Tunnel Vision

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A new Brooklyn apartment complex takes on the challenge of building over an existing New York subway facility—and comes out on top.

STATE RENAISSANCE COURT IS A NEW EIGHT-STORY APARTMENT BUILDING IN BROOKLYN, N.Y.

While large, urban residential buildings are the norm in New York, the building is unique is that approximately 90 percent of it sits on top of the existing roof of the Hoyt Schermerhorn Subway Transit Station running below the site.

The 158-unit, nearly 200,000-sq.-ft complex is the first building to be constructed almost entirely on top of a New York City subway tunnel since seismic considerations were introduced into New York City's building codes five years ago—about the same time that stringent seismic performance standards were introduced by the International Building Code. (Although the city has yet to adopt IBC, this project does meet those seismic standards.) While building over an existing subway tunnel isn't a new idea, constructing a residential building whose vertical support will be provided by the existing subway structure—without the first floor being rigidly affixed to the subway structure itself—is.

Changing Course

From the outset, Strategic Construction Corp., the project's general contractor, was faced with unprecedented challenges, among them the steel design of the building. The initial design of the structure called for the use of ordinary steel moment frames (OSMF) throughout the project, which resulted in a higher than anticipated base shear. However, while this original design was being finalized, Strategic Construction determined that it would be more economical to switch to a braced-frame system and revised the design accordingly. The project used nearly 1,500 tons of structural steel in all.

Because of the building's long and narrow geometry—the site is 447 ft by 90 ft—braces were placed at close intervals in orthogonal directions. This design enhanced redundancy and stability, and produced rigid floor diaphragms in compliance with the New York State Building Code (NYSBC).

Thinking Seismically

Given the building's location above a functioning subway station, seismic considerations were a necessity—and a unique challenge—for the developers, a joint venture partnership of Strategic Development and Construction Group and IBEC Building Corp., and the engineering/design team they assembled for the project. Extensive studies were carried out to analyze seismic isolation versus seismic separation options. With seismic isolation the new building adopts new dynamic properties through the use of base isolators, which effectively decouple the building from its base.

With seismic separation the dynamic properties are mostly left unaffected. However, the seismic forces created by the new building are separated from the subway base and directed through a special diaphragm to reaction blocks. Because seismic isolation would have produced unacceptably large lateral displacements, seismic separation was selected instead.

The building columns over the subway tunnel are supported on continuous steel transfer girders—basically, a 440-ft by 90-ft truss

Lateral force resistance is provided by braced frames. Brace members were typically HSS shapes.

Steel transfer girders at the first floor level are supported by isolators made of springs, rubber, and Teflon.

turned sideways—which are supported on the subway columns below. The building columns had fixed bases, but the transfer girders were mounted on a network of 270 isolators. The isolators, in turn, sit on top of 26 concrete-encased steel girders, which are part of the original subway structure. As such, the entire first floor level, essentially a "floating platform," can move laterally, relative to the subway structure, up to a half-inch.

The isolators are made of springs, rubber, and Teflon. This materials combination was chosen after extensive studies of alternate materials, and each component serves a different purpose, as follows:

- **Springs** attenuate sound transmission in the low-frequency range of 10-15 hz.
- **Rubber** accounts for any accidental high frequency that may be generated.
- **Teflon** prevents seismic forces from overstressing the subway structure below.

The building columns over the reaction blocks had different connections. In those areas, Teflon was omitted. Instead, seismic fixity was created using internal and external snubbers, which offer zero lateral clearance, thereby resisting loads due to any excitation. Shear, compression, and tension were safely resisted by these snubbers.

Because of the high eccentricity caused by the location of the reaction blocks, the first floor was designed as a diaphragm. The diaphragm was designed with metal deck and concrete, and strengthened with reinforcing bars. Additionally, special horizontal trusses were added for additional strength at openings.

