Shelter/NFI Sector's Position on ARUP's Structural/Wind Assessment of Shelter Options

The coastal area of Bangladesh is suseptable to cyclones. The Cox's Bazar district situated by the Bay of Bengal has witnessed devastating cyclones over the past decades. Currently more than 211,000 Rohingya refugee households are residing in emergency shelters that are situated in locations that offer minimum natural protection against heavy wind loads. The Shelter/NFI Sector in Cox's Bazar collaborated with Arup in conducting a structural assessment of the shelter options (existing and proposed designs) against wind loading. The aim is to assess the structural strength of the common shelters found in the camps and sites as well as plan for new shelter options that are more durable to wind loading. The results of this structural assessment is intended to provide an indicative assumption of their performance. It is important to highlight that the bamboo shelters are non-engineered and as they are constructed by beneficiaries, it is difficult to precisely determine the capacities of many of the elements and connections. Also, wind loading is difficult to predict accurately.

In line with thorough discussions at the level of the Shelter/NFI TWiG that were based on the Shelter/NFI Sector Survey findings conducted in July and August 2018 as well as the approved design parameters and designs of Transitional Shelters and Mid Term Shelters, the Shelter/NFI Sector assumes the below:

- TYPE 1 shelter option assessed by Arup is comparable to existing shelters constructed using an upgrade shelter kit (USK) in addition to other shelter materials provided earlier and/or purchased by households.
- TYPE 2 shelter option assessed by Arup is comparable to the above mention existing shelter option + tie down kit (TDK).
- TYPE 4, 5 and, 6 shelter options assessed by Arup includes features found in the Shelter/NFI Sector's phase three shelter options: Transitional Shelters (TS) and Mid-Term Shelters (MTS) inclusive of a TDK.

The indicative wind resistance of the Sector's shelter options is illustrated below. It is important to note that **none of the shelter options are cyclone resistant.** The Arup report provides sufficient insight on assumptions and limitations taken into account while carrying out the assessment.

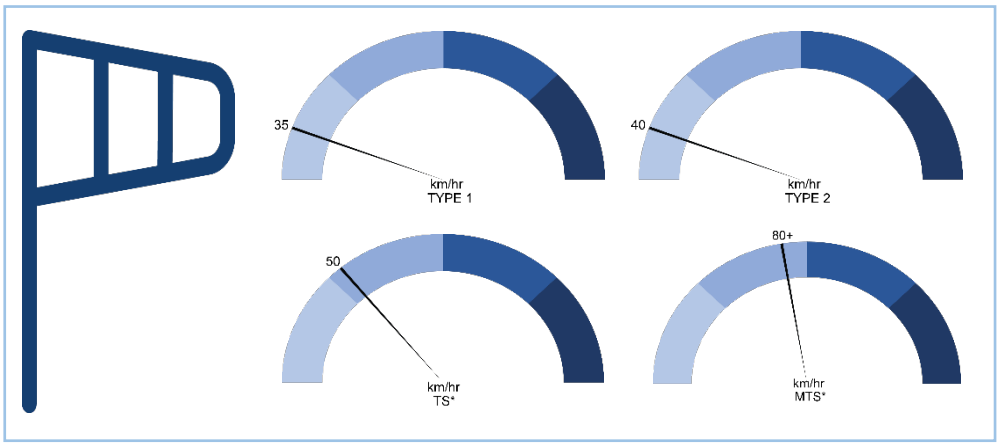


Figure: Indicative wind resistance of Shelter/NFI Sector's shelter options

*Proposed Phase Three Shelter Options

Arup Technical Guidance Note 02:

Structural Assessment of Emergency Shelters Under Wind Loading

Rohingya Refugee Camps and Sites, Cox's Bazar Region, Bangladesh

VERSION 1.0: Issued 27/08/2018

EXECUTIVE SUMMARY 1/2

The Cox's Bazar Shelter and NFI Sector in Bangladesh have asked Arup to conduct structural assessments of lightweight bamboo upgraded shelters (both existing and proposed designs) against wind loading. The refugee camps and sites in the region are very vulnerable to cyclone loads, and therefore this is considered a significant risk to safety and life of the refugees.

This report provides a summary of the results of the structural assessments conducted, and provides recommendations for improvements. **The aim of this report is to provide an approximate range of strengths for different upgraded shelter types, in order to inform the Shelter and NFI Sector how vulnerable the different shelter types are, and very roughly what sort of wind event may cause these shelters to collapse.**

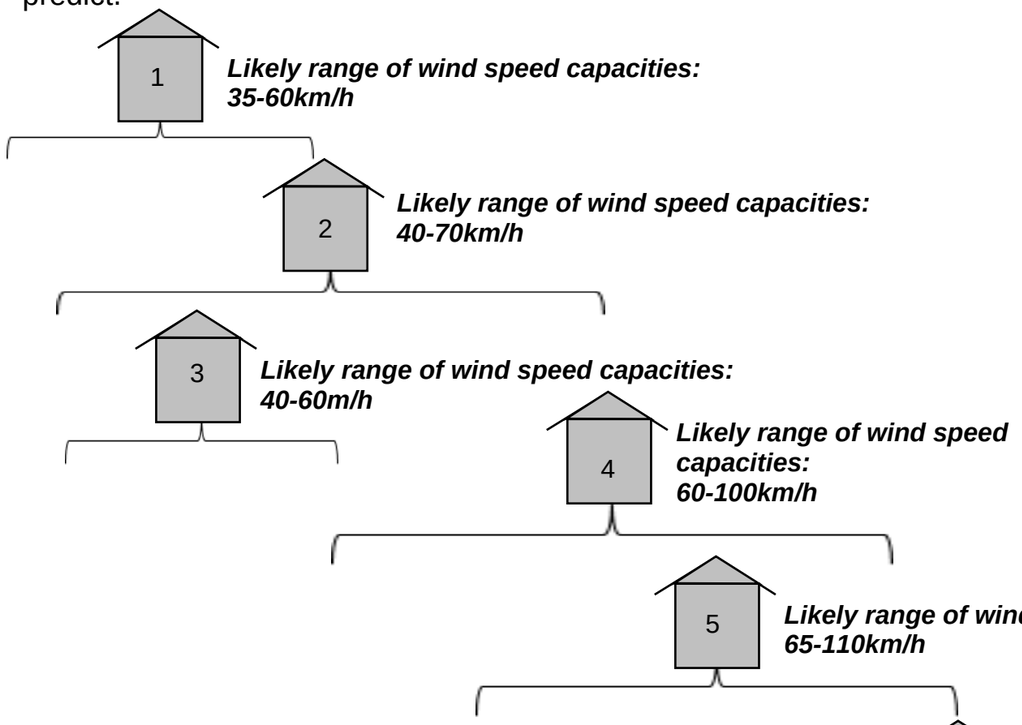
The results of the structural assessment against wind loading are only intended to provide an indicative idea of their performance. These bamboo shelters are non-engineered and constructed by informal labour, and so it is very difficult to precisely determine the strengths of many of the elements and connections. In addition, the structural assessment focuses exclusively on how the bamboo frame will behave in wind - it is unclear how the plastic sheeting will behave. Lastly, wind loading is complex and difficult to accurately predict.

The results of the assessment show that without vertical rope bracing or guy ropes, the strength of the shelters is low. Vertical rope bracing is recommended in all walls (rope bracing is recommended rather than bamboo bracing, as bamboo bracing connections are much more difficult to construct, and the majority seen on site have little strength). Guy ropes also help considerably to tie the structure down. The strength can be further increased and made more reliable by adding plan roof rope bracing, by reducing the horizontal spacing of the muli rafters (i.e. place them closer together), by improving the base connection and by doubling up key connections and bracing with more rope.

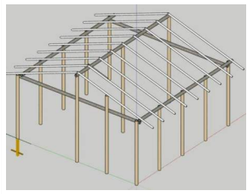
This report has been prepared by Arup at the request of the Shelter & NFI Sector as a contribution to the humanitarian response, and is subject always to the disclaimers set out in Section 9 herein. In brief, Arup accepts no liability whatsoever to third parties for the contents of this report. You must rely on your own skill, judgment and expertise (or that of appropriately qualified professional consultants) in any matter to which this report relates.

