Structural Wind Load Analysis

April 2010

CORDAID

Haiti Transitional Shelter Program

IASC Inter-Agency Standing Committee HAITI SHELTER CLUSTER

UNOPS HAITI OPERATIONS CENTRE

Contents

This report was prepared for client Agency, CORDAID. The analysis was performed and the report prepared by UNOPS and facilitated through the IASC Shelter Cluster, Haiti.

Introduction

With more than 40 agencies planning to implement over 127,000 transitional shelters following the Haiti Earthquake in 2010, one of Shelter Cluster's roles is to coordinate the identification of relevant standards/parameters and to encourage partner agencies to meet those standards/parameters. Due to Haiti's history of vulnerability to hurricanes and tropical storms, it is vital that shelters constructed are able to survive a reasonable degree of high wind.

One of the main obstacles lies in the fact that over 30 different designs are planned, with a range of variables, from structural system, cladding material, and types of fasteners. The highly technical process involved in verifying how resilient transitional individual shelters will be to high wind conditions can be difficult for agencies without specific technical capacity to process.

UNOPS has been requested to provide structural windload analysis to agencies that might need this service. The method is to create a finite element model of the structure and analyze it with a given wind load in order to gauge the performance of the structure. Results may then draw attention to specific areas of design where further engineering measures will improve the performance of the structure in a high wind. It is possible that some small adjustments may be possible in shelter designs that result in significant performance improvements. Additionally, in areas where significant over-design is apparent then these will also be highlighted.

The objective is to help provide an efficient means to a more durable shelter, for beneficiaries in Haiti.

Design Standards and References

The American Society of Civil Engineers (ASCE)/Structural Engineering Institute Standards 7-05 approximate a Category 1 hurricane on the Saffir/Simpson Scale with a gust wind speed of 108mph. Another study has mapped Haiti within a 50year return period as being within this threshold. This benchmark has been set with the understanding that structures must also remain within the framework of a 'Transitional Shelter' style of construction.

The main wind-force resisting system (MWFRS) of the transitional shelter was analyzed according to ASCE 7-05 using exposure C and an Importance factor of 1. Four load cases were tested. Transverse and longitudinal wind loads were calculated from a base wind speed of 108 mph with both positive and negative internal pressure. A 3D finite element model of the transitional shelter was constructed in STAAD 3D and the wind loads were applied to the structure. From the results of this model recommendations were made to improve the overall strength of the structure.

The finite element model analysis outputs data on the forces, and deflection in members, nodes and reaction points. This analysis focused on the wood material (members) and the foundation (reaction points). The screwed and nailed wood connections in the shelter (nodes) were not checked. A thorough analysis of all the connections in the structure is beyond the scope and resources of this rapid analysis. In this regard, implementing the recommendations given by the report does not guarantee that the building will not be damaged in the case of a hurricane.

Recommendations

The analysis assumed that the plastic sheeting used for the shelter walls would have sufficient strength to transfer load to the structure. To ensure plastic sheeting would not rip, or shred in the wind, the plastic sheeting and the fastening of the sheets to the frame need to be able to withstand 0.88 kPa (18.4 psf) of pressure to transfer the load.

The Metal roof and roof fasteners need to be able to withstand 0.78 kPa (16.2 psf) of uplift without failure. Most reputable manufacturers can provide design specifications on request.

The metal roof of the verandah and the roof fasteners need to be able to withstand 1.15 KPa (24 psf) of uplift without failure. The foundation blocks for the verandah need to withstand 5.0 kN (1,100 lbf) of uplift. This could be accomplished by using 0.21 m^3 (7.3 ft^3) at these foundation points.

The maximum uplift load exceeded the foundation weight, therefore foundation modification to be done to withstand the maximum uplift. The foundation blocks in the center of the front and back walls need to withstand 7.0 kN (1,600 lbf) of uplift. This could be accomplished by using 0.30 m^3, 10.7 ft^3) of concrete at these foundation point. The other foundation blocks need to withstand 4.0 kN (900 lbf) of uplift. This could be accomplished by using 0.17 m^3 (6.0 ft^3) at each of these foundation points. Other options are to increase the amount of anchor points by using more foundation footings, or alternative solutions such as earth anchors, etc.

While the screwed and nailed wood connections have not been analyzed, care should be taken to ensure all connections are made with an adequate amount of quality materials. The two critical connections are the truss to the wall top plate, and the top chord of the truss to the purlins. At these points steel straps would be advisable.

The 2x4 at the bottom of the gable back door frame fail in uplift on either side of the foundation connection. This could be fixed by centering the foundation block on the back wall, and making the gable back door frame and the gable closed frame the same length so that the 2-2x4 studs are in the center of the wall running from the center of the truss to top chord of the foundation block.

The dwang blocking between the doors on the front wall fail when a direct wind pressure is applied. A second row of blocking should be added between the doors.

Appendix A: Disclaimer

The UNOPS service assistance is circumscribed to assessment of the shelters, expected performance, weaknesses and others of an assessment nature for improvement purposes. Under such extent and the nature of UNOPS services, the implementing Agency responsible for the construction of the shelter shall bear all risks in regard to shelters constructed. Any claims brought by other parties are the sole responsibility of the implementing agency, neither UNOPS nor agencies leading or otherwise participating in the Shelter/NFI Cluster will be accountable in respect of claims or liabilities arising from the contents of this report.

The IASC Shelter Cluster coordination team facilitates the link between the cluster members and UNOPS. Thus, it bears no responsibility or liability for the report produced by UNOPS or for any subsequent use of this report by partners or third parties.

Appendix B: Summary of design data and analysis

Temporary Shelter Project – Haiti			
Project: CORDAID Transitional Shelter	**Date: 7th May, 2010**		
Design Standard and Codes			
American Society of Civil Engineers/Structural Engineering Institute Standard 7-05 (ASCE 7-05) Caribbean Application Document for the ASCE 7-05 Western Lumber Product User Manual			
General Loads			
Wind	48.3	m/s	108 mph
Material Densities			
Spruce-Pine-Fir (South) Grade 2	5.0	kN/m^3	
Reinforced Concrete	24.0	kN/m^3	
Tools			
STADDPro V8i	Structural Analysis & Design		

Job Information

	Engineer	Checked	Approved
Name:			
Date:	29-Apr-10		

Structure Type	SPACE FRAME

Number of Nodes	128	Highest Node	130
Number of Elements	243	Highest Beam	247

Number of Basic Load Cases	5
Number of Combination Load Cases	4

Included in this printout are data for:

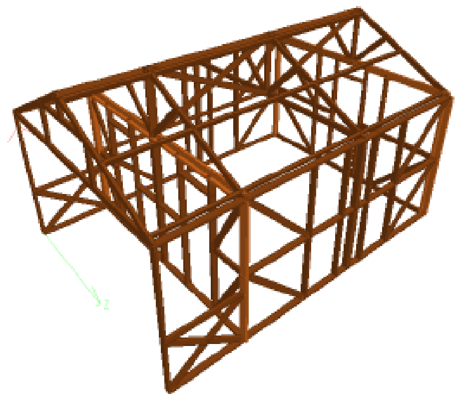
All	The Whole Structure

Included in this printout are results for load cases:

Type	L/C	Name
Primary	1	DEAD
Primary	3	W1
Primary	4	W2
Primary	5	W3
Primary	6	W4
Combination	8	1.2D + 1.6W1
Combination	9	1.2D + 1.6W2
Combination	10	1.2D + 1.6W3
Combination	11	1.2D + 1.6W4

Supports

Node	X (kN/mm)	Y (kN/mm)	Z (kN/mm)	rX (kN˙m/deg)	rY (kN˙m/deg)	rZ (kN˙m/deg)
1	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
3	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
4	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
6	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
7	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
9	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
10	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
26	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed



3D Rendered View (Input data was modified after picture taken)

