ARUP

SHELTER/NFI SECTOR

ARUP TECHNICAL GUIDANCE NOTE 01:

WIND LOADING FOR THE DESIGN OF UPGRADED EMERGENCY SHELTERS, MID-TERM SHELTERS AND COMMUNITY STRUCTURES

ROHINGYA REFUGEE CAMPS
COX'S BAZAR REGION

Version 1.0: Issued 24/08/2018

WIND LOADING FOR THE DESIGN OF UPGRADED EMERGENCY SHELTERS, MID-TERM SHELTERS AND COMMUNITY STRUCTURES

The Cox's Bazar Shelter & NFI Sector have identified a need to minimise the risk of loss of life and damage to shelter and buildings in strong winds, recognising that it is not possible to design lightweight emergency shelters to withstand the wind loads in the Bangladesh National Code which are applicable to permanent structures, typically in masonry or concrete.

This Technical Guidance Note provides the following:

1. Key messages for designing lightweight bamboo shelters for strong winds.
2. A simplified procedure for calculating wind loads.

These can be applied to the design of upgraded emergency shelters, mid-term shelters and community structures.

The Bangladesh code provides wind loads for permanent structures based on large cyclones with a statistical return period of at least 50 years. This is appropriate for longer term structures and community buildings that may be used as cyclone shelters, but a reduced design load based on more common seasonal winds and smaller cyclones with an approximate 20 year return period is considered more appropriate and more practical to design for in the case of upgraded emergency and mid-term shelters.

Figure 1: View of Kutupalong Balukhali Expansion refugee camp, Cox's Bazar, January 2018, dry season

SECTION 1: CONTEXT AND RISKS

The Northern Indian Ocean, and in particular the Bay of Bengal, experiences some of the most damaging tropical cyclones in the world. The 1991 Bangladesh cyclone for example struck Chittagong (150km from Cox's Bazar) with winds of around 250km/h, killing at least 138,000 and leaving 10 million homeless[1]. In Kutubdia, an island 40km from Cox's Bazar, 20,000 people (nearly 20% of the local population) were killed[2].

In Cox's Bazar, hundreds of thousands of refugees are living in simple emergency shelters. The refugee camps are particularly vulnerable due to a combination of open relatively flat terrain, close proximity to the sea, deforestation of protective vegetation, and lightweight simply constructed shelters. Figure 1 illustrates a typical view of the exposure in the camp, and Figure 2 illustrates typical self-built bamboo shelters without technical input.

Figure 2: Typical self-built bamboo shelters without technical input - the structural frame is light and not robustly connected, and the plastic sheeting is only loosely connected back to the frame.

SECTION 2:
KEY MESSAGES FOR DESIGNING LIGHTWEIGHT BAMBOO EMERGENCY SHELTERS FOR STRONG WINDS

The Shelter & NFI Sector and various NGOs working on the ground have already produced good guidance on constructing shelters. Rather than replicate this, 7 of the main "key" messages are provided here, to serve as rules of thumb for reducing lightweight bamboo emergency shelter vulnerability in strong winds. It is recommended that these form the starting point when designing temporary or transitional shelter.

1. Situate shelter away from exposed tops of hills.
2. Construct a strong and robust structure with bracing in the walls and roof. For example, if using local bamboo, use borak bamboo at close centres (~1m column centres), vertical rope bracing to all walls and a rope roof bracing diaphragm. Bracing walls should be every 3-4m (9'-12') inside the structure.
3. Bury columns deep >600mm (2') into ground, with pegs placed through the columns inside the ground to help secure them to the soil.
4. Optimum roof pitch is 30-40 degrees (and ideally hipped) (Figure 3).
5. Allow ventilation to all four sides to reduce wind forces.
6. Minimise overhangs - suggest a maximum of 0.3m (1').
7. Consider protection against debris impact to walls and roof by e.g. using sandbags or mud render on or against the walls.

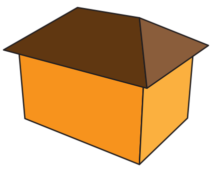

Figure 3: Hipped roof

Figure 4: 7 key messages for designing shelters for strong winds

The recommendations above will help to reduce the impact of strong winds on individual shelters. The location of shelters should also consider the possibility of flooding and landslides.
In cyclonic events, airborne debris poses a significant additional risk as it can easily pierce plastic sheeting, wooden or metal panel walls, and flying objects such as bamboo poles could result in severe injury or fatalities (Figure 5 and 6). All building elements must be secured properly, and where possible temporary shelter should be provided in buildings with solid masonry or concrete walls.

