Title: **Rising High in Manhattan, Trump World Tower, The Tallest Residential Building in the World**

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# Rising High in Manhattan Trump World Tower The Tallest Residential Building in the World

Figure 1. East River Skyline with Trump World Tower.

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**ABSTRACT**

This paper presents the pioneering solutions in the design and construction of the Trump World Tower. These solutions include the introduction of 12000 psi (844 kg/sq. cm.) high strength concrete, 63mm diameter rebar, and the structure's lateral force resisting system. The 70 story, 860 ft (262 m.) high tower has a slenderness ratio of 11:1. The tower's lateral force resisting system is a combination of central shearwalls, acting as the spine, which are connected to the perimeter columns via perimeter "Belt" and "Hat" systems.

**STRUCTURE**

Rising above Manhattan's East River skyline with its pristine geometry, the Trump World Tower sets a new record as the tallest residential building in the world. The 880,000 sq. ft. (81,840 sq. m.) residential tower is located on First Avenue between 47th and 48th Streets. The site was previously the twenty-five story United Engineering Building, which was demolished to accommodate the new construction. The 70 story tower rises 860 ft. (262 m.) above street level with two underground levels, as illustrated in Figure 1.

The superstructure is a cast-in-place concrete frame. The building footprint is a constant rectangle measuring 77'x 144' (23.5 m. x 43.9 m.) at its full height with no setbacks. This results in a slenderness ratio of approximately 11:1. The slenderness ratio, in combination with the building's height, presents several engineering and construction challenges. These are peculiar and cannot be extrapolated from a 430 ft. (131 m.) building that is half of its height. From a structural engineering and construction point of view, two 430 ft. (131 m.) buildings do not amount to an 860 ft. (262 m.) tower.

Even though the tower has a constant horizontal cross-section, there are four different floor plans, with different spans and column locations, necessitating transfer systems as illustrated in Figures 3 and 4. The effect of the transfer floors was minimized by coordinating the column layouts to meet the needs of the various floor designs. The typical floor slab is an 8″ (20.3 mm) flat plate with a maximum span of 24′ (7.3 m.). The exterior columns are spaced from 16′ to 20′ (4.9 m. to 6.1 m.) on center. Floor to floor heights vary from 10′-8″ (3.3 m.) at the low-rise floor to 16′-8″ (5.1 m.) at the penthouse levels.

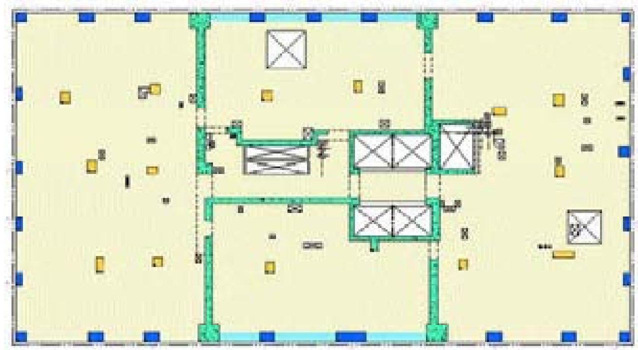

Figure 2. Mid-Rise Levels

The lateral load resisting system was designed to meet the wind and seismic criteria of the New York City Building Code. In addition, a series of wind tunnel tests were performed at the RWDI Wind Tunnel laboratory in Canada in order to obtain more accurate wind information. The lateral system is comprised of a combination of a center spine, made out of three linked shearwalls, linked with perimeter columns. The location of the shearwalls was the result of intense coordination with the architecture to provide flexibility for the interior layout. For maximum efficiency, the walls are full depth in the East-West direction, where they resist maximum wind forces.

