An Introduction to Steel and Concrete Modular Construction

S. English, P.E.[1] and B. Brown[2]

[1] Larson Design Group, Inc., 1000 Commerce Park Drive, Williamsport, PA 17701; PH (570) 323-6603; FAX (570) 323-9902; email: sje@larsondesigngroup.com

[2] NRB (USA), Inc., 440 Wenger Drive, Ephrata, PA 17522; PH (717) 733-1794; FAX (717) 733-2412; email: billbrown@nrbusa.com

ABSTRACT

For many years, wood framed modular construction has been a useful and cost-effective solution in the residential market. While this type of construction has been a good solution for one- and two-family residential construction, it has been limited by factors such as available beam spans, lateral force resisting system requirements, and fire resistance, affecting its use in larger multi-story projects, such as hotels and dormitories. This presentation will explore the benefits of using steel-framed modules to achieve greater exterior opening distances, increased floor plan flexibility, LEED certification, and non-combustible occupancies.

Additionally, we will discuss the concept of the off-site "Build Together" process used by one manufacturer to ensure a precise fit of components, including structural, plumbing, electric, HVAC, and fire protection systems.

INTRODUCTION

History. Modular construction has been used in residential construction for more than a century. For the purposes of this paper, "residential" shall include one- and two-family dwellings and townhouses – as covered by the International Residential Code – and commercial enterprises, including dormitories, apartments, and hotels – as covered by the International Building Code R-1, R-2, R-3, and R-4 occupancies. While the concept of building in modular units is not new, some relatively recent advances in modular technology have made the process very attractive to certain project types and conditions.

It is important to make a distinction between modular construction and manufactured or "mobile" homes. The most significant differences between these types of structures from a construction perspective is that modular construction must be built to the same building codes as conventional stick-built construction and be placed on a permanent foundation, while manufactured homes are built to the less-stringent Housing and Urban Development standard and may not be required to be installed on a permanent foundation. Manufactured homes are limited to one- and two-family residences and would not be appropriate for use with R-1, R-2, R-3, or R-4 occupancies.

Process. The modular construction process involves the construction of modules – three dimensional sections or boxes – off-site and then transported to the permanent building site and lifted into place by crane. The modules are constructed in a controlled environment, often in an assembly line. Constructing within a controlled environment allows the materials to remain dry and protected. The protected environment also promotes worker comfort, which in turn increases productivity.

Figure 1 - Placement by crane, top pick

The traditional building design process by the design team, involving the Owner, Architects and Engineers, is unchanged. However, a benefit to choosing modular early in the design development is that it allows the manufacturer to provide input on the design to ease the modular detailing process.

Modular construction requires specialized detailing to accommodate the connection of the modules and additional ceiling to floor space to allow for framing in the top of the lower module and in the floor of the upper module.

Materials. In the past, wood construction was the obvious choice for residential construction, whether modular or conventionally built. Practically speaking, wood remains the most economical material for one- and two-family housing, as well as for many R occupancies.

Steel modules have come onto the market more recently. These modules are typically constructed with a structural steel frame, steel and concrete floor deck, and cold-formed steel wall panels.

ADVANTAGES OF MODULAR CONSTRUCTION

Quality. The modular manufacturing and approval process requires adherence to all applicable codes. Quality control staff within the manufacturing facilities are responsible for reviewing the work for each trade. While code enforcement rigor can differ by locality, all modular units are required to be inspected by a third party agency prior to being shipped. Several states also require a separate code review and approval process for modular units prior to issuing a permit for construction.

For steel modular structures, additional certifications are often required for welders and concrete finishers.

Speed. Because the superstructure is constructed off-site, the fabrication of the building can begin in conjunction with the site and foundation preparation. This can reduce the time from beginning of construction to occupancy by 30%-50%. The time saved on site can translate into reduced costs for general conditions, for such items as construction trailer rental, Construction Management staff on-site, and utility costs. The ability to occupy the building in a shorter period of time from the start of construction also represents a faster return on investment.