Materials

Mat	Name	E (kN/mm^2)	v	Density (kg/m^3)	α (1/°K)
1	STEEL	205.000	0.300	7.83E+3	12E -6
2	TIMBER	8.500	0.150	509.858	12E-12
3	SPF_SELSTR_4X4_B	8.500	0.150	509.858	12E-12
4	STAINLESSSTEEL	197.930	0.300	7.83E+3	18E -6
5	SPF_SELSTR_2X4_B	8.500	0.150	509.858	12E-12
6	ALUMINUM	68.948	0.330	2.71E+3	23E -6
7	MATERIAL1	0.000	0.450	509.858	0.000
8	CONCRETE	21.718	0.170	2.4E+3	10E -6

Basic Load Cases

Number	Name
1	DEAD
3	W1
4	W2
5	W3
6	W4

Combination Load Cases

Comb.	Combination L/C Name	Primary	Primary L/C Name	Factor
8	1.2D + 1.6W1	1	DEAD	1.20
		3	W1	1.60
9	1.2D + 1.6W2	4	W2	1.60
		1	DEAD	1.20
10	1.2D + 1.6W3	1	DEAD	1.20
		5	W3	1.60
11	1.2D + 1.6W4	6	W4	1.60
		1	DEAD	1.20

Node Displacement Summary

	Node	L/C	X (mm)	Y (mm)	Z (mm)	Resultant (mm)	rX (rad)	rY (rad)	rZ (rad)
Max X	35	10:1.2D + 1.6W	**21.837**	-0.070	0.210	21.838	0.000	0.000	-0.000
Min X	94	9:1.2D + 1.6W2	**-9.567**	-1.931	-8.452	12.911	-0.007	0.006	0.000
Max Y	19	8:1.2D + 1.6W1	-1.003	**5.258**	-0.184	5.356	-0.009	-0.002	0.001
Min Y	22	8:1.2D + 1.6W1	-2.527	**-5.440**	-0.231	6.003	-0.009	0.003	0.005
Max Z	71	11:1.2D + 1.6W	2.829	-3.588	**8.735**	9.858	0.000	-0.000	-0.001
Min Z	116	8:1.2D + 1.6W1	-1.643	-2.285	**-46.766**	46.851	0.005	-0.003	0.000
Max rX	39	11:1.2D + 1.6W	5.471	2.705	-2.295	6.520	**0.006**	-0.001	0.001
Min rX	73	8:1.2D + 1.6W1	-1.456	-0.032	-24.009	24.053	**-0.025**	-0.003	0.001
Max rY	25	9:1.2D + 1.6W2	16.319	-0.748	-0.024	16.336	0.002	**0.019**	-0.004
Min rY	39	8:1.2D + 1.6W1	2.653	1.109	-31.689	31.819	-0.010	**-0.022**	0.000
Max rZ	49	9:1.2D + 1.6W2	1.685	-1.223	-3.184	3.804	0.000	0.001	**0.016**
Min rZ	92	10:1.2D + 1.6W	15.028	-0.037	0.072	15.029	0.000	0.000	**-0.013**
Max Rst	116	8:1.2D + 1.6W1	-1.643	-2.285	-46.766	**46.851**	0.005	-0.003	0.000

Beam Force Detail Summary

Sign convention as diagrams:- positive above line, negative below line except Fx where positive is compression. Distance d is given from bea end A.

				Axial	Shear		Torsion	Bending	
	Beam	L/C	d (m)	Fx (kN)	Fy (kN)	Fz (kN)	Mx (kNm)	My (kNm)	Mz (kNm)
Max Fx	31	8:1.2D + 1.6W1	0.000	**9.064**	-0.227	-0.925	0.081	0.673	-0.066
Min Fx	166	8:1.2D + 1.6W1	0.900	**-7.975**	0.365	0.367	0.083	0.203	0.029
Max Fy	132	10:1.2D + 1.6W	0.000	-4.110	**3.749**	2.082	0.138	-0.503	0.730
Min Fy	26	8:1.2D + 1.6W1	0.450	-3.426	**-3.226**	-0.501	-0.092	-0.093	0.607
Max Fz	29	8:1.2D + 1.6W1	0.000	1.811	-0.238	**3.073**	0.060	-2.654	-0.184
Min Fz	140	10:1.2D + 1.6W	0.000	-4.178	1.160	**-4.040**	-0.179	0.748	0.299
Max Mx	3	8:1.2D + 1.6W1	0.000	-0.158	1.721	-0.053	**0.733**	0.019	0.528
Min Mx	15	8:1.2D + 1.6W1	0.000	-1.193	-1.685	-0.069	**-0.840**	-0.019	0.096
Max My	72	8:1.2D + 1.6W1	0.000	-0.153	1.676	-3.995	-0.089	**2.340**	0.487
Min My	29	8:1.2D + 1.6W1	0.000	1.811	-0.238	3.073	0.060	**-2.654**	-0.184

Beam Force Detail Summary Cont...

	Beam	L/C	d	Axial Fx	Shear Fy	Shear Fz	Torsion Mx	Bending My	Bending Mz
			(m)	(kN)	(kN)	(kN)	(kNm)	(kNm)	(kNm)
Max Mz	35	10:1.2D + 1.6W	0.000	2.106	2.787	-0.002	-0.001	0.005	**1.917**
Min Mz	35	9:1.2D + 1.6W2	0.000	-6.933	-1.919	1.073	0.022	-0.954	**-1.005**

Reaction Summary

	Node	L/C	Horizontal FX	Vertical FY	Horizontal FZ	Moment MX	Moment MY	Moment MZ
			(kN)	(kN)	(kN)	(kNm)	(kNm)	(kNm)
Max FX	10	9:1.2D + 1.6W2	**3.574**	-7.016	7.478	0.819	0.124	-1.326
Min FX	10	10:1.2D + 1.6W	**-4.961**	2.231	0.030	-0.010	-0.006	2.472
Max FY	6	8:1.2D + 1.6W1	-0.799	**8.587**	2.186	1.024	0.148	0.377
Min FY	26	8:1.2D + 1.6W1	-2.065	**-7.070**	4.919	-1.024	-0.214	0.578
Max FZ	10	8:1.2D + 1.6W1	2.278	0.291	**11.164**	1.484	0.146	-0.810
Min FZ	3	11:1.2D + 1.6W	-0.692	-3.954	**-4.028**	-1.408	-0.097	0.300
Max MX	3	8:1.2D + 1.6W1	1.273	1.801	6.479	**4.227**	0.133	-0.126
Min MX	3	11:1.2D + 1.6W	-0.692	-3.954	-4.028	**-1.408**	-0.097	0.300
Max MY	4	9:1.2D + 1.6W2	-0.735	-2.408	1.655	0.539	**0.542**	0.096
Min MY	26	9:1.2D + 1.6W2	-3.175	-5.295	3.217	-0.531	**-0.297**	0.870
Max MZ	10	10:1.2D + 1.6W	-4.961	2.231	0.030	-0.010	-0.006	**2.472**
Min MZ	10	9:1.2D + 1.6W2	3.574	-7.016	7.478	0.819	0.124	**-1.326**

Appendix C: Saffir / Simpson Hurricane Scale

TABLE C6-1 SAFFIR/SIMPSON HURRICANE SCALE

Hurricane Category	Sustained Wind Speed[a]		Central Barometric Pressure		Storm Surge		Damage Potential
	mph	(m/s)	inches of mercury	millibars	ft	(m)	
1	74–95	33.1–42.5	>28.91	> 979	4 to 5	0.8 to 1.2	Minimal
2	96–110	42.6–49.2	28.50–28.91	965–979	6 to 8	1.3 to 1.8	Moderate
3	111–130	49.3–58.1	27.91–28.47	945–964	9 to 12	1.9 to 2.7	Extensive
4	131–155	58.2–69.3	27.17–27.88	920–944	13 to 18	2.8 to 3.7	Extreme
5	>155	> 69.3	<27.17	<920	>18	>3.7	Catastrophic

