Arup Technical Feedback to CRS/Caritas, IOM and StC, Cox's Bazar, Bangladesh

Technical mission Report: 11-22 January 2018

ARUP

Arup Team and Report Authors

Prepared by: Tom Hallewell (Senior Civil Engineer, T&R, Melbourne)

Seb Kaminski (Senior Structural Engineer, AT&R, London)

Checked by: Seb Kaminski, Tom Hallewell

Report issued: 13th February 2018 – ISSUE

Funded and supported by the Disaster Response and Recovery Fund, Community Engagement, Arup

Contents

1) Scope of report

ARUP

Scope

- Arup sent a team of 3 persons to work closely with the Shelter Sector and associated international NGOs scope out the situation on the ground, provide training on bamboo construction and provide technical support.

- This support took the form of site visits with observations on shelter construction and site improvement works shared with iNGO colleagues as well as two workshops related to enhancing the quality and durability of structures in Bamboo.

- This Memo summarises Arup's comments on use of bamboo in general, shelters, community buildings, footbridges, stormwater drainage and slope stability and retaining walls.

Recommendation levels

In order to assist in prioritisation, each of the observations in this report have been categorised in terms of: a) the benefit they provide and b) the ease and cost of achieving them. Both of these take into account the *current* context in CXB.

SIGNIFICANT	Significant benefit / step change in performance
AVERAGE	Average benefit / reasonable change in performance
SMALL	Small benefit / small change in performance

EASY	Easy to do at little to no extra cost
MODERATE	Moderately easy to do with some additional cost
DIFFICULT	More difficult to do (but still perfectly doable) and may cost considerably more

2) Use of bamboo in general

ARUP

Summary

- Bamboo currently being used is particularly vulnerable to insects (termites and beetles) and rot, and will likely last ~6 months in soil contact, 0.5-4 years outside exposed to rain, and 2-6 years internally.
- Simple measures can improve its resistance to beetles and rot.
- More complex measures can considerably improve its resistance to beetles, termites and rot.

(i) Harvest mature bamboo

SMALL

DIFFICULT

- Mature bamboo is stronger and more durable than immature bamboo. Growing bamboo is typically mature after 3-4 years, and after around 6 years it is more likely to have been attacked by insects and rot, so the window for harvesting is ~4-6 years. Some immature bamboo has been spotted on site.

- Harvest by an experienced professional in a sustainable manner to ensure the clump is not damaged.

The greener bamboo in the image is believed to be an indication that it is immature

(ii) Treat bamboo by soaking in water

AVERAGE

MODERATE

- Bamboo is very susceptible to termites and beetles and is currently being used untreated. Soaking in water (also known as leaching) removes some of the sugars, making it less susceptible to beetle attack (does not protect against rot or termites).

- To treat by water soaking, puncture the nodes of the culm or drill two holes into each internodal region, submerge the culms entirely in water (can be fresh, stagnant or saline) for ideally 6-8 weeks. Season (dry) after treating → see (iii).

Left: beetle attack in camp; Middle: termite attack in camp

Right: example of soaking in water in India

(iii) Season (dry) bamboo before use

AVERAGE

DIFFICULT

- Seasoning (also known as drying) bamboo makes it stronger and more durable. Bamboo is currently being used green (unseasoned). To season, dry for as long as possible in a covered and protected area, elevated above the ground, and allowing natural ventilation in and in-between the culms. Air drying will take 2-3 months, but even partial drying will be beneficial.

Above: partial seasoning of bamboo left outside but stacked such that air can flow around culms and rainwater drips off

Right: drying of bamboo in a solar kiln made from a steel shack

(iv) Consider boron treatment in future

SIGNIFICANT

DIFFICULT

- Boron is a cost-effective, easy to apply and safe treatment chemical that is effective against termites and beetles. In CXB it is best applied using a cold or hot (50+ degrees) water bath, the former will take 7-14 days to treat, the latter 7 hours. It will increase the cost of bamboo considerably, however if the bamboo is kept dry then boron treated bamboo will last indefinitely. Boron is available in Bangladesh.

Above: empty shrimp hatcheries that could be used for boron bath treatment of bamboo

Right: hot water boron treatment in Colombia

ARUP

3) Shelters

ARUP

Summary

- Current shelters have a very short lifespan and are vulnerable to strong winds
- Simple measures can considerably improve their behaviour in winds
- More complex measures can considerably improve the resistance to rot and insect attack
- Measures to improve the durability of bamboo should be considered, as discussed in Section 2.

Recommend at least water soaking and seasoning.

- Two storey structures are strongly discouraged

(i) Use rope and holes/pegs for connections

SIGNIFICANT

EASY

- Many existing connections are weak and loose, can easily slip off, and the use of plastic packaging strips isn't very strong.

- Recommend making holes in each element connecting, and using rope to connect everything together. It is cheap, easy and relatively quick to install, hard to go wrong, easy to check quality.

Above: existing connection using plastic packaging strips which is very loose

Right: new connection using rope with holes in each incoming element

ARUP

(ii) Add diagonal rope bracing to walls

SIGNIFICANT

EASY

- Bamboo vertical bracing not really engaged in tension or compression in the end connections, so very little capacity. Relying upon columns cantilevering, which is of varying depth, and may rot in as little as 6 months.

- Recommend adding vertical rope X-bracing. Cheap, easy to install, hard to go wrong, easy to check quality. Easy to add to new and existing shelters.

