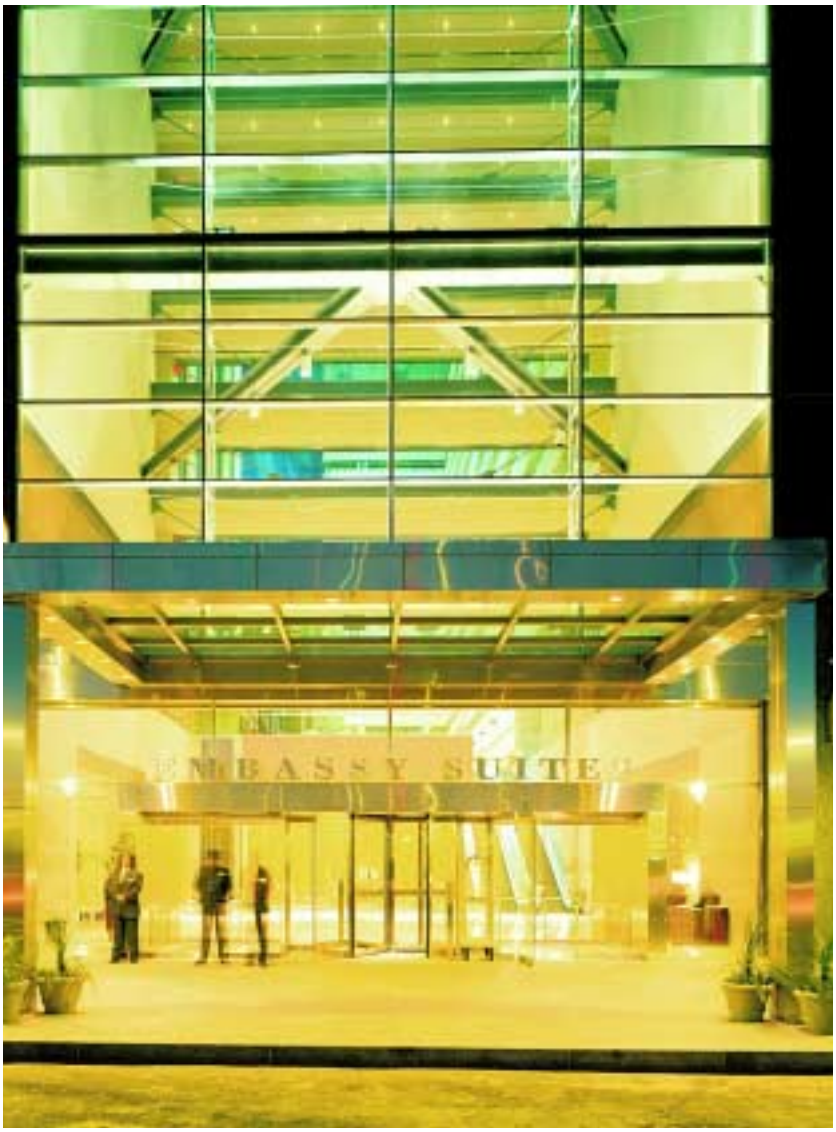


Staggered Truss System Proves Economical For Hotels

By Aine Brazil, P.E.

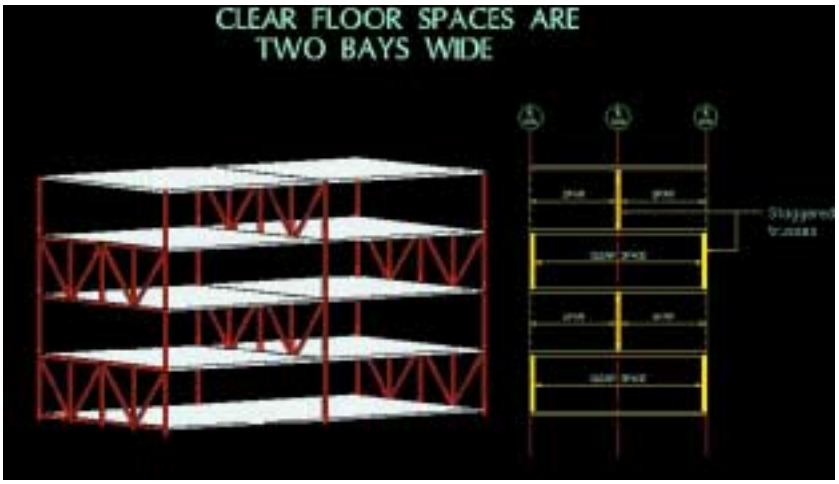
Totaling approximately 617,000 sq. ft, the mixed-use Embassy Suites hotel development is among the largest of several newly built hotels in the business district adjoining New York's bustling Wall Street area. The combination hotel-retail-cinema complex was conceived in 1996 as a way to attract people to Battery Park City, located near the southern tip of Manhattan, during the evenings and on weekends, when it is largely empty.

