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Performance Framework for Modular Construction

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ABSTRACT: This paper presents a performance framework for modular construction. Modular construction is a method of construction that uses factory-produced building units called modules that are delivered as components, parts or whole buildings to be erected on site. The particular aspect of performance discussed in this paper is construction performance. The performance framework**,** in this context, is a description of the required structural characteristics of the module and its attachments for all stages of construction, from manufacturing, transport to installation. There are four elements of a performance framework: user requirement, performance description, performance parameter and evaluation. The performance framework can be used to prepare related regulation, standard, specification or check list for design and construction. The use of performance concept is encouraged because it allows innovative and efficient construction methods to be developed and still maintain a level playing field for safety and competition.

1 INTRODUCTION

The Sustainable Built Environment National Research Centre (SBEnrc) is conducting an investigation into the feasibility of mainstreaming of building manufacture in Australia. As part of the project on Performance Verification and Overcoming Barriers to Financing (SBEnrc 2015), a performance framework for modular construction is proposed as a basic step in identifying what is needed to deliver manufactured buildings.

This paper outlines the proposed performance framework for modular building construction. Precast concrete construction is excluded from the scope of this paper since it has been well covered elsewhere (Standards Australia 2015a, b). The particular aspect of performance discussed in this paper is construction performance. Other aspects of performance of interest are economic performance and environmental performance; they are not discussed in this paper. The performance framework in this context is the description of the required characteristics of the module for all stages of construction, from manufacturing, transport to installation. It is different from prescription in that it only describes WHAT need to be considered but not HOW to do them.

A performance framework has four elements: user requirement, performance description, performance parameter and evaluation (International Standard 2015). *User requirement* is a statement of needs as seen by all stakeholders of the modular unit during all phases of construction: fabrication, lifting, transport and installation. The objective is to prevent any damage to the modular unit. The requirements however may be different for each phase. These include transport, work safety, quality, damage control and inspection. Performance description is a qualitative statement of the ability of the modular unit to fulfil the user requirements. These include consideration of the support conditions for the unit and resistance to all actions that arise during all phases of the operation including resistance to impact, vibration and other design actions. *Performance parameters* are a listing of variables used to quantify the performance description. Factors to be considered include size and weight of the module, supports for the module during all phases of construction and transport and any additional consideration for post installation performance**.** *Evaluation* describes the methods used to demonstrate conformance with the performance description. These include identification of relevant standards or specifications for design and testing and criteria for acceptance.

The performance framework can be used to prepare related regulation, standard, specification or check list for design and construction. The use of performance concept is encouraged because it allows innovative and efficient construction methods to be developed and still maintain a level playing field for safety and competition.

2 MODULAR CONSTRUCTION

2.1 *Concept*

Modular building construction is a method of construction that uses factory-produced building units called modules that are delivered as components, parts or whole buildings to be erected on site. The module is characterized by its repeatability and connectivity with other units.

The concept of modular construction is not limited to building structure. It is also applicable to service and other non-structural components of a building. The modular unit may be self-supporting or may rely on a structural framework. Modular buildings are to meet the same regulatory requirements and user specifications as site built when completed. Modular buildings need not be temporary structures or mobile structures. They are expected generally to stay permanently at the same location.

2.2 *Advantages*

The benefits of modular construction could include faster construction time, improved safety, better quality and improved sustainable practice. They are generally more robust to survive the handling and transport.

Full benefit of this form of construction can only be realized if-

- the module can be standardized for manufacture, handling and installation
- multiple handling is minimized
- reuse of additional supporting components are maximized
- universal adaptable interface for connection between the modules can be standardized

The designer must pay special attention to the interface between the units and must plan for the manufacture, handling and installation sequences.

The approach taken in this paper for the construction of the performance framework is to treat the module as a 'black box'. Certain structural characteristics of the 'black box' must be assessed so that its manufacturing, transport and installation can be planned.

3 MODULE PERFORMANCE

3.1 *User requirement*

The users in this context include all stakeholders in all phases of construction. Thus the requirements of the building, transport and work safe regulations are parts of the user requirements.