1000 millibars = 100 kPa
[a] 1-min average wind speed at 33 ft (10 m) above open water

TABLE C6-2 APPROXIMATE RELATIONSHIP BETWEEN WIND SPEEDS IN ASCE 7 AND SAFFIR/SIMPSON HURRICANE SCALE

Saffir/Simpson Hurricane Category	Sustained Wind Speed Over Water[a]		Gust Wind Speed Over Water[b]		Gust Wind Speed Over Land[c]	
	mph	(m/s)	mph	(m/s)	mph	(m/s)
1	74–95	33.1–42.5	91–116	40.7–51.9	82–108	36.7–48.3
2	96–110	42.6–49.2	117–140	52.0–62.6	109–130	48.4–58.1
3	111–130	49.3–58.1	141–165	62.7–73.8	131–156	58.2–69.7
4	131–155	58.2–69.3	166–195	73.9–87.2	157–191	69.8–85.4
5	> 155	> 69.3	> 195	> 87.2	> 191	> 85.4

[a] 1-minute average wind speed at 33 ft (10 m) above open water
[b] 3-second gust wind speed at 33 ft (10 m) above open water
[c] 3-second gust wind speed at 33 ft (10 m) above open ground in Exposure Category C. This column has the same basis (averaging time, height, and exposure) as the basic wind speed from Fig. 6-1.

From: “Commentary to American Society of Civil Engineers/Structural Engineering Institute Standard 7-05” page 314.

Appendix D: Peak gust wind for the Island of Hispaniola

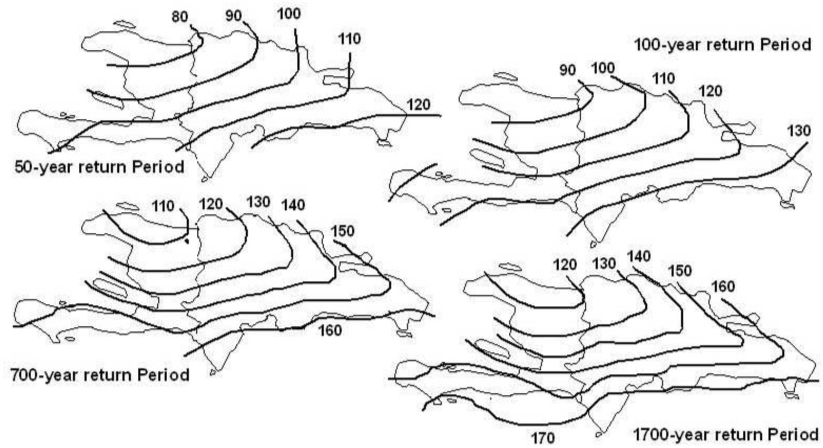
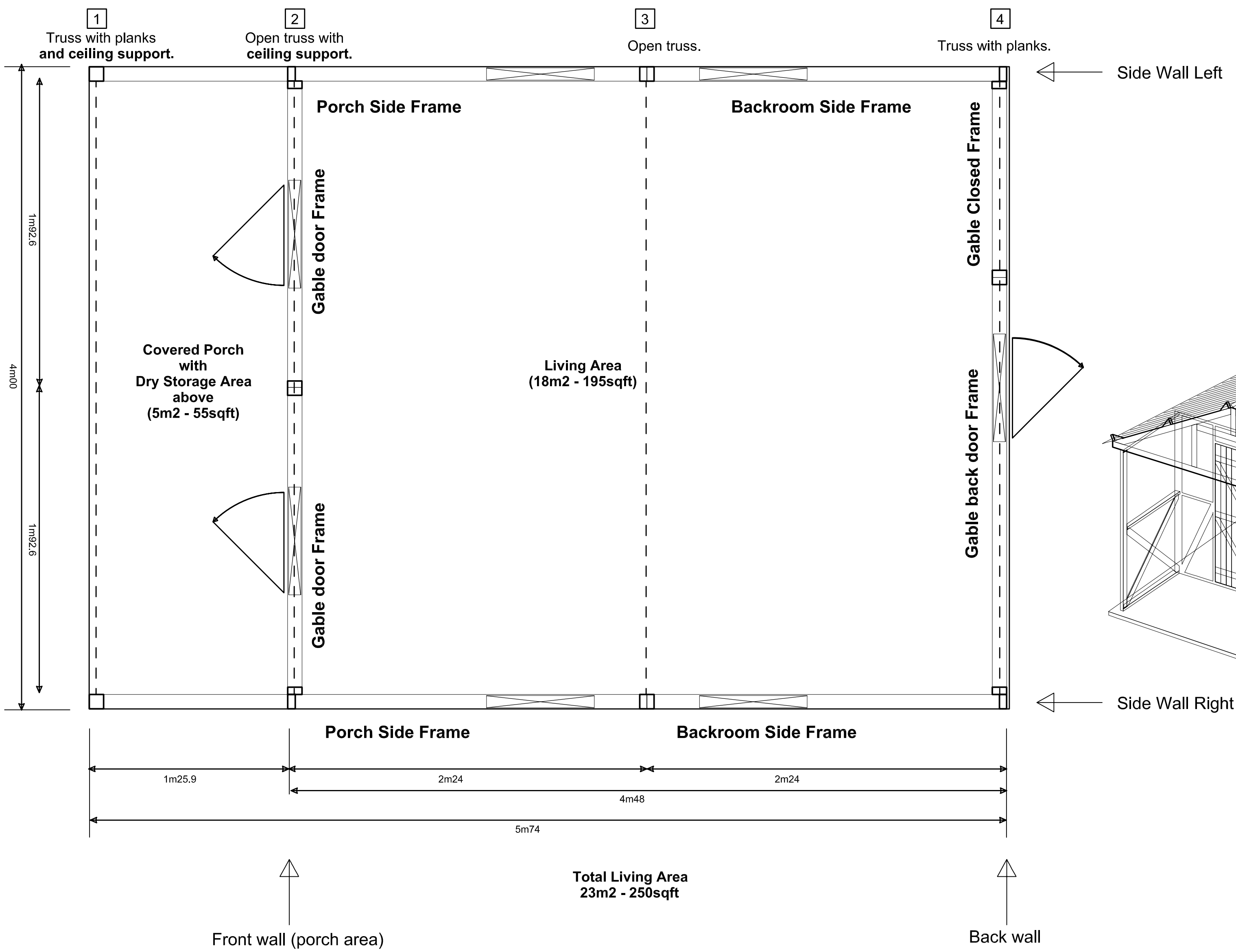
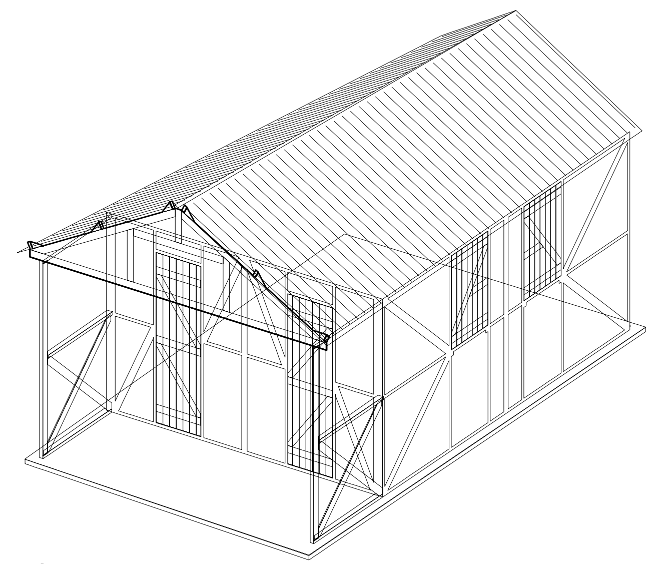


