Steel is Sustainable Construction

Green Acres

By William B. Kussro, P.E., S.E.

Photo courtesy of Walbridge Aldinger, Inc

A new truck-assembly building for the Ford Motor Company in Dearborn, MI integrates green building concepts into a modern manufacturing facility.

When the Ford Dearborn Truck Assembly Building opens later this year, it will be the new home of F-150 passenger truck production in southeast Michigan. The new 1.15 million square foot facility is the largest of several new structures recently constructed at the historical Ford Motor Company Rouge River Industrial Complex in Dearborn, MI. The project will allow the automobile manufacturer to produce vehicles efficiently and profitably in an environmentally friendly, modern and versatile manufacturing facility.

The project posed many structural challenges as well as the opportunity to use "green building" concepts in designing a new automobile-manufacturing facility. The use of structural steel contributed to the building's sustainable design: steel's recycled content is near 100%, and it's a material that can be recycled repeatedly without losing its quality. Incorporating structural steel into a building design can earn LEED™ points for the use of recycled and locally manufactured materials. Probably the most notable feature of the project was the creation of the largest living green roof system in the world, which was incorporated into the design of the Assembly Building. The physical size of the project and rigid schedule demands made the project challenging.

Steel Superstructure

One of the biggest structural challenges was designing the complex roof-framing system. The structure primarily consisted of welded steel trusses of varying depths that framed the roof of the manufacturing area. Although the typical bay sizes were 50′ by 50′, many of the bays were 50′ by 100′ with the jack trusses spanning the longer dimension. The larger bay size was required to increase column-free space and provide utmost flexibility for the process functions. The clear height to the truss bottom chord was 34′ in the manufacturing areas but somewhat lower in other areas. The overall truss depths were limited to 12′ for most trusses due to over-the-road shipping restrictions. In most non-manufacturing areas, such as the receiving areas not subject to process hanging loads, long-span steel bar joists were used to span up to 135′. Column sizes ranged from W14×90 for lightly loaded perimeter columns to W14×500 at the columns supporting the rooftop electrical penthouses. A 3″-deep rib 20-gage galvanized metal roof deck was used to widen the purlin spacing and to minimize the number of pieces to be fabricated and erected. It also provides increased stiffness to carry the weight of the roofing materials and vegetation. Structural expansion joints consisting of double columns were placed at about 500′ on center and separated the building into four rectangular quadrants.

The roof trusses were designed for process hanging loads as required by Ford. Most carrying trusses were 50'-long warren-type parallel chord trusses. Conversely, most jack trusses were 50'- or 100'-long inverted warren-type trusses with $^{3}/_{16}$" per foot sloping top chords to promote positive drainage. While most trusses had WT top chords and wide-flange bottom chords, some of the 100'-long jack trusses required wide-flange shapes due to the magnitude of the chord forces that approached almost 1,300 kips at some locations. Unlike many conventional industrial building trusses where the hanging loads must be positioned at the truss panel points, the wide-flange bottom chords were designed for combined axial tension and flexure so the process hanging loads could be supported anywhere along the bottom chord. This greatly increased flexibility in designing the process functions supported from the roof structure.

The truss web members were generally double angles with the long leg back-to-back. Sway trusses or sway frames provide lateral stability and maintain alignment of the carrying trusses. The overall truss depth was restricted to about 12' for fabrication and shipping limits, and most of the trusses were below this depth. Several of the employee-entrance trusses spanned 150' and were 18' deep, and had to be field-assembled. A complex catwalk system was installed at the truss bottom-chord level to provide maintenance access to the air-handling units, to two large electrical substations, and to miscellaneous building equipment located in the truss space. The catwalk system also provided for general roof access. Several of the truss-web member configurations had to be modified slightly to provide clearance for the catwalk to pass through. In total, the building included more than 1,200 trusses of more than 350 different types.