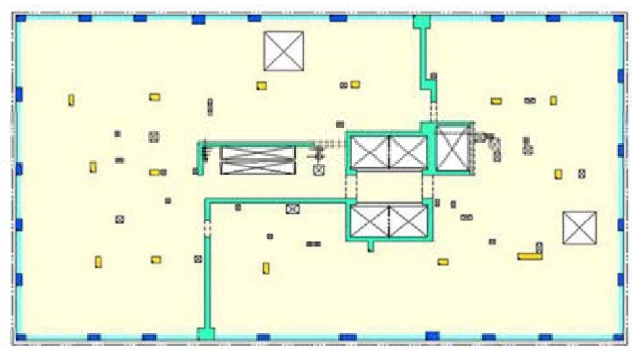

Figure 3. High-Rise Levels

For additional stiffness the shear walls are linked to the perimeter columns by full height walls at two levels. The “Belt System” at the 22nd floor mechanical room and the “Hat System” above the main roof are full height walls around the perimeter and are integral parts of the lateral load resisting system. Figure 4 shows the finite element stress contours at the belt wall.

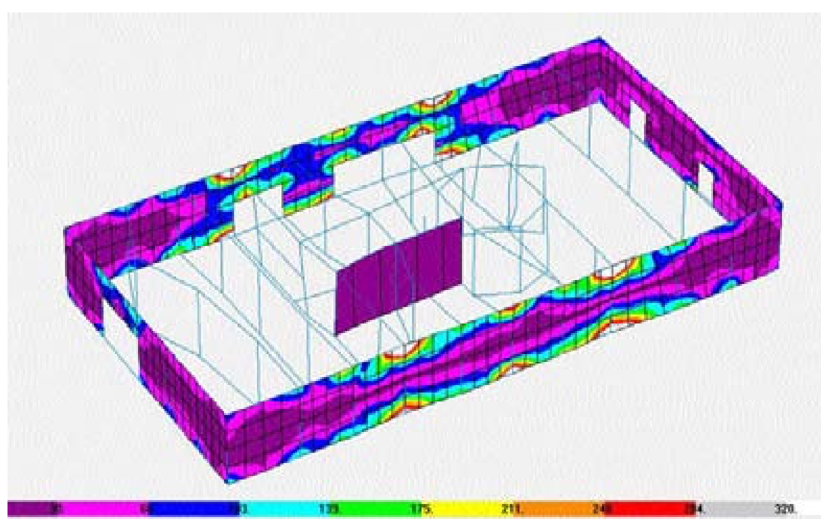

Figure 4. Finite Element Model of the Belt System

A 3-dimensional computer model, using the finite element method, was generated to simulate the tower's lateral force resisting system. The computer model was instrumental for successful design phases as well as the coordination stage. Separate computer models were created to monitor the building's performance at different stages of construction. During construction, the actual frequency of the tower was compared with that of the computer model. A comparison showed remarkable consistency between the analytical results and field test results. In general, the field measured stiffness and frequencies were higher than the analytical computation. For the first mode the variation between the computed (.221 Hz) and measured frequency (.216 Hz) amounts to a 2.3% variation. Figure 5 shows a computer generated model.

In residential towers, the standard practice for wind induced acceleration criterion is 15 mili-g for a strong event with a 10-year return period. This is strictly a comfort criteria and not a safety issue. While there have been reports of buildings successfully performing with accelerations exceeding this limit, the acceleration criterion for this project was limited to below 15 mili-g. In order to satisfy the criteria in a most effective, predictable and reliable manner, the tower was designed to utilize a supplemental damping system. The supplemental damping system used in this project is a Tuned Mass Damper system. Figure 6 shows a concept rendering of the system.

