INTRODUCTION TO AN INTEGRAL ASSEMBLY SYSTEM FOR MODULAR CONSTRUCTION

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Abstract- This paper introduces an innovative mechanical connection system to be applied in modular construction projects. The proposed connection system can be applied for modular construction to facilitate and accelerate the assembly process. This connection is a patented product with the AU patent number of 174860 under the name of Modular Integrating System (MIS). To evaluate the structural behaviour of the system, a set of experimental and numerical studies are performed. The results show that the proposed system increases the overall integrity of the modular structure while providing the time saving benefits.

Index Terms— integral connection, interlocking connection, Modular construction

I. INTRODUCTION

In the construction industry, pre-fabrication of structural elements in a factory located remotely from a construction site, is increasingly popular as this allows component parts of the structure, to be manufactured efficiently by automated apparatus off-site and subsequently efficiently erected on-site. Such pre-fabricated construction elements are typically configured to be simple to connect together thereby allowing large volumes to be enclosed quickly, significantly reducing complexity and duration of the construction process and consequently the cost of construction. To enhance the advantages of pre-fabricated construction elements, such elements are also often configured as a modular system having standardised dimensions and fittings allowing a range of different structures to be readily constructed from a kit comprising a few different modules[1, 2].

In spite of the mentioned advantages of modular construction procedure, such systems also suffer from a number of drawbacks. Modular construction units are typically connected together along edges at defined points with fasteners[3]. These connection points typically allow a degree of fit tolerance which can result in play between modules. The relative movement of modules is undesirable as this can mean that the structure lacks structural integrity and is consequently vulnerable to damage due to impact loadings. To resolve this lack of integrity, additional bracing is often secured between modules, such as braces or ties, however this increases complexity and cost of the modular system. Also, connecting modular units together with fasteners typically requires tool operations to secure the fasteners, and may require specific skills. Accordingly, it would be advantageous to provide an assembly for constructing a structure from modular units which is more robust than prior art approaches, and/or which can be erected more efficiently.

In this article, a patented modular integrating system (MIS) [4] is introduced which improves the integrity of modular structure while facilitating the assembly process.

II. DESCRIPTION OF THE MECHANISM

Modular Integrating System (MIS) is generally made of a pair of integral joints (fig 1) which would be fitted into each other with a method of assembling the individual units to form an integral structure. As depicted in figure 1, each connection part is shaped from an equilateral L shaped base with two sets of tongues and grooves. By attaching the integral connection strips to the four top and bottom corners of each module, a fully engaged edge would be provided in each direction for every individual unit.

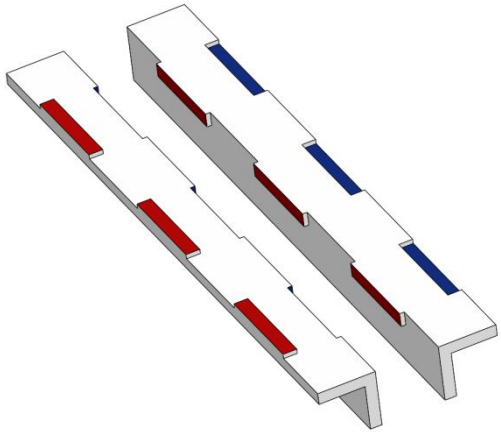

Figure 1- Integral connection strips

Figure 2 illustrates the combination of two strips at the adjoining corners of four unites. It is clear that by mating the tongues and grooves, they can resist out of plane shears to maintain the connecting modules in orientation and alignment.

Fig. 3 illustrates how the integrating connection resists the imposed shear and compression arisen from an externally-applied load that tries to cause displacement between the modules. There normally is

no locked-in or residual stress present in properly designed and fabricated integrated connection when no external lateral or accidental load exists.

III. RESEARCH METHODOLOGY

In order to evaluate the potential improvements provided by the proposed system, a 3 storey modular structure composed of 27 individual units is considered. Each story contains 9 modules (3x3) offering the most possible number of interactions for the module in the middle of second floor as shown in figure 4 (connected to 6 adjacent modules).

The structure is both experimentally and numerically evaluated under the following loading conditions and the results are compared for the structures with and without MIS.

