International Journal of Scientific & Engineering Research Volume 11, Issue 3, March-2020
ISSN 2229-5518

STRUCTURAL RESPONCE OF MODULAR BUILDING

SAFEEK ; M.E (structural) JCT college of engineering and technology

Abstract

Prefabrication by off-site manufacturing leads to a reduced overall construction schedule, improved quality, and reduced resource wastage. Modular building is therefore increasingly popular and promoted. With the recent promotion a number of relevant studies have been completed, however, a review of the design, construction, and performance of modular buildings under different loading conditions is lacking. This paper presents a state-of-the-art review of modular building structures. First, structural forms and construction materials are presented as a brief introduction to the modular structures. Modular building is shown to refer not to a single structure type, but a variety of structural systems and materials. These modular structures might perform differently to similar traditional structures and the structural performance is highly dependent on inter- and intra-module connections. The structural response of modules to different hazards is then considered, followed by the current design practice and methodology. As a currently developing area there is great potential for innovation in modular structures and several key research areas are identified for further work.

1. Introduction

Modular building is a construction technique whereby building modules are prefabricated off-site. It is a type of off-site fabrication referring specifically to volumetric units which may be a structural element of a building. Modular building refers to the application of a variety of structural systems and building materials, rather than a single type of structure. Prefabrication by off-site manufacturing leads to a reduced overall construction schedule, improved quality, and reduced resource wastage . The disadvantages include the lack of design guidance and relatively small structural spans due to modular transport limits. The advantages of modular building outweigh the disadvantages particularly for hotel and residential development applications. Modular building is therefore increasingly popular and promoted. With the recent promotion a number of relevant studies have been conducted. This paper presents a state-of-the-art review of modular building structures. First, recently developed structural forms and construction materials are presented as a brief introduction to the modular structures. The focus is on steel framed modules with concrete and timber frame modules excluded, not for lack of importance, but for lack of recent research into the structures. Structural connections are thekey to overall performance and so a detailed review of connection types is presented. Then, the structural response of modules to different hazards is considered, followed by the potential applications and future research work.

2. Module classification and developments in structural form

Modules are classified as steel, precast concrete and timber frame modules according to the primary construction material. Steel modules are further classified as Modular Steel Building (MSB) modules , light steel framed modules and container modules. Their applications, advantages and disadvantages are given in. Load bearing steel modules are also categorised as column supported or continuously supported. Column supported modules have edge beams which span between corner or intermediate columns. Continuously supported modules have load bearing walls which provide continuous support .Recent study of modular building was focussed on light steel framing applied to modular buildings followed by consideration of overall building design using modules and then high-rise building applications . A broad overview of modular construction using light steel framing was given with the application of relevant British and European standards. Several types of modular construction have been presented. Many modular buildings are not exclusively modular but are hybrid structures. Modular construction is combined with a primary steel or concrete structure, for example, using a podium or skeletal structure, or a concrete core around which modules are arranged Column supported MSBs are well suited to medium and high-rise building applications and popularly used in current practice.

3. Component materials

Prefabricated components should be as light as possible as they are transported sometimes long distances. Traditional materials of steel, concrete and timber are commonly used. The potential applications of composite sandwich structures have not been well explored Manalo et al. gives an overview of fibre reinforced Polymer (FRP) sandwich systems in the context of lightweight civil infrastructure. Many of the developing materials presented by Manalo et al. may find application in modular buildings. To date such composite systems