Figure 3-8. **Contours of period peak gust wind speeds (mph) at a height of 10m in flat open terrain for various return periods for the island of Hispaniola(ASCE 7 Exposure C).**

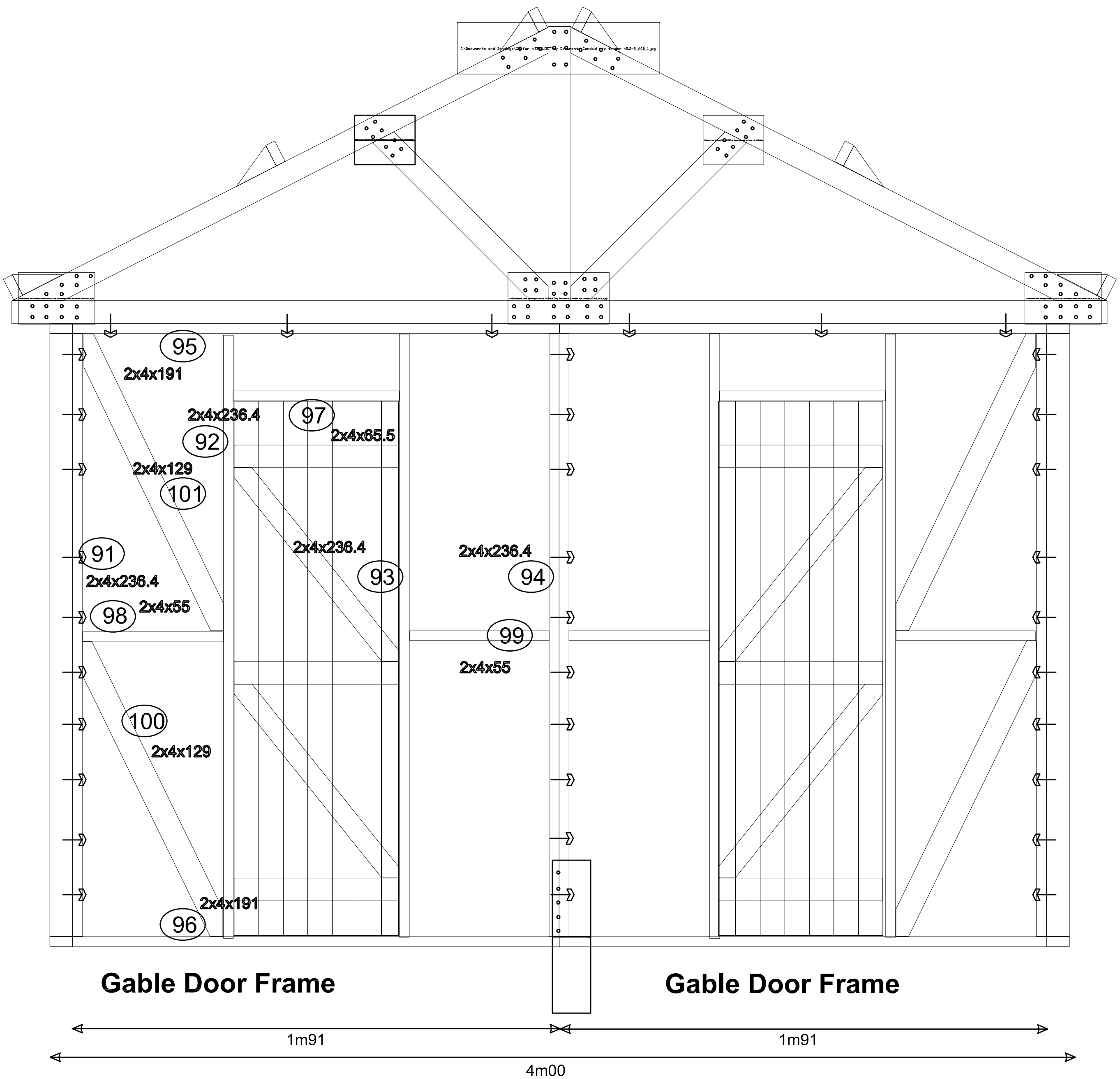
From: "Caribbean Application Document for the ASCE 7-05" November 2008.

