Steel Structure-2015
Dubai, 16 – 18 November 2015

EVALUATION OF CONNECTION SYSTEMS IN MODULAR CONSTRUCTIONS

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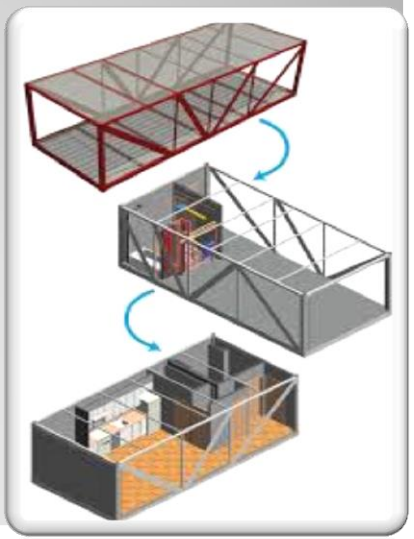
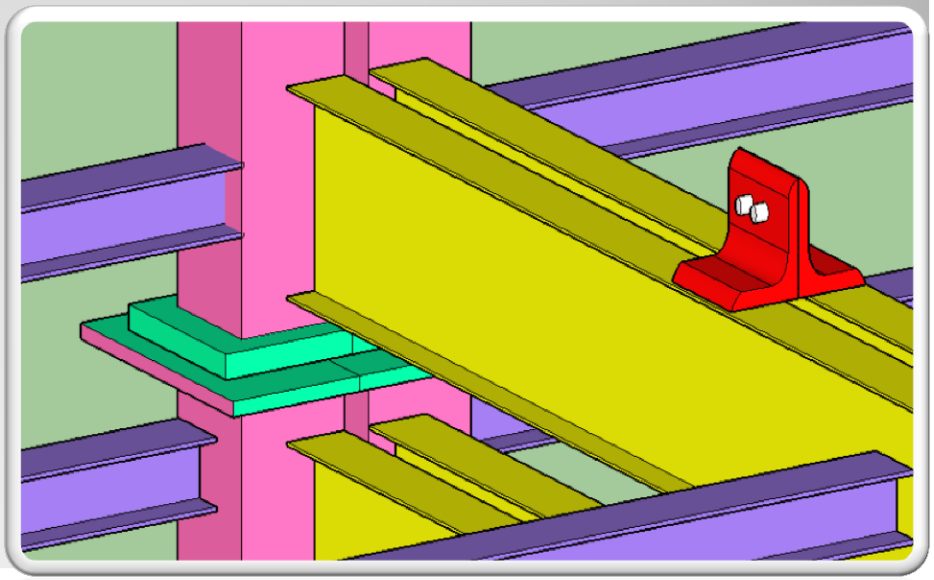


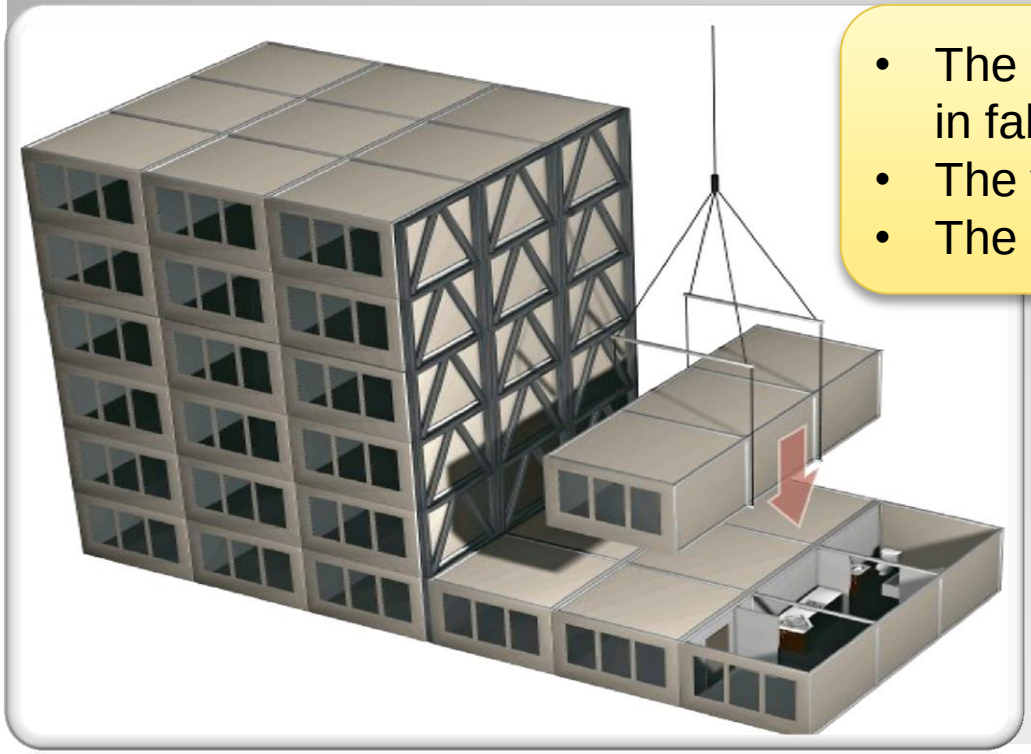
Goals of this study

- to introduce commonly used connection systems in several types of modular construction
- to explore the limitations for constructing taller modular building
- to offer suggestion for improved structural-connection systems



Modular building

- Modular buildings are developed as an alternative to conventional on-site construction