Above: diagonal bracing has very little if any capacity because of the weak and loose connections at each end

Right: new connection using rope is much stronger

ARUP

(iii) Improve carpentry connections

SMALL

EASY

- Traditional bamboo cuts are very simple and not able to connect elements of the same size, often resulting in splitting.

- Recommend teaching carpenters the improved “fish mouth” technique, where the edges of both sides are cut down so that the other piece of bamboo sits snugly.

Above: ill-fitting bamboo connection

Right: The bamboo on the left uses the traditional cut, which results in a weaker connection that is likely to split. The bamboo on the right uses the improved cut, resulting in a stronger connection that is much less likely to split.

(iv) Stronger eaves beams

SIGNIFICANT

MODERATE

- Currently both existing shelters and shelter upgrades are using small diameter bamboos for the eaves – the eaves beam is normally heavily loaded in a cyclone, and should be stronger.

- Recommend using larger borak for the eaves beams.

Above: small diameter or split bamboo being used for eaves is weak
Right: large diameter borak stronger for eaves on all four sides

ARUP

(v) Simpler roof

AVERAGE

EASY

- Currently large diameter borak being used in roof as rafter has little added benefit. Double layer of muli also has little added benefit.

- Recommend remove borak from rafters, only use muli for rafters, have them closer spaced,, and no need for purlins.

- Recommend using larger borak for the perimeter eaves, columns and ridge.

Above: borak as rafter has little benefit, double layer of muli has little benefit

Right: using closer spaced muli for rafters and having no purlins is simpler and gives better performance

(vi) Add plan rope bracing in roof or eaves plane

SIGNIFICANT

EASY

- Currently none or ineffective bracing in roof. Eaves and gable end beams are likely to fail in strong wind.

- Recommend adding horizontal plan rope X-bracing to break up spans of eaves and gable ends.

Above: none or ineffective bracing seen in shelters

Right: rope tension plan bracing at eaves level

ARUP

(vii) Protect frame from rain

SIGNIFICANT

EASY

- Bamboo will rot if exposed to driving rain. Protect using plastic sheeting or woven bamboo/split bamboo matrix.

Left: external bamboo fully exposed to rain

Right: split bamboo matrix used as sacrificial façade to protect external bamboo column from driving rain

ARUP

(viii) Build long overhangs or verandas

SIGNIFICANT

DIFFICULT

- Walls can be protected from driving rain by long overhangs or verandas. Although these may be blown away in a cyclone, they protect the wall from rain.

Left: bamboo walls fully exposed to driving rain due to very small overhang

Right: long overhang protecting the wall, with support from external bamboo columns

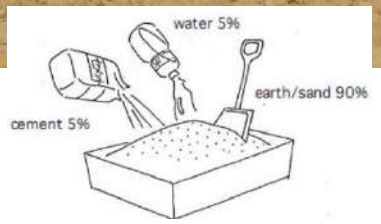
(ix) Plaster walls with mud

AVERAGE

EASY

- Plastering the wall matrix with mud is a natural shelter upgrade. It provides a shelter which is cooler in the summer, more solid, more privacy and provides some protection for the bamboo matrix from rain. Also provides some protection against fire.

- Mud plaster can be cement stabilised (using cement or lime) which notably increases durability.



Above left: existing registered camp with mud wall upgrade

Above right: mud wall shelter in expanded camp

Right: suggested mix for cement stabilised mud

ARUP

(x) Raise building on plinth

SMALL

MODERATE

- Flooding in the monsoon is very likely to occur. Raising the buildings on a small mud plinth will provide some protection against localised flooding.

- Plinth can be cement stabilised which notably increases durability.

Traditional bamboo and mud house in India, with raised plinth to protect against flooding

ARUP

(xi) Use RC foundations

SIGNIFICANT

DIFFICULT

- Bamboo when placed into the ground in CXB will likely last between 6 months and 1-2 years before it fully rots. **CASTING BAMBOO IN CONCRETE AND PAINTING TAR WILL NOT PROVIDE ANY ADDITIONAL PROTECTION AND MAY MAKE THE BAMBOO ROT FASTER**. This will make it much weaker in a cyclone and will require periodic replacement.

- A simple RC footing that raises the bamboo above the ground will keep the bamboo dry and significantly improve it's life. The connection between the footing and the bamboo could be a bolt, rebar or rope.

Left: placing bamboo directly into the ground, even if painted in tar and/or cast into concrete, will only last 6-24 months

Right: raising the bamboo above the ground on an RC footing will significantly improve its life

(xii) Avoid two-storey shelters

SIGNIFICANT

EASY

- There are suggestions of building two-storey shelters. These are strongly discouraged because: the experience of using bamboo well in the camp is low, and a two storey shelter is considerably more dangerous in winds, flooding and rot.

Left: shelter on stilts in camp, which is poorly constructed and has no vertical bracing. This is very vulnerable to wind, rot and flooding.

Right: trial two storey shelter in UNHCR compound. Experience of using bamboo is evidently low, and constructing these is likely to significantly increase the vulnerability of people.

4) Community buildings (schools, child friendly spaces, mosques)

ARUP

Summary

- Current buildings are generally significantly more vulnerable to strong winds than shelters. Some structures may be unsafe in even small winds and may fail entirely, particularly mosques and some constructed by some inexperienced NGOs.