Appendix E: CORDAID Transitional Shelter Plans

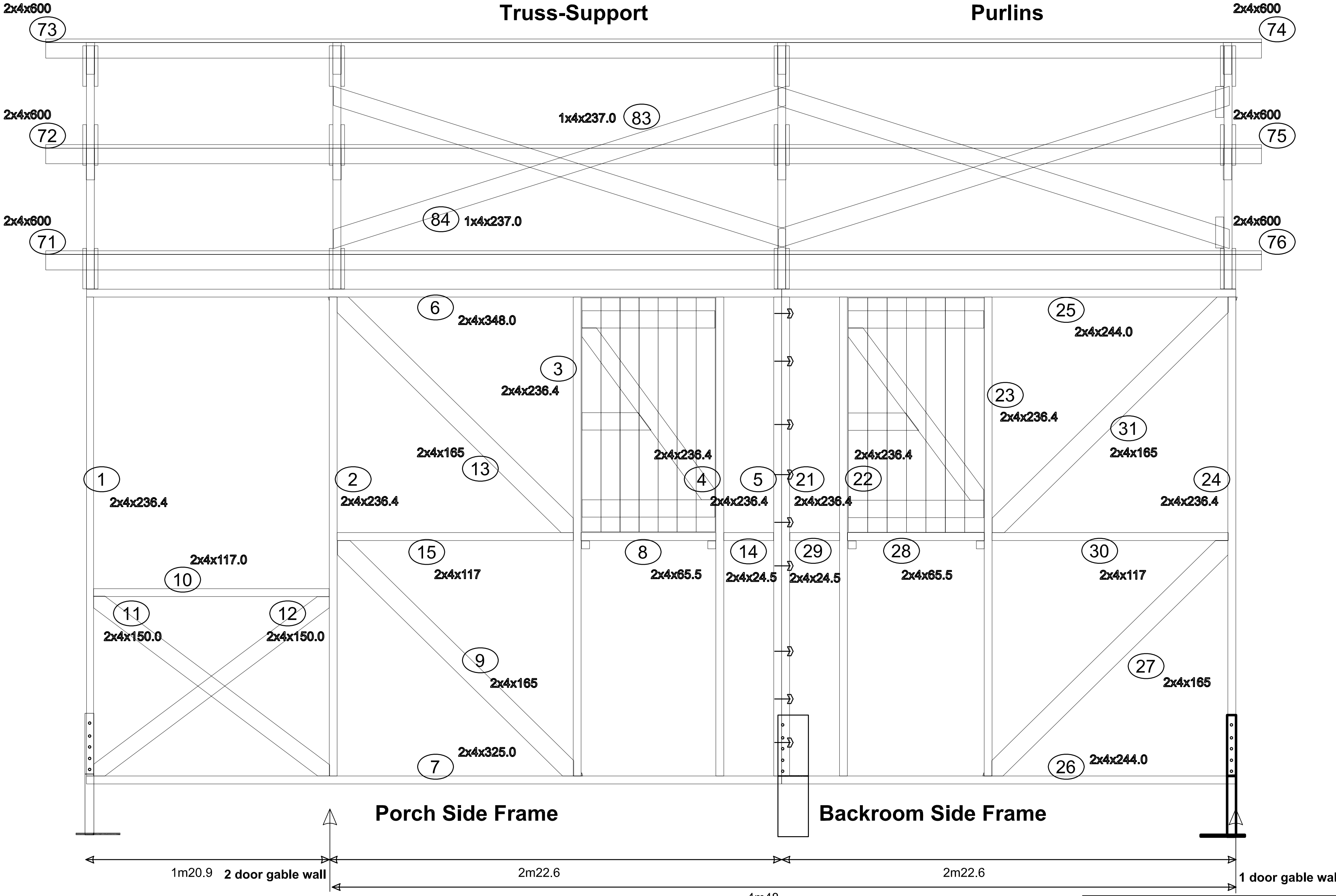




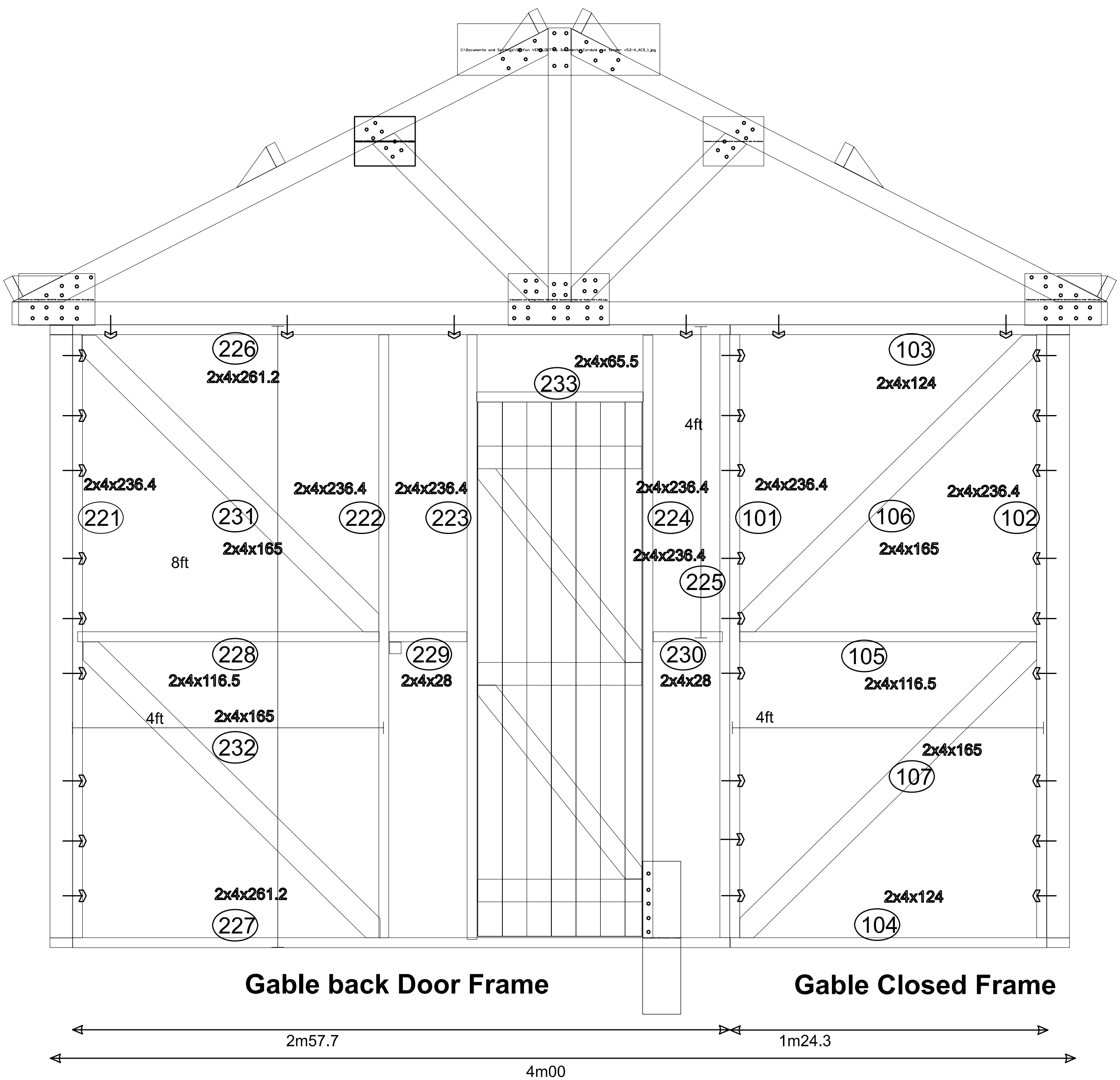
CORDAID NEW TENDER v5.2
3-door 4-shutter 18m2 +5m2 porch
HAITI, April 10, 2010 — 1



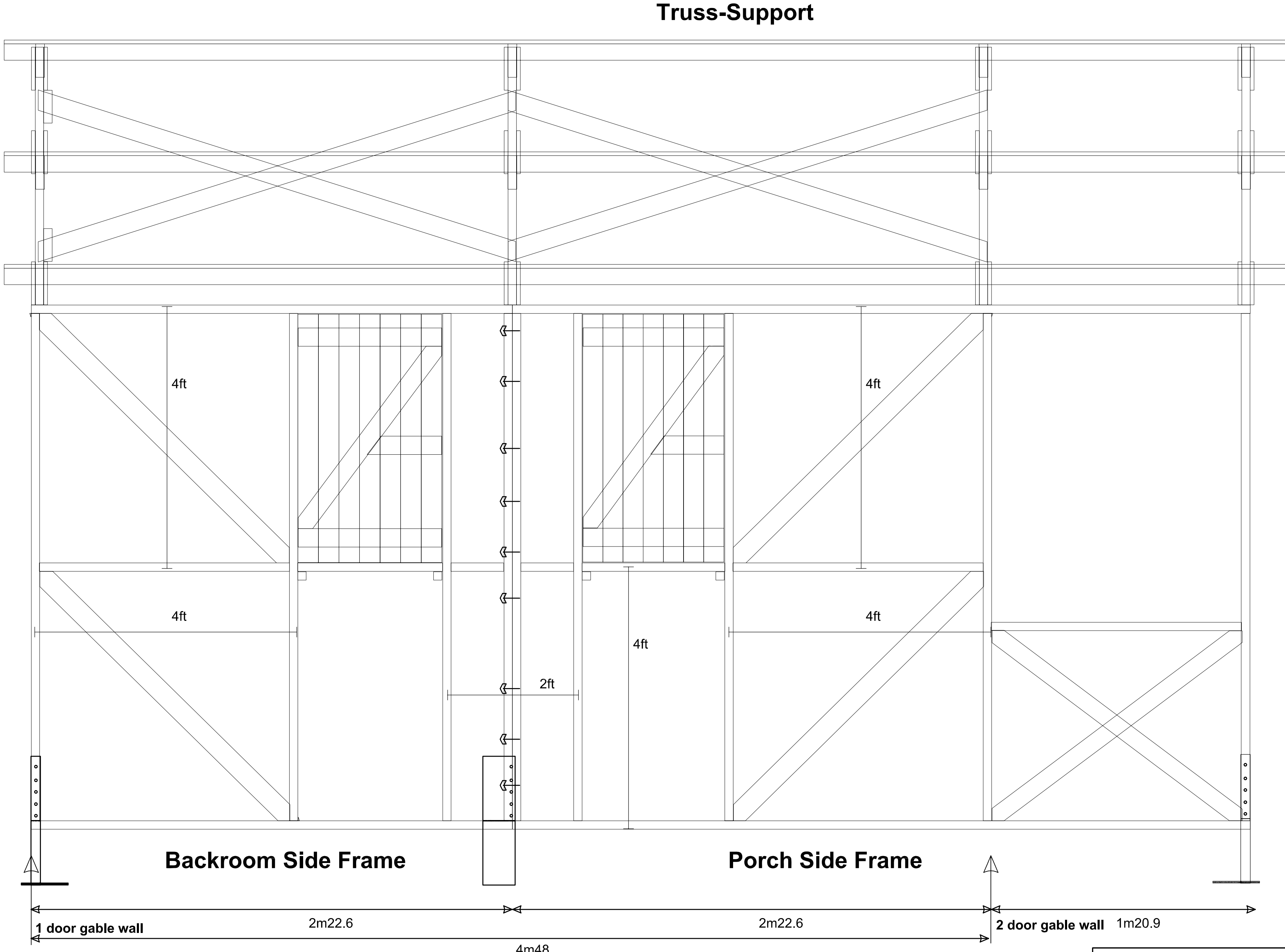
CORDAID NEW TENDER v5.2
Front wall (porch area)
HAITI, April 10, 2010 — 2