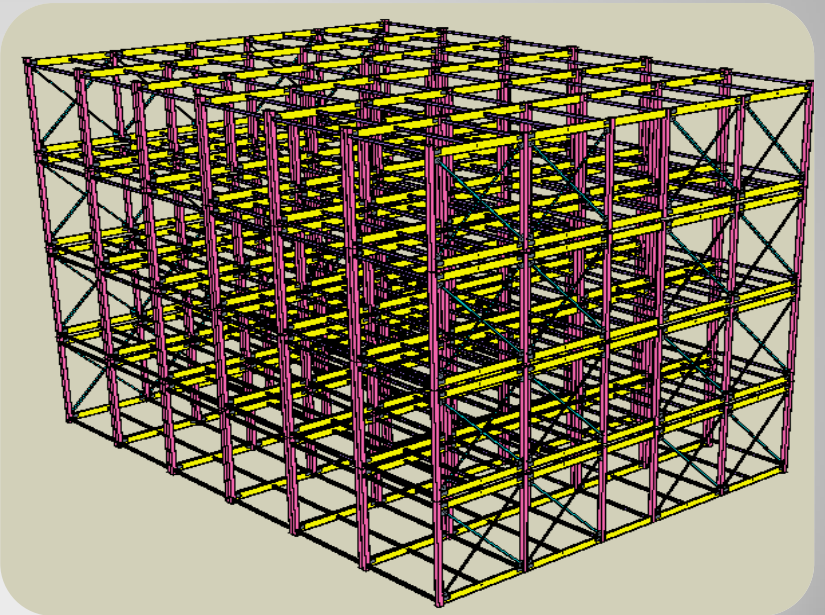


- The modular units are manufactured in fabrication plants off-site,
- The whole units shipped to the site,
- The units installed on-site

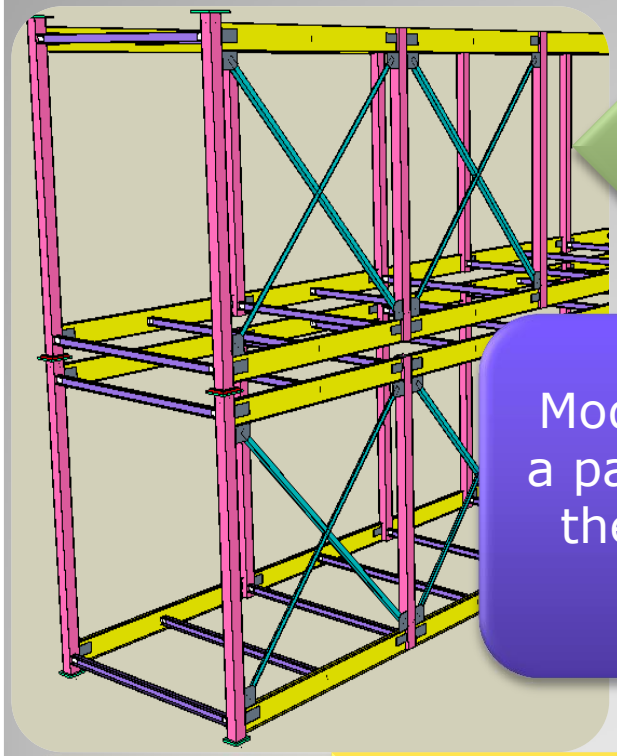
Modular building

The advantages of modular construction:

- saving time because of speedy installation
- high quality,
- less equipment needs
- reduced environmental disturbance because of off-site manufacturing.

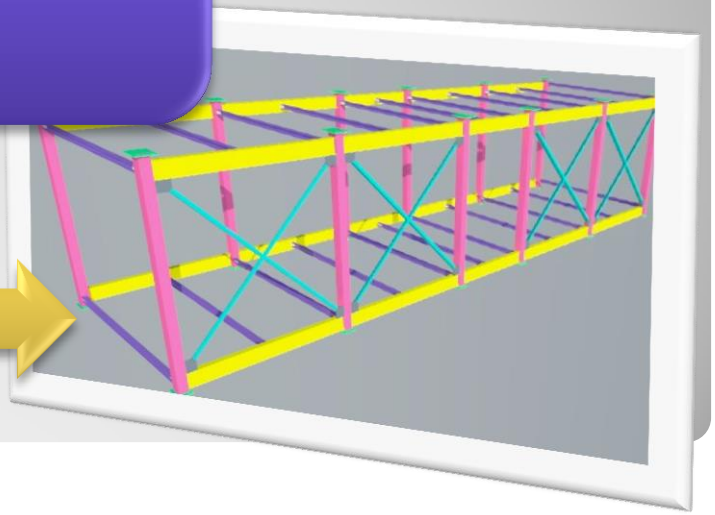


Modular building



Modular construction basically involves stacking the modular units and connecting them to one another.

Modules are used either as a part of the structure or as the main structure of the building.



A corner-supported module unit as an example before stacking process

Modules

Modules can be divided into three types according to their load-bearing characteristic:

- Load bearing modules -- gravity loads are transferred through the side walls in the modules,
- Load bearing corner-supported modules -- gravity loads are transferred via edge beams, and
- Non-load bearing modules – modules are supported by any structure.

Modular building

- The various module types that resist both vertical and horizontal loads are the primary type of structural systems used in the stack erection system

- However, the height of the system is normally limited in these systems unless another (supplemental) stabilization system is used as well

High-rise modular building

- The most important limitation for constructing taller modular building is to provide the resistance against lateral loads. Because, the lateral load resistance mechanism type depends on the height of the building

Lawson et al. [2] define the following three categories of modular building resisting systems that are functions of the building height:

For 4- to 6-story modular buildings → diaphragm action or bracing within modules

For up to 10-story modular buildings → separate bracing system in lift or stair

For taller than 10-story modular buildings → additional concrete core or steel frame

