NATIONAL BUILDING REVIEW BOARD

NBRB

Safe Building, Better Living

GUIDELINES FOR THE DESIGN AND CONSTRUCTION

OF

STRUCTURES WITH STEEL, TIMBER AND CONCRETE

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1. Preamble

Designers and builders who wish to use the three materials of steel, timber and concrete as structural materials in combination, either as independent members or behaving as composite assemblies need to follow basic guidelines to ensure safe and durable structures. The flowchart in Figure 1 illustrates the process that the designer and builder would normally go through to arrive at a satisfactory construction involving the three materials.

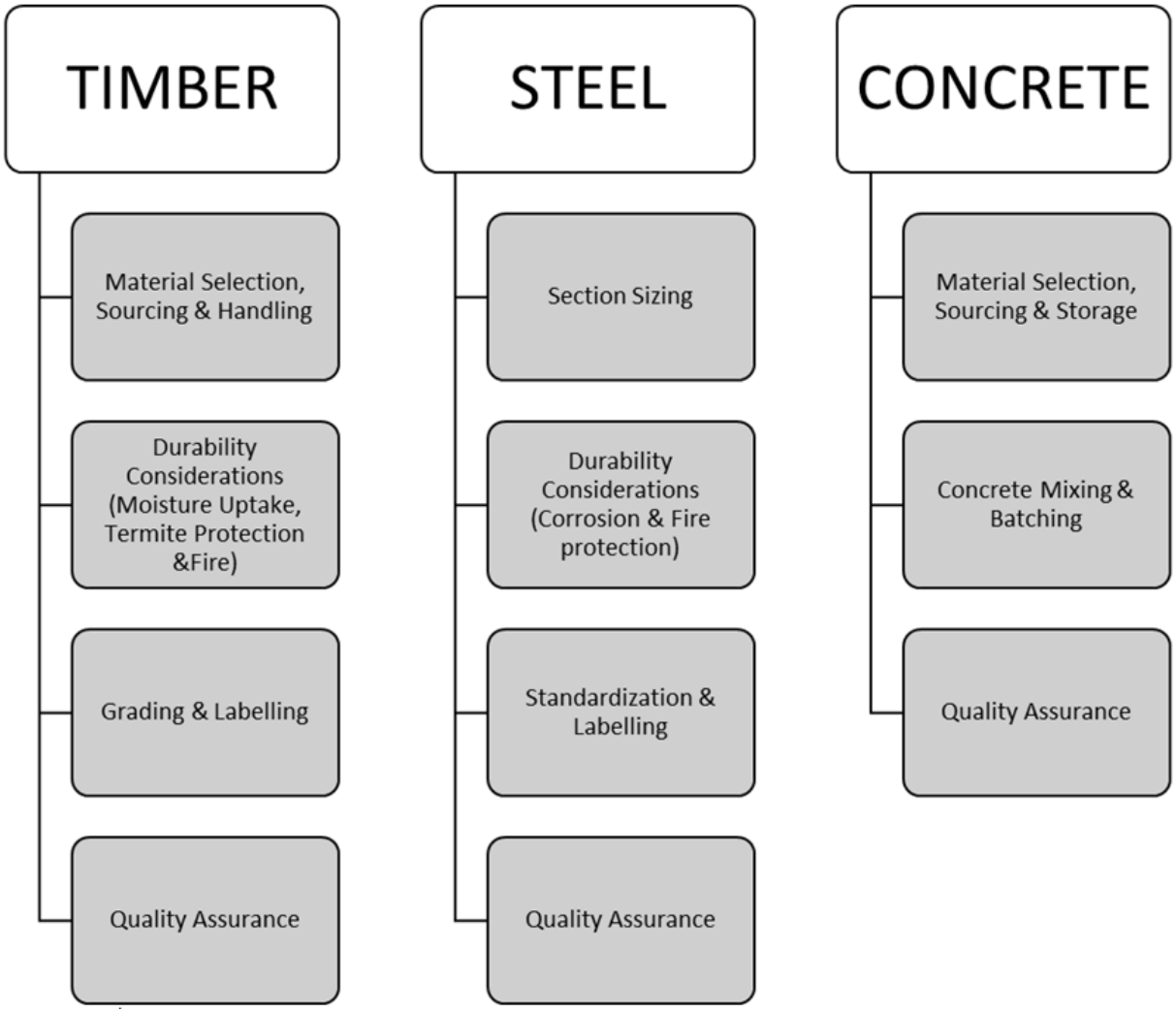


Figure 1:Process flow in the use of the three materials in construction

2. Structural Timber

2.1 Source of Timber

Most of the construction timber in Uganda comes from timber hotspots such as Ndeeba and Bwaise, and smaller ones in urban centres around the country. Timber from these hotspots is normally green (not seasoned) and not graded. It is purchased at varying moisture contents with most pieces still above the Fibre Saturation Point i.e. >30% Moisture Content, without the knowledge of most clients.

Guidelines

i. *Developers should procure structural timber from reputable suppliers who are certified by UNBS or any other authorised regulator/ certification organisation.*
ii. *Developers should procure structural timber that is graded and with a grading certificate, showing the strength properties and nominal sizes*

2.2 Selection and Handling of Structural Timber

Selection of structural timber largely depends on the purpose as this will determine the size, grade and sometimes the species required. For wall cladding and ceiling boards for instance, the visual aspects of timber may be more important than in roof trusses where stress grades and absence of defects may be preferred. Timber should be seasoned to avoid stain, fungal attacks, post harvesting defects, and reduction in strength. Fungi require Moisture Content (MC) above 20% in order to attack wood.

Guidelines

i. *Timber should be seasoned to a maximum of 18% Moisture Content in accordance with US 833-2:2020.*
ii. *Timber should be machine stress graded and marked visibly with the grade.*
iii. *Timber pieces of the same species, grade, and nominal thickness should be packed together in a bundle, and then the bundles properly stacked in store.*

2.3 Keeping Timber Free from Moisture Uptake

Wood can pick up water by absorption when in contact with water or a wet material but it can also pick up moisture by adsorption from humid air and lose moisture by desorption to the surrounding air if the air is relatively drier. It is