- Simple measures can considerably improve their behaviour in winds. It is strongly recommended to add vertical and plan rope cross-bracing as a retrofit to many of the existing buildings. It is strongly recommended to add additional internal vertical columns to some of the existing buildings with longer spans. As a general rule, we would suggest that: a) ensuring borak does not span more than 3m as a beam or perimeter column, and; b) ensuring that the spacings in-between beams or columns is no more than 1m, will lead to a sensible structure (note this will still not be sufficient to be “code compliant”.

- More complex measures can considerably improve their resistance to rot and insect attack.

- Measures to improve the durability of bamboo should be considered, as discussed in Section 2. Recommend at least water soaking and seasoning – also consider boron.

Summary

- Just prior to a hurricane, the roofs of the larger structures missing internal walls (mosques and those constructed by other NGOs) should be removed; other buildings could have new temporary internal vertical bracing added.
- Consider strengthening/constructing community centres as cyclone-resilient buildings.

(i) Use rope and holes/pegs for connections

SIGNIFICANT

EASY

- Many existing connections are weak and loose, can easily slip off, and the use of plastic packaging strips isn't very strong.

- Recommend making holes in each element connecting, and using rope to connect everything together. It is cheap, easy and relatively quick to install, hard to go wrong, easy to check quality.

Above: existing connection using plastic packaging strips which is very loose

Right: new connection using rope with holes in each incoming element

(ii) Add diagonal rope bracing to walls

SIGNIFICANT

EASY

- Bamboo vertical bracing not really engaged in tension or compression in the end connections, so very little capacity. Relying upon columns cantilevering, which is of varying depth, and may rot in as little as 6 months.

- Recommend adding vertical rope X-bracing. Cheap, easy to install, hard to go wrong, easy to check quality. Easy to add to new and existing buildings.

Above: diagonal bracing has very little if any capacity because of weak and loose connections at both ends

Right: new connection using rope is much stronger

(iii) Improve carpentry connections

AVERAGE

EASY

- Traditional bamboo cuts are very simple and unable to connect elements of the same size, resulting in splitting.

- Recommend teaching carpenters the improved “fish mouth” technique, where the edges of both sides are cut down so that the other piece of bamboo sits snugly.

Above: ill-fitting bamboo brace

Right: The bamboo on the left uses the traditional cut, which results in a weaker connection that is likely to split. The bamboo on the right uses the improved cut, resulting in a stronger connection that is much less likely to split.

(iv) Stronger eaves beams

SIGNIFICANT

MODERATE

- Small diameter bamboos seen in some eaves – the eaves beam is normally heavily loaded in a cyclone, and should be stronger.

- Recommend using larger borak for the eaves.

Above: small diameter or split bamboo being used for eaves is weak.

Right: large diameter borak is stronger for eaves on all four sides

(v) Simpler roof

AVERAGE

EASY

- Currently large diameter borak being used in roof as rafter has little added benefit. Double layer of muli also has little added benefit.

- Recommend remove borak from rafters, only use muli for rafters, have them closer spaced,, and no need for purlins.

- Recommend using larger borak for the perimeter eaves, columns and ridge.

Above: borak as rafter has little benefit, double layer of muli has little benefit

Right: using closer spaced muli for rafters and having no purlins is simpler and gives better performance

(vi) Add plan rope bracing in roof or eaves plane

SIGNIFICANT

EASY

- No or ineffective plan bracing in roof or eaves. Eaves and gable end beams likely to fail in strong wind.

- Recommend adding horizontal plan rope X-bracing to break up spans of eaves and gable ends.

Above: no or ineffective plan bracing seen in shelters

Right: rope tension plan bracing at eaves level

(vii) Protect frame from rain

SIGNIFICANT

EASY

- Bamboo will rot if exposed to driving rain. Protect using plastic sheeting or woven bamboo/split bamboo matrix.

Left: external bamboo fully exposed to rain

Right: split bamboo matrix used as sacrificial façade to protect external bamboo column from driving rain

(viii) Build long overhangs or verandas

SIGNIFICANT

MODERATE

- Walls can be protected from driving rain by long overhangs or verandas. Although these may be blown away in a cyclone, they protect the wall from rain.

Left: bamboo walls fully exposed to driving rain due to very small overhang

Right: long overhang protecting the wall, with support from external bamboo columns

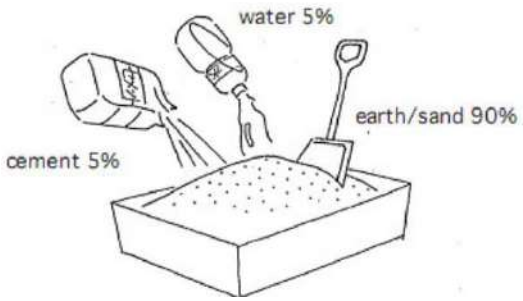
(ix) Plaster walls with mud

AVERAGE

EASY

- Plastering the wall matrix with mud is a natural building upgrade. It provides a building which is cooler in the summer, more solid, more privacy and provides some protection for the bamboo matrix from rain. Also provides some protection against fire.

- Plaster can be cement stabilised (using cement or lime) which notably increases durability.



Top: suggested mix for cement stabilised mud

Right: existing registered camp with mud wall upgrade

ARUP

(x) Raise building on plinth

SMALL

MODERATE

- Flooding in the monsoon is very likely to occur. Raising the buildings on a small mud plinth will provide some protection against localised flooding.

- Plinth can be cement stabilised which notably increases durability.

