B (*Continued*). Basic Wind Speeds for Risk Category II Buildings and Other Structures

Florida can be considered as a similar zone to Bahamas for its proximity and similar wind exposure from the Atlantic Ocean and Caribbean. In the map above, the basic wind speed for Florida is 180 mph = 80.47 m/s.

The Country Risk Profile by CCRIF Caribbean Catastrophe Risk Insurance Facility issued in August 2013 is also consulted. The following map, taken from the previous publications, shows the peak wind speed in the Bahamas with a return period of 50 years. Great Exuma is between 131-140 mph for a peak wind speed. As it is a peak wind speed and the measurement criteria are unknown, such value cannot be used for calculation but it can be taken as reference.



As can be drawn from the previous analysis, there are great similarities between the American Standard values for the Florida area and the design requirements of the client, in which a wind speed of **300km/h is contemplated**.

Taking the similarities of the values, a basic wind speed value of 300 km/h is taken so as to provide an acceptable reliability level for hurricanes in the Bahamas with a return period of 50 years: **V_{ASCE-7}=300km/h=83.33m/s=197mph.**

The basics wind speed value is determined by the American Standard ASCE 7. According to ASCE 7-16, to obtain the wind speed VO, an interval of 3 seconds is used whereas according to Eurocode the interval is of 10 minutes.

Therefore, it is necessary to translate the two intervals to carry out structural verification in accordance with Eurocodes. The translation is carried out using the formula suggested by Solari (G.Solari (1993a). Gust Buffeting. O: Peak wind velocity and equivalent pressure. Journal of Structural Engineering 119 (2), 365-382).

To translate the wind speed using an interval of 3 seconds into a 10 minutes interval, the first speed should be multiplied by 0.676.

The basic wind speed for the calculation of the wind load is:
vb = 300 km/h · 0.676 = **202.8 km/h = 133.17 mph = 56.33 m/s.**

3.5.2.3.1 Wind pressure calculation in bulding

In the table herein under the pressure corresponding to the peak wind speed (peak dynamic pressure) is shown: $qp=ce\cdot qb$

For the following calculations, the project is considered as category ground 0, open sea or coastal zone exposed to open sea.

Pressure corresponding to the average wind reference speed (qp)			
Return period	50	*years*	
Correcting Coeficient T 1			
$v_b(T)$	56.33	*m/s*	
ρ	1.25	*kg/m³*	
$\mathbf{q_p}$	**1.983**	***kN/m²***	*expression (4.8.)*
Exposure factor (C_e)			
Category of land 0. Open sea or coastal zone exposed to open sea			Table 4.1
z	7.8	*m*	
Land factor / Kr	0.156		*expression (4.5.)*
Roughness length /Z0	0.003	*m*	*Table 4.1.*
Minimum height /Zmin	1	*m*	*Table 4.1.*
Roughness factor /Cr(Z)	1.23		*expression (4.4.)*
$\mathbf{C_e}$	**2.84**		$c_{?} = c_{?} \cdot (c_{?} + 7 \cdot k_{?})$
Dynamic Peak pressure (qp)			
qp = Ce · qb	**5.64 kN/m²**		

The effect wind has on the structure is calculated using the wind pressure acting in a perpendicular direction to the exposed exterior surface and is obtained as follows: $we=qp\cdot cpe$
The following sections show wind pressure in vertical walls and hips.
The structure verification has been carried out considering the action of the wind in the two main directions of the building and taking into account the effects of pressure and suction that is generated on the vertical walls and the roof.