CORDAID NEW TENDER v5.2	
Side Wall Right	
HAITI, April 10, 2010	3



CORDAID NEW TENDER v5.2	
Back wall	
HAITI, April 10, 2010	4



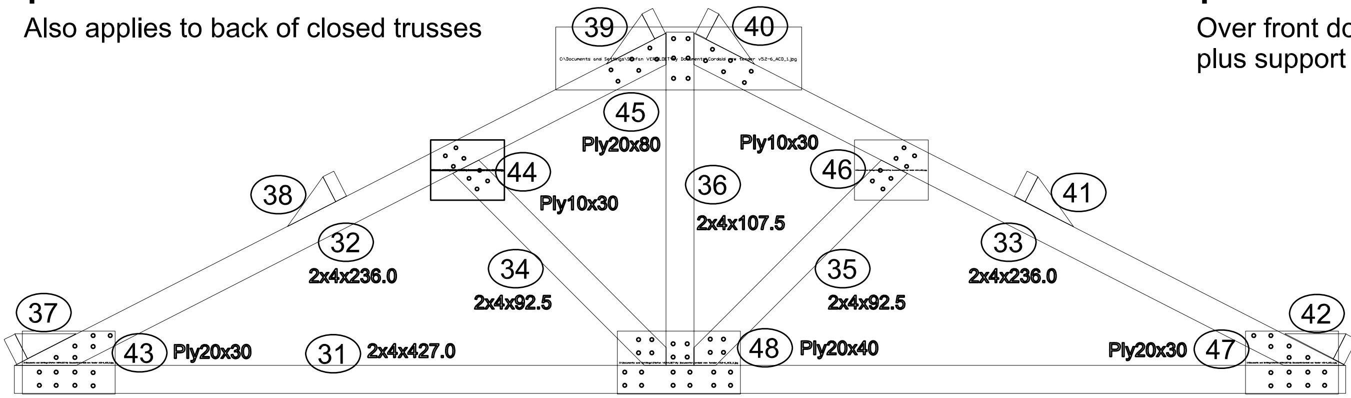
CORDAID NEW TENDER v5.2
Side Wall Left
HAITI, April 10, 2010 | 5

3 Open Center Trusses

Also applies to back of closed trusses

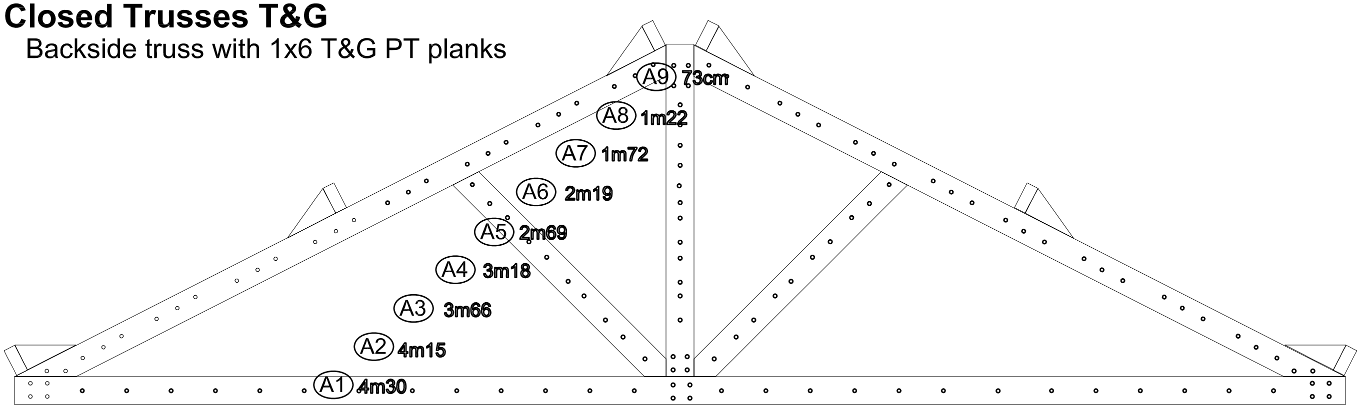
Open Center Trusses

Over front door is the same
plus support for ceiling beams.

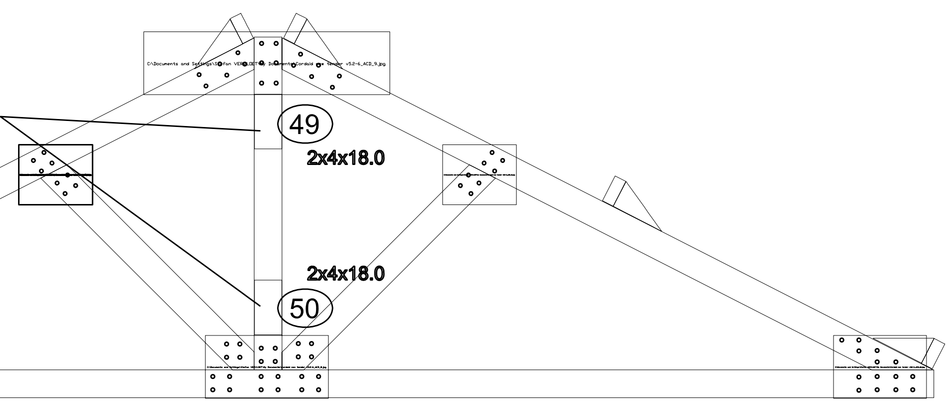


4 Closed Trusses T&G

Backside truss with 1x6 T&G PT planks



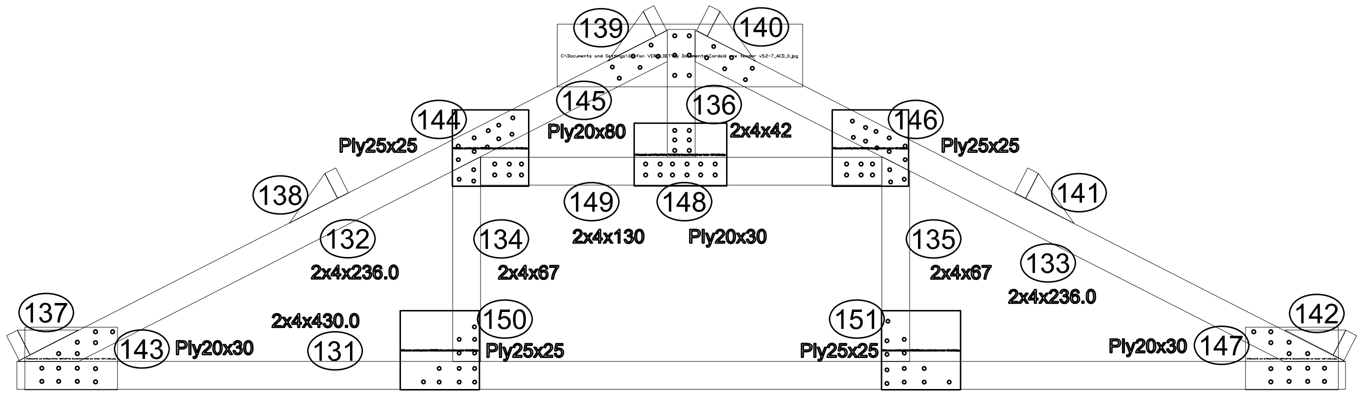
These 2 blocks are provided to allow the cross-support for the back truss to be nailed further away from the end of the plank.



SV/-MAXIMA S.A.