expected that seasoned timber members would pick water from wet concrete a few days after casting but later on it is expected to attain the Equilibrium Moisture Content (EMC) with the surrounding environment.

Guideline

A plastic material or any other suitable waterproofing material should be placed between the concrete and timber members to avoid contact of water from wet concrete with seasoned timber as well as from any water leakages before or after the building is occupied.

2.4 Durability Treatment against Termite Attack

Termites are one of the leading agents of wood degradation in service in buildings. They degrade all wood components including cellulose, hemicellulose and lignin.

Guidelines

i. *Ensure that the site is treated with approved anti-termite chemicals.*
ii. *Ensure regular inspection and maintenance of the structures, for timely regular anti-termite treatments.*
iii. *Apply anti-termite treatment to the timber. For structures whose design life is at least 50 years, the timber should undergo pressure treatment with preservatives such as Chromated Copper Arsenate (CCA).*

2.5 Grading and Marking

Grading and Marking is essential for traceability of timber and to allow designers access to available grades of timber and properties for initial design. The Uganda Standards US 833-2:2020 and US 2248: 2021 require that timber conforming to these standards be marked with information including the manufacturer's name, the appropriate stress-grade identification; and the date or the batch number of the stress grading.

Guidelines

i. *Timber suppliers should comply with the US 833-2 and US 2248 requirements and mark their structural timber before dispatch to the market with:*
   - *Manufacturer's name*
   - *Appropriate stress grade*
   - *Date or batch number of the stress grading*

- *Certification body logo or mark*

ii. *Developers should only procure timber that is appropriately marked as advised in (i)*

2.6 Quality Assurance

Uganda has local capacity to test for timber properties and machine stress grading. Laboratories at UNBS, MoWT Central Materials Laboratory and Universities are equipped for the typical tests.

Guideline

Developers and their professionals should sample timber and test in order to verify declared properties of timber as part of the typical quality assurance tests.

3. Use Of Structural Steel

3.1 Section Sizing

Selection of structural steel member section sizes and shapes is dependent on:-

- Actions (loads) that the member is expected to be subjected to during its design life.
- The grade of the steel material.
- The availability of sections on the market.
- Economic and commercial considerations.

The selection of a size of structural steel is solely an output of a design, done by a professional engineer.