EXECUTIVE SUMMARY 2/2

The image below shows the relative performance of the different shelter types. The bar below represents different wind speeds in km/h, the commonly used Beaufort Scale, and the North Indian Ocean wind event scale. The range of approximate strengths of the different shelter types has been plotted against these scales. Each shelter has a range of strengths because the strength of all of the different elements will vary (the bamboo, the rope and the foundations), and wind loading is difficult to accurately predict.

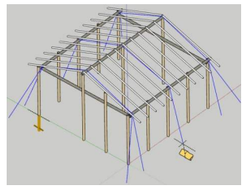


TYPE 1



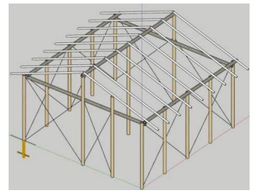
- No vertical bracing.
- No roof plan bracing.
- No guy ropes.

TYPE 2



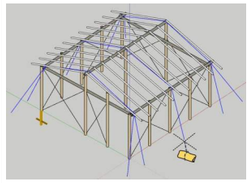
- No vertical bracing.
- No roof plan bracing.
- Guy ropes.

TYPE 3



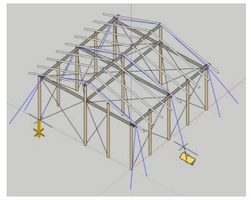
- Vertical bracing.
- No roof plan bracing.
- No guy ropes.

TYPE 4



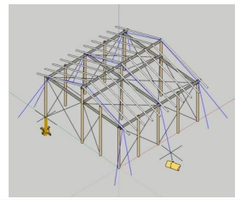
- Vertical bracing.
- No roof plan bracing.
- Guy ropes.

TYPE 5



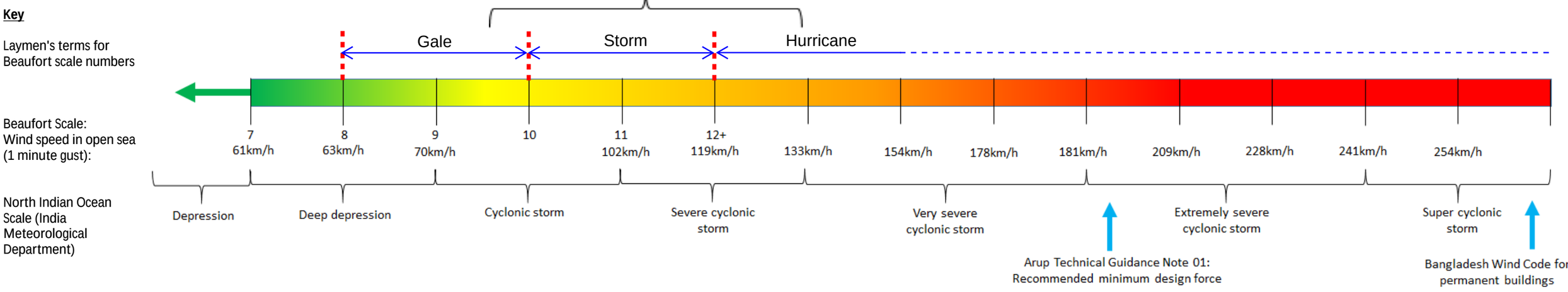
- Vertical bracing.
- Roof plan bracing.
- Guy ropes.
- Improved base detail.

TYPE 6



- Vertical bracing.
- Roof plan bracing.
- Guy ropes.
- Improved base detail.
- Muli rafters at closer centres.
- Key connections and bracing have doubled up rope.

Key



CONTENTS

1. INTRODUCTION

The Cox's Bazar Shelter and NFI Sector in Bangladesh have asked Arup to conduct structural assessments of lightweight bamboo upgraded shelters (both existing and proposed designs) against wind loading. The refugee camps and sites in the region are very vulnerable to cyclone loads, and therefore this is considered a significant risk to safety and life of the refugees.

This report provides a summary of the results of the structural assessments conducted, and provides recommendations for improvements. The aim of this report is to provide an approximate range of strengths for different upgraded shelter types, in order to inform the Shelter and NFI Sector how vulnerable the different shelter types are, and very roughly what sort of wind event may fail these shelters.

The results of the structural assessment against wind loading are only intended to provide an indicative idea of their performance. These bamboo shelters are non-engineered and constructed by informal labour, and so it is very difficult to precisely determine the capacities of many of the elements and connections. In addition, the structural assessment focuses exclusively on how the bamboo frame will behave in wind - it is unclear how the plastic sheeting will behave. Lastly, wind loading is complex and difficult to accurately predict.

2. METHOD

The following method has been used to determine the capacities of the shelters:

1. Drawings were received from the Shelter & NFI Sector for several different shelter types. Five specific shelter types, with different vertical bracing, plan roof bracing and external guy ropes, were checked. Where information was missing, this was queried with the Sector.

2. A number of assumptions were made about the shelters in order to be able to indicatively determine their capacity. These are provided in Section 3: Assumptions.

3. The Arup Technical Guidance Note 01: Wind loading for the design of upgraded emergency shelters, mid-term shelters and community structures, was used to determine the wind loads on the shelter, which in turn is based on the Bangladesh Code.

4. Strengths of bamboo elements were based on the following papers:

- Kaminski, S., Lawrence, A., Trujillo, D., Feltham, I., López, L. (2016) ‘Structural Use of Bamboo 3: Design values’. The Structural Engineer, December 2016, pp. 42-45.
- Kaminski, S., Lawrence, A., Trujillo, D., Feltham, I., López, L. (2017) ‘Structural Use of Bamboo 4: Element design equations’. The Structural Engineer, March 2017, pp. 25-27.

Upper and lower bound material strengths were used, varying from design strengths, to strengths a little less than average, based on experience, in order to provide a range of actual likely strengths of the material.

5. The shelters are assumed fully clad on their walls, cantilevers and roofs, for loading purposes. The overall capacity of each of the shelter types has been determined based on the weakest part of the shelter frame. The capacity of the overhangs have been excluded from the analysis because they are considered secondary elements that do not form part of the main structure, and their failure will not result in failure of the structure. The capacity and behaviour of the plastic sheeting has also been excluded from the analysis, because it is considered very difficult to quantify, and also its failure would not result in failure of the structure. The capacities have been determined using upper and lower bound wind and material factors of safety, in order to provide a range of actual likely strengths, since the quality and details in each shelter may vary significantly

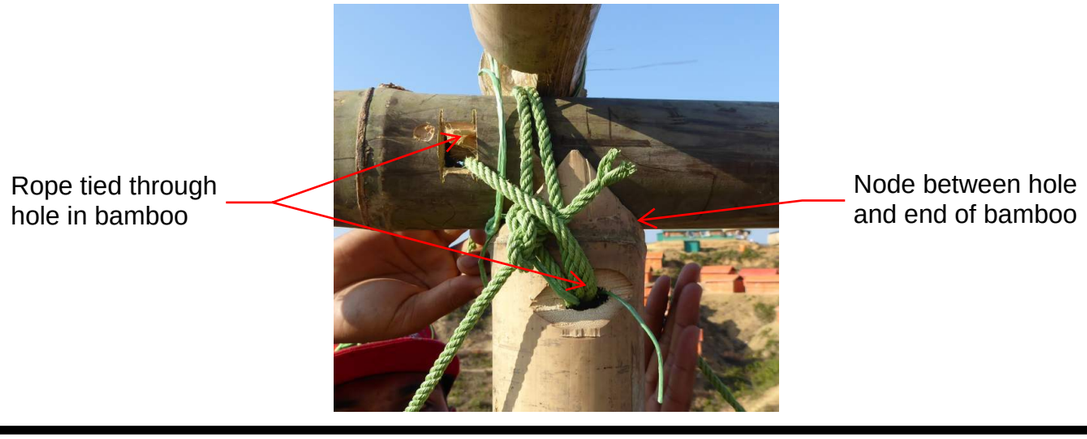
3. ASSUMPTIONS 1/2

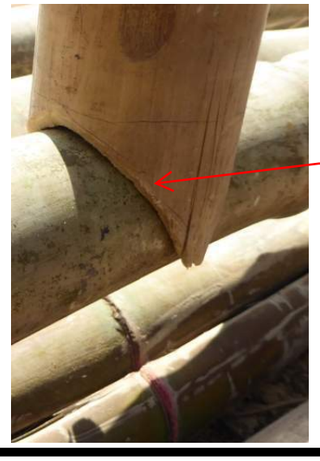
The following assumptions have been made in this assessment:

1. Bamboo properties
- All bamboo is mature air dry to approximately 12% moisture content at time of load.
- Strengths are based on a range from lower bound "design" strengths to strengths a little less than average, based on experience, in order to provide a range of actual likely strengths of the material.
- All large diameter bamboo is borak (Bambusa balcoa), with a dry, short term design bending strength varying between 28-52N/mm2 and a shear strength between 1.75-5N/mm2. Diameter is 75mm, and wall thickness is 10mm.
- All small diameter bamboo is muli (Melocanna baccifera), with a dry, short term design bending strength of 23-52N/mm2 and a shear strength between 1.72-5N/mm2. Diameter is 40mm, and wall thickness is 5mm.
- All bamboo is free of rot, insect attack, fissures and splits.
- Strengths of elements are based on:
    - Kaminski, S., Lawrence, A., Trujillo, D., Feltham, I., López, L. (2016) ‘Structural Use of Bamboo 3: Design values’. The Structural Engineer, December 2016, pp. 42-45.
    - Kaminski, S., Lawrence, A., Trujillo, D., Feltham, I., López, L. (2017) ‘Structural Use of Bamboo 4: Element design equations’. The Structural Engineer, March 2017, pp. 25-27.

2. Rope properties
- The rope used for the bracing and main connections is 6mm polypropylene rope, with a minimum breaking strength of 5kN. A factor of safety between 6 and 10 (to account for lower and upper bound strengths) has been used.
- The rope used for the purlin to rafter connections, is 3mm polypropylene rope, with a minimum breaking strength of 1.5kN. A factor of safety between 6 and 10 (to account for lower and upper bound strengths) has been used.
- Rope is taught and in good condition.

3. Bamboo-to-bamboo connections
- All bamboo-to-bamboo connections have been made with small holes in all interconnecting members, and (unless noted otherwise) two polypropylene ropes pass through all of the holes to tie them all together - the diameter of the rope varies according to the element (see **2. Rope properties** above).
- All bamboo-to-bamboo connections use a fish-mouth connection, where one piece has been shaped such that it fits snug around the other.
- At least one node exists between any hole made in the bamboo and the end of that piece.

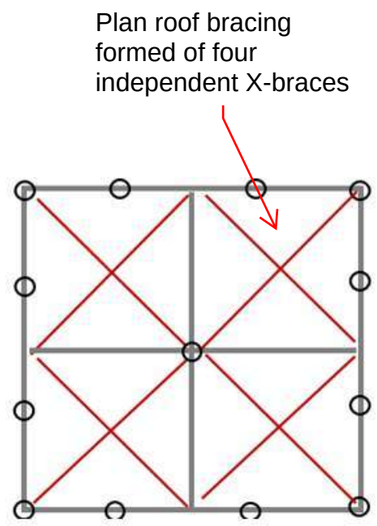




3. ASSUMPTIONS 2/2

4. Vertical Bracing
Vertical bracing consists of 6mm polypropylene rope (not bamboo bracing, which is considered much weaker and unreliable - see Section 8). The rope is fixed to each corner by passing it through a hole in the bamboo (connections which only rely upon friction are considered much weaker and unreliable). Unless noted otherwise, each diagonal is typically formed of two 6mm ropes, taut.

5. Plan roof rope bracing
Horizontal roof rope bracing consists of 6mm polypropylene rope (not bamboo bracing, which is considered much weaker and unreliable). The rope is fixed to each corner by passing it through a hole in the bamboo (connections which rely upon friction only are considered much weaker and unreliable). Each diagonal is formed of two 6mm ropes, taut. The plan bracing is formed of four independent X-braces, each connected to the frame, rather than one large X-bracing (which is much weaker)

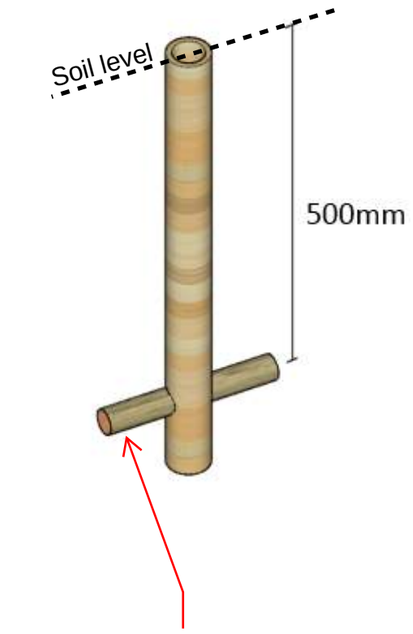


6. Foundations
- Unless noted otherwise, the base of the borak bamboos is embedded 500mm into the soil, with typically a single piece of muli passing through a hole in the borak (not simply tied together with rope, which is considered weak and unreliable), and at least one node situated between the muli and the end of the borak.
- The soil has been well compacted around the embedded borak.
- Two improved versions exist, which are described in the specific types.
- Foundation pull-out is based on the minimum of the capacity of the embedded bamboo to resist the load, or the self-weight of the soil above, assuming a cone pullout of soil with a steep angle, since the soil is made ground.

7. Plastic sheeting
- The plastic sheeting to the walls and roof has not been assessed. It is assumed that these will apply a wind load perpendicular to the walls and roof – no catenary affects have been assumed.
- The plastic sheeting may fail but this is not considered to be a life safety risk and would be easily repairable.

8. Roof overhangs
- Overhangs are no greater than 300mm.
- The strength of the roof overhangs has not been assessed separately as they are particularly weak.

9. Exposure
- The loads have been based on shelters being fully exposed (i.e. towards the tops of hills).



4. LIMITATIONS

This assessment is intended to provide only an indicative idea of the structural performance of these emergency shelters. It is not considered possible to conduct an accurate assessment because of the following variables and unknowns:

- These bamboo shelters are non-engineered, so the actual construction details will vary significantly.
- These bamboo shelters are constructed by informal labour, so the actual construction method and quality will vary significantly.
- A number of assumptions that have been made where necessary to be able to determine a quantifiable strength, however are known to vary in practice. These include:
    - Bamboo maturity - some of the bamboo arriving on site is immature.
    - Bamboo moisture content - some of the bamboo may have a moisture content >12%.
    - Bamboo species - other species are being mixed up with the borak and muli.
    - Bamboo diameter and wall thickness - the diameter and wall thickness may be lower than assumed.
    - Bamboo condition - some of the bamboo will be rotten, suffer insect attack or have splits and fissures.
    - Rope strength and diameter - other types of rope are being used on site.
    - Bamboo-to-bamboo connections - many of the connections used on site rely upon friction only, and do not always have a node at the end.
    - Foundations - some of the foundations have been constructed with different details, such as the muli connected to the borak in friction only.
    - Vertical bracing - some of the vertical bracing systems use bamboo instead of rope.
    - Plan roof bracing - some of the horizontal bracing systems use bamboo instead of rope, and/or are formed of one large X-bracing instead of four.
- The structural assessment focuses exclusively on how the bamboo frame will behave in wind - it is unclear how the plastic sheeting will behave, or how it may affect the structure.
- Wind loading is complex and difficult to accurately predict.

Notwithstanding the above, this assessment aims to provide an indication of which are the most vulnerable shelter types, and approximately what sort of wind loads will effect each shelter type.