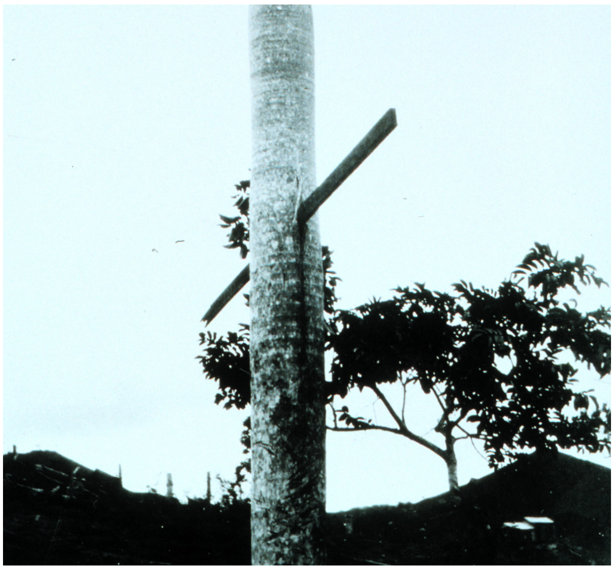

Figure 5: Hurricane wind damage in Puerto Rico[3]

Figure 6: Hurricane wind damage in Florida[4]

SECTION 3: SIMPLIFIED PROCEDURE FOR CALCULATING WIND LOADS

INTRODUCTION TO WIND PRESSURES

Wind blowing over, around and through buildings leads to pressure on the walls and roof that must be resisted by the structure. Figure 7 shows the wind pressure over the walls and roof of a building is not uniform. Wind pressures need to be calculated based on the basic wind speed, orientation, location and building configuration.

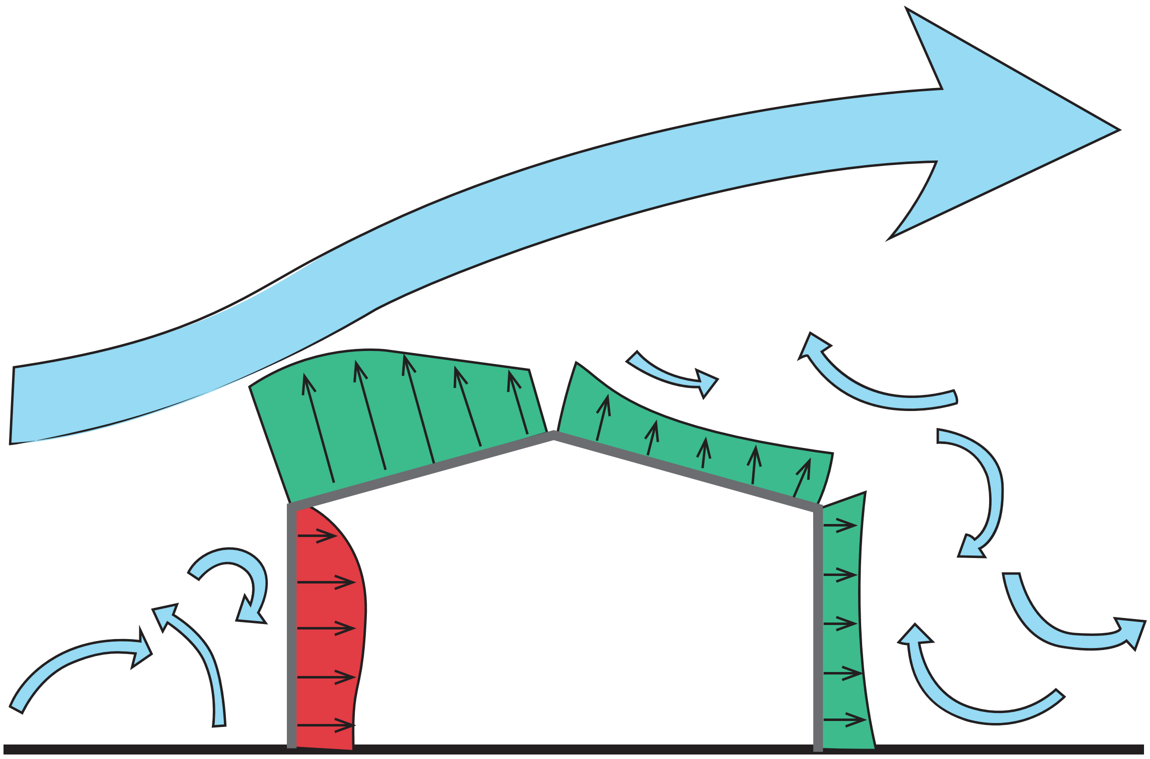

Figure 7: Wind blowing over building leads to positive/inward (red) and negative/outward (green) pressure on walls and roof. The most critical areas are the one behind the windward leading edge and the windward edge of the lateral walls (not shown)

