55 HUDSON YARDS

By

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POST-TENSIONING INSTITUTE ®

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INTRODUCTION

Hyperstatic forces were recently used to resolve a major challenge facing the structural design of 55 Hudson Yards, a Manhattan, NY, high-rise that will be partially constructed over and supported by an existing structure (Fig. 1). The design scheme required the columns of the existing structure to provide partial support for the new construction. The challenge was to match the anticipated reactions of the new construction, which are governed by the building's architectural design and construction scheme, to the location and capacity of the columns of the existing structure.

While the combined capacity of the columns of the existing structure could support the weight of the new construction, the distribution of the reactions from the new construction was considerably different from the capacities of the existing supports. Among the several options explored, the use of post-tensioning configured to generate a set of hyperstatic reactions so that the reactions from the new structure matched the capacity of the existing supports proved to be the most practical and effective scheme.

HUDSON YARDS

According to its developers, Related Companies and Oxford Properties, Hudson Yards is the largest private real estate development in the history of the United States and the largest development in New York City since Rockefeller Center (Fig. 2). The project covers 28 acres (11.33 ha) on the West Side of Manhattan, and when it is completed in 2024, 125,000 people per day will work at, visit, or call Hudson Yards their home. The site will include more than 17 million ft^2 (1.6 million m^2) of commercial and residential space, state-of-the-art office towers, more than 100 shops, a collection of restaurants, approximately 4000 residences, 14 acres (5.67 ha) of public open space, and a 750-seat public school. Half of the project extends over an existing rail yard; the 30 active train tracks are slowly being covered by a massive plat-

Fig. 1—55 Hudson Yards, Manhattan, NY.

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form that will hold three towers, a retail complex, a 6 acre (2.43 ha) public square, and a new cultural space. The construction is expected to be completed in 2019 and is taking place while the trains remain in operation.

55 HUDSON YARDS

A prominent part of the project is a 51-story commercial office building, 55 Hudson Yards. One of the first fully concrete-framed high-rises of its class in New York City, the tower will include over 1.3 million ft^2 (120,773 m^2) of office space. The developers wanted the building to provide modern, efficient floor spaces uninterrupted by columns and with floor-to-ceiling windows. The solution comprises long-span post-tensioned flat slabs supported by a central core and perimeter columns. The architects are Kohn Pedersen Fox Associates plus Kevin Roche John Dinkello Associates, and the structural engineer is WSP USA. ADAPT Corporation was consulted on the post-tensioned aspects of the design.

The projection of the building beyond the central core, shown on the left of the structural model of the building, is supported on the column ends of the existing MTA (Metropolitan Transit Area) ventilation building. A post-tensioned wall system was developed in the new construction over the existing building to bring the reactions from the new construction to within the allowable values of the existing supports.

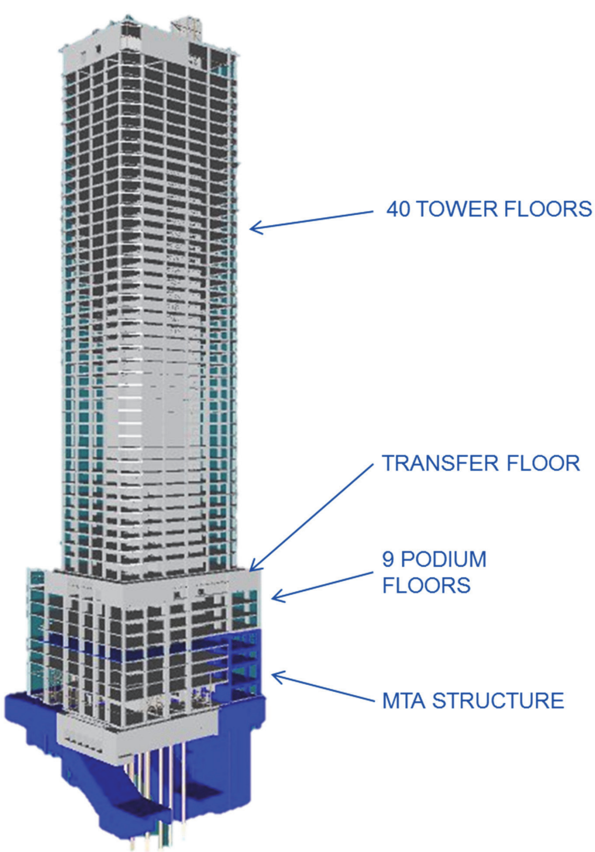

Fig. 2—Structural model of 55 Hudson Yards.