Vertical walls

VARTICAL PARAMETERS

Dimenions	b	11.49	*m*	$q_p \cdot c_e$	5.64
	d	7.83	*m*		
	h	7.80	*m*		

Cross winds

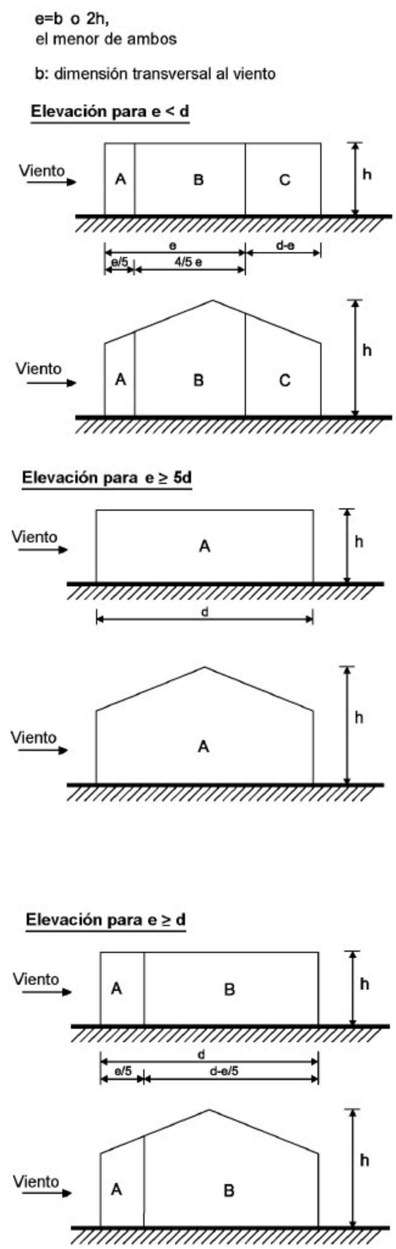
b	11.492	*m*
d	7.834	*m*
h	7.8	*m*
e	11.492	

	h/d	A	B	C	D	E
c_p	1.00	-1.20	-0.80	-0.50	0,.0	-0.50
q_e	**kN/m²**	**-6.77**	**-4.51**	**-2.82**	**4.51**	**-2.81**
					3.83	-2.39

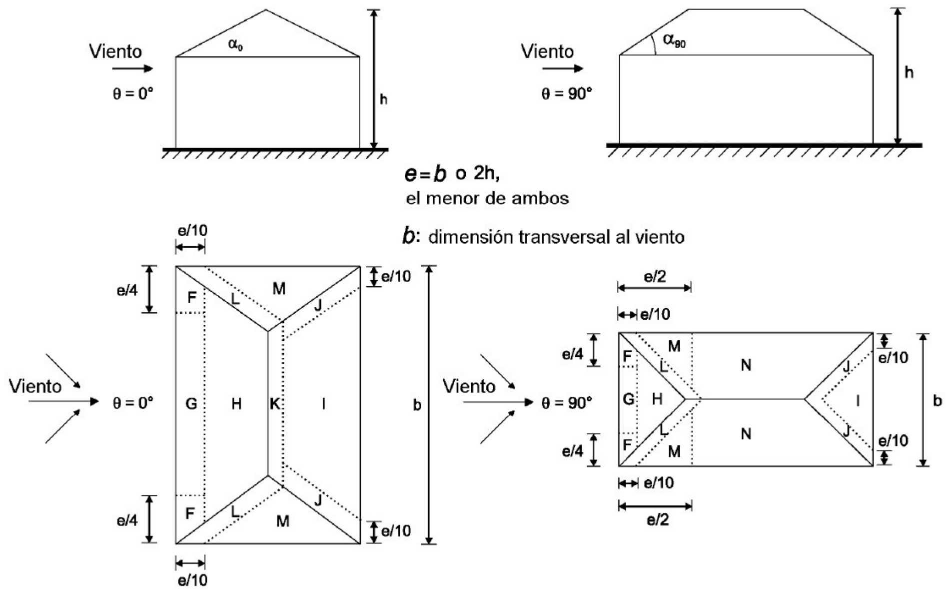
Longitudinal wind

b	7,834	*m*
d	11,492	*m*
h	7,8	*m*
e	7,834	

	h/d	A	B	C	D	E
c_p	0.68	-1.20	-0.80	-0.50	0.76	-0.41
q_e	**kN/m²**	**-6.77**	**-4.51**	**-2.82**	**4.27**	**-2.34**
					3.63	-1.99