For the completed structure, compliance with the National Construction Code (NCC) performance requirements must be demonstrated (ABCB 2016). The applicability of the NCC during construction however is open to interpretation. Except for Clause E 1.9 – Fire precautions during construction which is about fire-fighting equipment, there no specific NCC requirements for construction. Performance requirements BP1.1 and BP1.2 of the Structural Provisions, which are about strength and robustness, are applicable to the modular unit during construction. The Deemed-to- Satisfy provisions however are not necessarily applicable during construction.

The requirements of transport and work safety regulations are relevant to the handling and transport of the modular units. Transport regulations impose limits on weight and size of the modular units (Heavy Vehicle National Law 2013). Work safety regulations impose control measures on the operation. It is interesting to note that the operation associated with manufacturing and transporting of the modular unit is not considered as 'construction work' under Safe Work Australia Construction Work Code of Practice (Safe Work Australia 2013).

Local conditions should also be considered such as site limitation, street access, overhead obstructions, crane size etc. as they may also impose limits on handling and transport.

3.2 *Performance description*

Three structural performance requirements to be fulfilled are: strength, damage and robustness. At each stage of construction: fabrication, lifting, transport etc., the modular unit is a *different structure* due to changing supporting conditions and varying degree of completeness of the structure. Thus the modular unit and its supports must be assessed again and again for each stage of construction. The unit must have adequate strength for the supporting conditions available for each stage; additional temporary supports may have to be provided for lifting and transport. The unit must also not be damaged during all stages of construction, particularly during transport to site because it will be difficult to perform any repair operation at this stage. Of particular importance is the robustness, i.e. the prevention of disproportionate collapse. The failure of a single element (e.g. a bracing) should not lead to a total collapse of the unit.

3.3 *Performance parameters*

3.3.1 *Support conditions*

Support conditions for the unit during fabrication, handling and installation might be different for each phase. Consideration should be given to whether the additional supports for construction are to be left as part of the permanent structure or to be removed for reuse.

3.3.2 *Actions*

- Permanent action: the self-weight of the module and elements attached to the module for handling and transport are the components of the permanent action. Consideration should be given to whether the attached elements are part of the permanent structure or as temporary supporting elements to be removed from the module for reuse.
- Action effects induced by the fabrication process: these include the support conditions for fabrication and the handling of the unit during fabrication. Consideration should be given to the fabrication sequences and procedures including whether the unit is required to be lifted and/or turned over during fabrication. Casting of concrete for example may require the unit to be turned over and lifted to position for further fabrication.
- Action effects induced by handling process: these include effects on the handling equipment and on the module (including sling angle factor, impacts due to lifting and put down, vibration and impacts due to transport, wind action, stacking and the suction effect of lifting if appropriate)
- Action effects induced by installation including connections between the modules

3.3.3 *Resistance*

For each stage of construction, the module and its additional supporting elements is a different structure depending on its supporting conditions (e.g. during lifting, the lifting points are the supports). The action effects and the resistance of the unit to the actions are therefore different for different stages of the operation and needs to be reassessed for each stage. Additional supports provided for fabrication, handling and installation and the effects of the removal of these supports also need to be considered in assessing the resistance of the module. Factors to be considered include rigging configuration, lifting inserts, brace inserts and temporary bracing.

3.4 *Evaluation*

3.4.1 *Evaluation of the actions*

- Permanent actions can be evaluated using AS/NZS 1170.1 (Standards Australia 2002).
- Action effects induced by manufacturing and handling are generally dynamic effects but can be allowed for applying factors to the permanent actions to convert them to equivalent static loads. There is no guidance on what these factors should be apart from guidance given in AS 3850 (not a NCC referenced document) for precast concrete elements. AS3850 provides three factors to be ‘applied to the element and lifting points’: (a) sling angle factors (1.0 - 2.0), (b) suction factors (1.2 - 1.4) and (c) dynamic factors (1.2 – 5.0). These factors are not to be confused with the ‘load combination factors’ given in AS/NZS 1170.0 for ultimate limit state design.
- Dynamic action due to transport is dependent on the mode of transport whether it is by road, rail or ship.
- Wind action effects due to handling and transport is not the same as the wind action effects on the completed structure since the exposure type and time is much different.
- Action effects due to storing and stacking are depending on specific circumstance.
- Action effects induced by installation are dependent on how the units are put together and the design of the interface.