Adding to the structural complexity was the design and integration of the office core area within the plant. The core area, also termed the "monument," was three stories high, and contained most of the office, maintenance and support functions, including repair areas, locker rooms, cafeteria, medical center and other employee amenities. An employee mezzanine, which circles the facility, is about 140,000 sq. ft in size. The mezzanine is positioned 16' above the plant

Photo courtesy of Walbridge Aldinger, Inc

Everything's Greener...

The living green-roof system incorporated into the design of the Assembly Building is the largest green-roof system in the world at 454,000 sq. ft (about 10½ acres). The green-roof design was initiated by consulting architect William McDonough and Partners and then implemented by ARCADIS and Xero Flor, an international firm specializing in green-roof and other related systems.

The green-roof construction consisted of a modified bitumen roof membrane over rigid insulation on galvanized metal deck. A protection board, a thin, four-layer growth media/drainage mat system, and a low-maintenance perennial ground cover called sedum were placed over the membrane. Although the actual green-roof system used on the project weighs only about 15 psf in its saturated condition, a design dead load of 25 psf was used due to system unknowns, and because the final roof and natural vegetative covering system was not selected at the time the structural steel was designed. Further, Ford design standards called for the use of a 30 psf non-reducible roof live load in addition to all imposed dead loads.

The additional dead load from the green-roof system increased the steel weight about 1.5-2.0 psf on average, but the roof has many benefits. It filters storm water and minimizes the storm-water runoff, provides positive insulating properties, protects the roof membrane and extends the roof's useful life, helps to clean pollutants in the surrounding air, and provides a natural habitat for birds, butterflies and insects. The impact of the additional dead load on the design was less than expected since the trusses were very deep and efficient. However, serviceability was a concern due to the unknowns in the green-roof system having a tendency to retain water and become saturated, especially since an irrigation system was installed on the roof to promote initial growth of the vegetation. Accumulations of irrigation water, rainwater, snow, ice, etc. were all studied as well as the roof ponding and deflection characteristics. The inherent stiffness of the deep roof trusses provided adequate stiffness to preclude a ponding instability and failure.

Green-building concepts also helped introduce extensive natural light into the building. Light monitors and large gabled skylights were added to provide a positive working environment while reducing demand for artificial light during daylight shifts. Monitors were positioned over the employee mezzanine, and smaller skylights were placed over manufacturing areas to provide natural light. The natural light was introduced strategically to avoid glare and light-reflection problems in assembly areas of the building that have a large glass, chrome and plastic part content. A total of ten 33'-4" by 100'-0" light monitors were installed. Solid-rod vertical bracing was used to minimize shadow lines and provide unobstructed views to the outside. In addition, a total of 36 gabled skylights, 12'-6" by 25'-0" with translucent glazing, also were used to introduce natural light into the manufacturing areas and produce an invigorating work environment. Photo sensors brighten or darken the artificial light provided by light fixtures to provide an even lighting distribution when the sun is moving in and out of the clouds. Finally, the steel was painted a bright white to provide reflectance and to further lighten the spaces.

One of the many truss-to-column connections in the Assembly Building. The frame-line trusses and the columns form rigid moment-resisting frames in both principle directions to resist lateral wind and seismic forces. In total, the Assembly Building included more than 1,200 trusses of greater than 350 different types.

floor and provided additional space for team rooms, break rooms and other similar functions. Stairs join the mezzanine to the plant floor below. Due to the column-free space required below, more than half of the mezzanine was hung from the roof structure. Extended mezzanine beams and double-angle hangers in a starred configuration were used to hang the mezzanine. The starred angles simplified connection details while eliminating eccentricity of both the members being supported and the members providing support at the truss bottom chord, regardless of member orientation. High-strength steel, composite construction and lightweight concrete of minimum thickness required to obtain the fire rating were used for the mezzanine construction to minimize the hanger loads as much as possible.