Guidelines

i. *Developers should engage professional engineers to design with structural steel as per Reg.5 and Reg.6 of the Building Control Regulations, 2020.*
ii. *Building Committees should only consider applications for approval of developments with structural steel which are accompanied by design calculations and certificates of good structural practice, signed off and stamped by registered (professional) engineers.*
iii. *Structural steel components shall be designed to facilitate fabrication, erection and future maintenance of the works.*

3.2 Durability of Structural Steel- Protection against Corrosion

One of the shortcomings of structural steel is proneness to rusting when in contact with moisture. It is, therefore, important to protect structural steel members against corrosion.

Guideline

Designers should specify protective measures against moisture and air, which are the key agents of corrosion. These could include coatings/barrier methods, encasement of critical elements, galvanisation, electro-plating or use of stainless steel, among others.

3.3 Durability of Structural Steel-Protection against Fire

Fire affects the strength of steel. At temperatures as low as 300 degrees Celsius, steel could lose as much as 50% of its strength. Whereas there may be some residual strength after a fire, usually the connections give way faster than material failure, which is an irreversible failure.

Guideline

Designers should specify protective measures against fire. These could include embedment into or coating with materials that shield the steel against fire exposure, intumescent paints, etc.

3.4 Standardisation and Labelling/Marking

It is important that structural steel is labelled/marked at source, and be accompanied by a mill test certificate declaring the properties of the steel. Structural steel sections, especially hollow sections in Uganda are seldom marked, making it unlikely that designers and developers will know its properties unless they run independent tests. The situation is made worse by the fact that catalogues of most manufacturers are rarely comprehensive enough.

Guideline

Steel manufacturers should label their steel products before marketing with information on: -

- *Grade of steel*
- *Manufacturer*
- *Nominal dimensions*
- *Certification mark*

3.5 Quality Assurance

Uganda has local capacity to test for structural steel properties. Laboratories at UNBS, MoWT Central Materials Laboratory and Universities are equipped for the typical tests.

Guideline

Developers and their professionals should sample and test structural steel in order to verify the declared properties of steel as part of the routine quality assurance tests.

4. Concrete in Construction

4.1 Sourcing, Selection and Storage of Materials

The quality of coarse aggregates, fine aggregates, water and cement binder affects the quality of concrete.

Guidelines

i. *Cement for use in reinforced concrete should have a minimum strength Class 32.5 MPa.*
ii. *Aggregates should be stored under cover to avoid water uptake.*
iii. *Mixing water should preferably be of potable quality, free of algae and clear.*

4.2 Concrete Mixing – Design and Batching

The majority of construction sites use batching by volume, batch per bag of cement, do not measure the amount of water, use CEM IV 32.5 cement, and hardly test the concrete. The Water-Cement ratio significantly affects the strength of concrete.

Guidelines

i. *Industry should use a rigid batching box of size 0.3mx0.3mx0.3m, which shall be taken as equivalent to 1 bag of cement*[1]*.The cement bag need not be poured into batching boxes, to avoid wastage.*
ii. *A maximum water cement ratio of 0.5 should be used with dry aggregates. For 1 bag of cement, a maximum of 25 litres of water should be used for mixing concrete.*