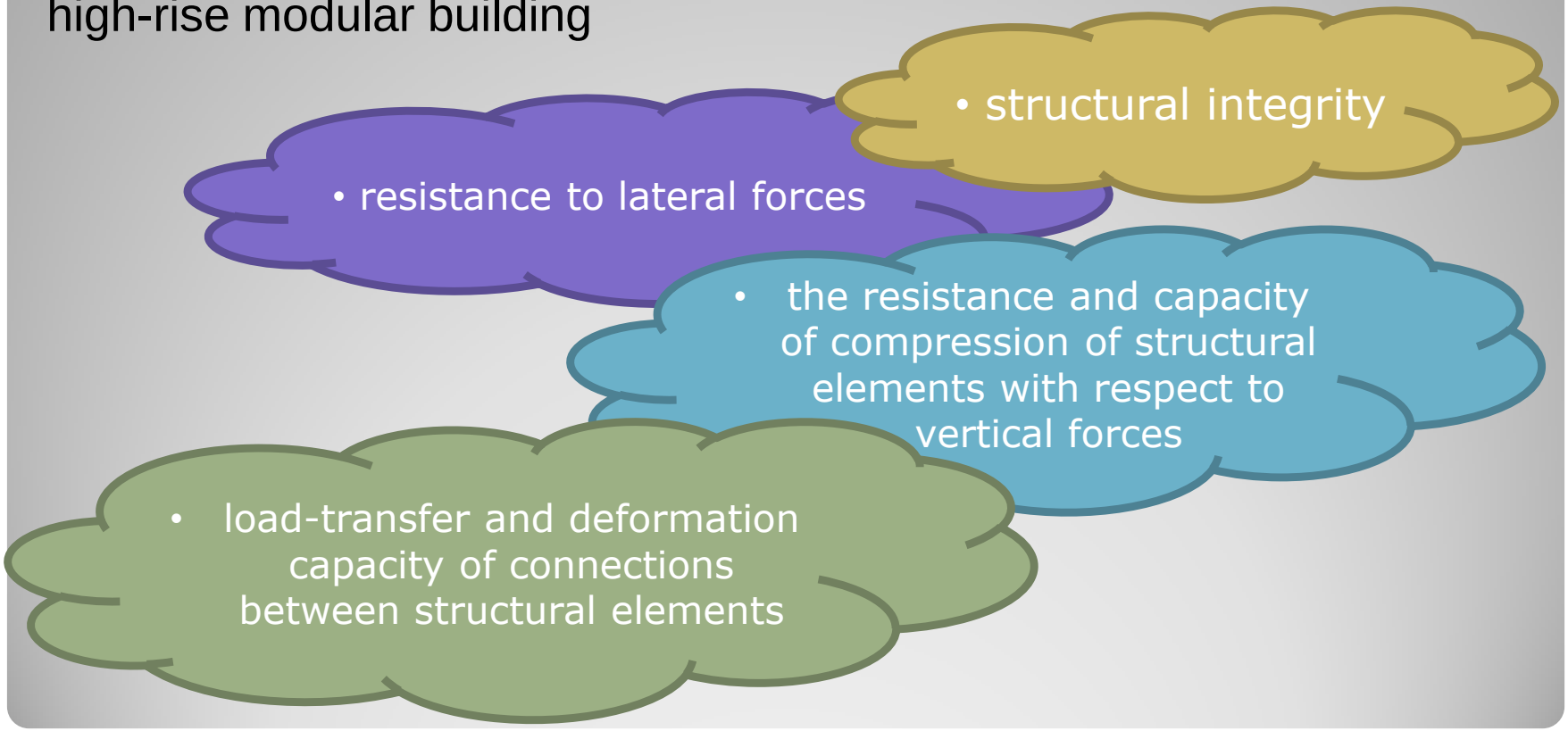
High-rise modular building

The common types of modular constructions that uses another stabilization systems:

- Concrete core construction system
- Hybrid podium system
- Open building systems
- Hybrid-skeletal structures

High-rise modular building

Some of the main topics that need to be addressed in design of a high-rise modular building



Connections in modular building

The behavior of connections in analysis and design of buildings should particularly be taken into account in detail because of their effects on the distribution of internal forces and on structural deformations

Their behavior can be defined depending on strength, stiffness and deformation capacity.

"The connections are critical components of structural systems"

Unlike conventional construction, modular buildings have additional interior connections, which further add to the complexity.

"The behavior of multi-story modular construction under lateral loading is still not well-understood because of the complexities of modular connections"

Connections in modular building

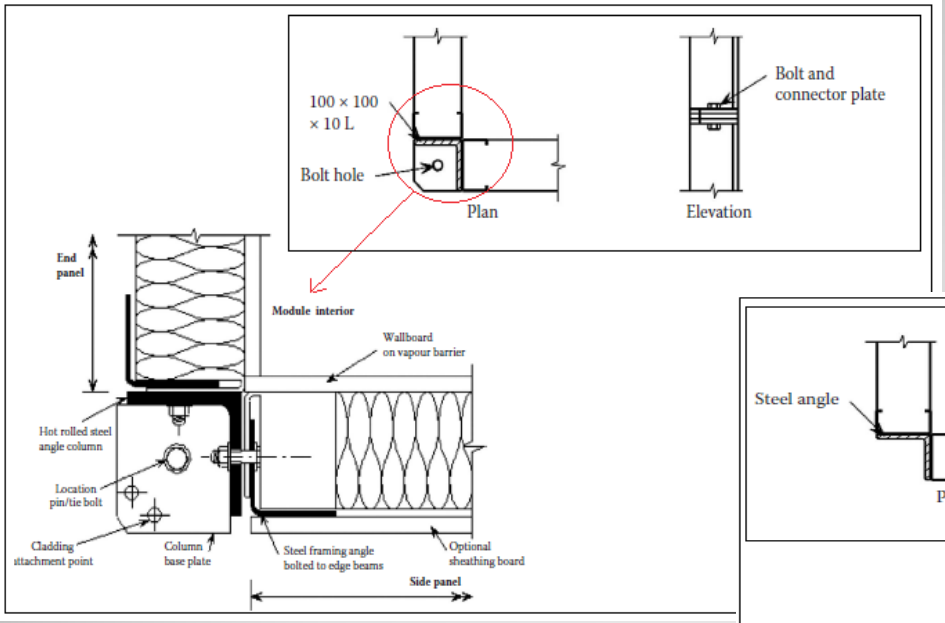
- The modules are attached to each other or to other structural systems to form a complete modular building

"The connections between modules transfer the applied lateral forces to the group of modules"

"The connections also ensure the stability and robustness of the assembly of modules in modular construction"

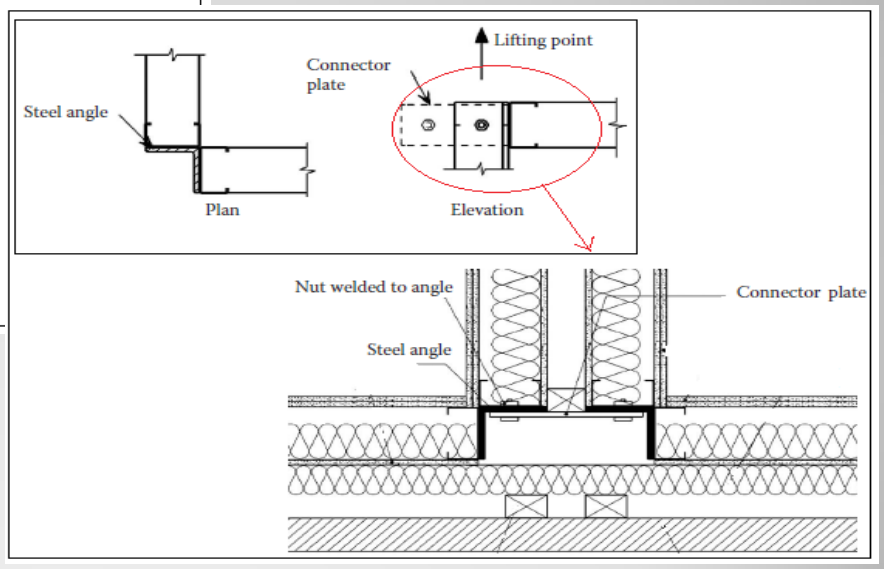
Connections between modules in 4-sided modules