Traditional bamboo and mud house in India, with raised plinth to protect against flooding

ARUP

(xi) Use RC foundations

SIGNIFICANT

MODERATE

- Bamboo when placed into the ground in CXB will likely last between 6 months and 1-2 years before it fully rots. **CASTING BAMBOO IN CONCRETE AND PAINTING TAR WILL NOT PROVIDE ANY ADDITIONAL PROTECTION AND MAY MAKE THE BAMBOO ROT FASTER**. This will make it much weaker in a cyclone and will require periodic replacement.

- A simple RC footing that raises the bamboo above the ground will keep the bamboo dry and significantly improve it's life. The connection between the footing and the bamboo could be a bolt, rebar or rope.

Left: placing bamboo directly into the ground, even if painted in tar and/or cast into concrete, will only last 6-24 months.

Right: raising the bamboo above the ground on an RC footing will significantly improve it's life

(xii) Avoid two-storey buildings

SIGNIFICANT

EASY

- There are suggestions of building two-storey buildings. These are strongly discouraged because: the experience of using bamboo well in the camp is low, and a two storey building is considerably more dangerous in winds, flooding and rot.

Left: shelter on stilts in camp, which is poorly constructed and has no vertical bracing. This is very vulnerable to wind, rot and flooding.

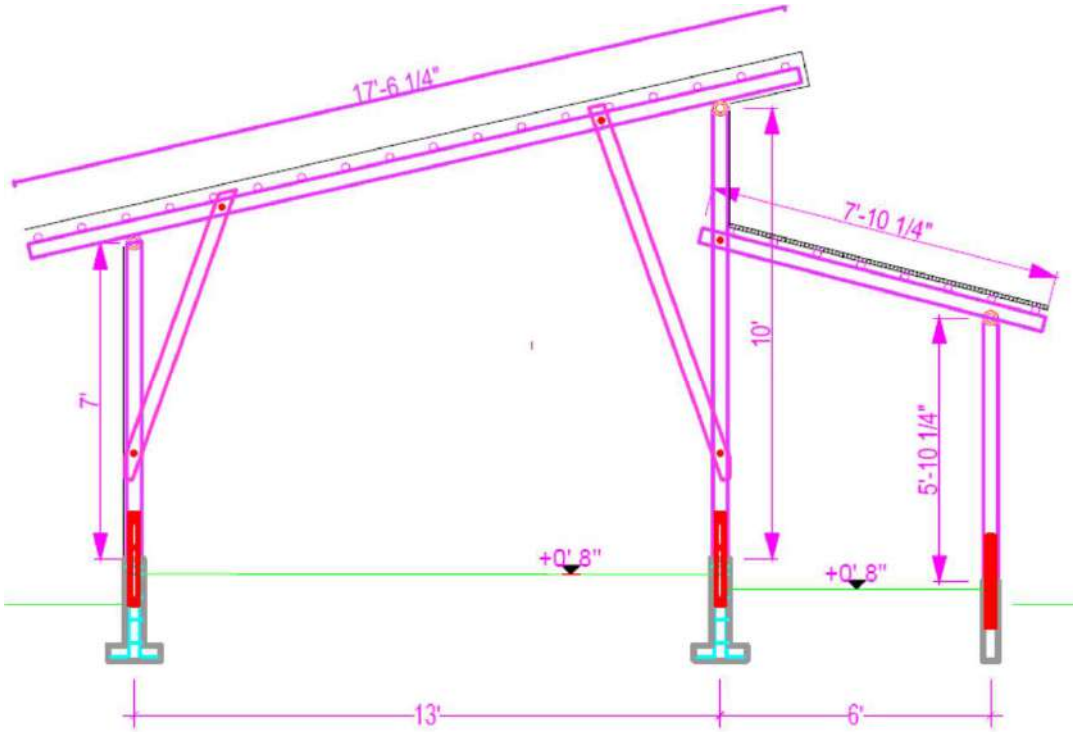
Right: trial two storey shelter in UNHCR compound. Experience of using bamboo is evidently low, and constructing these is likely to significantly increase the vulnerability of people.

(xiii) Ensure lateral stability in short direction

SIGNIFICANT

MODERATE

- Some buildings missing internal walls and have limited lateral stability in short direction.
- Recommend adding internal braced walls (best scenario), or use closely spaced bamboo portal (haunched) frames.



Left: building missing stability in short direction

Right: Save the Children's design using portal frames in short direction

ARUP

(xiv) Add internal columns to break span

SIGNIFICANT

EASY

- Some buildings have long spans which means the frames have very little extra capacity under wind.

- Recommend adding internal columns to break span, which improves ability of building to resist both gravity and wind loads. 3m is a sensible maximum span for a borak roof beam.

Left: OBAT's community buildings have very long spans without internal walls or any bracing

Right: internal columns break spans and increase building's capacity in winds

(xv) Reduce distance between columns and primary beams to </=1m and avoid bunched columns and beams

SIGNIFICANT

EASY

- Columns and primary beams should ideally be spaced at centres </=1m, which increases the capacity of the buildings to resist wind loads. There is no advantage structurally to bunching culms together to form a single element – it is better to spread out the individual culms.

Left: building with bunched columns spaced >1m apart

Right: building with columns separated and closer to ~1m apart

(xvi) Develop building alteration plan for cyclones

SIGNIFICANT

EASY

- Recommend developing alteration plan for larger community buildings for cyclones, such as:
  - Install internal vertical bracing prior to cyclone
  - Remove entire roof prior to cyclone

Large mosque with no internal bracing and long roof spans. This is likely to completely fail in even small winds.