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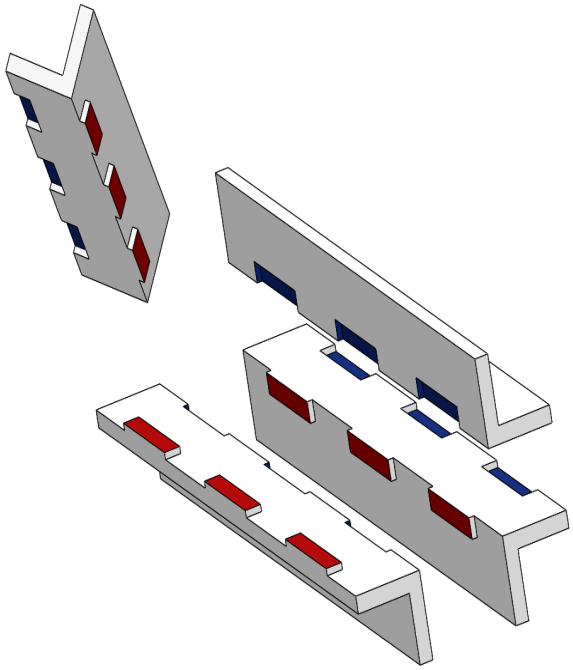
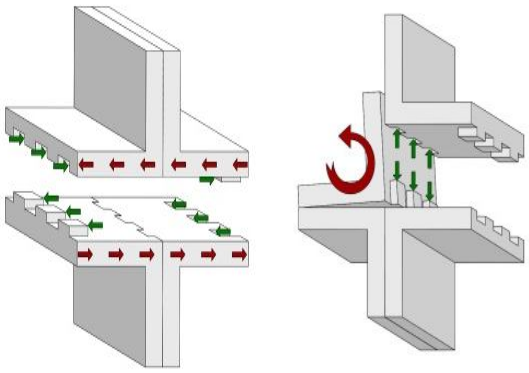


Figure 2- Connection strips meeting at the corners of four adjacent modules



(a) **(b)**

Figure 3- Load resisting mechanism in integrating connection: a) horizontal movement (b) overturning

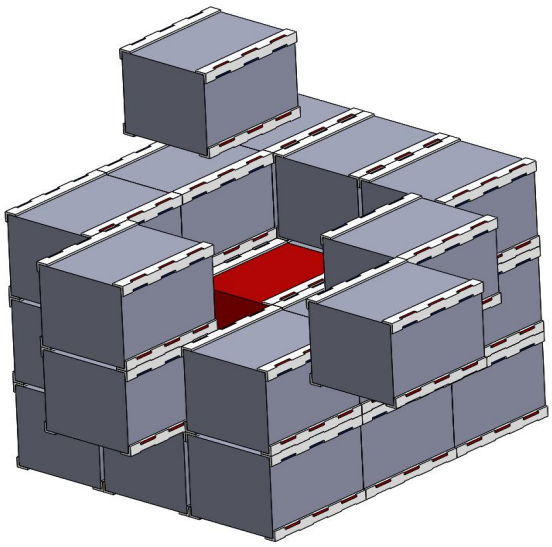


Figure 4- A three story structure made of 27 modules with all possible connection combinations

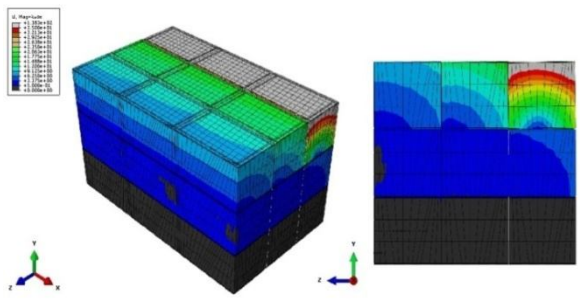
A. Horizontal static load

This loading condition may be produced due to a side-sway developed by eccentricity of vertical loads or inevitable positioning tolerance. The integrity of the 3 story building is numerically evaluated under a static lateral load and the relative displacements of every individual module are observed.

By applying a lateral displacement-controlled static load, the displacements of each module in the building for two different cases are compared. First when the modules are only connected through the corner springs, then when MIS is added to the first case. The scaled building was fixed at the bottom to a rigid surface, while a corner module on the top was gradually loaded up to 500N. Displacements of two corners in the same line of the applied load were recorded using displacement sensors. The numerical and experimental results for the horizontal tests are depicted in Figs. 5.

