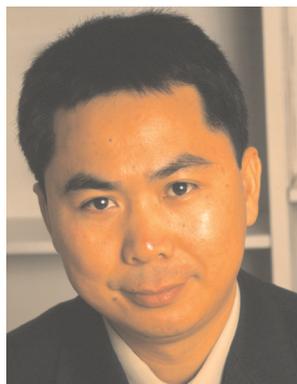


COMPREHENSIVE DESIGN AND A913 GRADE 65 STEEL SHAPES: THE KEY DESIGN FACTORS OF 300 MADISON AVENUE, NEW YORK CITY



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SUMMARY

300 Madison Avenue is a 36-story, 1.1 mil-sq-ft office building across from Grand Central Station in New York City. It will serve as the CIBC World Markets' U.S. headquarters and is scheduled for completion in 2004. The developer Brookfield Properties wanted a building that would be easy to build, given the accelerated construction schedule. Moreover, the developer focused on containing costs, providing adequate interior space and having an elegant curtain wall. Contractors aimed for a simple design. GMS met these objectives whilst ensuring the structure's integrity and serviceability. To achieve these goals, a range of structural designs and building materials were taken into consideration.

The design considered several different schemes and even carried two core schemes (concrete core vs. steel core) to the bidding stage. The steel core was eventually chosen due in part to the use of high-strength steel and its simplicity of construction. The design was also flexible enough to accommodate the architect's request to remove a tower column without affecting safety or aesthetics. Quality and serviceability were not sacrificed as the design provided simplicity in construction, clear architectural floor space and an elegant curtain wall. The most cost efficient solution to achieve the set objectives proved to be the use of high yield strength A913 Grade 65 structural steel shapes and belt trusses.

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KARL CHEN AND GEORGES AXMANN

INTRODUCTION

300 Madison Avenue is a 1,086,000 sq-ft, 36-story office tower, reaching a height of 550 ft above ground and 30 ft below. The building is located across from Grand Central Station in New York City. It will serve as the CIBC World Markets' U.S. headquarters and is scheduled for completion in 2004. For this building, the objective of the structural engineer Gilsanz Murray Steficek (GMS) was efficiency, flexibility and strength. The developer Brookfield Properties wanted a building that would be easy to build, given the accelerated construction schedule. Moreover, the developer focused on containing costs, providing adequate interior space and having an elegant curtain wall. Contractors aimed for a simple design. GMS met these requirements whilst ensuring the structure's integrity and serviceability. To achieve these goals, GMS took into consideration a range of structural designs and building materials.

THE USE OF HIGH STRENGTH STEEL

Initially, GMS worked with A992 Grade 50 structural steel, but soon began to consider the use of higher strength A913 Grade 65. The advantage of Grade 65 is that it provides strength with less steel, therefore reducing the weight of the steel that needs to be fabricated, transported and positioned, and also reducing the total weight of the building. Moreover in fabrication, the easier weldability of A913 Grade 65 compared to common A992 Grade 50 outweighed the use of more expensive higher strength electrodes, needed in a few cases.

However, as the New York City Seismic Code (adopting UBC 1991) was written prior to the initial appearance of A913 in 1993, Grade 65 was excluded from being used for lateral force resisting systems. In light of the significant advantages of Grade 65, GMS applied for and was granted a reconsideration from the New York City Building Department

permitting the use of A913 Grade 65 in the lateral force resisting system.

Cap- acity	Shape Size		Weight diff.	Weight saving
	Gr. 65	Gr. 50	lbs/ft	%
7300	14x730	14x730 with cover plates		
5452	14x550	14x730	180	25%
2756	14x283	14x370	87	23%
1698	14x176	14x233	57	24%

Table 1: Comparison of Grade 65 and Grade 50 columns

Table 1 shows the typical weight saving of using columns in Grade 65 steel over standard Grade 50 steel – for an effective length of about 13 ft, which is the common floor-to-floor height of a steel framed office building. Table 1 illustrates that using Grade 65 allows for the use of a column shape 3 sizes lighter than Grade 50.

This downsizing allowed an average weight saving of 24% in the columns. For highly loaded columns, the use of Grade 65 avoids the use of some cover plates.