(xvii) Consider strengthening/building community shelters as cyclone shelters

SIGNIFICANT

DIFFICULT

- Community shelters could become significantly more resilient by: treating bamboo as described in Section 2, reducing spacing of primary bamboo elements, tying connections together as described in Section 4, adding vertical and plan bracing as described in Section 4, adding RC footings as described in Section 4, adding internal columns and braced walls as described in section 4, and using CGI sheeting for wall and roof.

5) Footbridges

ARUP

Summary

- Current bridges are vulnerable to strong winds and high water flows.
- Simple measures can considerably improve their structural integrity. It is strongly recommended to add vertical and plan rope cross-bracing as a retrofit to existing footbridges.
- More complex measures can considerably improve their resistance to rot and insect attack.
- Measures to improve the durability of bamboo should be considered, as discussed in Section 2. Recommend at least water soaking and seasoning – also consider boron.
- Prior to high rainfall, bridges should be cleared of any debris to reduce risk of bridge collapse and localised flooding.
- Alternative bridge material/design (e.g. suspension bridge) could be considered for strategic locations or areas of high flood risk.

(i) Use rope and holes/pegs for connections

SIGNIFICANT

EASY

- Many existing connections are weak and loose, can easily slip off, and the use of plastic packaging strips isn't very strong. Rope is stronger.

- Recommend making holes in each element connecting, and using rope to connect everything together. Cheap, easy to install, relatively quick to install, hard to go wrong, easy to check quality.

Top: existing bridge connection using metal wire which is weak and loose

Right: new connection using rope with holes in each incoming element

(ii) Add diagonal rope bracing to bays

SIGNIFICANT

EASY

- Bamboo vertical bracing not really engaged in tension or compression in the end connections, so very little capacity. Relying upon columns cantilevering, which is of varying depth, and may rot in as little as 6 months.

- Recommend adding vertical rope X-bracing. Cheap, easy to install, hard to go wrong, easy to check quality. Easy to add to new and existing bridges.

Above: diagonal bracing has very little if any capacity because of weak and loose connections at end

Right: new connection using rope is much stronger

(iii) Improve carpentry connections

AVERAGE

EASY

- Traditional bamboo cuts are very simple and unable to connect elements of the same size, resulting in splitting.

- Recommend teaching carpenters the improved “fish mouth” technique, where the edges of both sides are cut down so that the other piece of bamboo sits snugly.

Above: ill-fitting bamboo brace

Right: The bamboo on the left uses the traditional cut, which results in a weaker connection that is likely to split. The bamboo on the right uses the improved cut, resulting in a stronger connection that is much less likely to split.

(iv) Protect frame from rain

SIGNIFICANT

EASY

- Bamboo will rot if exposed to driving rain. Protect using plastic sheeting or woven bamboo/split bamboo matrix.

Above: existing bridges are completely exposed to rain

Right: use split bamboo matrix or similar as sacrificial façade to protect external bamboo column from driving rain

(v) Use RC foundations

SIGNIFICANT

MODERATE

- Bamboo when placed into the ground in CXB will likely last around 6-12 months before it fully rots, even if painted in tar and/or cast into concrete. This will make it much weaker in a cyclone and will require periodic replacement.

- A simple RC footing that raises the bamboo above the ground will keep the bamboo dry and significantly improve it's life. The connection between the footing and the bamboo could be a bolt, rebar or rope.

Left: placing bamboo directly into the ground, even if painted in tar and/or cast into concrete, will only last 6-12 months.

Right: raising the bamboo above the ground on an RC footing will significantly improve it's life

(vi) Avoid nailing into bamboo

SMALL

EASY

- Bamboo tends to split if nailed into, especially if that piece is then fully exposed to rain.
- Avoid nailing and instead use rope to tie bamboo decking down.

Nailing bamboo decking down will very likely split it, reducing it's lifespan. Tying down with rope is better

(vii) Avoid creating watercourse blockage

AVERAGE

EASY

- Closely spaced bridge supports increased the risk of debris collecting against the structure. This increases the lateral load on the bridge in high river flows, increasing the risk of failure. Debris around the bridge will also reduce river flows leading to increased risk of localised flooding.

- Existing bridges should be well maintained and any debris should be removed regularly and prior to any significant rainfall.

- New bridges should consider wider column spacing over watercourse, subject to adequate structural design of bridge to ensure adequate stability.

- Strategic footbridges could consider suspension bridge.

Bamboo bridge with closely spaced supports

6) Stormwater drainage

ARUP

Summary

- Much of the camp lacks adequate drainage which poses a localised flood risk households and community building, as well as larger scale erosion and potential for landslides.
- Localised drainage channels help to mitigate issues at an individual house level but need to ensure flows are controls to avoid erosion, maintained to avoid blockage and located below ground level.
- Any drainage interventions should take into account larger scale catchment issues, especially impacts on downstream flood risk.
- A site-wide drainage strategy should be developed in conjunction with ongoing flood risk mapping.