4. Connection systems

Interconnection of frame members and modules is critical to the capability of modular buildings to withstand applied loads [45]. Despite the need for a thorough understanding, studies on the connections are limited [45]. Connections are grouped into three types: inter-module, intra-module, and module to foundation as shown in Fig. 4. Table 3 provides a summary of connections for steel modules with further details given in the following Sections. Inter-module connection Inter-module connection includes horizontal connections (HC) between adjacent modules in two plan directions, and vertical connection (VC) between stacked modules. It is reported that bolted connection is preferred over site welding. A gap is usually provided between the floor and ceiling beams, as shown in Fig. 1(L), allowing for external access to inter-module connections and for services to pass between the beams.This suits connection between the columns, rather than between the beams. Bolted connections can be complex to accommodate connection of modules stacked in three directions while ensuring access to fasteners is provided during the install sequence. Use of long slotted holes may introduce the potential for tolerance accumulation over multiple levels, and vulnerability to slip failure in the event of large horizontal force . The potential for connection slip may be controlled with the use of friction-grip or pre-tensioned bolts. VCs may incorporate a shear key or spigot [46], which assists in positioning modules and may provide structural connection where physical access is not possible or practical. In some cases, concrete or grout is used to lock the joint in place, creating a composite concrete-steel connection. Table 4 presents a summary of inter-module connections for steel modules from the literature, and identifies the numerical and experimental investigation completed. In the latest studies, force-displacement (F-d) and moment-rotation (M-θ) behaviours of the connection are established by detailed numerical analysis of the connection.

4.1. Intra-module connection

Intra-module connections, i.e. connections within a module, are generally representative of traditional connection details. For MSBs both welded and bolted connections are used. Considering column to beam connections, the bolted connection types include single web (or fin) plates double angle cleats [4and bolted end plates It is suggested that a moment resisting connection consisting of an end plate or a deep fin plate may provide lateral stiffness for low rise buildings . This is unusual in that fin plate connections are often classified as simple shear connections. Fin plate connections have relatively low moment capacity, ductility and rotation capacity], hence their use is suggested only for low rise (3-storey or less) buildings However, the use of such connections may make open modules susceptible to progressive collapse In this case the fin plate connection may have inadequate moment capacity, and so require strengthening. In contrast, Annan et a investigated steel floor framing with secondary beams welded directly to the main beams. This is compared with conventional steel construction which may use clip angles permitting greater rotation. The welded connections do not necessarily permit rotation such that steel members should be designed for hogging moments and axial forces which may be developed as a result Linear elastic analysis is demonstrated to be adequate for this issue and Annan et al. present a process which may be adopted in design.

4.2. Module to foundation connection

Foundations may consist of in situ or precast concrete footings, bored concrete piles, augered steel piles, or some combinations. Low rise modular buildings located in areas with high lateral loading may be vulnerable to overturning and sliding failures if not adequately restrained by connection to an appropriate foundation. Building modules are commonly connected by chains, cables, keeper plates or welding to concrete or steel piles, or large mass concrete footings. Each connection type has associated disadvantages including tensioning requirements for chain and cable. In medium and high-rise construction foundations are more substantial. Base plates may be incorporated in modules and fixed to cast-in anchors, or welded on site to accessible cast-in plates. Park et al. [45] developed an embedded column connection (Fig. 5), as an alternative to the traditional. cast-in or post-fixed steel bearing plate. This connection was developed to ensure best use of the full column strength and provide good ductility. The disadvantages include the requirement for site welding between MSB columns and the end plate.

5. Case study

To define the range of existing modular buildings, a list of multi-storey modular building projects has been compiled based on a review of the literature. Table 5 shows a selected sample. The tallest identified prefabricated building is J57 Mini Sky City located in Changsha, China, being 57 storeys or 207.8m tall In Australia, the tallest prefabricated building identified is La Trobe Tower, Melbourne, being 44 storeys or 133m tall. It is in an area with relatively low wind and earthquake loading. In areas with higher lateral load requirements the maximum building height is less. For example, the tallest building within Australia's severe cyclone region is Concorde South, being 6 storeys.