[1] *Considering a bulking factor of cement of 20-25%*

4.3 Quality Control

QUALITY CONTROL PROCESS – CONCRETE

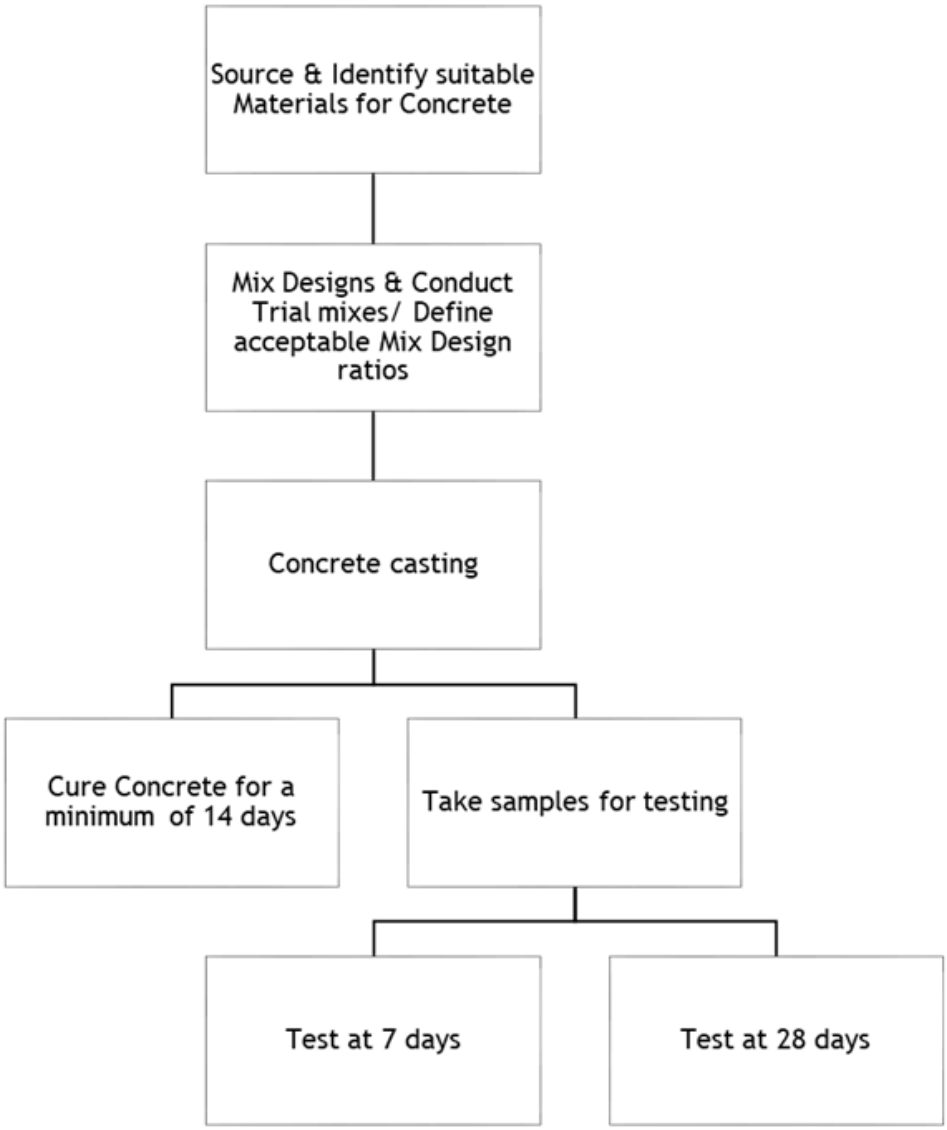


Figure 2: Quality control process for concrete

Guidelines

i. *Supervision for concrete works should be superintended over by a professional, preferably the designer in compliance with Reg.6 of the Building control regulations, 2020.*

ii. *At least 6 Concrete cube samples should be picked for each mix, at least 3 of which should be tested at 7 days. At least another 3 should be tested*

at 28 days.

iii. *Curing of concrete should be done for at least 14 days.*

iv. *Compaction of concrete should be by mechanical means such as poker vibrators.*

v. *For all reinforcing steel, the manufacturer's certificate shall be required as proof of the characteristic strength.*

5. Connections

5.1 Welded Connections

Weld production positions are classified as Flat (F), Horizontal (H), Vertical-Up (V-U), Vertical Down (V-D) or Overhead. A higher skill level is needed for Vertical, horizontal and overhead positions. In actual shop fabrication, welding can be done satisfactorily.

The composition of the base materials affects the strength and quality of a weld. The type of base material influences the choice of filler material/electrode/welding rod.

The choice of filler material/electrode/welding rod is dependent on the thickness of the base materials, and anticipated load. The majority of the welds in Uganda are using 6013 welding rods, which points to lack of design consideration.

Most of the weld connections inspected by the technical committee were single passes and were inadequate. The number of passes and sequence of welding are required before fabrication.

None of the sites inspected by the technical committee were done by certified welders. The lack of readily available skill needed for the connections results in poor quality welds. There are 6 levels of certification of welders (1-3 for artisans, 4 typically for engineers, 5-6 for supervisors).