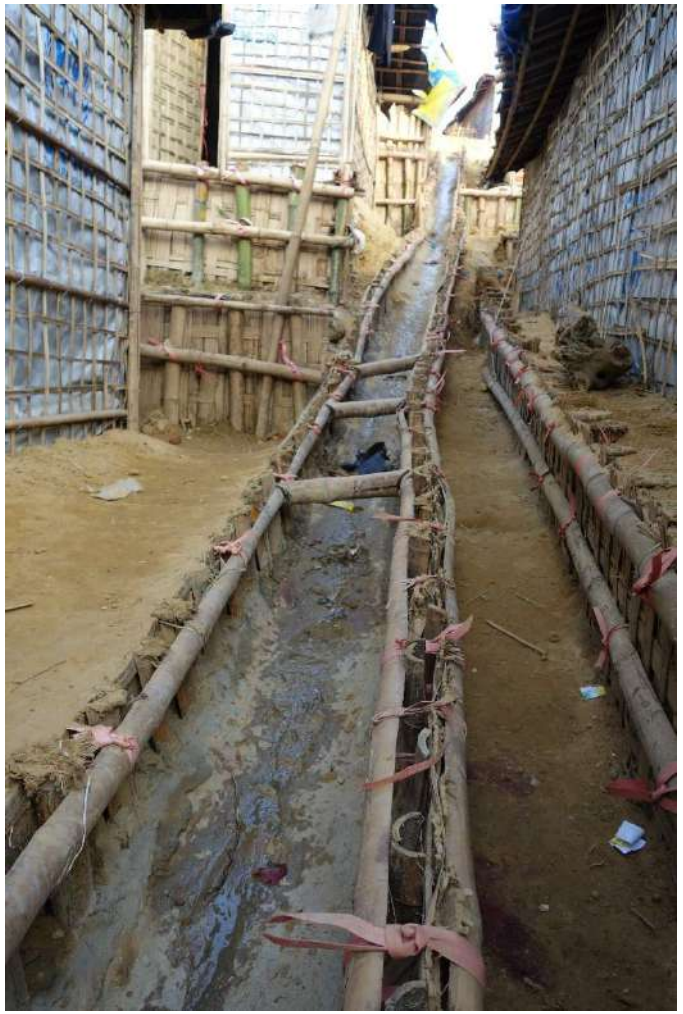
(i) Avoid steep drainage channels & control flow

AVERAGE

EASY

- Some drainage channels have been constructed using long steep sections. This increases water velocity which increases the likelihood of scouring/erosion of channels and localised flooding at changes in direction and potentially larger flooding downstream.

- Long steep drainage channels should be avoided. Existing channels could be retrofitted with check dams every 5-10m to reduce flow velocity. These could be made from bricks cast into the channel (if channel is thick enough) or cement stablised sand bags. Any check dams require regular maintenance to remove debris.



Right: Steep drainage channel resulting in scouring/erosion and flooding

(ii) Smoother drainage & reinforce key locations

AVERAGE

EASY

- Some drainage channels have rapid changes in direction which are prone to erosion in high flows, leading to localised flooding.

- Sudden changes in direction where high flows are expected (bottom of steep channel or lower section of catchment) should be reinforced with more durable material such as brick or cement stablised sand bags.

- Use of more gradual changes in direction reduce risk of erosion.

Above: Sudden changes in channel direction susceptible to erosion

Right: Smoother change in direction with sand bag reinforcement

(iii) Ensure drainage is below building threshold

AVERAGE

MODERATE

- Some footpaths and building plots are missing adequate drainage creating a risk of flooding within buildings.

- Buildings should be located on plinths where possible. Drainage channels should be installed either at plot level below the building threshold and/or at the downstream end of higher terraces.

Flood risk to shelter due to lack of drainage below threshold. Raise building on plinth, install channel below ground level or channel at downstream side of footpath

(iv) Ensure drainage walls finish at ground level

AVERAGE

EASY

- Some drainage channels have raised walls. This limits how easily water can drain into the channel and if at capacity results in localised flooding unless channel is perfectly watertight.

- Ensure drainage channels walls are flush to ground level.

Above: Raised drainage channel limiting water entry and overall capacity in high flow

Above: Flush channel allowing easy water entry and ensuring better capacity due to greater below ground depth.

(v) Improve durability of channel lining

AVERAGE

MODERATE

- Some drainage channels are lined with a thin cement plaster. This has a limited lifespan and in some areas has already started to erode.

- Flow velocities should be minimised to prevent scour. Channels should repaired as soon as possible to avoid further damage.

- Cement liner should be thickener in high flow areas. Alternative channel construction could be considered (cement rendered brick or cement stabilised sand bags)

Above/right: Damage to cement lined drainage channels

Right: Option for more robust drainage channel in strategic locations

(vi) Ensure drainage channel maintenance

AVERAGE

EASY

- Some drainage channels have built up with debris. This causes localised flooding, and increases potential health risks.

- Channels should be cleared of debris wherever possible.

Debris collection along drainage channel

ARUP

(vii) Avoid bamboo for drainage channels

SIGNIFICANT

MODERATE

- Some drainage channels have been built using bamboo which offers limited durability (6-12 months).

- Consider use of man-made material that are more durable e.g. cement stablised sand bags or cement rendered brick channels.

- Cut bamboo such that exposed piece is cut near the node, hence water cannot easily collect in the end.

Bamboo drainage channel

7) Slope stability and retaining walls

ARUP

Summary

- The undulating topography of the camps has driven extensive use of retaining walls. Poor quality wall materials poses a high risk of localised failures. Larger scale deforestation and inadequate drainage poses a risk of larger scale landslides.