Using Grade 65 led to an efficient design using 22 lbs/sq.ft steel in this 36-story office tower. The total weight of the structural steel was 11,600 tons. Of this, approximately 2000 t or 17% of the structural steel weight was comprised of columns. Hence the 24% weight saving in the columns translated into savings of 480 tons of steel compared to a structure using solely Grade 50. The overall weight of the structure was reduced by 4%. Additionally, the use of Grade 65 reduced the price gap between steel and concrete so significantly that an all-steel framed structure became preferred.

CORE SCHEMES

GMS provided several core schemes in a three-phase process, ultimately picking an all steel core, aided by belt trusses.

Phase One – Four Options

- Concrete Core with Web Walls in the N/S, E/W Direction with Concrete Link Beams. (Figure 1)
- Concrete Core with Web Walls in the N/S, E/W Direction with Steel Link Beams (Figure 2)
- Concrete Web Walls in the N/S, and Steel Bracing in E/W Direction with Steel Link Beams
- Steel Core with Outriggers. (Fig. 3)

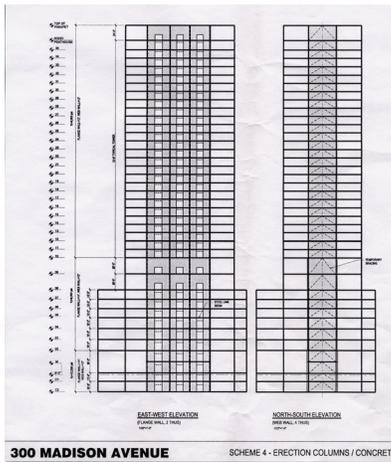


Figure 1 - Concrete Core w/ Web Walls (Concrete Link Beams)

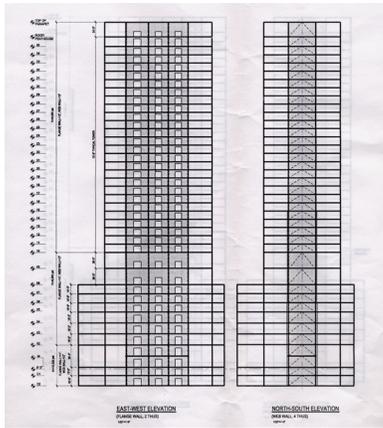


Figure 2 - Concrete Core w/ Web Walls (Steel Link Beams)

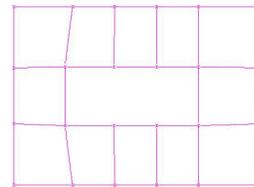
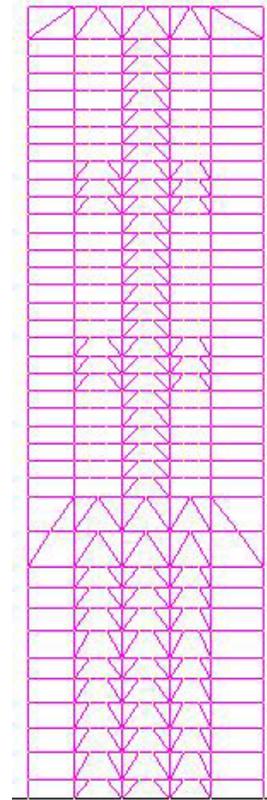


Figure 3 - Steel Core with Outriggers

Phase Two – Two Options

Outriggers or belt trusses are needed to reduce uplift, deflection and to satisfy the building’s torsional requirement for wind tunnel testing. Engaging the exterior columns with the core columns reduces uplift in the core columns and increases the building’s lateral stiffness and torsional resistance. Both outriggers and belt trusses achieve these results, but through different load paths.

- Outriggers
Outriggers are the conventionally used method. They work by shifting shear from the core to the outrigger’s diagonal members and thus relieve the core bracing in the core columns. The disadvantages

of using outriggers are 1) engaging fewer outside columns and 2) intruding on floor space, generating coordination issues between trades and allowing for less usable floor space for the occupants.

- Belt Trusses (Fig. 4, 5 and 13)

The selected core scheme consists of a steel core with belt trusses along the perimeter of the building. Belt trusses work by shifting shear from the core to the exterior trusses and engages all exterior columns through the reinforced floor slab (see figures 6, 7 and 13). Belt trusses provide much more torsional resistance due to their location (around the perimeter from the 9th to 11th floors and the 36th floor) and lead to increased clear floor space.