The loads are transferred by:



Vertical loads;

by the modules walls



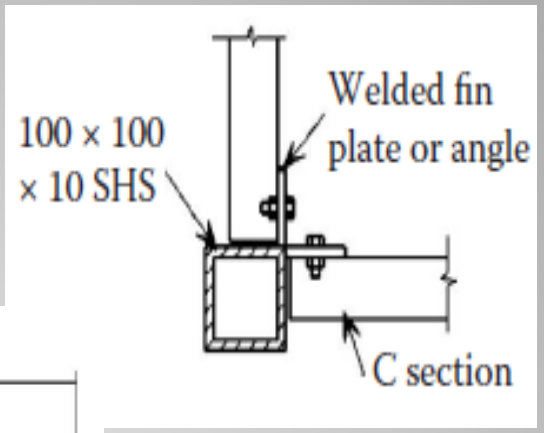
Lateral loads;

by the bracing or diaphragm action of the board materials

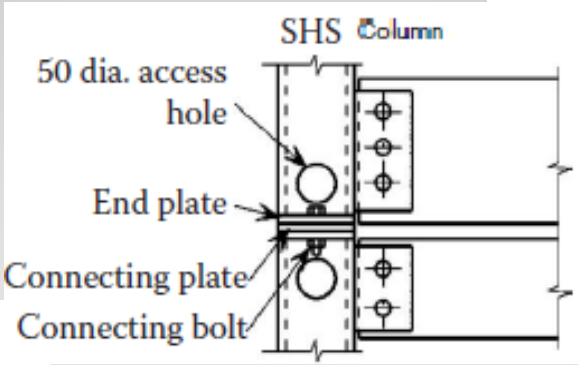
Connections between modules in open-sided modules

The loads are transferred by:

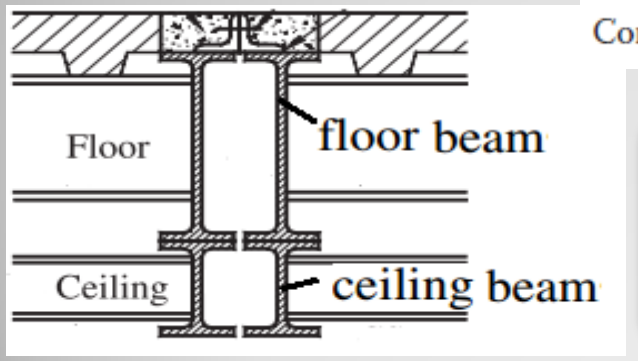
Vertical loads;
by columns and edge beams



"Column-to-column connections ensure bending resistance"



Lateral loads;
by the bracing system or sheatings

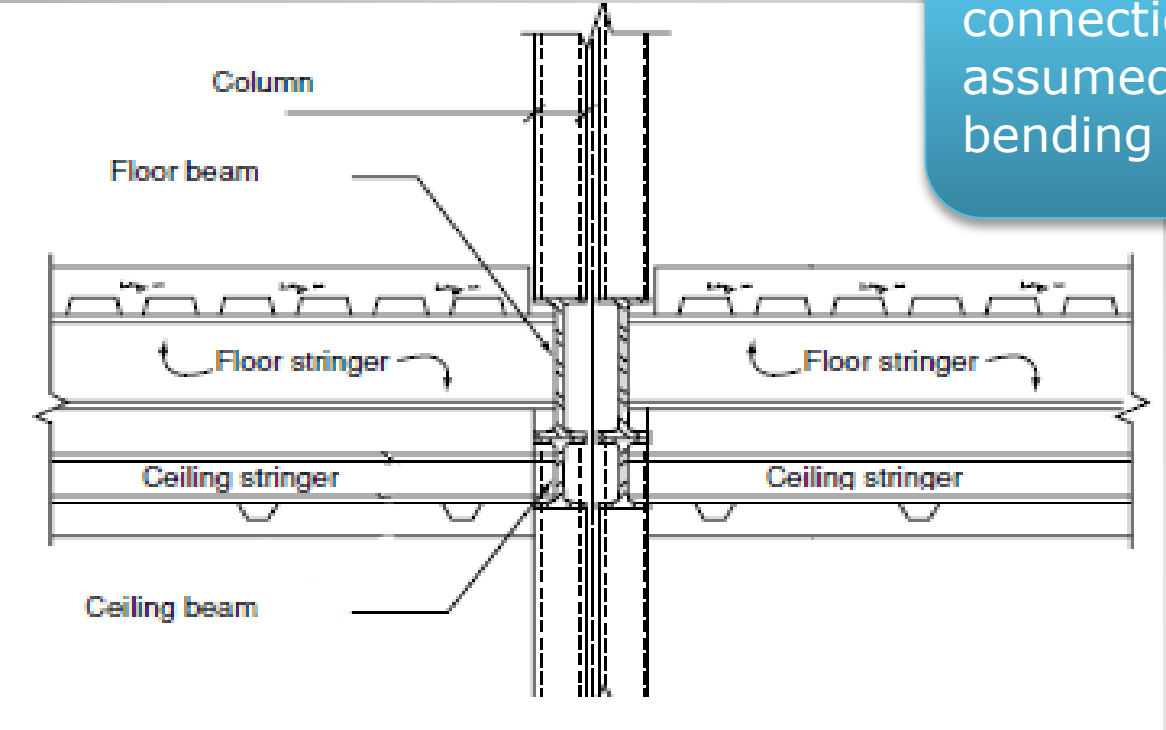


"The column-to-beam connection makes some lateral stiffness possible and can provide stability to modules in low-rise building"