- More efficient plot earthworks, shorter steeper walls with adequate drainage and improved wall material (e.g. stabilised sand bags and vegetation) will significantly improve the current situation, although will not address the larger scale landslide risk.

- Landslide hazards need to better understood through geotechnical investigation and more detailed hazard mapping. Development of steep slopes should be avoided. Careful consideration of global slip failure is required for any development on slopes.

(i) Limit retaining wall height

SIGNIFICANT

EASY

- Some large retaining walls have been constructed. This increases the risk of failure due to higher loads and potential impact due to larger soil volume retention.

- Avoid building retaining walls greater than 1-1.5m high and use stepping to deal with larger level differences.

Stepped bamboo retaining wall

(ii) Use improved sand bags

SIGNIFICANT

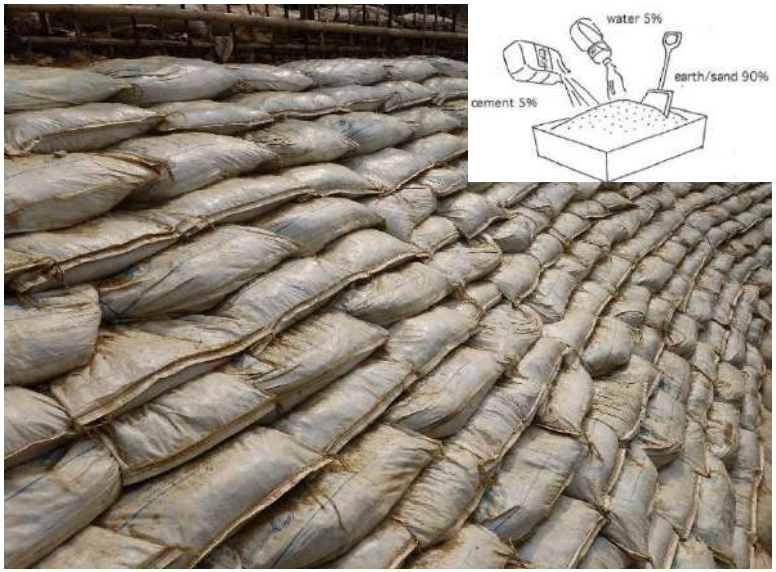
MODERATE

- Most sand bags are of poor quality and quickly deteriorate, leaving no slope protection and an increased risk of erosion and failure.

- Use better quality sand bags (rot proof hessian or heavy duty plastic). Use stablised material in facing of wall to create residual stability after sand bag degrades. Use cement to stabilise sandy material and lime to stabilise clayey material.

- Consider seeding and planting walls to provide natural earth retention.

Above: rapid degradation of sand bags and failure of slope



Above: consider better quality bags, stablised fill material and planting

ARUP

(iii) Establish natural slope stabilisation

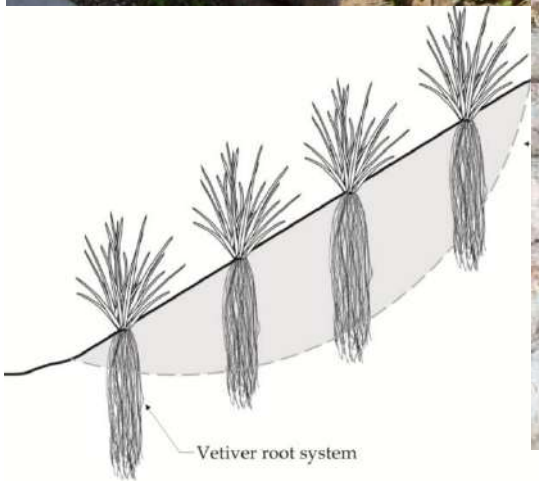
SIGNIFICANT

MODERATE

- Mass deforestation, construction on steep slopes and high rainfall drives risk of localised and large-scale landslides.

- Consider re-vegetation wherever possible to assist with slope stabilisation.

Above: Loss of natural slope stabilisation increases risk of landslides



Above: consider seeded sand bags and replanting slopes

ARUP

(iv) Consider durability of bamboo walls

AVERAGE

MODERATE

- Some retaining walls have been constructed using untreated bamboo. This is likely to last 6-12 months.
- Large, critical walls should avoid using bamboo.
- Consider planting in and around existing bamboo walls.
- Use cement stablised sand bag retaining walls.

Bamboo retaining walls will have limited durability without additional slope stabilisation.

(v) Ensure efficient slope terracing

SIGNIFICANT

MODERATE

- Some terracing for buildings is larger than required, which increases the cost and duration of construction while increasing the risk of landslides.

- Minimise footprint of building perpendicular to slope. Orientate building inline with contours. Avoid construction on steepest slopes. Consider larger scale earthworks.

Above: Buildings should be orientated with long elevation inline with slope to minimise terrace height and extent.

Above: Wider more efficient terracing

(vi) Ensure wall stability

SIGNIFICANT

MODERATE

- Some retaining walls lack adequate anchoring at top and bottom into existing ground, increasing risk of wall collapse.

- Large walls should be tied into slopes with sandbag toes at top and bottom and/or nails to restrain lateral movement – consider limited durability of using bamboo nails.