5. SUMMARY OF SHELTER DESIGNS CHECKED

Six different shelter designed were assessed. The different permutations of structure were as follows:

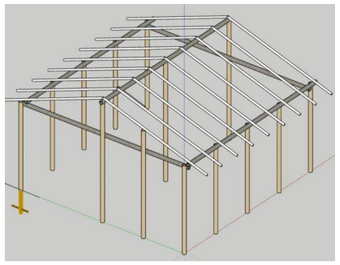
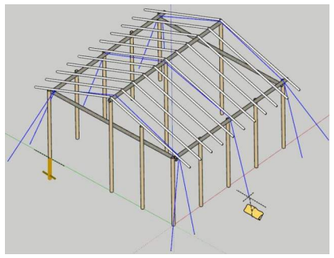
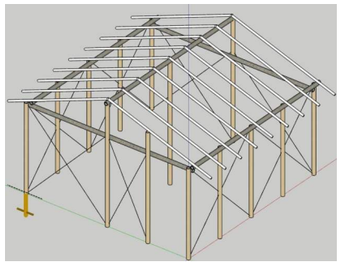
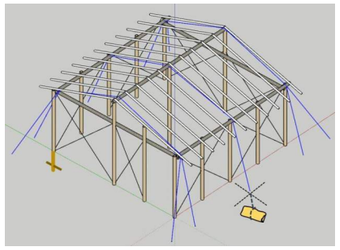
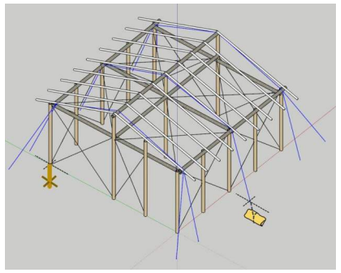
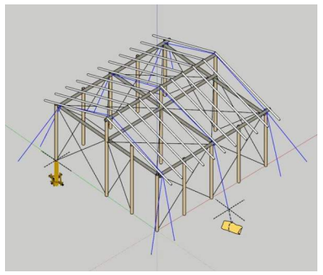
EXAMPLES CONSTRUCTED ON SITE:

Type 1: No vertical bracing, no roof plan bracing, no guy ropes.
Type 2: No vertical bracing, no roof plan bracing, with guy ropes.
Type 3: With vertical bracing, no roof plan bracing, no guy ropes.
Type 4: With vertical bracing, no roof plan bracing, with guy ropes.

THEORETICAL EXAMPLES NOT YET CONSTRUCTED:

Type 5: With vertical bracing, with roof plan bracing, with guy ropes, with improved base connection.
Type 6: With vertical bracing, with roof plan bracing, with guy ropes, with further improved base connection, with muli rafters at closer centres, with key connections and bracing doubled up.

The six shelter designs are shown below.

TYPE 1  - No vertical bracing. - No roof plan bracing. - No guy ropes.	**TYPE 2**  - No vertical bracing. - No roof plan bracing. - Guy ropes.	**TYPE 3**  - Vertical bracing. - No roof plan bracing. - No guy ropes.
TYPE 4  - Vertical bracing. - No roof plan bracing. - Guy ropes.	**TYPE 5**  - Vertical bracing. - Roof plan bracing. - Guy ropes. - Improved base detail.	**TYPE 6**  - Vertical bracing. - Roof plan bracing. - Guy ropes. - Improved base detail. - Muli rafters at closer centres. - Key connections and bracing have doubled up rope.

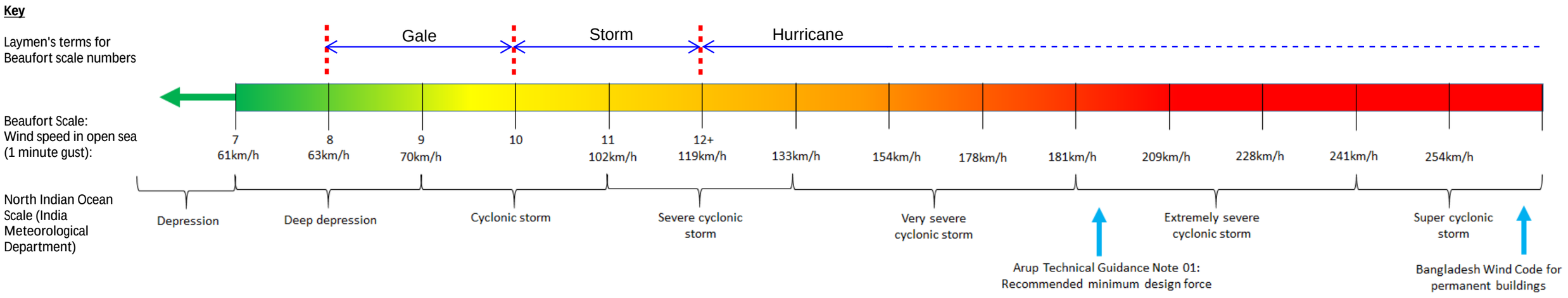
6. CATEGORISATION OF SHELTER CAPACITY IN WIND

Care should be taken when comparing wind speeds stated in this document with those in the Bangladesh Code, those in the media and those from the Bangladesh Meteorological Department. Design wind speeds are very specific, for example we have quoted the speed in both m/s and km/h as a 1-minute sustained wind speed over open sea. The same force can be quoted as a different speed if it's reported differently, for example as a 3 second gust, or over land. Media often report speeds without clarifying their source nor defining what they are. It is recommended to use the Bangladesh Meteorological Department website http://bmd.gov.bd/?/home/ when seeing what wind speed a specific event is generating, and checking how that speed is reported.

Because of the many assumptions and limitations described in Sections 4 and 5, and the significant variability in how wind speeds are reported, it is not considered appropriate to provide a specific capacity of each shelter. Instead, the shelters are each plotted indicatively on a wind scale. This is intended to provide an indicative capacity of how they might behave, if all of the assumptions were correct. The capacities have been determined using upper and lower bound wind and material factors of safety, in order to provide a range of actual likely strengths, since the quality and details in each shelter may vary significantly.

The wind scale is provided below, with the following scales:

- Beaufort Scale between 7-12+, and associated laymen's terms.
- Wind speed in open sea (1 minute gust) in km/h.
- North Indian Ocean scale (by the Indian Meteorological Department).

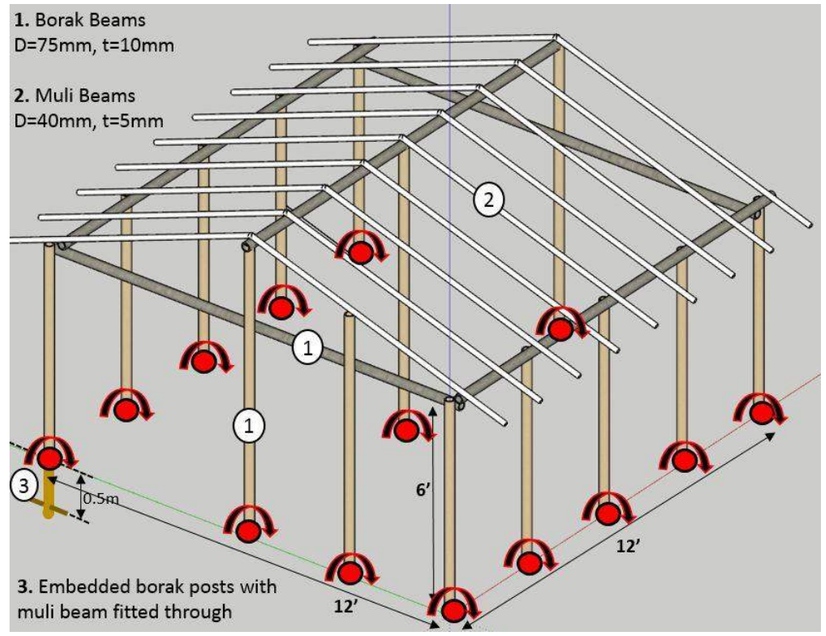


7. SHELTER DESIGN ASSESSMENTS

TYPE 1: NO VERTICAL BRACING, NO PLAN BRACING, NO GUY ROPES

Shelter Description

The bamboo frame structure measures 3.6m x 3.6m (12'x12') or 4.6m x 3.6m (15'x12') on plan, is 2.5m tall and has a duo-pitched roof of around 20 degrees. The frame has borak columns every 1m (3') centres on the eaves side and every 2m (6') on the gable ends. Rafters are at 450mm centres (1.5'). All columns are embedded ~500mm into the ground. The eaves and ridge beams are borak, and muli rafters form the roof. There is no vertical bracing, nor any horizontal plan roof rope bracing. Stability is provided by cantilevering action at the base of the embedded borak columns.