Beam-to-stringer connections in light steel modules

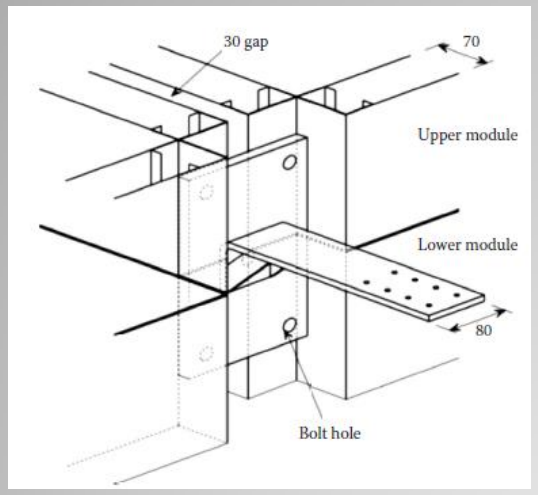
The connection consists of directly welding these members to each other

"This connection is a shear connection, which is assumed not to transfer bending moment"



Connections between corridor cassette and modules

The loads are transferred by:

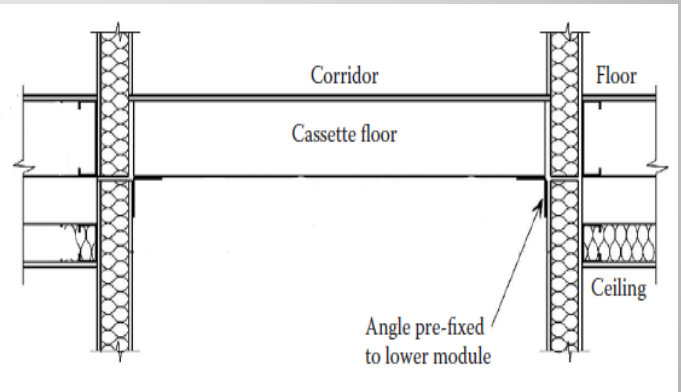


Lateral loads;

by the corridor to the braced system or core

"The beams ensure vertical support to the corridor and provide additional stiffness to improve the rigidity of longitudinal sides of the open-sided modules "

"The connection does not ensure vertical support to the corridor and just transfers shear forces



Connections between modules and structural components in frame unit system

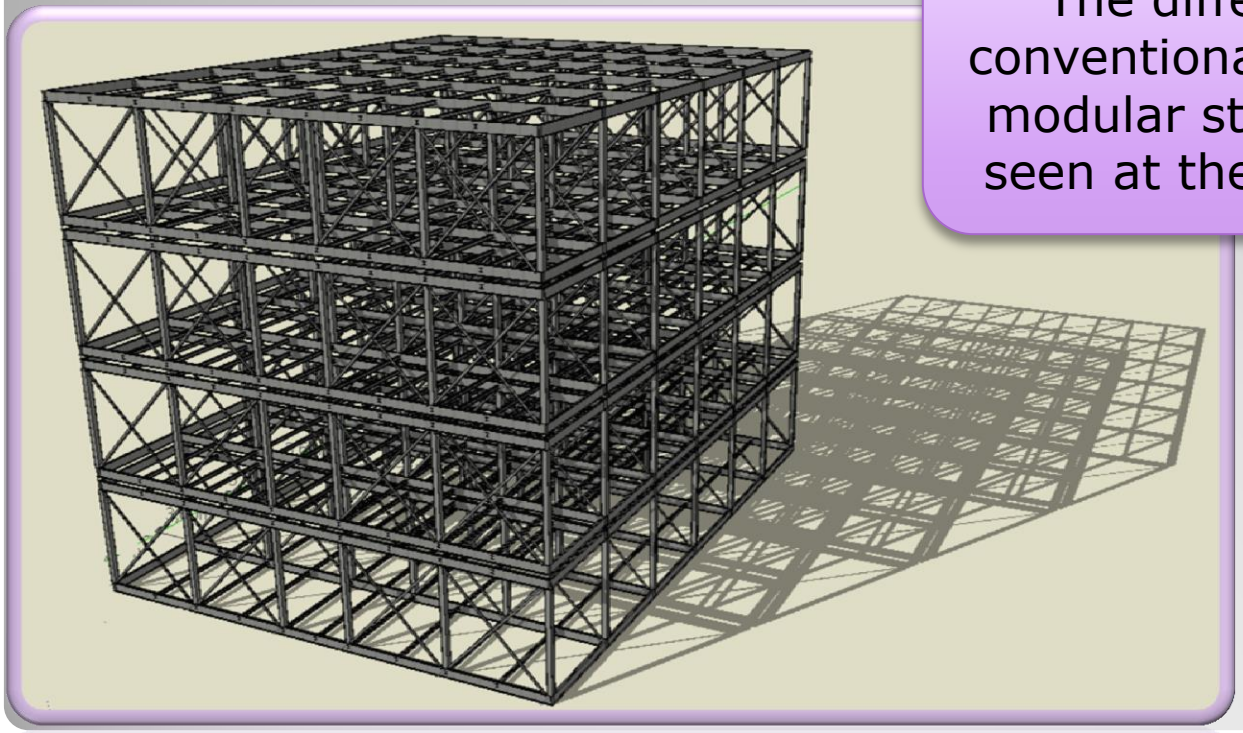
Properties of the system are not considered dependent on the modules

"The connection between the frame and the modules must be strong enough to transfer gravity loads although modules do not bear any loads except their own gravity loads "

"A diaphragm system should be taken into account for the integration the modules and frame in the system "

MODELING IN MODULAR BUILDING

Conventional steel technologies are generally used in modular building modeling and analysis due to the lack of special modular building analysis methods.