Opened to the public in June 2000, the L-shaped hotel is situated on a site measuring 62,500 sq. ft and has two wings connected by a 9,200 sq. ft east-west atrium with skylights and glass walls on its west. The development, which represents an $80 million dollar investment on behave of its developer Forest City Rantner, showcases a 463-room hotel, a 16-screen movie theater, a sizable retail complex and a 13-story-high, glass-walled public atrium forming a centerpiece offering sweeping views of the Hudson River.

Complex Requirements

The functional needs of the project's components could not have been more diverse. Movie theaters require long clear spans of up to 60', with high floor-to-floor heights, typically 32'. In contrast, hotels generally need short spans for 13 to 5' wide rooms and low floor-to-floor heights, normally in the range of 8' 8" to 10'. Retail spaces offer somewhat more flexibility: they benefit from longer open spaces, however spans of 30 to 40' are generally acceptable.

Space usage also dictated the types of ceilings that had to be used in the project. As large-volume, high-occupancy spaces, movie theaters need a ceiling plenum for air and service distribution, as well as acoustic enhancement. Where as, hotel rooms are small, private spaces served by individual HVAC units. With bathrooms stacked vertically,



Basic Staggered Truss System includes:

- *Story high trusses span building width*
- *Vierendeel panel permits central corridor.*
- *Trusses Alternate column lines on each floor*
- *Interior is typically column-free*
- *Floor system alternately supported on the top and bottom chords of trusses.*
- *Trusses resist both gravity and lateral loads.*

piping is distributed inside the walls, while the bedroom ceiling is usually the soffit of the floor slab above with a directly applied surface finish. Retail spaces will frequently use a ceiling plenum for service distribution and the installation of special features.

Flouting Tradition

Certain pieces of "conventional wisdom" are generally applied when choosing structural systems for a project, most of them dependent on the project's location and uses. For a New York mixed-use project like Embassy Suites, such wisdom would point to a concrete flat-slab system for the hotel and a steel-framed structure for the movie theaters. Transferring alternate columns under the hotel footprint to provide column spacing of up to 30' in order to accommodate the hotel's public spaces and retail at the base. However, it soon became clear that if the project was to survive the Thornton-Tomasetti engineers were going to need to throw a few traditions out the window.

Design Dilemma

During the initial stages of concept development, the project's budget estimate showed a very tight proforma. Unless the construction cost per square foot (psf) could be reduced, the project would not be financially feasible. The conceptual cost estimate, based on construction costs for similar projects built in the New York City market, called for a cast-in-place concrete system. The design team was charged with the task of finding significant cost savings—and fresh ideas were needed.

Thornton-Tomasetti Engineers proposed the use of a staggered truss system for the hotel combined with a conventional steel frame and composite slab-on-metal deck for the theater and retail components. Cost estimates by Bovis Lend Lease confirmed the value of the cost savings to be in excess of $2 million. The team had found a viable and economic solution, the next was to satisfy the client of the ability of the system to meet the program requirements while still providing the estimated cost savings.

Hotels: Concrete vs. Steel

Why is concrete flat slab so often the system of choice for hotel buildings? Flat-slab construction provides several important benefits:

- Shallow uniform thickness of the structure facilitates lower floor-to-floor heights, reducing the cost of the structure and the area of the exterior wall.
- Flat concrete slab soffit avoids the need for hung ceilings.

- Concrete slab satisfies the required fire rating for floor construction.
- Concrete slab provides good sound insulation and minimal floor vibration.

The staggered-truss system used for the Embassy Suites Hotel had many of the same advantages:

- The Filigree precast plank floor is 8" thick spanning to the staggered trusses, which are encapsulated in the partition walls between hotel suites and do not affect floor-to-floor heights.
- The soffit of the planks can be finished in the same way as the concrete slabs, without hung ceilings.
- The Filigree precast plank satisfies fire rating of the floor system.
- The detail at the ends of each plank provides system continuity, resulting in a stiff floor structure.

The decision to use the staggered truss system was, in the end, a financial judgment. For the specific project and site under evaluation, the steel system offered significant advantages:

- The weight of the steel and plank structure is 15% less than that of an equivalent concrete frame. Since the project site is located on land that was filled/reclaimed in the 1960s, deep end-bearing-pile foundations were required to support the structure. With depth-to-rock averaging 80', the reduction in structural weight resulted in approximately 15% fewer piles and smaller pile caps.
- Reduced dead load translates directly into reduced seismic load. Since the 14-story building's lateral systems were governed by seismic design, the reduced lateral design forces resulted in significantly lower cost.

In addition, the mixed-use nature of the project strengthened the case for an all-steel-framed structure. Composite steel framing with slab on metal deck was a logical, cost-effective choice for the theater clear spans of 40 to 60'. For retail uses, steel framing provides maximum flexibility, permitting easy modification when tenants change. The steel weight averaged 7 psf for the hotel and 15 psf for the theaters, which when combined came to a total steel tonnage on the project of 3500 tons. In a concrete structure, transfer girders would have been necessary to achieve the longer, more open spans needed at the lower public spaces.

Independent Structures or Combined?