POST-TENSIONED WALL

The existing ventilation tower had been designed with designated support locations to accommodate future development at the Hudson Yards project. The architectural requirements and the massing of the proposed new construction, however, led to a potential overloading of two of the interior existing support locations (Fig. 3), while the exterior support locations were underused. WSP USA evaluated several design and construction approaches to redistribute the loads, including the use of a large steel truss in combination with the delayed casting of the central columns (Fig. 4). Load redistribution would have been achieved by initially spanning the exterior columns with the steel truss. The central columns would be cast only after sufficient load had been transferred to the outer supports. After installation of the central columns, the remaining construction load would have been distributed among all supports.

Another option, developed in collaboration with ADAPT, was to redistribute the loads using post-tensioning tendons draped from the 10th floor at locations near the exterior columns down to the eighth level at the two interior columns (Fig. 5). This alternative allowed ducts to be placed during the level-by-level construction of a concrete wall. Multi-strand tendons, supplied by Freyssinet, Inc., would be fed through the ducts and could be stressed from the 10th level, where segments of the wall would terminate. Calculations showed that the proper load rebalancing would occur if the tendons were stressed after completing construction of the 20th floor.

Using post-tensioning in a cast-in-place wall provided a simple solution for rebalancing the reactions on the existing structure, with minimal requirements to manipulate the construction sequence. It also avoided the need for mixing structural steel construction with concrete construction and was shown to be less expensive to implement than the steel truss option.

The design concept of the post-tensioning alternative is based on the hyperstatic forces from post-tensioning (Fig. 6). In a statically indeterminate structure, the restraint of the supports to the movement caused by post-tensioning results in a set of forces in the structure; these forces are referred to as hyperstatic actions. In the structural design of post-tensioned members, the hyperstatic effects must be calculated and accounted for along with the other loads on the structure.

Through judicious selection of tendon profile and tendon forces, it is possible to configure the reactions to act in the direction and amounts required by design. This feature of post-tensioning was used to alter the reactions from the building loads so that they were within the allowable range of the existing supports.

Figure 7 illustrates the application of the concept to the 55 Hudson Yards concrete frame. The hyperstatic reactions from the post-tensioning in the wall were designed so that the column reactions framing into the wall were within the support capacity. The figure shows an elevation view of the lowest section of the wall and columns immediately above the four existing foundation supports, along with the profile of the tendons in the wall.

This figure is a schematic elevation of the lower wall section and its supports. W_1 through W_4 are the reactions from the superstructure at the base of the columns. Based on the elastic distribution of loads in the proposed structure, the W_2 and W_3 reactions exceeded the capacity of the existing supports, while the reactions at W_1 and W_4 were less than the capacity of their supports, but by different amounts. A total of three-hundred sixty seven 0.6 in. (15 mm) strands, providing a total of approximately 14,000 kip (62,275 kN), grouped in mostly 31 strands per tendon and arranged as shown, were used to create hyperstatic forces H_1 through H_4 at the base of the columns, where H_2 and H_3 are upward forces and H_1 and H_4 are downward forces. The sum of forces H_1 through H_4 is zero, but their result is to transfer load totaling over 5000 kip (22,240 kN) from central supports to

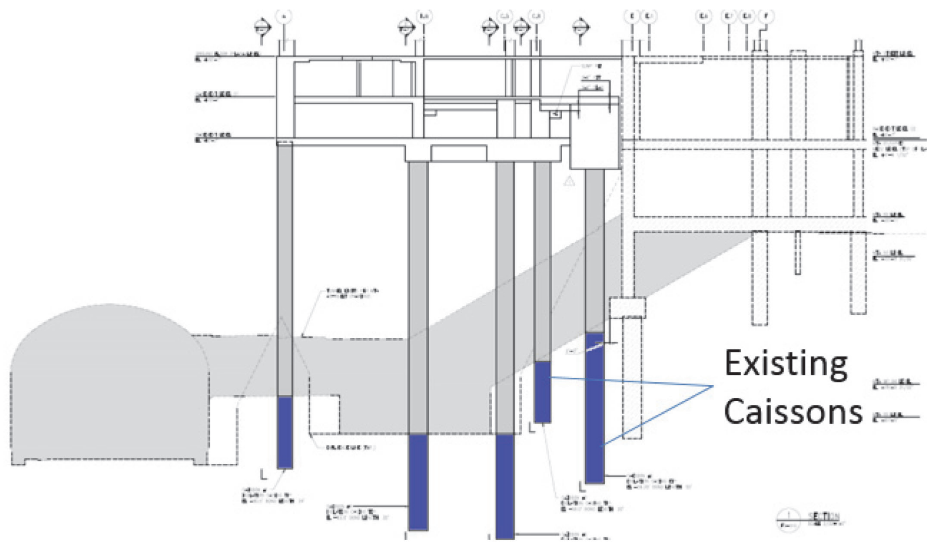

Fig. 3—Existing support locations.