"The differences between conventional steel frames and modular steel frames can be seen at the modelling stage"

MODELING IN MODULAR BUILDING

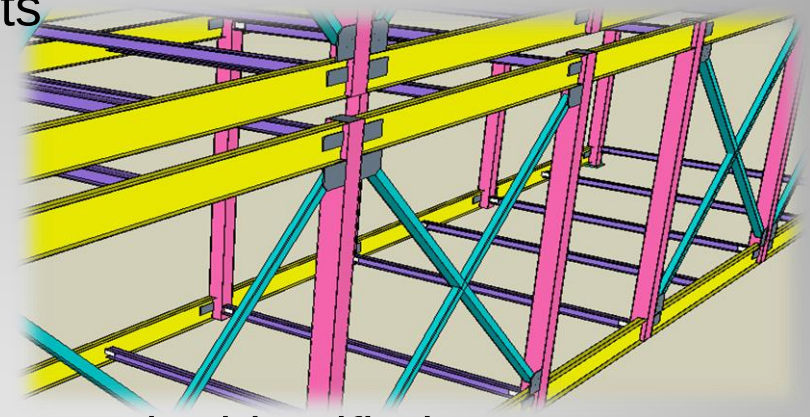
- Light steel sections are widely used in modular construction because of their efficiency and lighter weight
- Light steel framing in modular buildings is limited due to its range of applications; use of hot-rolled steel posts or beams in heavily loaded structures is more suitable and efficient

”Buildings are composed of vertical and horizontal structural members that resist lateral forces caused by wind or earthquake”

MODELING IN MODULAR BUILDING

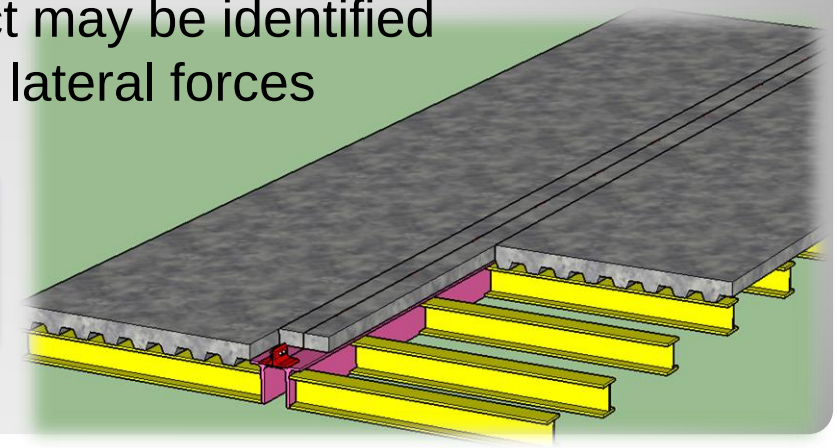
The lateral loads are reversible, braces are subjected to both compression and tension; consequently, they are mostly designed according to compression requirements

The braces are designed resisting the horizontal shear in axial compression and tension



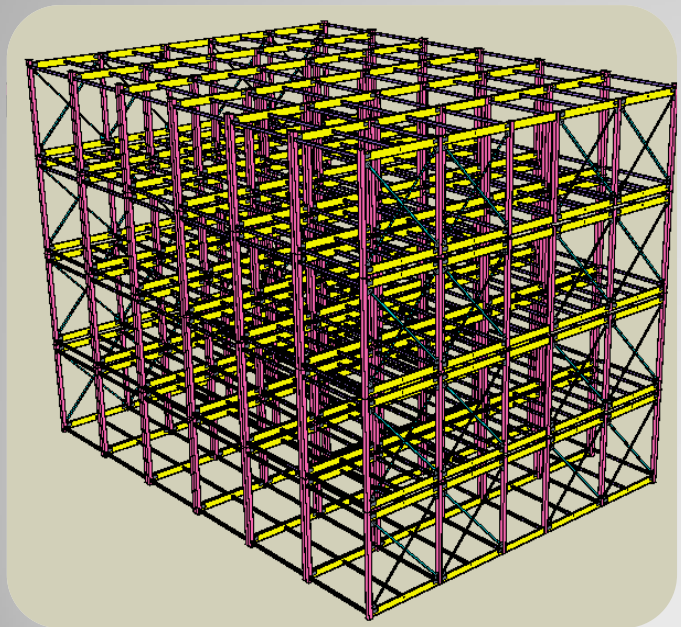
The floors having the diaphragm effect may be identified as horizontal resisting system against lateral forces

"The diaphragm behavior is an important aspect for transferring wind or seismic loads"



MODELING IN MODULAR BUILDING

This study was evaluated conventional modelling of modular steel building (MSB) to demonstrate potential shortcoming of the connections under selected combined lateral and gravity loading conditions.



”A typical story detail of the modular building in this study consists of a set of columns, a floor and a ceiling framing. A gap between floor beam and ceiling beam, and the diagonal braces providing lateral stability exist in these buildings”

“Lateral loads are transferred through the bracing elements via the horizontal connection between the modules and then to the foundation via the vertical connections”

EVALUATION OF THE CONNECTIONS

"The behavior of a connection is important for the distribution of internal forces and modular buildings consist of many inter-connections"

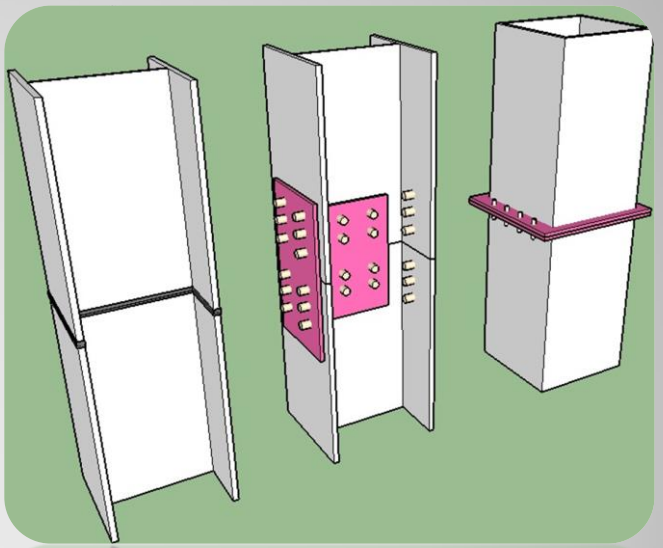
An evaluation of

- the vertical (column-to-column) connection,
- the horizontal (module-to-module connection for adjacent modules in the same story) connection,
- beam-to-column connection,
- beam-to-stringer connection is presented.