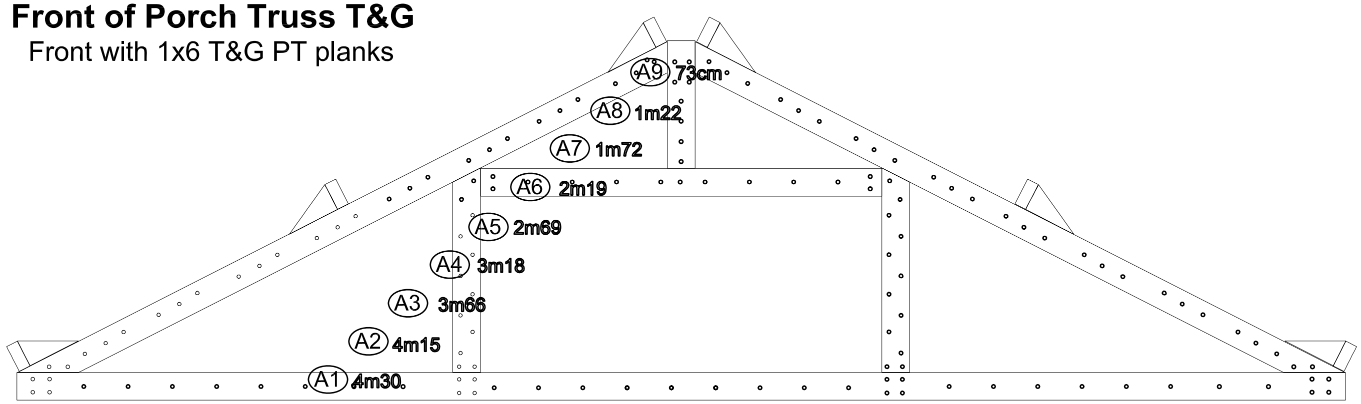
CORDAID NEW TENDER v5.2	
Center and closed Trusses	
HAITI, April 10, 2010	6

1 Back of Porch Trusses



1 Front of Porch Truss T&G

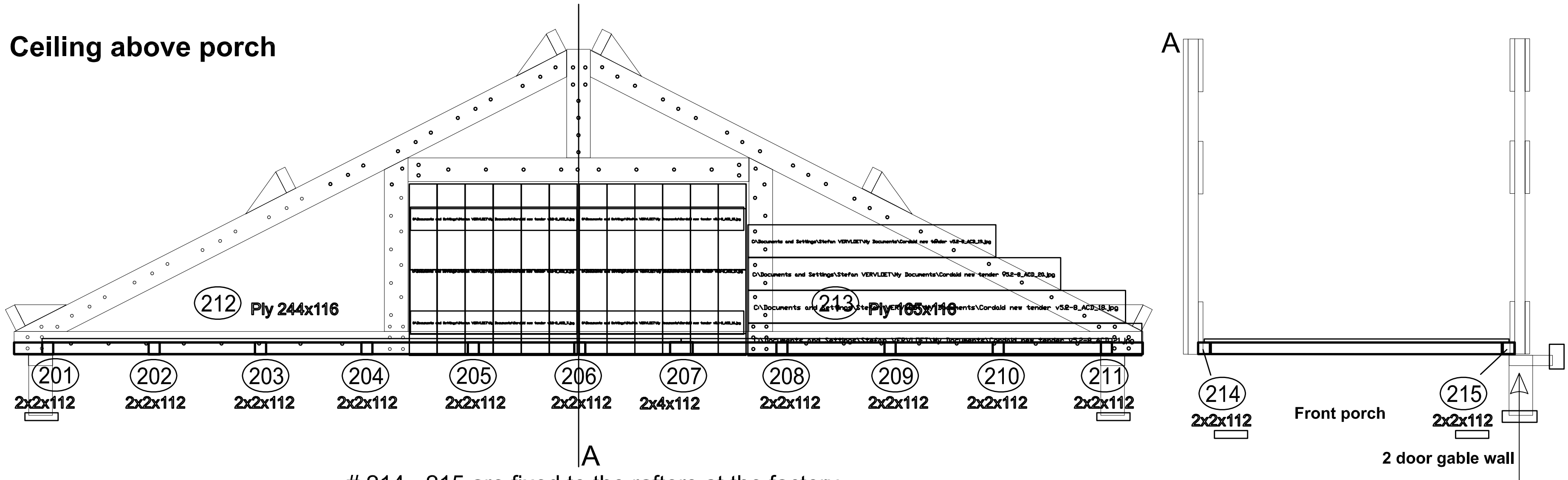
Front with 1x6 T&G PT planks



SV/-MAXIMA S.A.

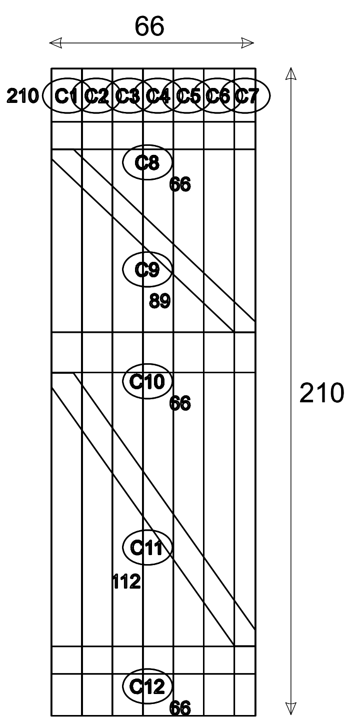
CORDAID NEW TENDER v5.2
Front Truss with Door
HAITI, April 10, 2010 — 7

Ceiling above porch

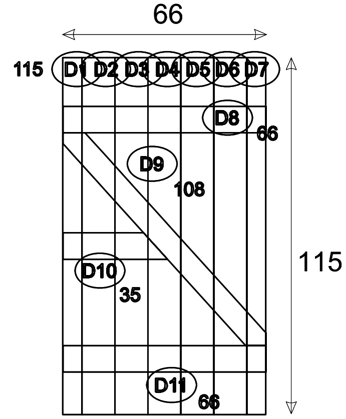


214 - 215 are fixed to the rafters at the factory.
201- 211 are fixed to the plywood at the factory.