The lateral-load resisting system consisted of trusses on the frame lines working with the columns to act as rigid moment-resisting frames in both principle directions. The metal roof deck, along with horizontal bracing at the truss top-chord level, provided stability for the trusses and transferred lateral loads to the moment frames. The truss end connections were designed for combined shear and axial wind and seismic forces due to the frame action, and considered the eccentricity and the resulting prying action forces within the connections. The truss bottom chords were designed for axial compression resulting from continuity forces. These forces result from vertical dead and live loads imposed after the top and bottom truss chord-to-column connections were installed and fully tightened. Supplemental double-angle vertical bracing was used in the receiving areas framed with joist roofs where the moment frames provided lateral-load resistance in only one direction. Each quadrant was designed as a freestanding, unshielded structure for the lateral-load analysis.

Steel Working Underground

Structural steel was used for the majority of the superstructure, and it also provided an important ingredient in the building foundation system. The Ford Rouge site is located in downriver Detroit and is about 3 miles from the Detroit River. The subsurface conditions at the site generally consist of variable fill materials overlying an extensive deposit of stiff to soft silty clay. This layer overlies compact-to-dense granular material and/or hard silty clay (hardpan), which is above limestone bedrock at a depth of about 115′ below the ground surface. The thickness of the soft clay layer was anywhere between 45′- to 85′- thick and the standard dynamic penetration resistance of this layer was between the weight of the hammer and 6 blows per foot, thus indicating an extremely soft soil layer with a structural consistency similar to toothpaste. In addition, the long-term groundwater level was located within 2′ to 3′ of the ground surface.

As a result of the poor soil conditions, several foundation systems were reviewed. Shallow spread footings were not viable due to the low bearing capacity and long-term settlement concerns. Drilled shafts or caissons were not cost effective due to the high water table and weak soils causing sloughing soil conditions, which required wet methods of construction or steel casings during construction. It was quickly determined that the most efficient and cost-effective solution was to provide end-bearing steel HP piles to support all significant loads. HP10x42 (50 tons and 75 tons working capacity) and HP12x53 (100 tons working capacity) piles were used to support the majority of the building loads. The piles were driven either to bedrock or the hardpan layer immediately above the bedrock, and designed for combined vertical and lateral shear loads causing flexure. Negative skin friction was a concern due to the thick layer of compressible clays that the piles were driven through. This was accounted for during the design. ASTM A572 Grade 50 material was chosen to obtain a high axial capacity. It was also the material grade that was most easily obtained for the HP shapes desired. On average, the 50-ton piles were 95′ long and the 75- and 100-ton piles were 115′ long. The piles were arranged in groups ranging from two to 10 piles per group, joined by a reinforced-

A view into the manufacturing area from one of the stops on the plant tour.

concrete cap at the top. The anchor rods were cast in the cap and provided anchorage for the wide-flange building columns.

Yet another challenge was the fact that the site has been used for various industrial purposes during the past 100 years, and as a result, many piles hit buried obstructions. In those circumstances, replacement piles were driven and the pile group and cap were redesigned for the eccentric loading. Although this was an additional design task, it was much easier to redesign the pile group compared to what would have been required using alternative deep-foundation systems like caissons. In total, about 6,500 tons of steel piling was used under the Assembly Building and 11,500 tons for the entire Heritage Project. The total length of piling installed is about 500,000 lineal feet.

Light monitors placed over the employee mezzanine areas and exposed steel framing painted white help promote an invigorating work environment.

The Best Choice

Structural steel was the best choice for the new Dearborn Truck Assembly Building. As with other manufacturing facilities, structural steel framing offered low cost, ease of construction and availability. Steel also is a "green" choice, with its high recycled content.

Most importantly, steel provided flexibility for changing framing configurations and process hanging loads. During the course of the project, trusses were reinforced, shortened, lengthened, made shallower and altered as required by process functions. A portion of the mezzanine was reworked and columns were reinforced as additional process mezzanine requirements were established. At one location, posts terminating at the bottom chord of several 100′-long jack trusses were converted into hangers supporting the mezzanine floor below, and the trusses were reinforced to carry the additional load.

The total weight of structural steel for the Assembly Building was about 8,500 tons. Public tours are available through the nearby Henry Ford Museum and Greenfield Village complex (**www.hfmgv.org/rouge**).

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For more information on the use of structural steel in sustainable design, please visit **www.aisc.org/sustainability**.