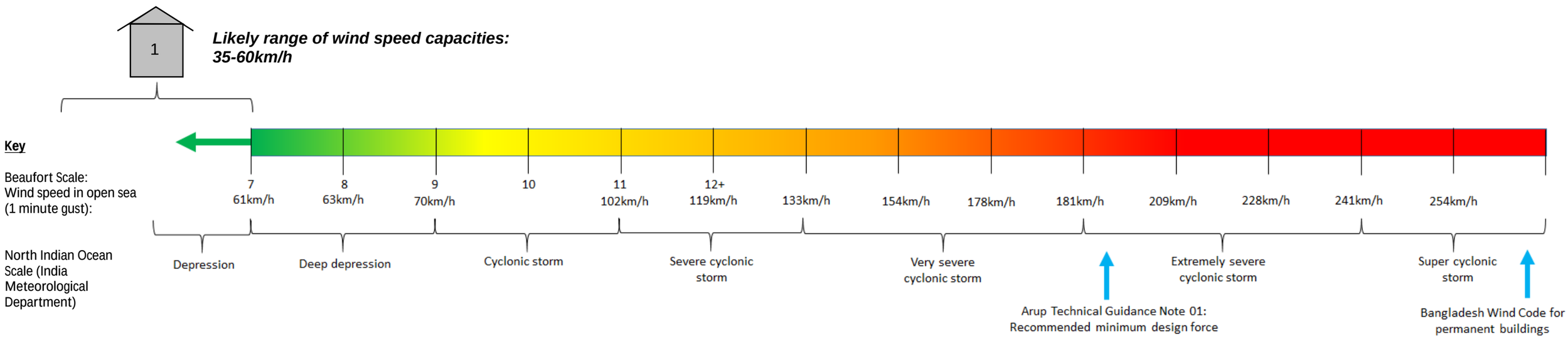


Likely Failure Point

The weakest part of the shelter is likely to be the base of the embedded columns, highlighted in red on the image on the right. The capacity of the soil to stop the columns from rotating is low and unpredictable.

Minimum Recommendations

Installing vertical rope bracing or guy ropes can improve the shelter's strength against winds.

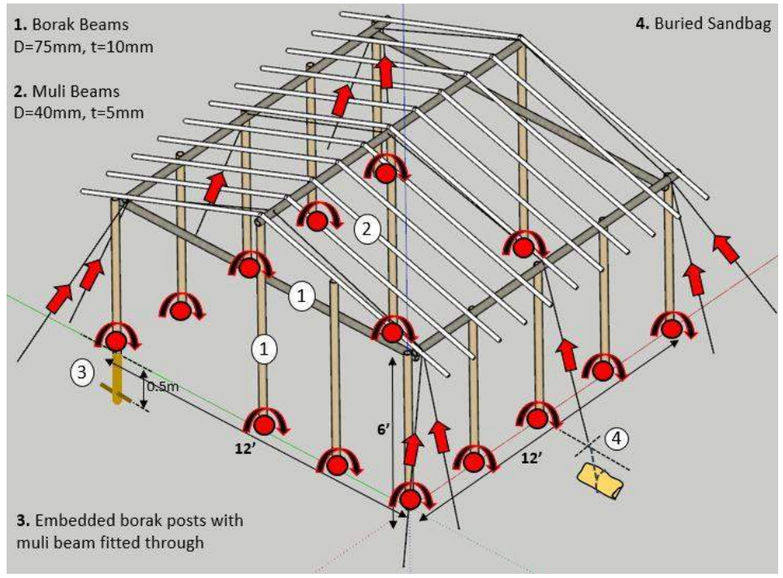


7. SHELTER DESIGN ASSESSMENTS

TYPE 2: NO VERTICAL BRACING, NO PLAN BRACING, WITH GUY ROPES

Shelter Description

The bamboo frame structure measures 3.6m x 3.6m (12'x12') or 4.6m x 3.6m (15'x12') on plan, is 2.5m tall and has a duo-pitched roof of around 20 degrees. The frame has borak columns every 1m (3') centres on the eaves side and every 2m (6') on the gable ends. Rafters are at 450mm centres (1.5'). All columns are embedded ~500mm into the ground. The eaves and ridge beams are borak, and muli rafters form the roof. There is no vertical bracing, nor any horizontal plan roof rope bracing. Stability is provided by cantilevering action at the base of the embedded borak columns. Guy ropes connected to some of the perimeter columns improve the shelter's capacity to resist upward wind forces, and provide a small amount of additional resistance to lateral stability.



Likely Failure Point

The weakest part of the shelter is likely to be the base of the embedded columns, highlighted in red on the image on the right. The capacity of the soil to stop the columns from rotating is low and unpredictable.

Minimum Recommendations

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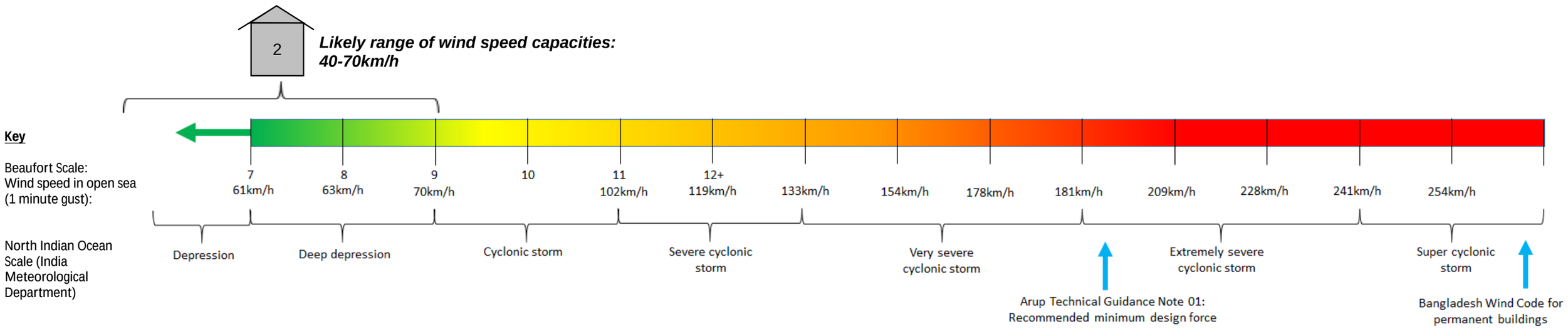
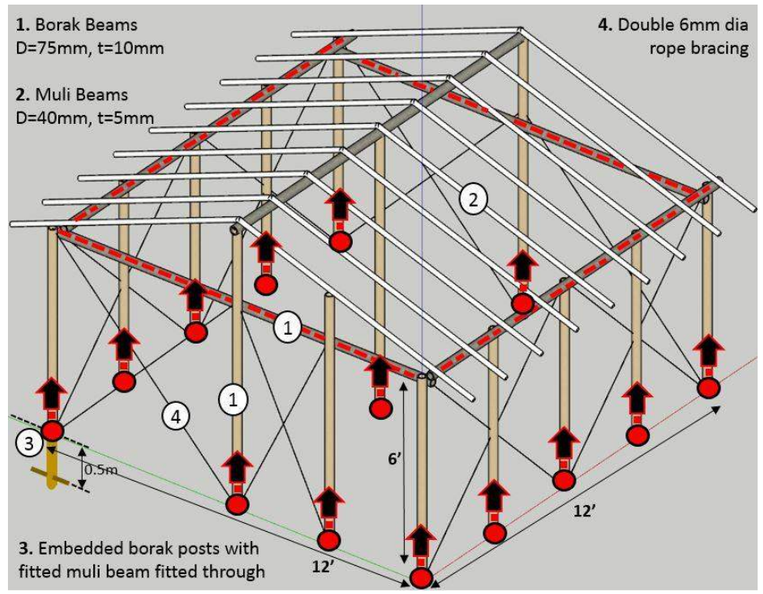


7. SHELTER DESIGN ASSESSMENTS

TYPE 3: WITH VERTICAL BRACING, NO PLAN BRACING, NO GUY ROPES

Shelter Description

The bamboo frame structure measures 3.6m x 3.6m (12'x12') or 4.6m x 3.6m (15'x12') on plan, is 2.5m tall and has a duo-pitched roof of around 20 degrees. The frame has borak columns every 1m (3') centres on the eaves side and every 2m (6') on the gable ends. Rafters are at 450mm centres (1.5'). All columns are embedded ~500mm into the ground. The eaves and ridge beams are borak, and muli rafters form the roof. Vertical rope bracing is provided in every wall. There is no plan roof rope bracing. Stability is primarily provided by the vertical bracing, which is considered to be stiffer than the columns cantilevering.