ADVANTAGES OF STEEL CONSTRUCTION

Sustainability. The off-site fabrication process results in less material waste than traditional site-built construction. Steel modular construction is exceptionally sustainable, as structural steel shapes produced in the United States contain approximately 80% recycled content. Because steel is the most widely recycled material, when a steel modular structure reaches the end of its useful life it may be easily dismantled and recycled, thus diverting what would otherwise be construction material headed for a landfill.

Steel modular buildings may be designed to be disassembled and relocated, prolonging the structure's useful life. This concept is currently being explored by developers following the Marcellus Shale development in northern Pennsylvania and the anticipated development in New York. While a steel modular structure could be disassembled with relative ease, the same cannot be said for wood framed modules.

Fire Resistance. Steel and concrete construction is compliant with Type II Construction. The inherent fire resistance of these materials allows for increased building height and footprint. In Europe, steel modular construction has been used in buildings up to 24 stories in height, and a 32 story high rise is currently underway in the Atlantic Yards sports village in Brooklyn, NY.

Structural. Steel modular construction allows for longer opening spans when compared to wood-framed modular construction. The rigidity of the module frame is greater than that of site-built construction and may be considered as part of the lateral force resisting system. Where additional capacity is required, steel cross bracing, knee braces, moment frames, or shearwall panels are all options available to the Engineer. Because of the ease of connection and the higher capacity of steel connections versus the capacity of wood connections, steel frames are more likely to act together when connected across mate lines.

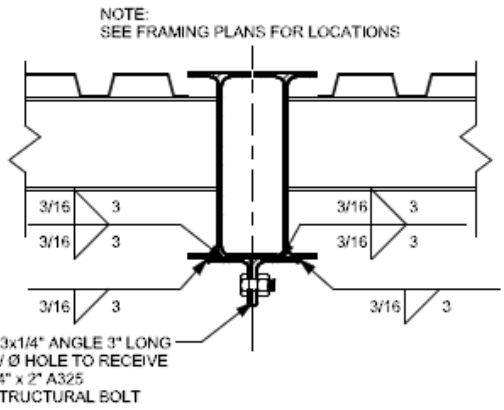

Figure 2 - Mate line connection

The use of steel also offers the advantage of consistent material properties and durable long term behavior. When the building design allows for repetitive module sizes and design, the Engineering analysis and detailing for such a structure also becomes simplified and more efficient.

Design Flexibility. The increased spans and tolerance for concentrated loads or cantilevered conditions allowed by steel construction provides a high degree of design flexibility for Architects. Because steel allows increased spacing between structural members and greater spans can be achieved with shallower members when comparing steel to wood construction, more space is available in the ceiling to floor space to run plumbing, electrical, and HVAC. A typical floor joist spacing with conventional wood or light-gage steel joist construction is 16" on center, while the joist spacing in the structural steel and concrete system is typically four feet for floors and up to five feet for roofs. In addition, the typical structural steel joist depth used can be shallower than wood or cold formed joist options.