Guidelines

i. *Weld connections should be designed and specified by a qualified engineer.*
ii. *Developers should adopt shop fabrication as much as possible to avoid quality issues in construction.*
iii. *Developers should obtain a copy of the mill test certificate that shows the chemical composition and grade of the base materials.*
iv. *Weld connections should be supervised by competent inspectors during implementation to ensure quality works.*
v. *The choice of filler material/electrode/welding rod should be a design output by a qualified engineer.*
vi. *Welding should be done by minimum Welding Level 4 certified persons.*
vii. *Engineers should furnish welders and fitters with a welding procedure specification (WPS), which shall describe the type of welding rods to use, how many passes, under what conditions the welding rods*

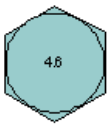
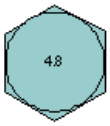
be kept, what interpass temperature should be maintained to minimise interference with mechanical properties of the sections being welded, which fit up gap to be kept, so that there is enough weld penetration.

5.2 Bolted Connections

Bolted connections are a type of structural joint used to join two or more structural components in a steel structure using bolts. The Technical committee did not find any bolted connections in the STC sites that were visited.

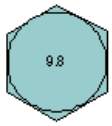
Bolt grades are defined by their specific material, as well as the strength of that material and are designated as shown in Table 1.

Table 1:Metric steel bolts - grades and property classes (ISO 898-1:2013)

`	Head Marking	Size Range *(mm)*	Minimum Proof Strength[2] *(MPa)*	Minimum Tensile Strength[3] *(MPa)*
4.6		M5 - M36	225	400
4.8		M1.6 - M16	310	420
5.8		M5 - M24	380	520
8.8		M1.6 - M36	600	830

[2] *Proof load is the limit of the elastic range of a bolt. If a bolt is tensioned beyond its specified proof load, it can't be used as it experiences plastic deformation.*

[3] *Tensile strength is the amount of stress or load that the fastener can withstand by a material before it stretches and breaks.*

`	Head Marking	Size Range (mm)	Minimum Proof Strength[2] (MPa)	Minimum Tensile Strength[3] (MPa)
				
9.8		M1.6 - M16	650	900
10.9		M5 - M36	830	1040
12.9		M1.6 - M36	970	1220

Guidelines

i. *Bolted connections are the preferred on-site type of connections because of their ease of installation, ease of inspection and speed of installation.*
ii. *Preferably, grade 8.8 bolts should be used for structural applications.*
iii. *Bolts should be tested for proof load and ultimate tensile strength against specifications.*

5.3 Timber to Timber Connections

The connection is mainly beam (primary joist) to secondary joist connection. The same connection is employed for ceilings in Uganda. The beam to joist connection is usually nailed, with the nails inclined at an angle to connect the two members. This is prone to the following failure mechanisms:

- Over time, as the timber dries, the nails become loose.
- If moisture reaches the ceiling the nails may rust.

In either case, the ceilings sag leading to cracked ceilings, leading to the need to refix. It is to be noted that ceilings in buildings only carry their own weight and rarely carry imposed loads except during inspections and repairs, which may

occur once a year. On the other hand, STC floors are meant to carry their self-weight and imposed loads almost every second of their service life.

Guidelines

i. *The timber-to-timber joints must be constructed in such a way that they do not weaken even when the timber dries and the connectors must resist rusting. This can be achieved by using galvanised plated connections (See Figure 3) and coated connectors respectively.*

ii. *The nail connection - number, length, diameter of nails are design outputs which should be left to a professional engineer to specify.*

iii. *The secondary and primary beams should be properly aligned to ensure proper load transfer.*