Among the "firsts" incorporated by this unique structure is 12,000 psi (844 kg/sq. cm.) concrete. It was specified for the first time in New York City at the lower shear walls and columns primarily to satisfy the stiffness requirements as well as to minimize column sizes for the lower floors. Although 4,000 psi (281 kg/sq. cm.) concrete met the structural requirements for the slabs, this was increased to comply with the load transfer requirements at the columns.  shows the variation of con-

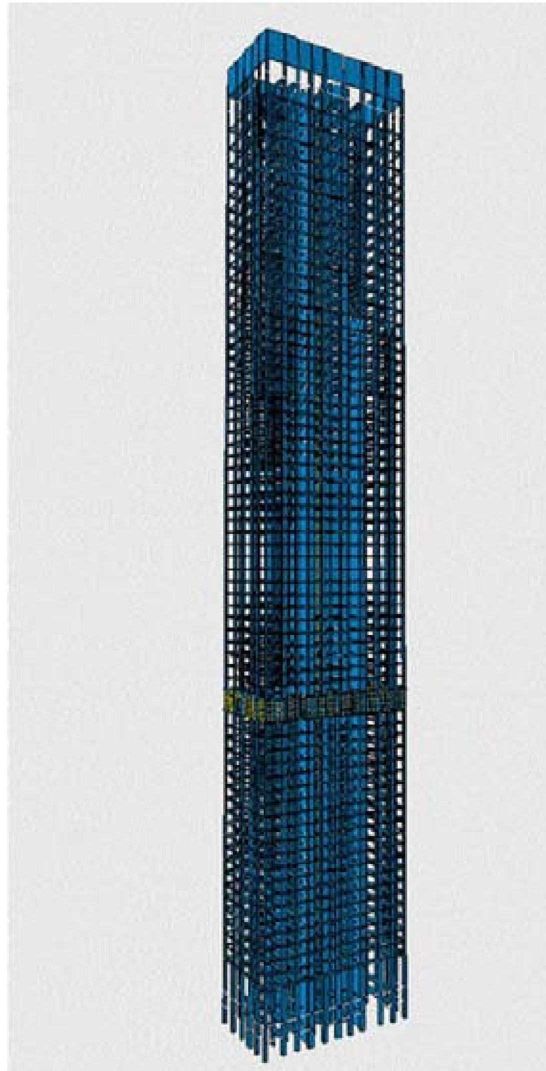

Figure 5. 3-D Computer Model of the Tower

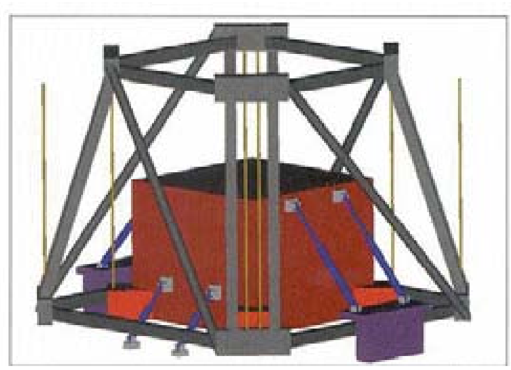

Figure 6. 3-D Rendering of the Tuned Mass Damper

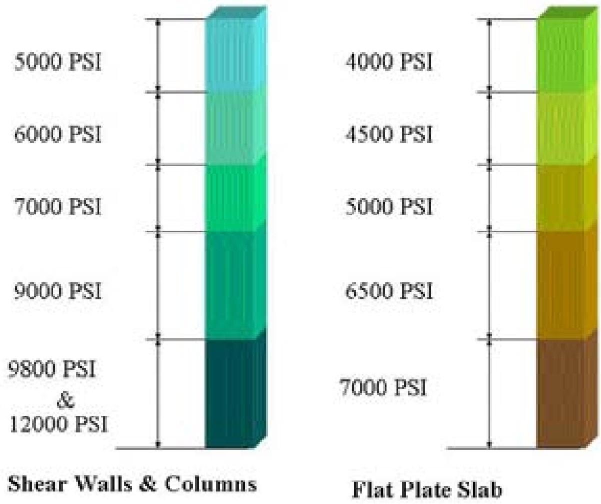


Figure 7.Profile of Concrete Strength

crete strength for shear walls, columns and slabs along the height of the tower.