Above: Sand bag retaining wall without adequate anchoring to slope

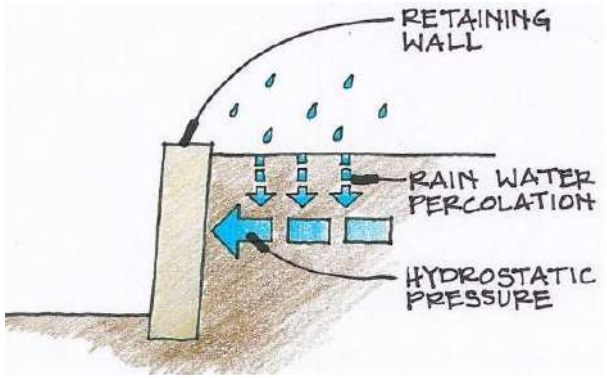
Above: Ensure large walls are tied to slope with footings and/or nails

(vii) Consider wall drainage

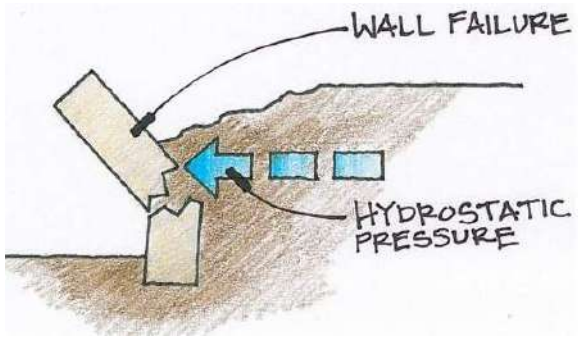
SIGNIFICANT

EASY

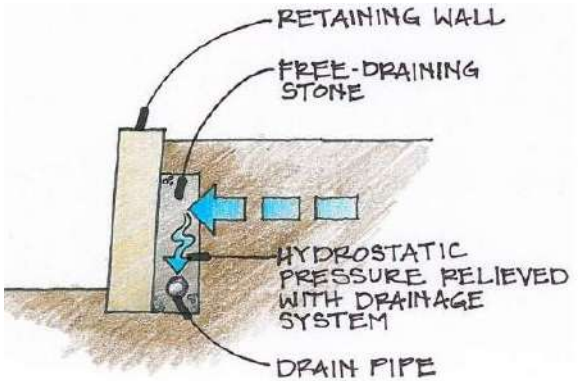
- Build up of water behind retaining walls increases the hydrostatic pressure which can lead to failure.
- Avoid collection of rainwater at top of retaining wall.
- Consider use of pipes placed through the wall, buried drainage and/or permeable layers (sand/gravel) behind the wall structure to reduce build-up of water.



Reduce water penetrating into soil behind wall



Increased water pressure behind wall can lead to failure



Drainage behind retaining walls reduces water pressure

ARUP

(viii) Consider slope steepness

SIGNIFICANT

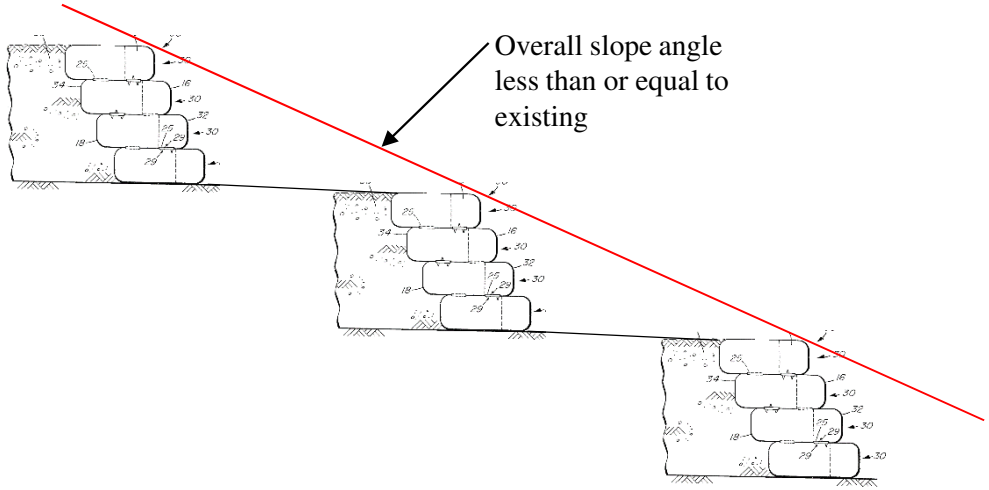
EASY

- Some retaining walls have been constructed at shallow gradients, similar to the surrounding slope. This limits the earth retaining benefit and requires larger, less efficient structures that also increase rainfall runoff. Large, shallow sandbag retaining walls also do not address global slope stability issues.

- Build smaller (1-1.5m) retaining walls to address local level changes and terracing. Ensure walls are steeper than surrounding slopes (but not vertical) and do not increase overall steepness of slope.

- Avoid larger walls and seek further professional advice regarding global scale slope stabilisation

Above: Overly large, shallow wall



Above: Small steep retaining walls

ARUP

(ix) Consider global slope stability

SIGNIFICANT

DIFFICULT

- When constructing on slopes, global stability should be carefully considered.
- Avoid constructing on steep slopes wherever possible.
- Avoid increasing overall slope angle when terracing as this will reduce global stability.
- Consider earthworks that remove soil at top of slope and increase soil at bottom. This reduces the risk of global slip failure.
- Consider slope drainage and avoid water attenuation on slope.
- Seek further professional advice regarding sitewide slope stabilisation strategies.