VERTICAL (COLUMN-TO-COLUMN) CONNECTION

Splice connections should be designed to allow for the transfer of stress resultants existing in the joint, with due allowance for second order effects, imperfections and load eccentricities

The connections must provide strength and continuity of stiffness in both axes of the columns

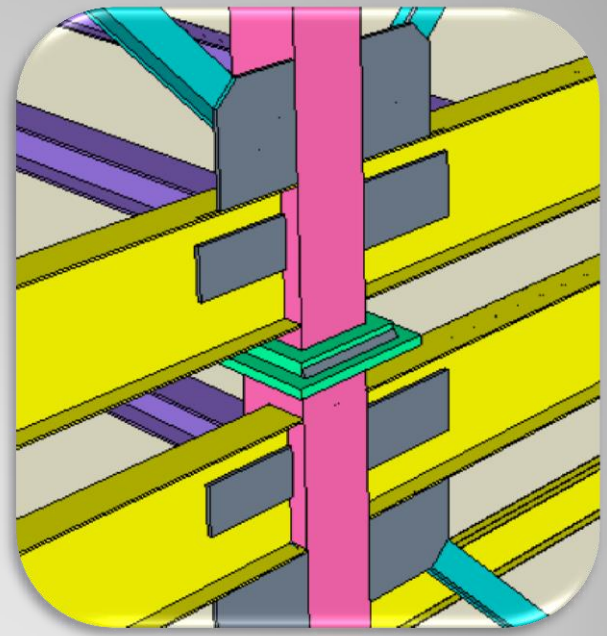


"Splice column connections should be generally used in the locations performing lower buckling strength"

VERTICAL (COLUMN-TO-COLUMN) CONNECTION

- The splice column connections consist of welding of base plates of upper module columns to cap plates of lower module columns in modular building

- Cap and base plates are welded on site to each other

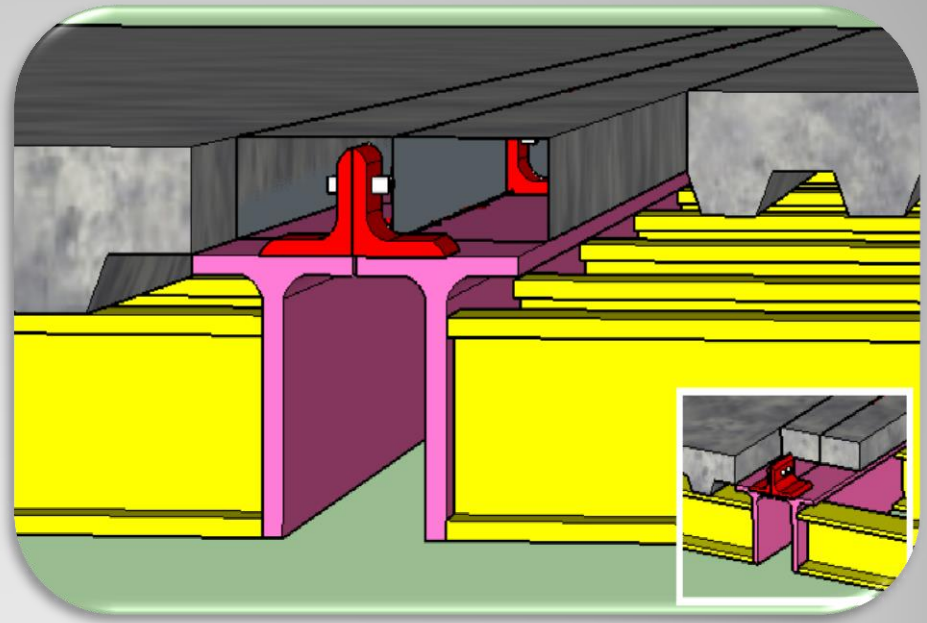


"Only the outer faces of the columns can have access to welding in these connections"

MODULE-TO-MODULE CONNECTION

"The connections are used to join to modules horizontally"

The module-to-module connection (horizontal connection) consisting of field bolting of clip angles that are shop-welded to the flange of floor beams



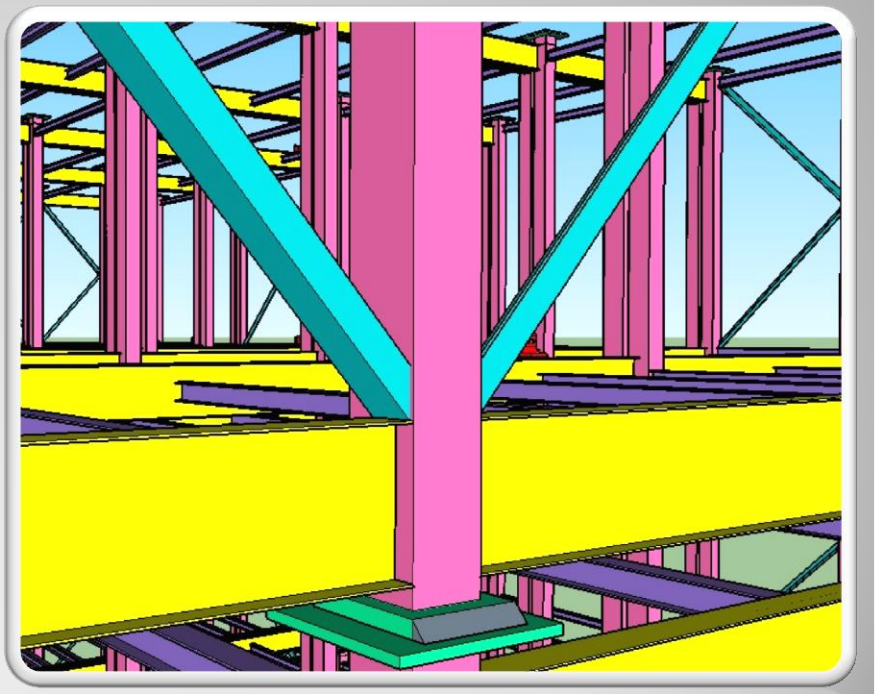
"The connections between modules transfer in-plane forces and provide the structural integrity and robustness"

EDGE BEAM-TO-COLUMN CONNECTION

"The connection between the corner column and edge beam makes some lateral stiffness possible and can provide stability to modules in low-rise buildings"