The project footprint is organized with the theater in a trapezoidal block measuring 135 to 170' east-west and approximately 200' north-south, located in the northeast corner of the site with retail beneath. The hotel occupies two wings in an L shape: the west wing is 65'×170', while the south wing is 45'×265'. The 13-story atrium separates the theaters and west wing from the south wing. The only connections are a 40' wide bay of rooms at the east end of the atrium and a 10' wide bridge at each hotel floor at the west end of the atrium. This "slot" isolates the structural systems and tends to favor a solution using two independent buildings. However, separating the building into two structures would have led to the use of undesirable expansion joints.

To avoid the use of expansion joints, the building was designed as a single unit. This presented an interesting challenge that was solved by tying the north and south sections together with horizontal K-bracing at the west end of the atrium at floors

four, eight and twelve. The bracing and open atrium space create an impressive visual effect that highlights both architectural and engineering design.

The combined structure lacks the normal symmetry found in a typical staggered truss building. With floor-to-floor heights varying significantly from the hotel to the theater (8' 9" vs. 32'), floor diaphragms aligned only at the lower retail floors. Careful attention was paid to the transfer of diaphragm forces throughout the footprint and between the different floor elevations. Precast plank diaphragm forces were transferred through a fully grouted joint over each truss chord with interlocking rebar. This detail also helped provide continuity to increase the floor stiffness and thus reduce vibrations.

Advantages of Staggered Truss System include:
• Improved layout flexibility due to elimination of interior columns & two-bay open space in longitudinal direction;
• Large open spaces at base of building;
• Faster erection due to fewer pieces;
• All-dry system speeds winter construction;
• Efficient lateral system due to inherent stiffness; and
• Reduced structure weight compared to concrete construction.

Structural Components

Hotel Tower

Story-deep staggered trusses span transversely across the narrow dimension of each hotel wing. The truss spacing matches the suite partition locations, typically varying from 26 to 30' on center. Staggering occurs on alternate lines from one floor to the next. The 8" deep precast Filigree planks span from the top chord of one truss to the bottom chord of the adjacent truss. Since the trusses are completely encapsulated by the partition walls of the hotel, minimal width truss members are desirable. HSS rectangular sections were determined to be the most efficient. Top and bottom chords vary from TS 4"× 6"×½" to TS 4"×16" ×½". Both diagonals and verticals are typically 4"×4"×½", except at the vierendeel bays.

The trusses frame into the weak axis of the steel columns with seated connections. Lateral resistance in the transverse direction is provided by the extremely stiff trusses, which provide adequate lateral resistance "for free" when sized for gravity loads. For this project, lateral loading (either wind or seismic) did not control the design of any truss members. In the longitudinal direction, conventional Chevron bracing was provided in stairwells for lateral resistance. The tube steel is A500 Grade B.

Movie Theaters

The floor construction consists of composite floor framing construction. Beams were designed using LRFD design approach. The grade of steel for the floor beams, columns and bracing was ASTM A572 Grade 50. Cambering of the beams permitted the use of W18 beams for the 40' spans and W27 beams for the 60' spans. Floor slabs varied from 2" metal deck plus 2½" normal weight concrete to 3" metal deck plus 4½" normal weight concrete where required for acoustic separation.

Roof framing over the theater area consisted of open web joists with 1 ½" roof deck.

Provision was made within the footprint of each theater for the tenant fit-out of a full stadium seating theater. Partial mezzanine levels were provided, framed in structural steel, approximately 19' above the floor, to house projection booths and provide secondary means of egress. The stadium seating was supported on light gage steel joists and stud walls sitting on top of the theater slabs. This solution permitted the design and construction of the theater fit-out to lag behind the base building construction and provided an economical framing method for the stadium-seating component.

Foundation System

The depth-to-rock and thickness of the fill layer mandated a deep foundation system. Steel pipe piles filled with concrete were chosen. Load tests indicated that a capacity of 200 tons could be achieved with a

12 ¾"-diameter pipe with wall thickness of ½", filled with 8000 psi concrete. Pile pipe steel was ASTM A252 Grade 3. They were 12 and 3/4 by 3/8 piles.

Though conventional wisdom often leads engineers in the right direction in making design decisions, at times we must not be afraid to take risks.

Meeting the objectives of a client—whether they be related to time, cost or function—is the primary goal of every project. In the case of the Embassy Suites Hotel development, the client's cost requirements would determine whether or not the project got built at all. In this restrictive circumstance, engineers decided to ignore everything that was known about typical residential construction in New York City in favor of the staggered steel-truss system. In a demonstration of the rule that some risks simply must be taken, the result they found was exactly what they—and their client—were looking for.

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Embassy Suites Hotel
Battery Park City

Location: New York City

Owner/Developer: Forest City Ratner Companies, New York City

Structural Engineer: Thornton-Tomasetti Engineers, New York City

Architect: Perkins Eastman Architects P.C., New York City

Construction Manager: Bovis Lend Lease, New York City

Steel Fabricator: Helmark Steel (AISC member), Wilmington, DE

Steel Erector: Helmark Steel (AISC member), Wilmington, DE

Steel Detailer: Helmark Steel (AISC member), Wilmington, DE