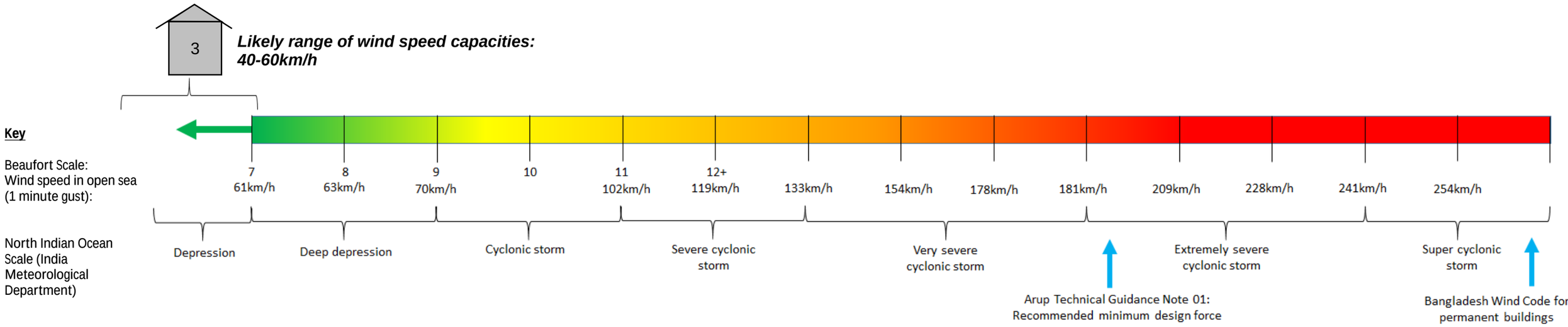


Likely Failure Point

The weakest part of the shelter is likely to be the columns pulling out at their base, and the eaves beam in bending on all four walls.

Minimum Recommendations

Installing perimeter guy ropes can improve the shelter's strength against winds.

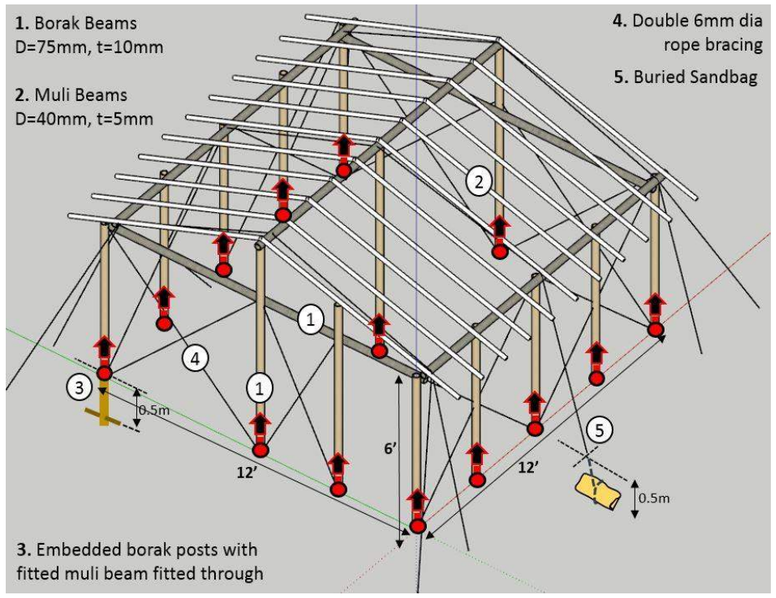


7. SHELTER DESIGN ASSESSMENTS

TYPE 4: WITH VERTICAL BRACING, NO PLAN BRACING, WITH GUY ROPES

Shelter Description

The bamboo frame structure measures 3.6m x 3.6m (12'x12') or 4.6m x 3.6m (15'x12') on plan, is 2.5m tall and has a duo-pitched roof of around 20 degrees. The frame has borak columns every 1m (3') centres on the eaves side and every 2m (6') on the gable ends. Rafters are at 450mm centres (1.5'). All columns are embedded ~500mm into the ground. The eaves and ridge beams are borak, and muli rafters form the roof. Vertical rope bracing is provided in every wall. There is no plan roof rope bracing. Stability is primarily provided by the vertical bracing, which is considered to be stiffer than the columns cantilevering. Guy ropes connected to some of the perimeter columns improve the shelter's capacity to resist upward wind forces, and provide a small amount of additional resistance to lateral stability.

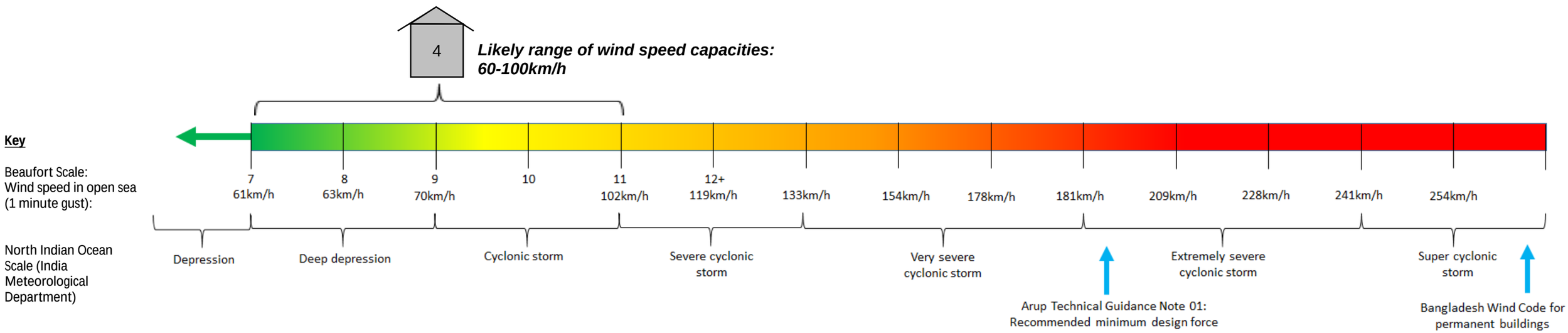


Likely Failure Point

The weakest part of the shelter is likely to be the columns pulling out at their base, and the eaves beam in bending on all four walls.

Minimum Recommendations

Installing a roof diaphragm on plan and improving the base detail to better resist pullout can improve the shelter's strength against winds.

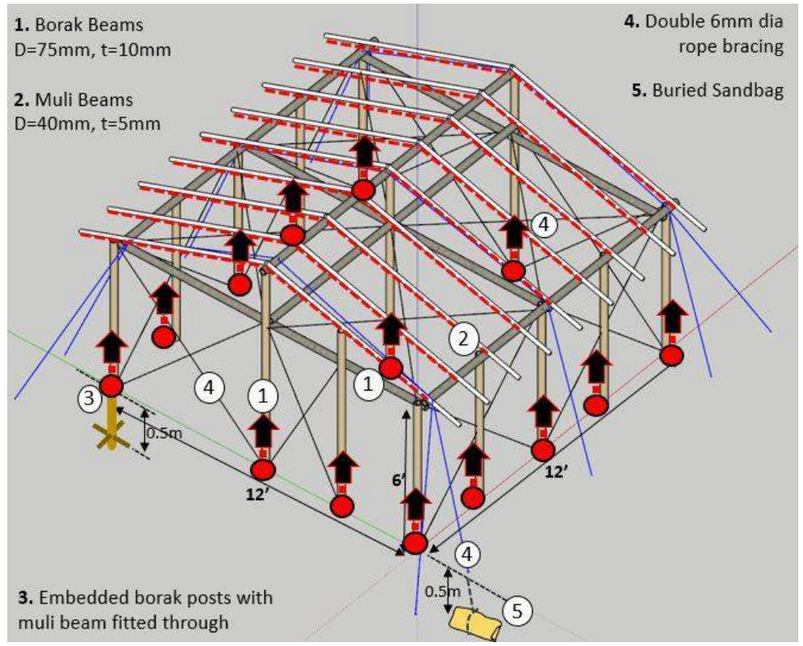


7. SHELTER DESIGN ASSESSMENTS

TYPE 5: WITH VERTICAL AND PLAN BRACING, WITH GUY ROPES, WITH IMPROVED BASE DETAIL

Shelter Description

The bamboo frame structure measures 3.6m x 3.6m (12'x12') or 4.6m x 3.6m (15'x12') on plan, is 2.5m tall and has a duo-pitched roof of around 20 degrees. The frame has borak columns every 1m (3') centres on the eaves side and every 2m (6') on the gable ends. Rafters are at 450mm centres (1.5'). All columns are embedded ~500mm into the ground. The eaves and ridge beams are borak, and muli rafters form the roof. Vertical rope bracing is provided in every wall. Plan roof rope bracing is provided. Stability is primarily provided by the vertical bracing, which is considered to be stiffer than the columns cantilevering. The roof is tied down with 3 additional guy ropes that are looped over the roof and tied to sandbags buried into the ground. The base detail is improved with 2no. muli beams passing through the borak columns where they are embedded.