3.4.2 *Evaluation of resistance*

- Material properties: These can be specified and evaluated in accordance with appropriate Australian Standards.
- Module and its attachments: Evaluation of resistance of the module and its attachments can be carried out by calculation or testing. It is essential that the procedure used should be referenced by the appropriate regulation. If not then it should be specified and verified by appropriate means. It is noted that structural design standards (e.g. Standard Australia 2009) are in limit state format while mechanical services standards (e.g. Standards Australia 2015) are still using the ‘working load’ procedures. There is a potential for misunderstanding between the erection designer and the building designer. Furthermore the load factors and material capacity factors in structural design standards are not necessarily applicable during the construction.
- Tolerance on the dimensions of the module particularly on the interface of the units may affect the erection and consequently strength and serviceability of the building. Three kinds of tolerance should be specified: (i) tolerances for the units (dimensions: linear and angular, out of straightness or flatness: warp and twist), (ii) location tolerances between the units (deviation from plumb from floor to floor, any specific height or between fixings) and (iii) tolerance for a completed structure.
- Inspection should be carried out at least at the ends of the following stages: manufacturing, transport and installation. The objectives of inspection are to ensure that the module and its attachments: (i) have been in accordance with the specifications, (ii) have not been damaged as the result of the activities of the stage, and (ii) are in accordance with the specifications for the next stage of the operation.

3.4.3 *Conformity assessment*

There are no clear definitions of what constitute conformity assessment at present. There are at least three sets of regulation that modular construction should follow namely building regulation, transport regulation and work safe regulation. Modular construction is not specifically mentioned in any of these, consequently provisions relevant to modular construction should be extracted to facilitate their applications.

There are no specific Australian standards for modular construction although AS3850 Prefabricated concrete elements (Standards Australia 2015a, b) contain many generic elements equally applicable to modular construction. Appendix A of Part 1 of AS3850 also contains may common elements with Standard Australia Technical Specification 101 (Standards Australia 2015c) for the design of concrete anchors. It will be sometime before these issues can be rationalized.

4 IMPACTS OF MODULAR CONSTRUCTION

4.1 *On building practice*

Traditional building practice involves only two major players: the building designer/architect and the builder. Modular building construction involves additional new players such as manufacturing and erection engineers. The division of responsibilities and liabilities of all players has to be well described. It also raises interesting problems on insurances for these parties.

In traditional building practice, the building designer is the initiator of the building design. For modular construction, the manufacturer may specify the basic module first and the building designer may have to adapt his design to the module for best economy.

Building regulation such as the National Construction Code refers to 'all on-site construction requirements', modular construction involves off-site manufacturing, transportation and on-site installation. In this context, the building design practice (e.g. the load factors and capacity factors) needs to be reviewed for the construction as it interfaces with the mechanical design practice. Furthermore, the roles of the building surveyor/certifier need clarification.

Documentation for modular construction should be more extensive than that for conventional construction. It should contain information required for all stages of construction for the correct use of components and system. These may include instructions for use, storage and maintenance, inspection procedures and criteria for acceptance, description of parts and components etc.

4.2 *On building design*

With modular buildings, the focus of design will no longer be material savings for a particular situation, but the adaptability of the modular unit for its repeated use.

Off-site fabrication also offers opportunities for incorporating remote sensors and other 'intelligent systems' while the module is being fabricated. This can be done much easier in the shop rather than on site.

The design of the interface between the module so that they can be connected for structural as well as service purpose is an important element of design that does not exist in onsite construction. The standardization of the interface is an important issue for the economy of the method.

5 CONCLUSION

This paper has outlined a performance framework for modular construction. The process was used to identify issues that may need further works to facilitate modular construction. The paper also notes the impacts that modular construction may have on future building practices and building design.

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