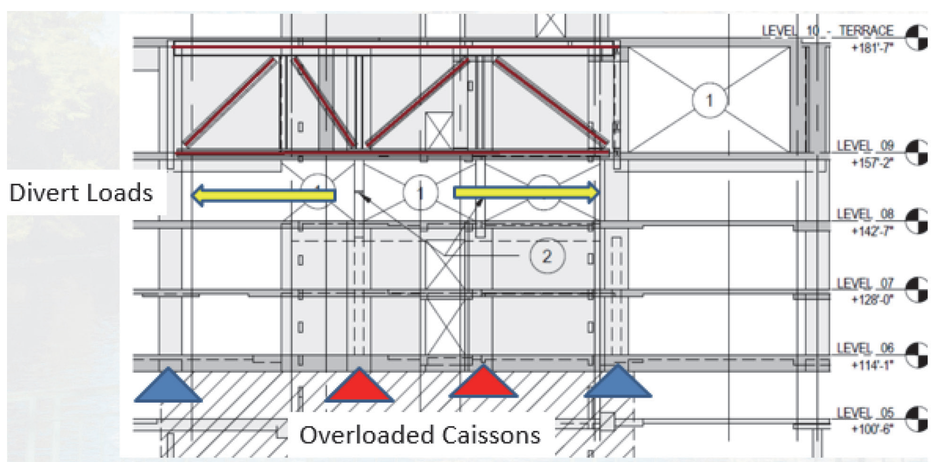

Fig. 4—Design approach using large steel truss.

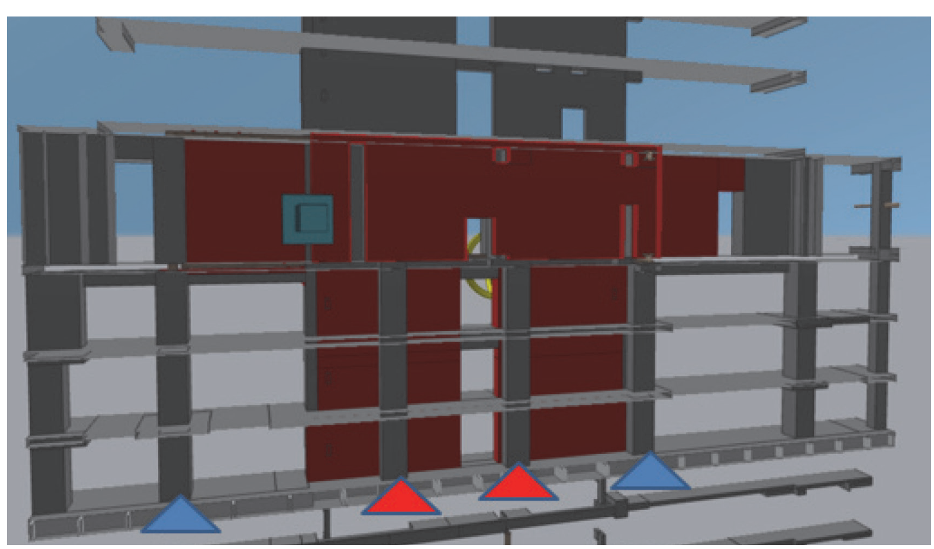

Fig. 5—Design approach using PT shear wall.