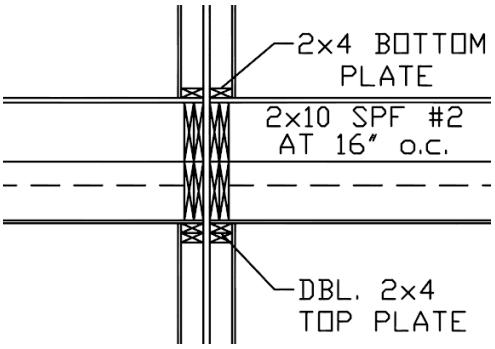

Figure 3 - Wood modular framing @ mate line, 2-story

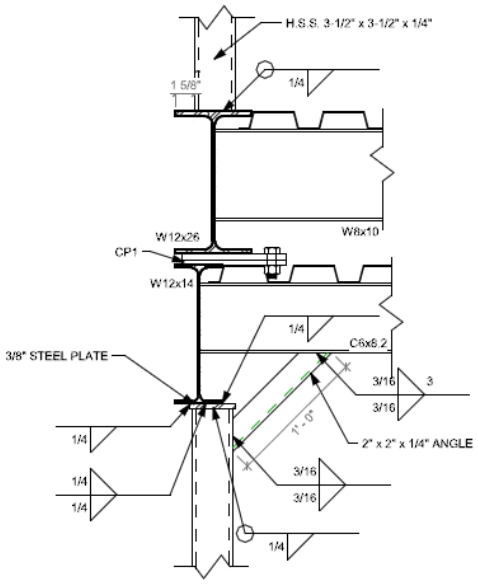

Figure 4 - Steel modular framing, 2-Story

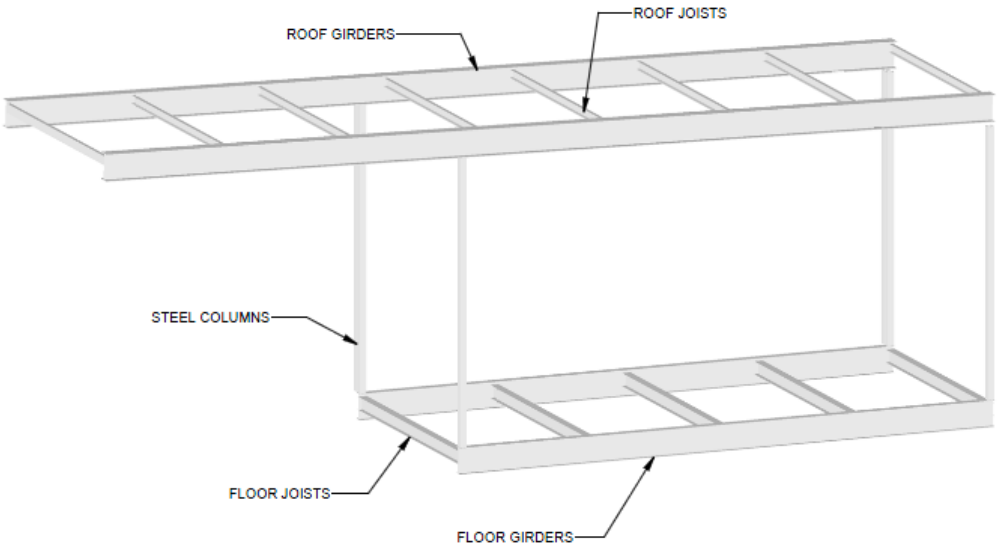

Figure 5 - Typical steel "box"

Figure 6 - Under construction

"BUILD-TOGETHER" TECHNOLOGY

NRB offers off-site construction in a process it has termed *The Build-Together Advantage*. Unlike assembly line manufacturing where individual modules never truly meet each other until they are on the site, NRB puts all the modules together, forming a complete structure at the plant, which means with *The Build Together Advantage* everything is finished and you can be sure the modules all fit together with incomparable precision. Plumbing, mechanical, and electrical components can be tested as a complete building system ahead of time; no surprises on site. NRB buildings are also inspected and certified by a Commercially Licensed Building Inspector, Third Party Inspection Agency (TPIA), and the project Architect or CM team at the facility.

As a direct result of *The Build-Together Advantage* construction process, shipping every NRB modular building is easier and faster; *The Site-to-Site Transfer* is an efficient, pre-planned transition between the factory and the site. Modules are configured to allow a top-pick craning method, allowing for a faster site set, with less site disturbance and no gaps between units.

As a result of the *Build Together* process, the subsequent product provides an easy, fast, and accurate on-site installation.

NRB's "Build-Together" "Off-Site" Method	**Assembly Line Construction**
1. Design is driven by Customer's or Architect's design	1. Design is driven by plant capabilities.
2. Schedule is driven by completion date.	2. Schedule is driven by the plant's need for volume; either dollars-out-the-door or units-out-the-door capacity.
3. Generally utilizes the Architect's construction drawings supplemented with structural steel drawings from NRB.	3. Requires production drawings to be developed by the manufacturer for each station in production.
4. Fewer restrictions or limitations on custom designs or materials.	4. Custom designs and use of custom materials are very limited. Custom production slows down an assembly line, which adds cost; decreases profit.
5. Generally built outside (same as on-site construction) due to size, complexity. (Very few factories have the capability to build large projects inside, all at one time.)	5. Generally built in a factory.