Hipped Roof



(a) Dirección del viento θ = 0°

(b) Dirección del viento θ = 90°

Geometry

α Accross	18.4	º
α Long	18.4	º
b	11.49	m
d	7.83	m
h	7.80	m

$q_p \cdot c_e$	5,64

Cross wind

	11.49 *m*			Cross./cos(18.4)	Long./cos(18.4)
d	7.83 *m*	e/10	1.15	1.21	1.21
h	7.80 *m*	e/4	2.87	3.03	3.03
e	11.49 *m*	e/2	5.75	6.06	6.06

	Slope (º)	F	G	H	I	J	K	L	M	N
$c_{p,10}$ Wind 1	18.4	-0.81	-0.73	-0.28	-0.48	-0.93	-1.04	-1.40	-0.65	***
$c_{p,10}$ Wind 2	18.4	0.27	0.31	0.25	-0.48	-0.93	-1.04	-1.40	-0.65	***
q_e Wind 1	**kN/m²**	**-4.57**	**-4.13**	**-1.56**	**-2.69**	**-5.26**	**-5.87**	**-7.90**	**-3.64**	*******
q_e Wind 2	**kN/m²**	**1.51**	**1.77**	**1.38**	**-2.69**	**-5.26**	**-5.87**	**-7.90**	**-3.64**	*******

Longitudinal wind

b	7.83 *m*			Cross./cos(18.4)	Long./cos(18.4)
d	11.49 *m*	e/10	0.78	0.83	0.83
h	7.80 *m*	e/4	1.96	2.06	2.06
e	7.83 *m*	e/2	3.92	4.13	4.13

	Slope (º)	F	G	H	I	J	K	L	M	N
$c_{p,10}$ wind 1	18.4	-0.81	-0.73	-0.28	-0.48	-0.93	***	-1.40	-0.65	-0.28
$c_{p,10}$ Wind 2	18.4	0.27	0.31	0.25	-0.8	-0.93	***	-1.40	-0.65	-0.28
q_e Wind 1	**kN/m²**	**-4.57**	**-4.13**	**-1.56**	**-2.69**	**-5.26**	*******	**-7.90**	**-3.64**	**-1.56**
q_e Wind 2	**kN/m²**	**1.51**	**1.77**	**1.38**	**-2.69**	**-5.26**	*******	**-7.90**	**-3.64**	**-1.56**

3.5.2.3.2 Calculation of wind pressure on annexed elements

Given that the wind has a great weight in the dimensioning of the joints and the structure, a distinction is made between the house and the annexed elements (entrance porch and back porch).

The back porch is adjacent to the house and, therefore, the wind force obstruction factor is Φ = 1. This fact, together with the size of the porch and the high wind overload to which the structure is exposed, implies that the porch may experience a very high suction force.

In accordance with the recommendations for the design of structures exposed to high winds, the structure of the annexed elements is designed independently.

It is expected that no person will use the porch areas as refuge during a hurricane. Nevertheless, as wind pressure on the structure of the annexed elements varies; a criteria for calculating said pressure was agreed with the client. As per their criteria, wind overload in the annexed elements is 60% of the basic wind speed that affects the main building. vb = 56.33 m / s · 60% = 33.80 m / s.