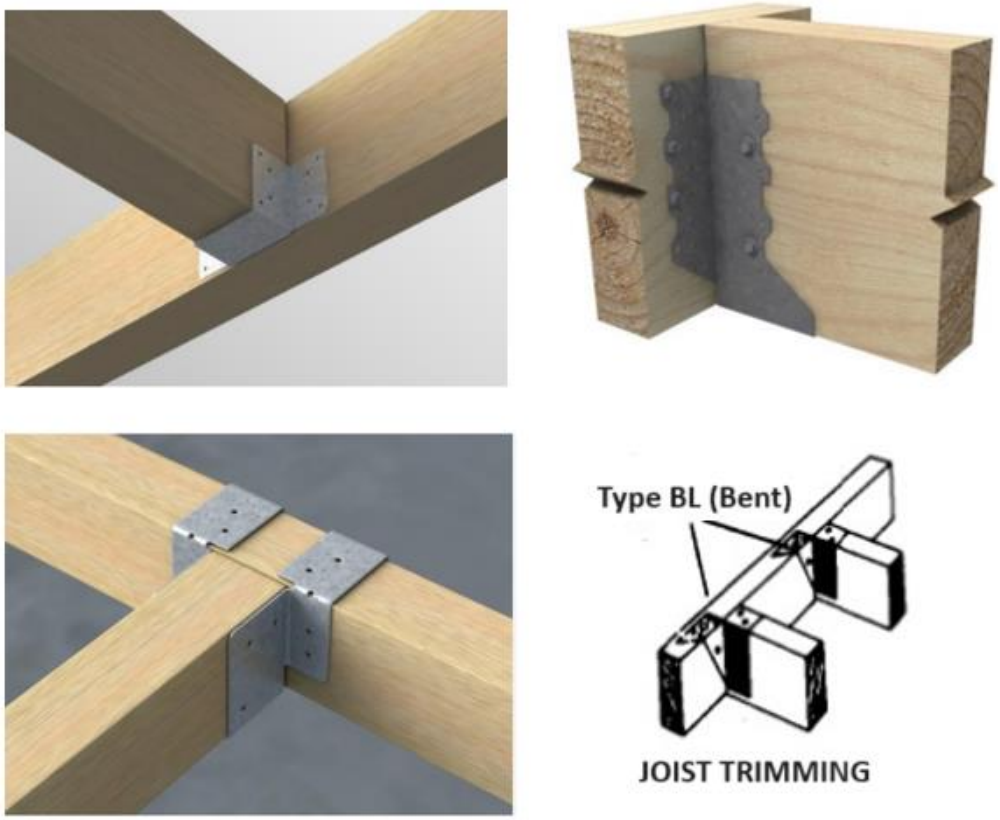


Figure 3: Best Practice Timber to Timber Joist Connection

5.4 Steel to Concrete Connections

The Technical Committee observed that:

a. Steel stanchions were in contact with the ground without concrete pedestals to prevent contact with the ground. Unprotected steel, in

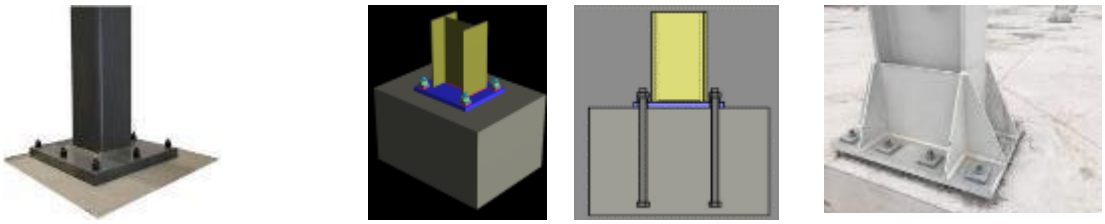
contact with moisture, would corrode, to disastrous effect.

b. There were no shear connectors on the steel beams (protruding into the concrete overlay), making the possibility of composite action unlikely.

Guidelines

i. Designed Shear connectors (number, spacing, type, length) should be included on top of the steel beam if any composite action is to be assumed.

ii. A concrete pedestal should be provided, off the ground to avoid contact of steel with moisture in the backfill, ease of constructability, and reduction in concentrated loads at the foundation. The steel column can then be bolted onto the stub column using bolts through base plates and holding down bolts (See Figure 4).



(a) Photos of unstiffened base plate (b) CAD renders (c) Stiffened base plate

Figure 4: Photos and CAD renderings steel column to concrete base connections

iii. For encased steel columns, the encasing concrete shall extend the full length of members and connections and be reinforced with steel fabric.

5.5 Timber to Steel Connections

There are two methods observed in the field that were used to connect the timber to the steel beams.

- Method 1: The timber joists are just laid (placed) on the top flange of the IPE steel beam without any anchors to the steel beam.
- Method 2: The timber joist is just fitted inside the I section (between the top and bottom flanges) without any anchoring.

Both methods 1 and 2 pose a danger and can lead to collapse of the floor slab in case of any movement of the steel beams in the lateral direction. Because the timber members are not anchored to the steel beams, they will not move together leading to collapse. Lateral movement of the structure could be caused by earthquakes, blasts, or strong wing loading.