BANGLADESH CODE AND ACTUAL WIND SPEEDS IN REGION

Arup have reviewed the wind anemometer data in the region. The wind speed proposed by the Bangladesh code is reasonable for a cyclonic storm with a return period of at least 50 years.

The wind speed in the Bangladesh code implies dynamic wind pressures that are applicable for permanent buildings but not for the type of emergency structures being built in Cox's Bazar camps. It is nevertheless still important to consider wind load in the design of shelters, and the following reduced wind loads are proposed.

1. Upgraded emergency and mid-term shelters to be designed for a minimum load equivalent to a cyclonic storm with a 52 m/s (187 km/h) 1-minute sustained wind speed over open sea (this guide has adjusted this pressure for the terrain in the camps). This type of cyclone appears to have a return period of about 20 years along the east side of the Bay of Bengal and is equivalent to the strongest monsoon wind in the region.

2. Shelters designed for the longer term and community buildings to be designed for a load equivalent to a large cyclonic storm with a 91 m/s (328 km/h) 1-minute sustained wind speed over open sea. This type of cyclone has a return period of at least 50 years and is in line with the Bangladesh code.

Note that "return period" does not imply that this wind speed occurs periodically every for example 20 years, but rather that it is generally exceeded once every 20 years on a very long term average. Statistically there is a 63% probability that a storm stronger than the 20 years return period one will occur in the next 20 years.

This is the same as saying that there is a 10% probability that a storm stronger than the 20 years period one will occur in the next 2 years.

Note that the windspeeds quoted to define the strength of an oncoming cyclone are '1-minute sustained windspeeds over open sea'. Windspeeds defined in other ways or uncorrected measurements as sometimes reported by news media are not reliable to define the incoming storm strength.

For determining incoming storm strengths, it is recommended to use either the Bangladesh Meteorological Department website http://bmd.gov.bd/?/home/ or the Indian Ocean cyclone warning centre website: http://www.rsmcnewdelhi.imd.gov.in/index.php?lang=en.

RECOMMENDED APPROACH FOR DETERMINING WIND LOADS ON SHELTERS

The recommended simplified approach in this guide for determining wind loads on shelters follows the Bangladesh code however makes some simplifications to the coefficients and the design procedure, for ease of use.

Symbols

Q = dynamic peak pressure	(kN/m^2 or kPa)
k_o = orography (terrain and exposure) coefficient	(no units)
C_p = pressure coefficient	(no units)
p = pressure acting on element	(kN/m^2 or kPa)
A = area on which pressure is acting	(m^2)
F = total force acting on each element with area A	(kN)

PROCEDURE FOR DETERMINING WIND LOADS

1. Select dynamic peak pressure Q based on building usage (e.g. emergency shelter or permanent community building) and any other requirements (e.g. client or local government)

2. Select orography coefficient k_o based on exposure of building.

3. Select pressure coefficient C_p based on element type (walls or roof) and whether local or total pressure required.

4. Determine pressure p acting on element and resulting force F on element or building.

5. Apply appropriate factors of safety for design.

Do not forget to follow the 7 key messages outlined in Figure 4.

1. Dynamic Peak Pressure Coefficient *Q*

For emergency shelters:
$Q_{min} = 1kN/m^2$

For permanent shelters, community buildings and storm shelters:
$Q = 2kN/m^2$

Notes:

- *It may not always be possible to achieve even the Q_{min} for emergency shelters, however the closest that the design can get to this the better.*
- *The designer may wish to consider exceeding the Q_{min} for emergency shelters, where the additional cost and complexity to make the building stronger is not significant.*

2. Orography (topography) Coefficient k_o

The orography (topography/exposure) coefficient can be assumed to be 1.5 for structures situated halfway up a hill or more. For structures below this, k_o=1 can be used (see Figures 8 and 9).