6. Multiple projects can be built at the same time. Your building does not have a "Line Lead-Time" so your project never waits in queue and therefore is much faster to start than assembly line lead-time methods.	6. Requires a "Line Lead-Time" which is the period of time your project has to wait in queue behind the other projects that are already "booked", or in production. Construction of multiple orders requires a plant to have multiple production lines and more production workers.
7. Uses sub-contracted, skilled or trained labor, so the level of quality is the same or better than site-built construction.	7. Generally uses unskilled, but trained, factory labor.
8. Uses "Just-in-Time" materials for construction; however, non-receipt of material does not create costly or time consuming delays or quality issues.	8. Requires custom materials to arrive "Just-in-Time" for production. Nonreceipt of materials creates costly and time consuming yard and potential delivery delays.
9. Not forced to use factory-stocked or "standardized" materials. Most any type of material can be incorporated in the "off-site" construction method.	9. Generally requires the use of the factory's standardized/stock materials and methods of installation for optimum efficiency.
10. Units have already "met" before arriving on site so the installation process is much faster than assembly line delivery.	10. In most cases, modules don't "meet up" with each other until they get to the customer's site.
11. Mechanical, plumbing, and sprinkler systems are built together at the factory and can be pre-tested.	11. Mechanical, sprinkler, and plumbing are generally not tested and fairly incomplete from the factory.
12. Welding certifications can be provided for all welding.	12. Welding certifications are rarely available.
13. Tour the building while it is under construction, just like a site-built building, even if multiple story.	13. Allows a limited walk-through of the project as units are in varying stages of completion on the assembly line or are already stored in the factory yard.
14. Last minute changes can be accommodated.	14. Last minute changes cannot be easily accommodated.
15. More scope is completed at the factory = faster speed to completion on site.	15. Level of finish when leaving the factory is generally lower, requiring more finish work to be completed on-site.

16. Project is bondable with invoicing by AIA monthly draw, verified to a schedule of values, with release of lien or waiver documents; all notarized, just as if site-built.	16. Most factories are not bondable and project is invoiced as each unit comes off line.
17. Allows proper application and installation of SCIF and fire spray treatments to code and specification.	17. Difficult to install SCIF and/or fire spray treatments. Continuity or integrity of treatments is difficult to maintain on-site.
18. Built to the latest edition of the International Building Codes, inspected and certified by an NRB Licensed Commercial Building Inspector, Third Party Inspection Agency, and project Architect or CM team.	18. Built to the latest edition of the International Building Codes and inspected by plant employees with a Third Party Inspection Agency.
19. Uses top pick craning, faster site set, no gaps between units.	19. Generally requires axles to be removed before set and a sling type set process. Slower process; more site work involved. Gaps between units up to 1".
20. Installation and completion is handled by experienced riggers and skilled tradespeople.	20. Installation and completion is generally handled by typical modular set crews.

SUMMARY

Where site and schedule constraints are limiting factors, modular construction is an excellent choice. For projects that require fire resistant construction or LEED certification, steel and concrete modular units combine the advantages of the modular process with the advantages of the strength and durability of those materials. And, where projects require a higher level of customization and precise fit, the off-site "Build-Together" method offers an advantage over a traditional assembly-line process.

REFERENCES

(2012). "History of Modular Homes & Buildings." <http://www.modulartoday.com/modular-history.html> (December 3, 2012).

(2012). "Arup's Modular High Rise at Atlantic Yards Breaks Ground." <http://www.prnewswire.com/news-releases/arups-modular-high-rise-at-atlantic-yards-breaks-ground-184434771.html> (December 21, 2012)