Guidelines

i. *Timber joist should be bolted to a designed angle cleat which is welded offsite to the web of IPE steel beams.*
ii. *For the case where the timber is placed on top of the IPE steel beam, the timber could be bolted to a designed angle cleat, which in turn is welded offsite onto the steel beam.*

5.6 Concrete to Timber Connections

Composite action can only be assumed if there are shear connectors in the STC set ups. Any composite action that could have been generated due to friction between concrete and timber members, is discounted in cases where the polythene is placed on top of timber to prevent ingress of moisture from concrete onto the timber. In cases where there is no polythene on top of the timber, it is arguable that adhesion between the timber and concrete exists, but the extent of this adhesion and composite action cannot be estimated without testing and research.

Guidelines

i. *STC slabs shall incorporate designed shear connectors (size, length, spacing) in order for the Concrete on Timber to behave as composite.*
ii. *Even without assumed composite action, some form of fixity will be needed to prevent relative movement between the two. Studs can be provided at the minimum at the ends to avoid free movement.*
iii. *Concrete should only be allowed direct contact with the timber, if the timber is treated. Timber must be protected from moisture ingress from the wet concrete by Damp Proofing before casting the concrete slab.*

5.7 Steel to Steel Connections

The majority of connections in the existing STC structures were welded. The welding was so poorly done that in 85% of the welds tested, the recommendation was that they be redone. None of the weld connections had drawings and specifications guiding the implementation.

Guidelines

i. *Weld connections shall be designed by qualified professionals, with*

detailed Weld Procedure Specifications (WPS) and preferably done off site.

ii. *Welders for structural applications should have minimum Skill Level 4.*

iii. *On-site fabrications should as much as possible be restricted to bolted connections, preferably with a single size specified for the project.*

iv. *All welded connections should be inspected for integrity by a qualified Welding Inspector who shall issue a report of compliance that shall form part of the requirements for issuance of an occupation permit.*

6. Reinforcement of the Concrete Slab

The STC overlay slab is reinforced with BRC mesh which is placed atop the polythene layer on top of the timber. In the majority of the cases, no concrete spacers are provided. It is not clear whether the mesh was only to control cracking or for flexural strength. In some of the sites, there were visible cracks at the top of the slab along the beam positions.

Guidelines

i. *The reinforcement to control cracking should be designed and appropriately placed near the top the slab in accordance with the standards.*
ii. *The reinforcement for flexural strength should be designed and appropriately placed near the bottom for span regions and near the top for the hogging zones, in accordance with the standards.*
iii. *Concrete spacers shall be incorporated, of the specified thickness for appropriate concrete cover for the mesh.*

7. Mechanical And Plumbing Installations

The mechanical and plumbing installations cannot run continuously within the slabs because of the timber framework. Consequently, in the majority of the cases, the wet areas are restricted to the peripheries of the building, which may not be achievable or practical in all cases. The typical slabs being only 100mm thick, are not adequate for plumbing installations to be embedded. The ceiling soffit is not thick enough for anchoring of service lines like HVAC, waste pipes, water pipes, etc. The nature of the slab creates constraints the installation of services across the slab.

Guidelines

i. *Structural designs should consider the impact of any loading of service lines clipped/anchored on the ceiling soffit for integrity*

ii. *Wet areas (toilets, bathrooms, kitchens, swimming pools) and services routes should be solid slab (reinforced concrete).*

iii. *Mechanical Ventilation and Air Conditioning Installation*

- *For Air Based Systems where the conditioned air is produced centrally and distributed via ductwork, the ductwork should be able run underneath the soffit with minimal interruption and adequately anchored.*
- *For Water Based Systems where hot or chilled water is used to convey heat to or from a conditioned space or process through piping, the piping should not be chased in the slab or wall at any point but rather clipped at the soffit or within a service duct.*

iv. *Plumbing Installations*

- *The water supply pipework may run within the slab; Bends must be minimised (to minimise pressure losses).*
- *The drainage piping shall be chased underneath the slab ensuring the proper drainage slopes are achieved.*
- *The plumbing should be accessible for maintenance.*

v. *Fire Fighting Installations: The horizontal network of pipes in the firefighting system shall be laid underneath the soffit and adequately supported.*

8. Electrical Installations

If the cables are directly clipped onto the timber, the risk of fire is high as well as damage to the cables by vermin. The spread of fire in STC frameworks is high, given the timber framework in the slab.