B. Horizontal dynamic load

Using a small scale shake table, a sinusoidal dynamic excitation is applied to the scaled down model of the structure. Two benchmarks marked on the diagonal of the outer face of each module are considered as reference points to measure the relative displacements of the modules. A speed camera was used to record the displacements of modules. The numerical and experimental results are depicted in Figs. 6.



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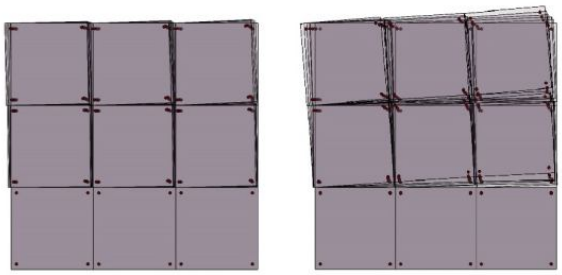
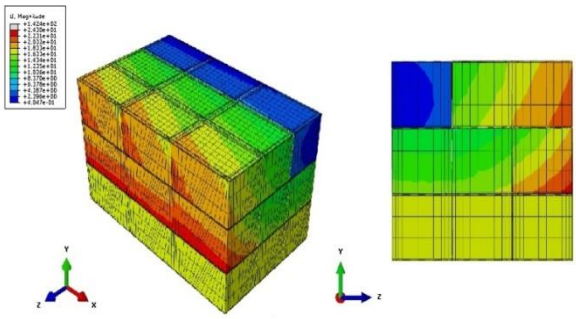


(b)

Figure 5- Static horizontal loading (a) Finite element modelling results with MIS (b) Displacements of modules (benchmarks) in the experiments



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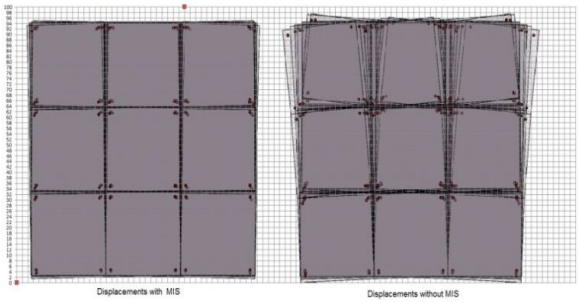

(b)

Figure 6- Dynamic horizontal loading (a) Finite element modelling results with MIS (b) Displacements of modules (benchmarks) in the experiments

C. Notional removal of elements

The final assessment method of the system is to ensure the overall integrity in an event of a complete module loss, as a result of a blast or car accident. In this regard, different scenarios can be considered such as immediate loss of the intermediate or any of the corner modules as illustrated in figure 7. The induced forces caused by the loss are beared by tying forces developed between the modules.

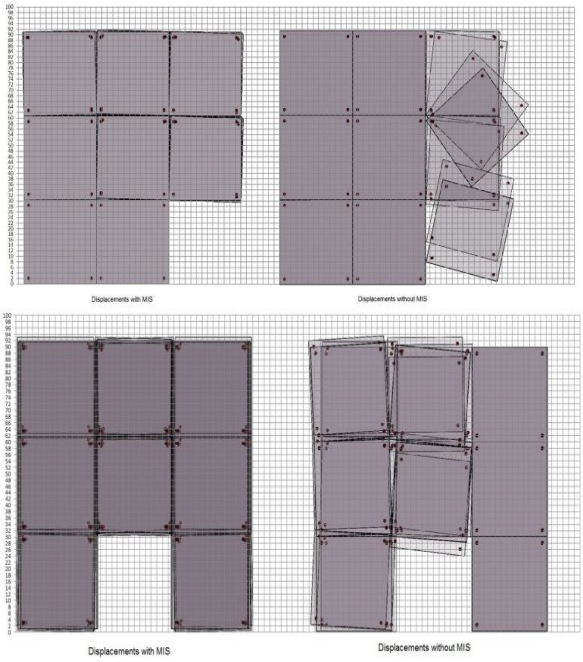

Figure 7-Notional Removal of Elements: Displacements of modules (benchmarks) in the experiments[5]

RESULTS AND CONCLUSION

The conducted numerical and experimental analysis revealed that MIS can considerably improve the integrity of the modular structure by developing an interlocking action between all attached corners of the modules along their length. Further details of the results of analytical and experimental studies are provided in the recent work by the authors[5]

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