The introduction of super high strength concrete mandated a particularly thoughtful approach to the design of the concrete mixes. The higher viscosities and extreme hot and cold temperatures can create placement and workability issues. The duration of the concrete placement was in excess of one year, which required constructing through several cycles of hot and cold temperature conditions. The cylinder breaks were consistently above design values for all strengths, including the 10,000 and 12,000 psi (703 and 844 kg/sq. cm.) concrete. The first 12,000 psi (844 kg/sq. cm.) pours were made during ambient temperatures in excess of 90˚ F (32˚ C) and, as expected, there were no problems.

In addition to the NYC Building Code mandated test procedures, a testing program was developed to evaluate shrinkage and Modulus of Elasticity for better evaluation of the stiffness and shrinkage properties of the concrete. This information was utilized in the study of axial shortening of the vertical elements of the structure and helped to provide guidelines for a compensation procedure during construction.

In order to avoid rebar congestion at the lower elevations of certain shear wall elements, a newly designated No. 20 bar with an 80,000 psi (5,625 kg/sq. cm.) yield strength was introduced. The bars are actually 63mm diameter as manufactured by Dywidag-Systems International and utilize mechanical tension splices conforming to ACI and NYC Building Code requirements.

**CONSTRUCTION**

In this area of New York City, hard Manhattan Schist, with a bearing capacity of 40T per square foot (39,000 g/sq. cm.), is found close to the surface. The footprint of the new structure conforms approximately to that of the existing building(s). However, the program required an increase of below-grade depth in certain areas, with additional rock excavations for the new footings.

The foundation system consists primarily of spread footings. A typical tower column footing size is about 8′x 8′x 5′ deep (2.4 m x 2.4 m x 1.5 m). 7,000 psi (492 kg/sq. cm.) concrete was specified for foundation elements supporting the tower. Rock anchors were introduced at the shear wall foundations, as necessary, to resist the overturning forces.

The foundation contractor, Mayrich Construction Corp. of New York, used large rock hammers to remove the rock for the increased depth and for the new column footings that did not coincide with the existing footings. The perimeter retention, in areas where rock was exposed during excavation, was by means of rock pinning. This was done to prevent the slope of bedding plane material to slide into the excavation.

Although the schist is hard, blasting was not used in this project. Its cost and the use restrictions in New York City made it inappropriate. Typically, rock excavation contractors resort to blasting only when mechanical methods are deemed to be ineffective due to the hardness of the rock.

In New York City, flat plate high rise residential buildings with +/-10,000 sf (930 sq. m.) footprints can generally be constructed on a two day cycle. Usually, after the initial start up for the lower few floors, the sequence can be synchronized to allow a floor to be poured every two days. This is accomplished by removing the soffit forms after 24 hours and promptly reshoring. This permits forming and rebar placement on the next floor the following day. Concrete pouring on the second day completes the cycle. The reshoring operation is critical from the standpoint of timing and span. The sequence cannot allow more than 8′ (2.4 m.) of unsupported span at any instance during the reshoring operation. Since a lot of activity takes place on green concrete, the surface is usually in need of refinishing. This occurs by follow-up finishing crews.

A building with a footprint of this size would normally be constructed with one climbing tower crane. In order to maintain the construction schedule, the concrete contractor, North Berry Concrete Corp. of New York City, used a second crane for the lower floors just to handle the heavy #20 rebar. As the building rose and the rebar became lighter, the second crane remained to maintain the two day cycle for the upper floors. All poured in place concrete was lifted by bucket.

Because of the unique shape of the building, an 860′ (262 m.) tower with no setbacks and the considerable forming requirements for exterior columns and spandrels, the concrete contractor chose to use a climbing form system designed by Peri Formwork Engineering. Climbing forms are seldom used in New York. Therefore, a learning period, as well as some initial adjustments in design and procedures, was necessary. The structure was tall enough so that the extra time allocated for the learning period was compensated for by the efficiencies that developed as the building rose. Climbing forms were also used for the core and shear walls. As an added benefit, the Peri system inherently provides a safe working environment around the building perimeter without the need for further safety measures. Figure 8 shows the building at the final stages of construction.

Figure 8. Trump World Tower at the Final Stages of