Door

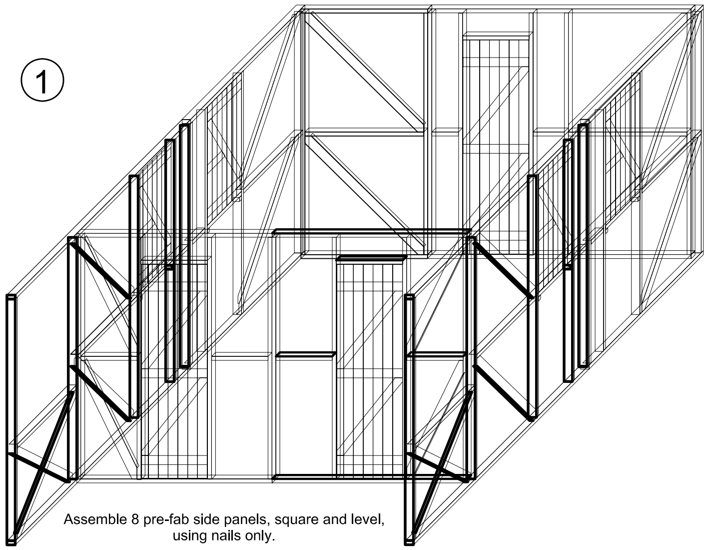


Shutter



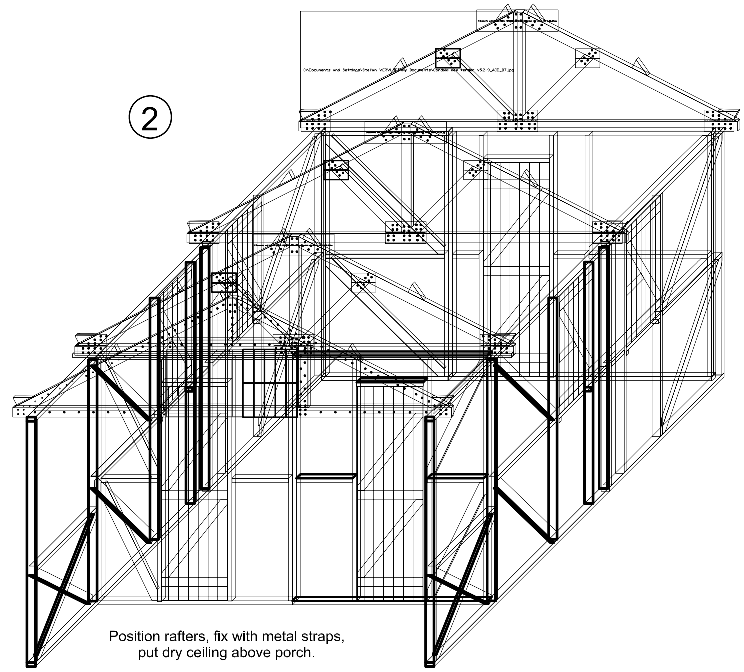
CORDAID NEW TENDER v5.2
Ceiling, Doors and Shutters
HAITI, April 10, 2010

1



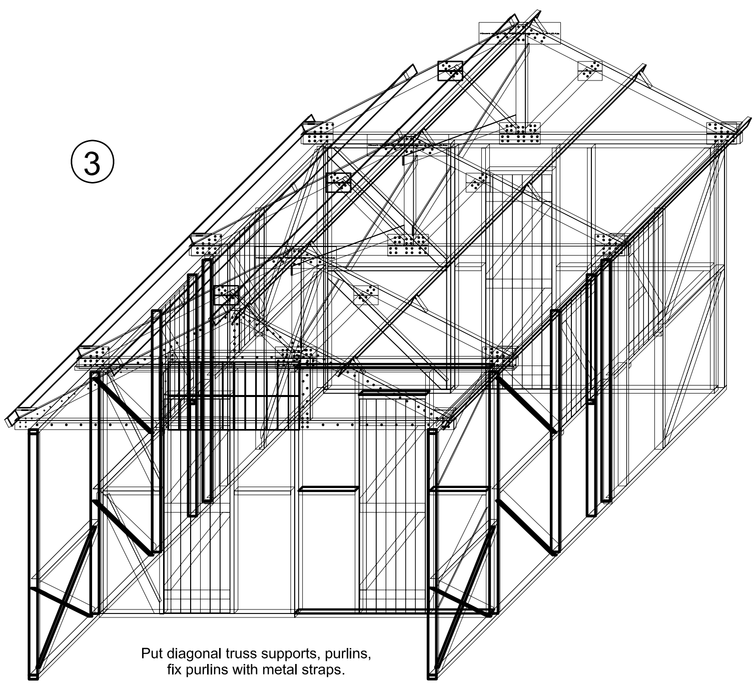
Assemble 8 pre-fab side panels, square and level, using nails only.

2



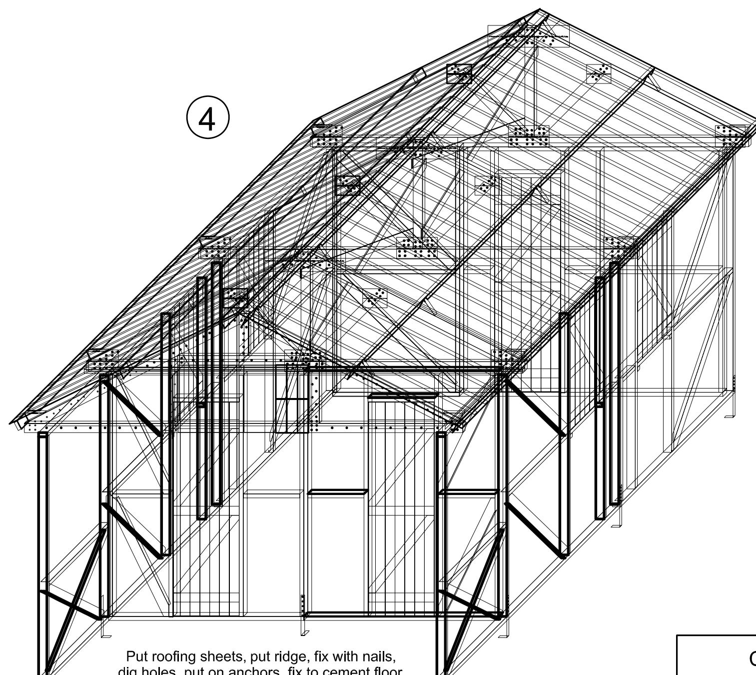
Position rafters, fix with metal straps, put dry ceiling above porch.

3



Put diagonal truss supports, purlins, fix purlins with metal straps.

4



Put roofing sheets, put ridge, fix with nails, dig holes, put on anchors, fix to cement floor.

CORDAID NEW TENDER v5.2	
3-door 4-shutter 18m2 +5m2 porch	
HAITI, April 10, 2010	9

HARDWARE

Hardware should be hot dip galvanized meeting ASTA-A153/A653

HARDWARE
Screws and nails
Screws Zinc 3.5" Gage 10 (majorD 0,190 inches/equivalent 5mm)
Screws Zinc 3" Gage 8 (majorD 0,1640 inches/equivqlent 4mm)
Scews Zinc 1.5" Gage 8 (majorD 0,1640 inches/equvivalent 4mm)
Scews Zinc 1.25" Gage 8 (majorD 0,1640 inches/ equivalent 4mm)
Nails 2" zinc 6D common nail HDG
Nails 3" zinc 10D common nail HDG
Nails 4" zinc 20D common nail HDG
Note: all mentioned quantities are pieces.

IRONMONGERY
T- Hinges shutters 6" zinc
Barel bolt 4" zinc

Fixing materials
Corner Anchors 3ft (3/32 1.5x1.5") supplied on 6mtr lengths
Center Anchors 3ft (3/32 x 1.5") supplied on 6 mtr lengths
Steel strap 3/4" to fix trusses, 2ft

ROOFING SHEETS AND RIDGE

General specifications

Pre-painted Aluzinc, corrugated / profiled, length per sheet 9 Feet by 42" wide, 26 gauge / 0.45mm, color off white or alternative light colors, color samples to be supplied with your Bid

Ridge Cover 26 gauge / 0,45 mm and to be used with the before mentioned pre-painted Aluzinc plates, factory sprayed, color off white or alternative light colors, color sample to be supplied with your Bid

Nails/screws/bolts for the above mentioned pre-pained Aluzinc currugated/profiled sheets, length and diameter of the nails should be sufficient for a durable connection to 2 x 4 inch timber beams

TIMBER

General specifications:		
	Southern Yellow Pine, construction grade, pressure treated. Timber must be termite resistant follow ACQ (Alkaline Copper Quat) method of treatment.	
	Moisture content as per Building Code Requirements: 19% or less	
	Drying	Kiln dried
	Grade (#) 1	Pine with relatively few knots and blemishes
	Grade (#) 2	Pine which has some knots and other abnormalities

Sub-lot 1 A 400 houses

Description	Size	Quantity	BFT	
Pressure Treated Pine #1 common or better	2x4x20	4,000	57,600	
Pressure Treated Pine #1 common or better	2x4x12	6,800	58,752	
Pressure Treated Pine #1 common or better	2x4x8	26,000	149,760	
Pressure Treated Pine #2 common or better	1x6x16	11,600	100,224	
Pressure Treated Pine #2 common or better	1x4x16	4,000	23,040	
Pressure Treated Exterior grade CD plywood	4x8 x 15/32"	1,200	1,200	sheets