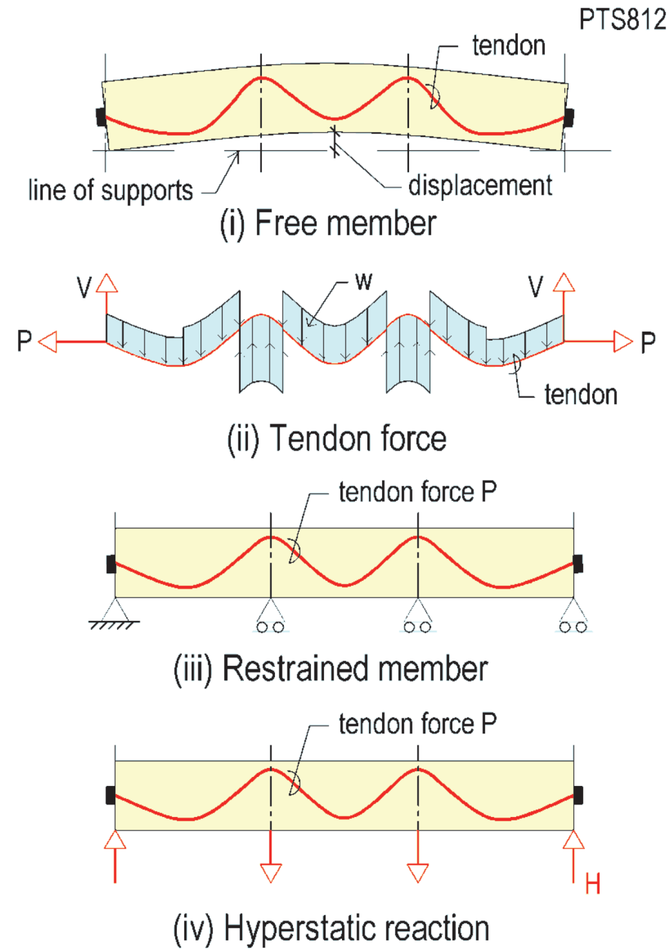

Fig. 6—Hyperstatic forces in post-tensioning.

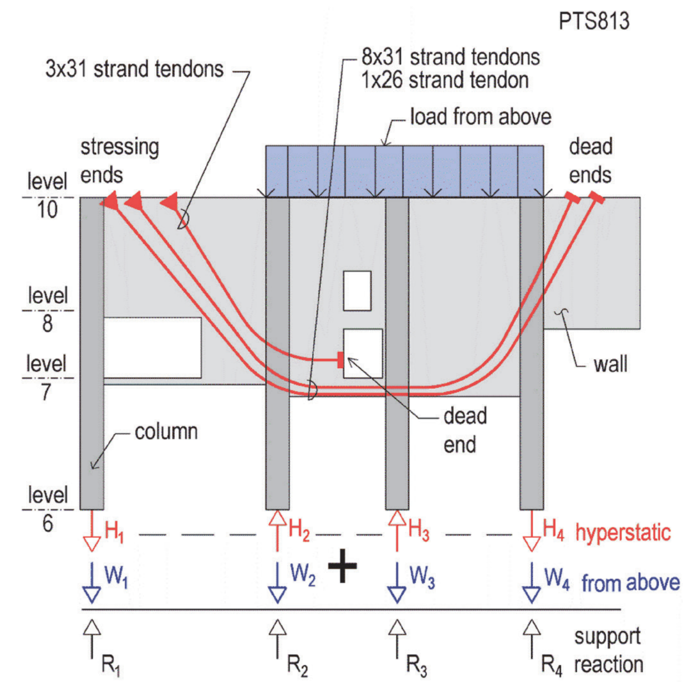

Fig. 7—Hyperstatic reactions used to redistribute column loads.

the end supports. This results in the net building reactions R_1 through R_4, which do not exceed the support capacity.

Figure 8 provides a partial view of the construction of the post-tensioned wall at Level 8 in the building. Ducts (white) for multi-strand bonded tendons are being positioned along the path specified in the design. The vertical reinforcing bars on each side of the wall extend up from the level below. The remainder of the wall reinforcement will be placed after the installation of the ducts has been completed. Slab reinforcement, including unbonded reinforcement (green), is also being placed.

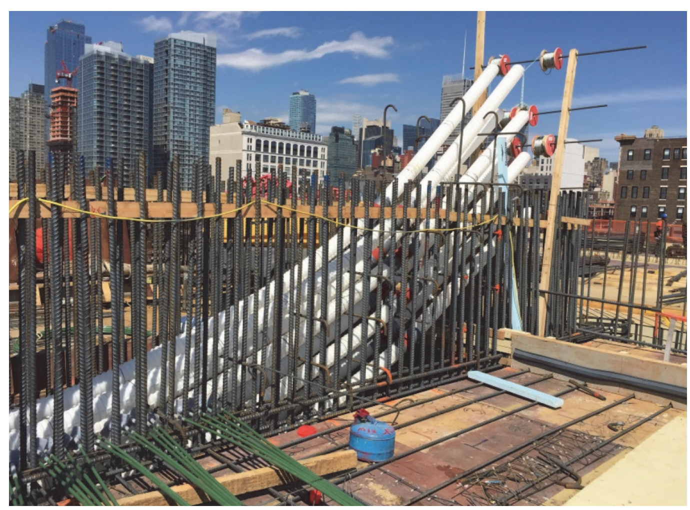

Fig. 8—PT wall under construction.

CONCLUSIONS

The use of tendon profiles and forces to alter the loads from the structure to match the capacity of an existing foundation is an innovative approach opening new possibilities.

Florian Aalami *is an expert in AEC software development and the design and construction of post-tensioned concrete structures. As President and CEO of ADAPT Corporation, he is responsible for the overall operation of the company, including its software development, sales, and consulting divisions. Aalami earned his bachelor's degree in civil engineering from the University of California, Berkeley, and both his master's degree in structural engineering and his doctoral degree from Stanford University's Center for Integrated Facility Engineering (CIFE), a leading think tank on Building Information Modeling (BIM).*