Since it serves as the major load-transfer platform, the diaphragm uses 40 percent of the building's steel. Another reason it uses so much steel is because the frame had to wrap around an existing above-ground subway ventilation structure, and thus couldn't be built in one continuous rectangular shape.

NYC Transit Authority Requirements

Throughout the entire design and review process the owner/design team was advised by a select team of engineers from the NYC Transit Authority. Each design and analysis option and intermediate results were reviewed; comments were made and adjustments implemented until final acceptance.

The Transit Authority required that construction on an existing transit facility meet the following criteria:

1. Conform to 2000 New York State Building Code (IBC) requirements.
2. Wind and seismic lateral loads must not be transferred into the existing subway tunnel; pile-supported reaction blocks must be used for anchorage.
3. Reaction blocks must be designed for seismic events using a dynamic analysis and an R value of 1.0.
4. Twenty-five percent of live load must be included in the dynamic mass.
5. Do not exceed prescribed deflection values at reaction blocks and transfer floors.
6. Seismic base shear is applied at some distance below the ground surface. Model the foundation as if it were part of the superstructure, elevated, and exposed above grade, but include soil-structure interaction and model the piles as needed for the lower part. Assume the exposed foundation to be free from soil-damping characteristics, but subject to forced seismic oscillations.
7. Steel frame R = 3.0: no column failure; some beam overstress is acceptable. Structural frame R = 5.0: no steel overstress. All connections to develop member capacity using over-strength factors.
8. Model the structure with various computer programs and ascertain accuracy of modeling and structural calculations.
9. Perform a dynamic analysis using a site-specific response spectra. Load combinations to include the addition of 25 percent perpendicular directions.
10. First floor must be analyzed for a potential accidental drop during construction.

New York State Building Code

The building was designed using the Equivalent Static Force method and checked using the Dynamic-Response Spectra Method. As can be seen, different design methods provide different results.

The difference in base shear magnitude is attributed to the different ways the building's natural frequencies are calculated by the following methods:

Static Method: The first natural frequency is calculated based on approximate code equations.

Dynamic Method: The natural frequencies are more correctly calculated by computer programs using the "exact" mass and stiffness matrices, and using modal analysis.

Modeling Concerns

3D modeling was performed with RISA 3D, then checked using the STAAD Pro program. While most commercial programs offer enhanced accuracy over hand methods, they also have limitations, mostly in terms of diaphragm modeling and base fixity and supports.

In STAAD Pro, plank floors were initially modeled with plate elements, which distribute loads in all directions. Concrete planks, however, are one-way slabs supported at each end. This difficulty was compensated by analyzing and designing beams outside of the STAAD program and applying loads manually in the 3D model, as needed.

Lateral analysis, performed with the plank floors modeled as plate elements in STAAD Pro, produced initially incorrect lateral stiffness, natural frequencies, dynamic behavior, and distribution of gravity loads. However, upon correcting the model, design agreement was achieved, and both STAAD Pro and RISA results were identical.

The base isolators were analyzed using STAAD Pro. In total, more than 30 load combinations were used, including static and dynamic load combinations. Building deflections showing individual mode shapes were instructive, as they identified overall behavior.

Seismic Success

In the end, the structural design of the State Renaissance Court project was performed in compliance with the requirements—including seismic—of the NYC Transit Authority and NYSBC. And structural calculations were verified using an independent 3D model.

A site-specific response spectra was created using the NYSBC, then modal analysis was conservatively applied. All base reactions were shown to exceed code requirements, based on existing subway drawings. Also, all deflections were shown to be acceptable.

Perhaps just as important as meeting the transit and building code requirements, and using seismic engineering rivaling that of buildings in areas with frequent earthquake activity, is the fact that the building became somewhat of a research and development project—one that has helped to establish previously unavailable design and engineering parameters and standards that can be used to evaluate similar projects in the future. MSC

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Software
RISA 3D, RISA Floor, STAAD Pro

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