Bottom of Hill: $k_o = 1$	for $0 < z < h/2$
Top of Hill: $k_o = 1.5$	for $h/2 < z < h$

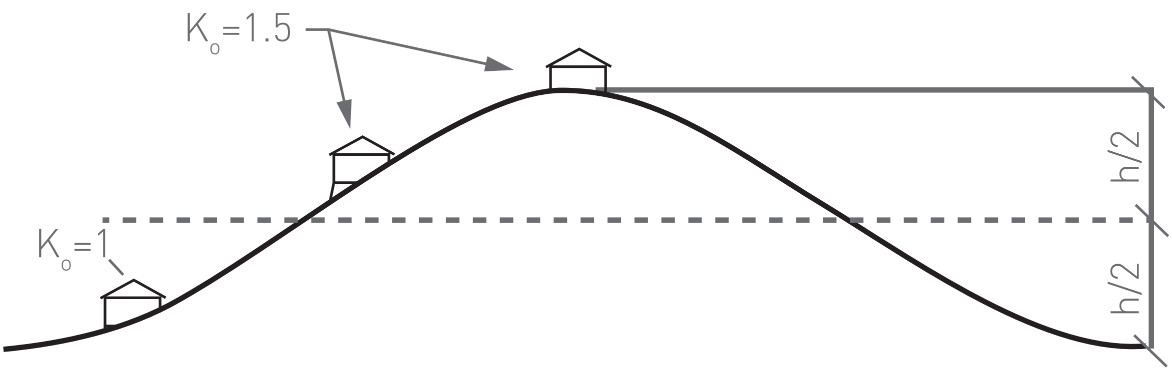

Figure 8: Orography coefficient k_o for different scenarios

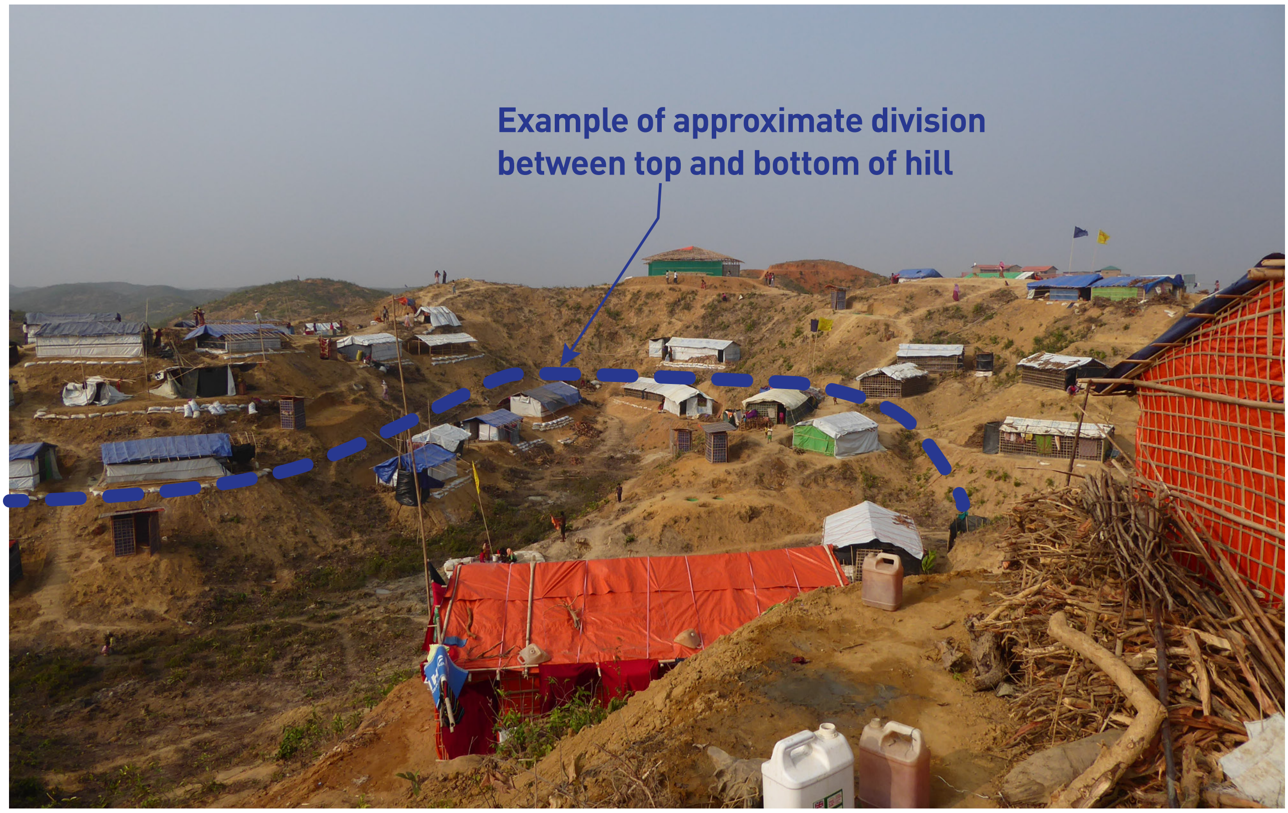

Figure 9: Example of approximate division between top and bottom of hill for orography coefficient (k_o)

3. Pressure Coefficient C_p

Walls

Walls are subject to both inward (positive) and outward/suction (negative) pressures in wind. Figure 10 represents the typical pressure distribution on the walls of a rectangular building for wind blowing from any direction (assuming null internal pressure).

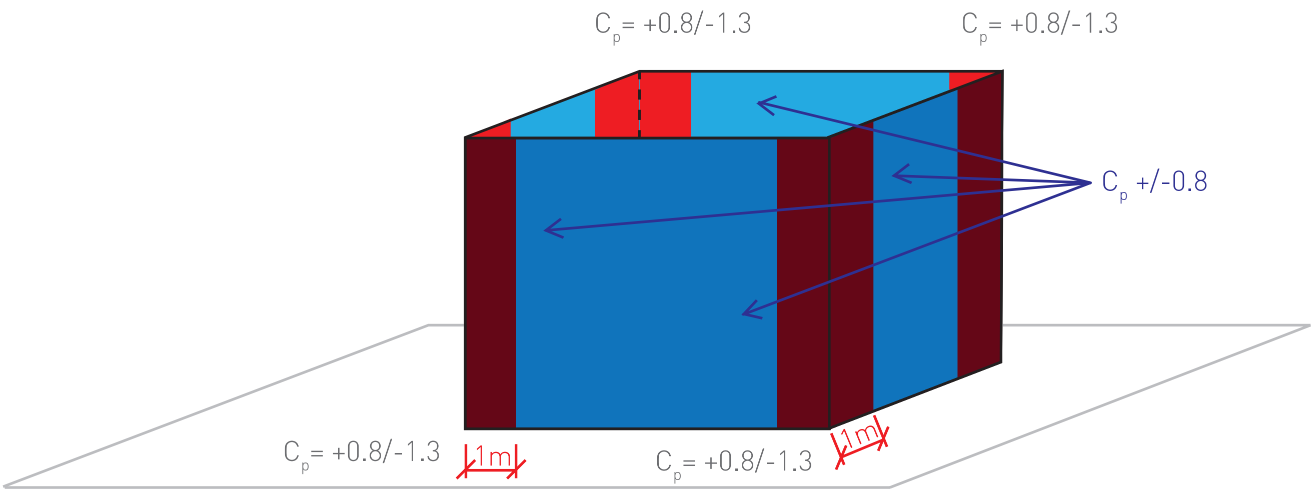

Figure 10: Pressure coefficients on walls

The pressure on each vertical wall can be calculated using (Figure 10):

$$C_p = \pm 0.8$$

The pressures will be higher within 1 m from the corners. In this area the maximum suction can be calculated using:

$$C_p = -1.3$$

The wind loads above assume that the buildings should be built with an approximately equal open area on each side to avoid internal pressure peaks due to dominant openings. This can be achieved with a ventilation grid at least 200mm high on each building side (Figure 11). These function when kept open in case of strong wind.

Figure 11: Example of ventilation grids

Roof

The optimal roof's pitch angle that minimises wind pressure is **30 to 40 degrees.** Hipped roofs (Figure 3) are less vulnerable to strong winds than an open gable roof, however can be slightly trickier to construct.