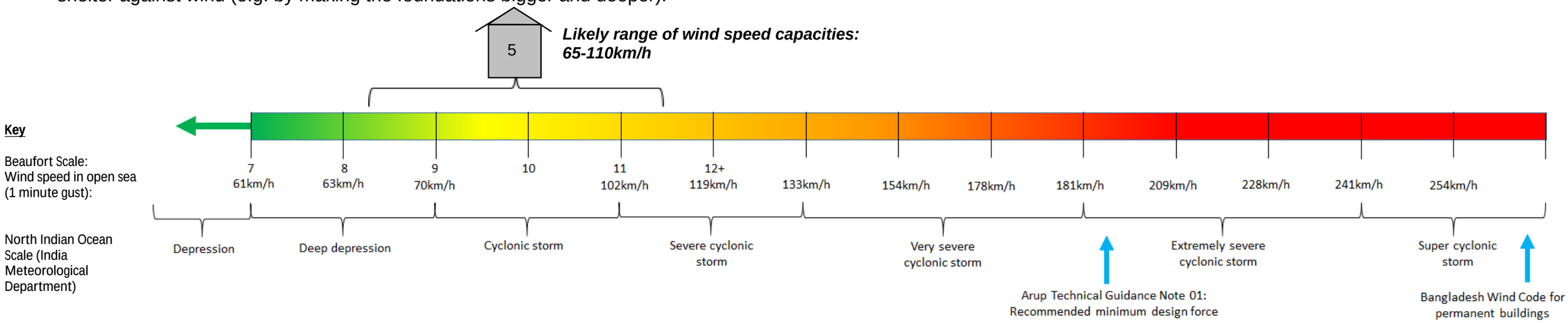


Likely Failure Point

The weakest part of the shelter is likely to be the muli rafters failing in bending, and the columns pulling out the ground in net uplift - the structure self-weight is very low and the columns are not able to pick up significant soil loads.

Minimum Recommendations

Adding additional muli rafters and improving the foundation detail further can increase the capacity of the shelter against wind (e.g. by making the foundations bigger and deeper).

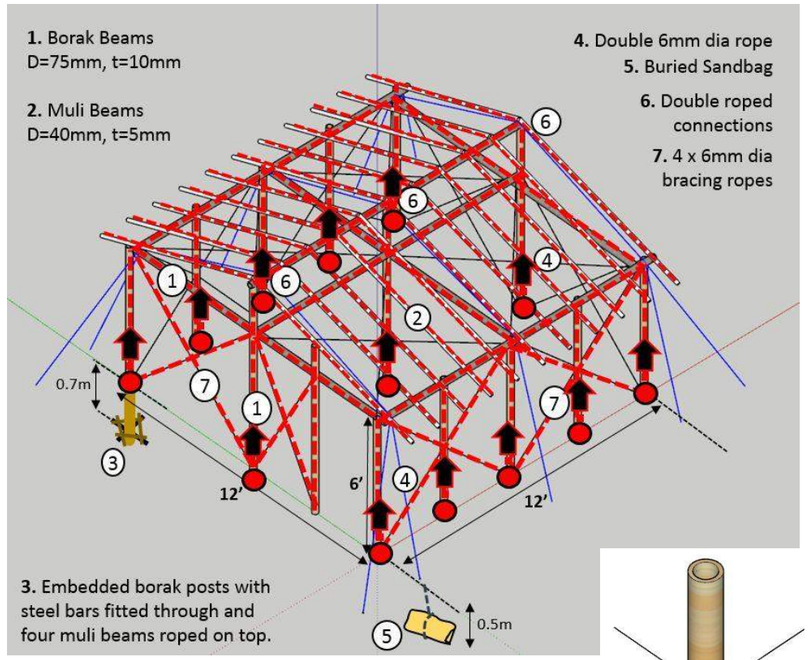


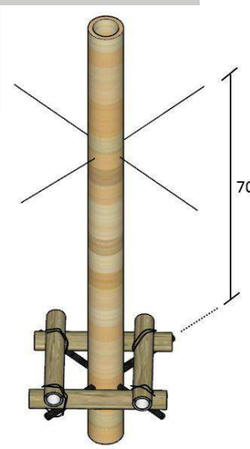
7. SHELTER DESIGN ASSESSMENTS

TYPE 6: WITH VERTICAL AND PLAN BRACING, WITH GUY ROPES, WITH FURTHER IMPROVED BASE DETAIL, WITH MULI RAFTERS AT CLOSER CENTRES

Shelter Description

The bamboo frame structure measures 3.6m x 3.6m (12'x12') or 4.6m x 3.6m (15'x12') on plan, is 2.5m tall and has a duo-pitched roof of around 20 degrees. The frame has borak columns every 1m (3') centres on the eaves side and every 2m (6') on the gable ends. All columns are embedded ~600mm into the ground. The eaves and ridge beams are borak, and muli rafters form the roof. Vertical rope bracing is provided in every wall. Plan roof rope bracing is provided. Stability is primarily provided by the vertical bracing, which is considered to be stiffer than the columns cantilevering. The roof is tied down with 3 additional guy ropes that are looped over the roof and tied to sandbags buried into the ground. The base detail is further improved by using two reinforcement bars piercing through the borak column, four small pieces of muli tied on top, and lowering this whole connection to 0.7m below ground (from 0.5m) (see sketch below). The muli rafter have been spaced closer, at 360mm (1.2') centres instead of 450mm (1.5').





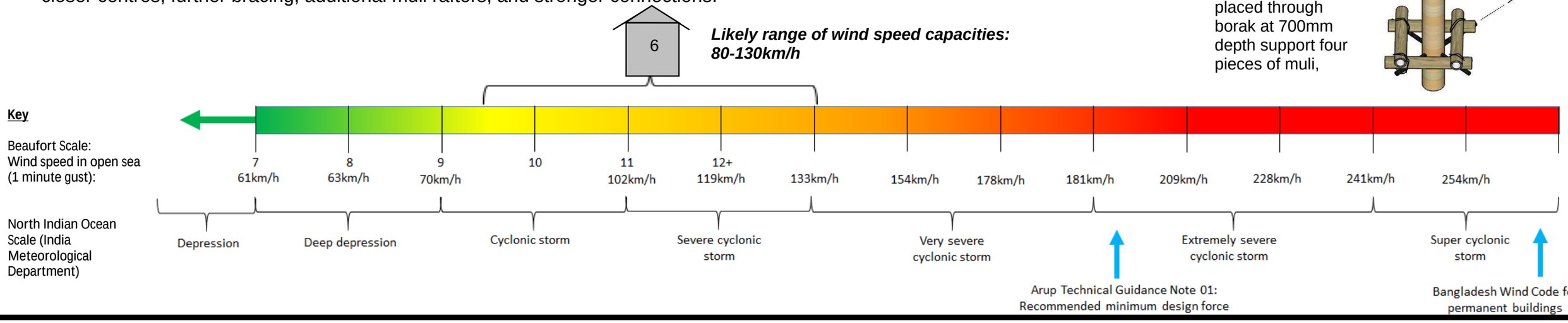
Improved base detail to right: two 12mm steel reinforcement bars placed through borak at 700mm depth support four pieces of muli,

Likely Failure Point

The shelter has now been strengthened to the point where the capacity of most of the elements is similar, and therefore failure may occur anywhere.