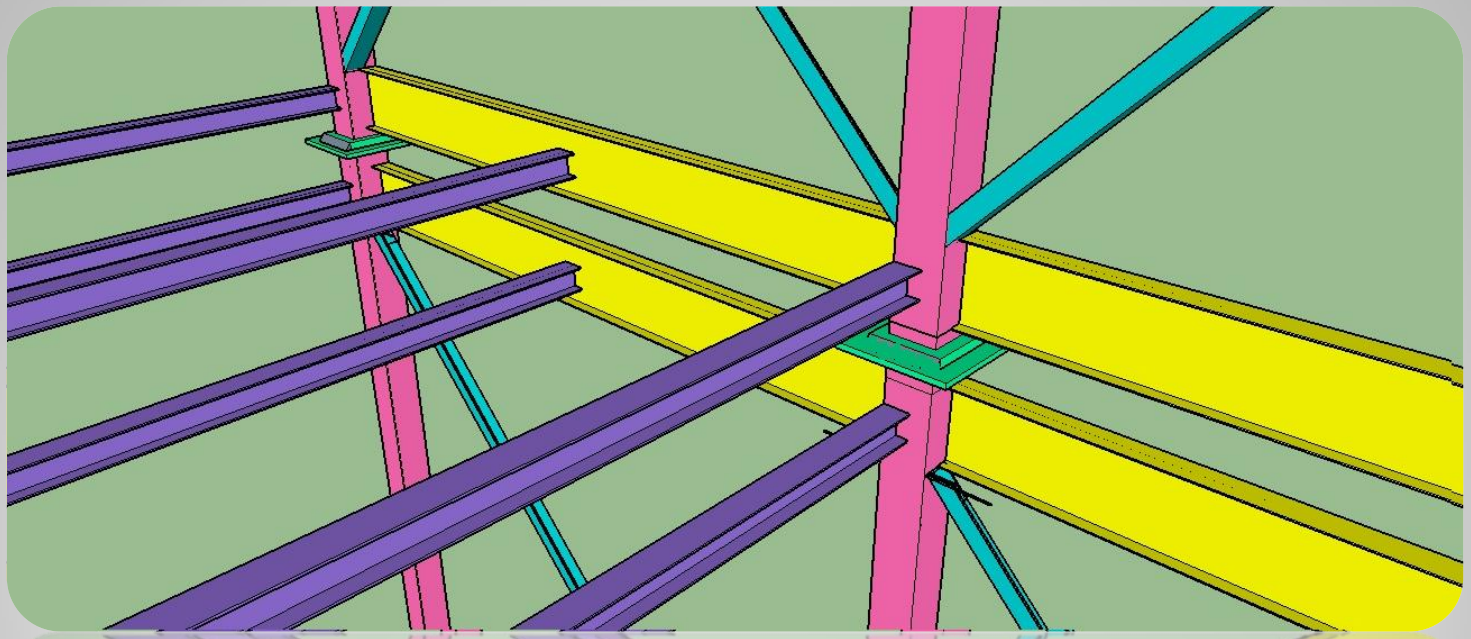
The connection between edge beams and column are generally designed as a moment-resisting connection

"This type of moment-resisting connection can be designed as the main stabilization system for low-rise buildings"



BEAM-TO-STRINGER CONNECTION

"The beam-to-stringer connection consists of directly welding of the stringer to web of the beam"



LIMITATIONS FOR HIGH-RISE MODULAR BUILDING

- Resistance to lateral forces, structural integrity, load-transfer and deformation capacity of connections between structural elements were examined as some of the main topics that need to be addressed in design of a high-rise modular building.

- These limitations revealed several necessary requirements for connection systems of modular buildings under the lateral loads.

LIMITATIONS OF EXISTING CONNECTIONS

The lack of special modular building analysis methods

Welds have limited deformation capacity and display brittle failure behavior

Welds of column-to-column connections in the worksite

Column and beam or stringer and beam are welded directly to each other

Fully-welded conn can cause damages due to their brittle response

Single side welds in the outer faces of the columns leads to independent upper and lower rotations at the same joint

Thanks for your attention

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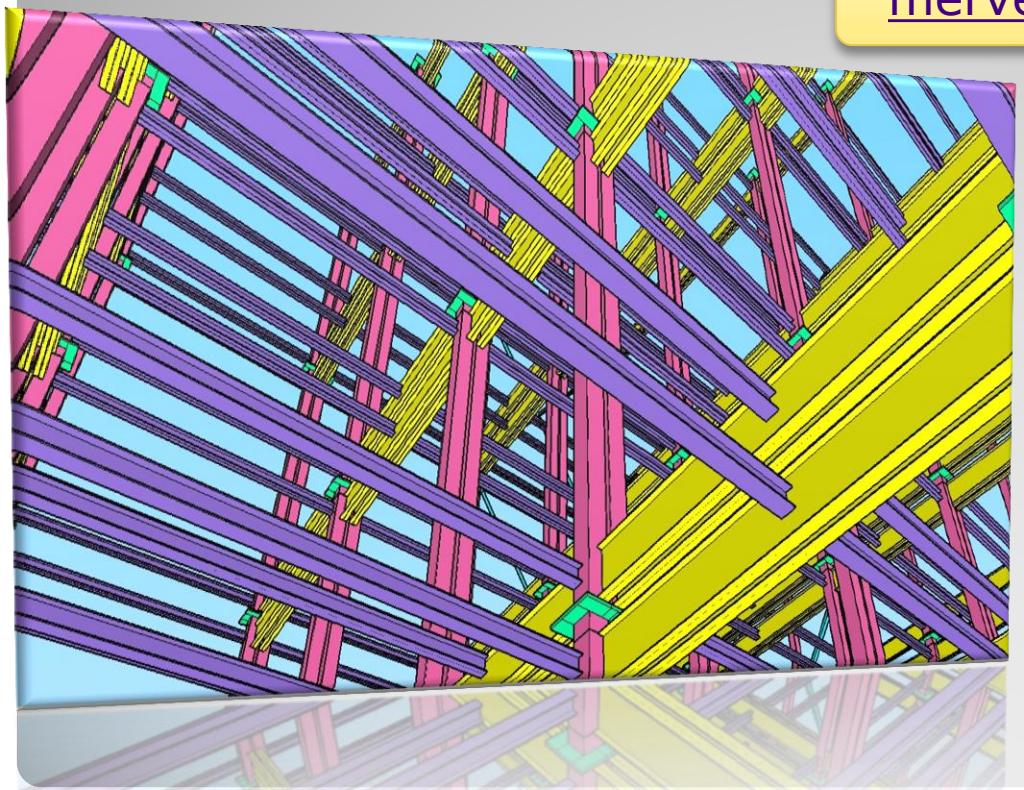

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