The pressure acting on each roof's pitch (perpendicularly to the pitch surface) can be calculated using (Figure 12):

$$C_p = \pm 0.7$$

The pressures will be higher within 0.5m from the edges. In this area the maximum suction can be calculated using:

$$C_p = -1.2$$

The pressures will be highest on roof overhangs. In this area the maximum net (bottom and top) pressure can be calculated using:

$$C_p = +/- 2.2$$

Two load cases should be considered:

A. both pitch subject to maximum negative pressure (outward suction)
B. one pitch subject to maximum negative pressure and one to maximum positive pressure

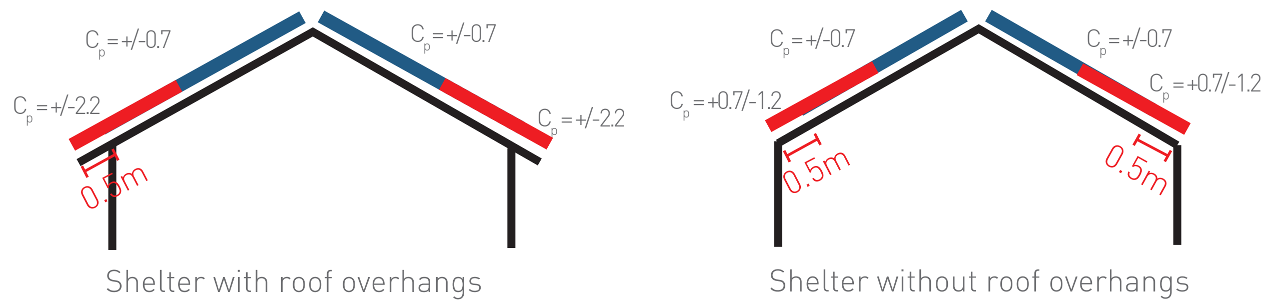

Figure 12 : Pressure coefficients on roof for shelter with and without roof overhangs

Overhangs should be minimised as much as possible as they can cause the whole roof to be ripped off. The pressure can be reduced by making these overhangs sacrificial or porous, e.g. by tying the plastic sheeting here only loosely, such that they vent upwards in a strong wind.

Total load on building

The total load on the building is used for designing the bracing systems and foundation connections.

The total force acting on the whole building simultaneously can be calculated using:

$$C_p = \pm 1.3$$

and applying the pressure only on the front face of the building + the projected roof area (Figure 13).

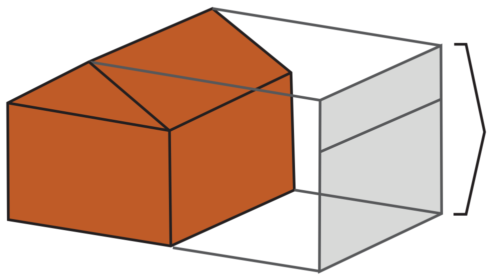

Figure 13: Projected area of building to use for total wind load calculation

4. Pressure *p* and Force *F* on Element or Building

The pressure acting on the walls, the roof or the entire building are the product of the design peak pressure (Q), the orography coefficient (k_o) and the pressure coefficient (C_p):

$$p = Qk_o\, C_p$$

The total force F acting on the walls, the roof or the entire building with area A can be calculated as follows:

$$F = pA$$

5. Factors of safety

All the loads provided in these guidelines are meant to be used together with the normal factors of safety provided by the Bangladeshi construction code[5].

FURTHER INFORMATION

This Technical Guidance Note has been prepared by Arup at the request of the Shelter & NFI Sector as a contribution to the humanitarian response.

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3. NOAA (1928) Hurricane winds drive a 10-foot 2X4 through a palm tree in Puerto Rico. Copyright: Public Domain. [ONLINE]. Available at: https://commons.wikimedia.org/wiki/File:Hurricane_winds_drive_a_10-foot_2X4_through_a_palm_tree.jpg. (Accessed March 2018).

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5. Bangladesh National Building Code (2014, Housing and building Research Institutes, Bangladesh Standards and Testing Institutes, Dhaka, Bangladesh.

DISCLAIMER

1. This guidance is provided for information purposes only. You must satisfy yourself regarding the application of statutory requirements, local building regulations, codes, insurance certification or other requirements or recommendations relevant to the location where and materials with which you plan to build. Examples of local conditions that will change the design include climate (flooding, temperature variation, insects), soil mechanics (foundations), seismic characteristics (earthquakes) and legislation regarding inclusive safe access (including emergency egress for fire).

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4. Construction is an inherently risky activity. You must ensure you have adequate skills to safely assemble (and disassemble) shelter buildings. You must procure advice from a competent person if there is any doubt as to your own competence to design, assemble, adapt, commission or disassemble emergency shelter buildings. Such advice can be readily obtained from professional architects, engineers, and builders.