Minimum Recommendations

Since the capacity of most of the elements is similar, if a stronger shelter is required, a step change in shelter design is suggested, using for example concrete pad footings for the foundations, borak bamboo columns at closer centres, further bracing, additional muli rafters, and stronger connections.



8. COMMENTARY ON BAMBOO VERSUS ROPE BRACING

This Technical Guidance Note assumes that rope bracing is provided instead of bamboo bracing. This is because bamboo bracing is considered much more difficult to install correctly and therefore will have much lower strength and stiffness. The photos below from Cox's Bazar show typical examples of bamboo bracing. This bracing is largely ineffective in compression and tension for the following reasons:

- The system normally has a lot of slack in tension and compression. The whole building will likely deflect laterally before the bracing kicks in, potentially leading to damage elsewhere before the bracing works.
- Where the connection relies upon friction only (and no rope or peg physically connects the elements together), the rope/twine/wire may slip off the bamboo, as friction by itself is not normally sufficient. This is exacerbated by the fact that the bamboo is normally still "green" during construction, and will therefore dry and shrink, further reducing the friction capacity.
- In compression, the brace needs to be constrained tightly in two directions at the connection for the connection to function. This was generally not seen.
- The experience of the local carpenters in making strong traditional connections in bamboo appears limited.

Rope bracing on the other hand has the following advantages (see photo below):

- It can be pre-tensioned, therefore taking out any slack.
- It is easier to inspect if it has been installed correctly.
- It may be cheaper overall, since one has to use a reasonable quantity of rope for the connections of bamboo bracing anyway.

9. 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.

For further information please contact: **sebastian.kaminski@arup.com** or **international-development@arup.com**

10. DISCLAIMER

1. This guidance is provided for information purposes only. Anyone using this guide must satisfy themselves 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 they 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).

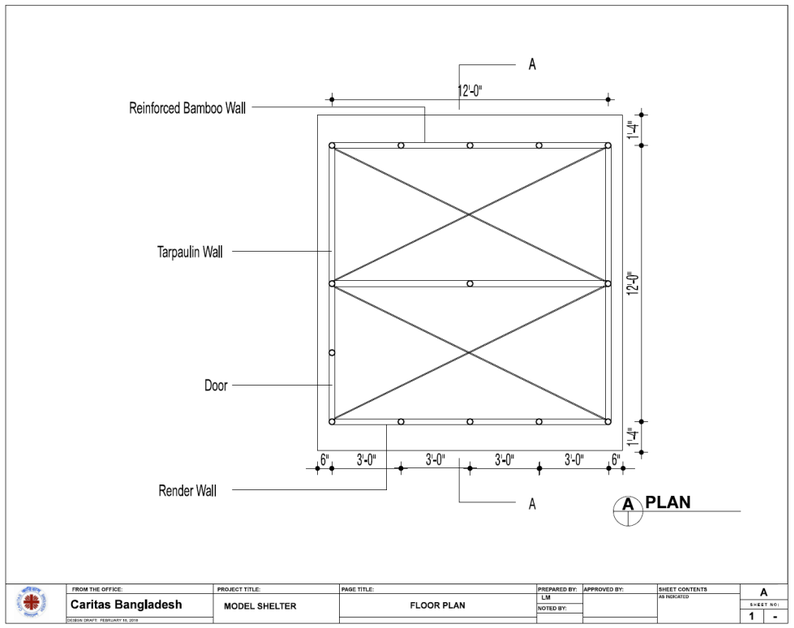
2. This guidance is provided on an “as is” basis, without representation, warranty or indemnity of any kind. To the maximum extent permitted by applicable law, Arup disclaims all representations or warranties – express, implied, statutory or otherwise – including (but not limited to) implied warranties of fitness for a particular purpose, accuracy or validity or completeness of information, merchantability, title, quality, and noninfringement.

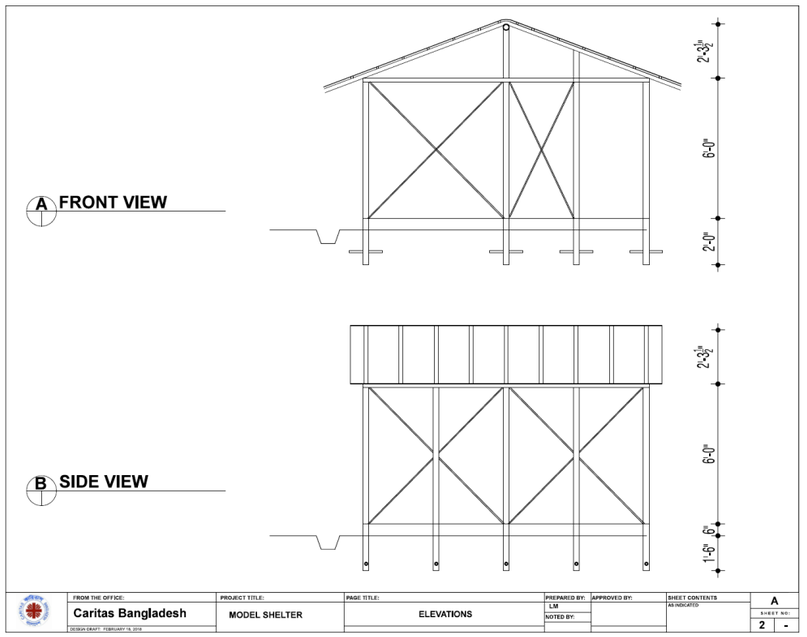
3. You assume full responsibility for any loss resulting from use of or inability to use the information, data or advice in this guidance.

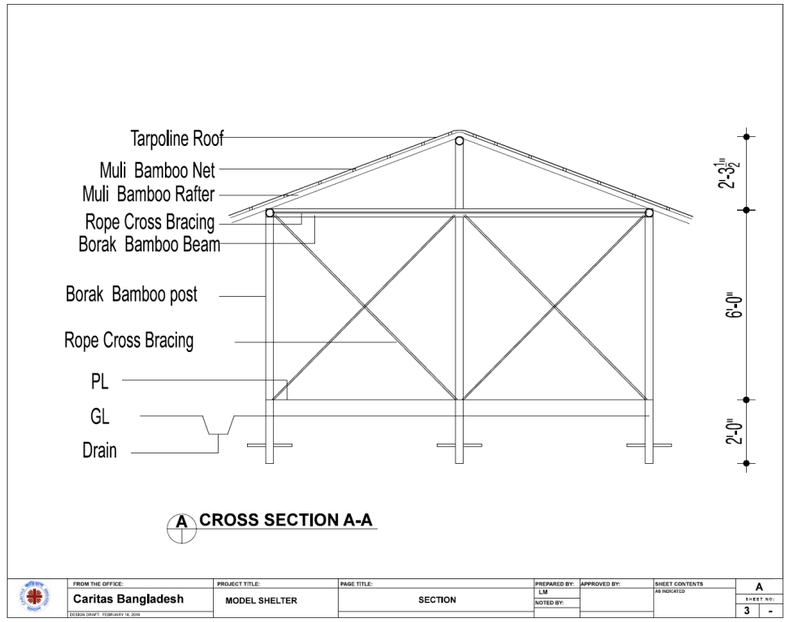
4. Construction is an inherently risky activity. You must ensure you have adequate skills to safely assemble (and disassemble) shelter buildings. You must procure advice from a competent person if there is any doubt as to your own competence to design, assemble, adapt, commission or disassemble emergency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

APPENDIX A1: ORIGINAL DRAWINGS

This Appendix contains the original drawings provided by the Shelter and NFI Sector in Bangladesh, which have formed the basis of the assessment.







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SHELTER/NFI SECTOR

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CARITAS BANGLADESH কারিতাস বাংলাদেশ

CRS CATHOLIC RELIEF SERVICES

christian aid

IOM THE UNITED NATIONS MIGRATION AGENCY

MEDAIR EMERGENCY RELIEF AND RECOVERY

World concern witness the transformation

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