10. References

[1] White RB. Prefabrication : a history of its development in Great Britain. London, England: Her Majesty's

[2] Gibb AGF. Off-site Fabrication: Prefabrication, Pre-assembly and Modularisation. Scotland, UK: Whittles

[3] Smith RE. Prefab Architecture : A guide to modular design and construction. Hoboken, NJ, USA: John

[4] Lawson RM, Ogden RG, Goodier C. Design in Modular Construction. Boca Raton, FL, USA: CRC Press; 2014.

[5] Lawson RM, Ogden RG, Bergin R. Application of Modular Construction in High-Rise Buildings. J Arch Eng.2012;18(2):148-54. doi: 10.1061/(asce)ae.1943-5568.0000057.

[6] Kamali M, Hewage K. Life cycle performance of modular buildings: A critical review. Renewable Sustainable Energy Rev. 2016;62:1171-83.

[7] Lopez D, Froese TM. Analysis of Costs and Benefits of Panelized and Modular Prefabricated Homes. Procedia Eng. 2016;145:1291-7. doi: 10.1016/j.proeng.2016.04.166.

[8] Annan CD. Applicability of Traditional Design Procedures to Modular Steel Buildings [PhD Thesis]. London, Ontario, Canada: The University of Western Ontario; 2008.

[9] Gorgolewski MT, Grubb PJ, Lawson RM. Modular Construction using Light Steel Framing: Design Of Residential Buildings. Ascot, Berkshire, England: The Steel Construction Institute; 2001.

[10] Lawson RM, Ogden RG, Pedreschi R, Grubb PJ, Popo-Ola SO. Developments in pre-fabricated systems in light steel and modular construction. Struct Eng. 2005;83(6):28-35.

9):720-30. doi: 10.1016/j.tws.2008.01.042.

[13] Lawson RM, Byfield MP, Popo-Ola SO, Grubb PJ. Robustness of light steel frames and modular construction. Proc Inst Civ Eng Struct Build. 2008;161(1):3-16. doi: 10.1680/stbu.2008.161.1.3.

[14] Lawson RM. Building Design Using Modules. Ascot, Berkshire, England: The Steel Construction Institute; 2007.

[15] Lawson RM, Richards J. Modular design for high-rise buildings. Proc Inst Civ Eng Struct Build. 2010;163(3):151-64. doi: 10.1680/stbu.2010.163.3.151.

[16] Fathieh A. Nonlinear Dynamic Analysis of Modular Steel Buildings in Two and Three Dimensions [Master's Thesis]. Canada: University of Toronto; 2013.

[17] Gunawardena T. Behaviour of prefabricated modular buildings subjected to lateral loads [PhD Thesis].

[18] Annan CD, Youssef MA, El Naggar MH. Seismic Overstrength in Braced Frames of Modular Steel Buildings. J Earthquake Eng. 2008;13(1):1-21. doi: 10.1080/13632460802212576.

[19] Annan CD, Youssef MA, El-Nagger MH. Effect of Directly Welded Stringer-to-Beam Connections on the

Analysis and Design of Modular Steel Building Floors. Adv Struct Eng. 2009;12(3):373-83. doi:

10.1260/136943309788708400.

[20] Annan CD, Youssef MA, El Naggar MH. Experimental evaluation of the seismic performance of modular

steel-braced frames. Eng Struct. 2009;31(7):1435-46. doi: 10.1016/j.engstruct.2009.02.024.

[21] Annan CD, Youssef MA, El Naggar MH. Seismic Vulnerability Assessment of Modular Steel Buildings. J

[22] Fathieh A, Mercan O. Seismic evaluation of modular steel buildings. Eng Struct. 2016;122:83-92.

doi:

10.1016/j.engstruct.2016.04.054.

[23] Gunawardena T, Ngo TD, Mendis P, Alfano J. Innovative Flexible Structural System Using Prefabricated

Modules. J Arch Eng. 2016;22(4):05016003. doi: 10.1061/(asce)ae.1943-5568.0000214.

[24] Gunawardena T, Ngo TD, Mendis P. Behaviour of Multi-Storey Prefabricated Modular Buildings under