Guidelines

i. *A licensed professional must be engaged in the design and supervision of electrical building services as per regulation 5 (1)(b) and 6 (1) of the Building Control Regulations, 2020.*

ii. *Electricians with a minimum of Class C installation permits from ERA (in compliance with regulation 14 of the Electricity Installations Permits Regulations, 2018) should carry out new installations, repairs and maintenance works of the buildings.*

iii. *All installations shall be in accordance with National Building (Standards for Electrical Installations in Buildings) Code, 2019. Specifically:*
Protective Devices:

- *Every installation and circuit shall be protected against overcurrent by devices*
- *All installations shall be protected against electric residual current with appropriate devices.*

Cable Conduiting:

- *All electrical cabling should be embedded in PVC conduits.*

Cable Wiring:

- *All cable wiring of the main and final sub-circuits shall be carried out in PVC insulated and PVC sheathed cables*
- *Connections between flexible cables and conduit wiring shall be made of an approved connector secured in a suitable case or box.*

iv. *All steel elements should be earthed.*

9. Fire Resistance

The range of overlay concrete thickness in STC constructions was 50-100mm. The thinner the slab, the less time it will take for the slab's integrity to be compromised in case it is exposed to a fire.

Guideline

The Minimum fire rating should be at least 1 hour, corresponding to a minimum slab thickness of 100mm, as per Table 5 (Schedule 11) of the National Building (Structural Design) Code, 2019.

10. Minimum Design Guidelines

There were no design calculations available for the STC constructions inspected. The single drawing, signed by a registered engineer, was disregarded at construction stage, with changes in steel sections, timber sections, orientation of timber elements and connection details changed at construction stage.

All STC constructions inspected did not have lateral force resistance systems (such as shear walls, bracings), making them susceptible to failure under significant lateral forces such as wind gusts, seismic actions and impact loads. It is unlikely that the poor welds observed would be moment resistant. The masonry infill walls which could offer some bracing were not anchored into the main framing elements.

Guidelines

i. *All constructions should be designed by qualified professionals (Architects and Engineers) and the design drawings should be backed up by design calculations and based on appropriate standards.*
ii. *All designs should consider Checks for Stability, Robustness, Durability and Strength against gravity loads as bare minimum limit states.*
iii. *Any Structural detail should allow for ease of inspection and maintenance. As best practice, steel columns should be clear off the ground, supported on reinforced concrete pedestals.*
iv. *Design drawings should be detailed enough to guide the builder, with specifications on materials (size, grades, etc.) and assumptions underlying the design.*

11. Skilling for Welding

The poor quality of welds is testament to the lack of adequate skill among welders in construction. Most of the welders in construction are uncertified. There is an urgent need to train a critical mass of welder technicians, welder fabricators, welding Inspectors, welding supervisors, and welding engineers to ensure quality of weld connections in construction.

Guidelines

i. *Welding practitioners should be required to undertake training in welding offered at various UBTEB accredited training institutions.*
ii. *Welding practitioners who have learnt on the job should undertake periodic training through the Directorate of Industrial Training (under Uganda Vocational Qualifications Framework), which offers certification from Level 1 up to Level 5*[4].
iii. *The minimum level of certification for welders for structural construction works should be Level 4.*

[4] Level 1: working category, Helpers, casuals (Equivalent to Junior certificate) Level 2: WorkersPAS (Equivalent to National Certificate) Level 3 & 4: Supervision and Instructor Level (Equivalent to Diploma level)

12. Post Construction and Maintenance

It is common for changes to a design to occur during construction. It is therefore important that a check on fitness for purpose of the as-built is done before a structure is occupied, to confirm that it is safe for occupation.

Maintenance of structures is essential to ensure that they continue to fulfil the functional requirements over their design life, and to increase the service life of the structure.

Guidelines

i. *Developers should ensure that as-built drawings (Architectural, Structural, MEP) are produced at practical completion of buildings.*
ii. *Developers should obtain certificates of fitness of electrical and mechanical installations issued by engineers.*
iii. *Developers should apply for Occupation permits from the Building Committees after practical completion.*
iv. *Developers should carry out inspections annually and carry out preventive maintenance in case of any observed defects.*

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