Pressure corresponding to the wind reference average speed (qp)			
Return period	50	*years*	
Correction coef. T	1		
$v_b(T)$	33.80	*m/s*	
ρ	1.25	*kg/m³*	
q_p	**0.714**	***kN/m²***	*expression (4.8.)*
Exposure factor (C_e)			
Land Category	0. Exposed to the ocean		*table 4.1*
z	78.	*m*	
Land factor | k_r	0.156		*expression (4.5.)*
Roughness length | z_0	0.003	*m*	*Table 4.1.*
Minimum height | z_{min}	1	*m*	*Table 4.1.*
Roughness factor | $c_r(z)$	1.23		*expression (4.4.)*
c_e	**2.84**		*ce = cr · (cr + 7 · kr)*
Dynamic peak pressure (q_p)			
qp = Ce · qb	**2.03 kN/m²**		

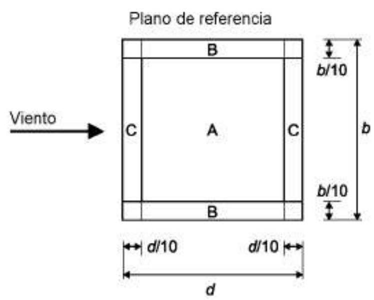
The action caused by the wind in the structure is calculated from the pressure of the wind acting in a direction perpendicular to the exposed outer surface and is obtained through the following expression: we = qp · cpe

The following sections show the wind pressure values for the back porch, the terrace railing and the entrance porch.

3.5.2.3.3 Back Porch

Wind pressure in the back porch is calculated considering a roof angle α = 0° and a value for the obstruction or blocking coefficient of Φ = 1, according to EC 1991-1-4, table 7.6.

Coeficientes de presión neta $c_{p,net}$



Longitudinal Wind					
b	11.59	m	b/10	1.159	m
d	4.17	m	d/10	0.417	m
h	7,80	m			
Cross Wind					
b	4.17	m	b/10	0.417	m
d	11,59	m	d/10	1.159	m
h	7,80	m			

	SI (º)	A	B	C
c_p Wind 1	0	-1.5	-1.8	-2.2
q_e Wind 1	**kN/m²**	**-3.05**	**-3.65**	**-4.47**

3.5.2.3.4 Terrace railing

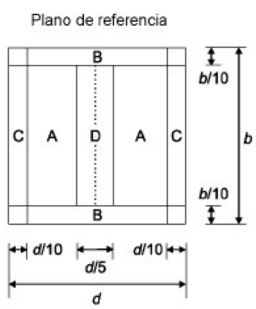
For the calculation of the wind pressure on the terrace railing, an obstruction coefficient or block value of Φ= 0.80 is considered, corresponding to a wall with a 20% of holes.

c_p Wind 1	1.2	
q_e Wind 1	**2.44**	**kN/m²**

3.5.2.3.5 Entrance Porch

Wind pressure in the entrance porch is calculated considering a roof angle α = 17° and a value for the obstruction or blocking coefficient of Φ = 1, according to EC 1991-1-4, table 7.7., roof at two pitches.

Φ



	slope (º)	A	B	C	D
c_p Wind 1	17	-1.6	-2.7	-2.6	-0.6
q_e Wind 1	**kN/m²**	**-3.25**	**-5.48**	**-5.27**	**-1.22**

3.5.2.3.6 3.5.2.3.6 Friction coefficient on annexed elements

For the verification of the structure of the annexed elements exposed to wind in the longitudinal axis of the back porch, the effect of friction on roof and floor is considered, according to EC 1991-1-4, table 7.10, taking the values of the following table for the friction coefficient

	Type of surface	c_{fr}
Floor	Rough	0.02
Roof	Very rough	0.04

3.5.2.3.7 Important design recommendations

Placement of shutters for protection of the windows of the carpentry of the house or Impact Windows.

The presence of openings in the building envelope may imply an increase in the magnitude of the total wind pressure. Therefore, to prevent the debris of a hurricane from impacting and breaking the glass, it is necessary that they be protected by shutters or impact windows.

Light fixing of the flooring boards on the back porch.

In case of hurricane winds it would be desirable that the flooring of the porch be detached from the main structure, this would imply a drastic reduction in the suction wind load.

In case of hurricane winds, it would be desirable that the flooring of the porch be detached from the main structure, this would imply a drastic reduction in the suction wind load