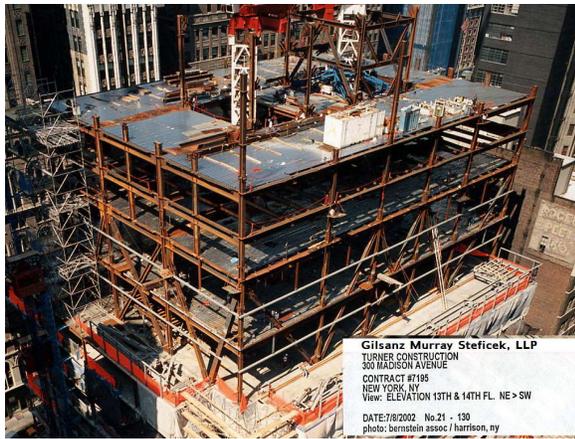


Figure 4 – Belt trusses



Figure 5 – Reinforced floor connecting belt trusses to core

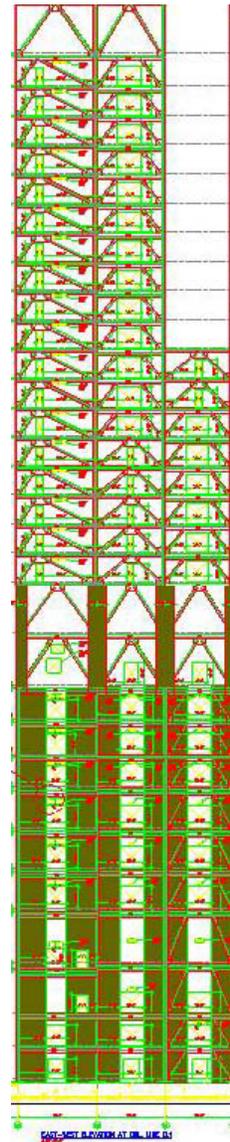


Figure 6 - Partial Concrete/Steel Core

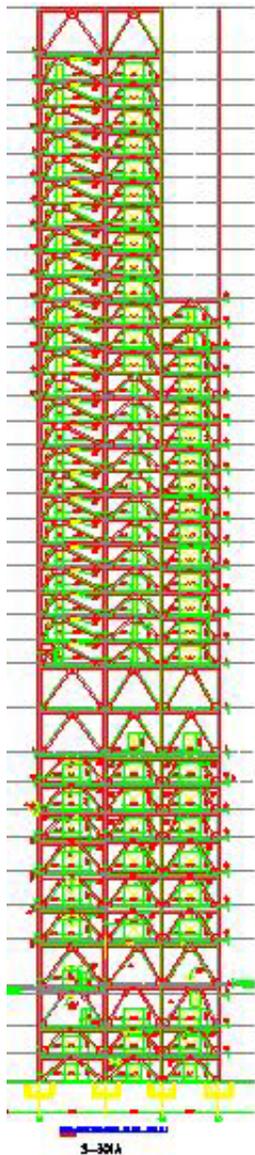


Figure 7 - Steel Core Elevation

Phase Three – Choosing the Final Scheme

- Partial Concrete Core (to 9th Floor) with steel link beams. (Fig. 6)

A concrete core to the 9th floor only, allowed flexibility for future changes in the upper floors, but used concrete in the lower floors. GMS explored this option in detail and it was one of the two schemes that made it to bid. (See Figure 6).

- Steel Core with Belt Trusses (Fig. 7)

This all steel core called for belt trusses to share the shear and moment load. These belt trusses were located at the mechanical floors (9th through 11th floors) and the 36th floor and worked with the reinforced floor slabs. The partial concrete core up to the 9th floor was estimated to be \$2 million cheaper than the steel core. However, the construction manager and owner opted for the steel core after negotiating an acceptable price with steel contractors as well as realizing that an all-steel core would minimize coordination between the concrete and steel contractors, thereby adhering to the construction schedule.

COLUMN REMOVAL STUDY

The architect requested that a tower column be removed in the lobby. GMS considered several schemes to solve this problem.

- Transfer at the lower floors (Fig. 8)

This required a few large transfer girders, which meant high cost and headroom problems at the 10th floor



Fig. 8 - Transfer Girders at Lower Floors

- Skewed columns (Fig. 11)
 4 columns would be skewed, from the 8th to the 2nd floor to carry the load diagonally. This scheme generated an irregular architectural layout and introduced a lateral in the core.

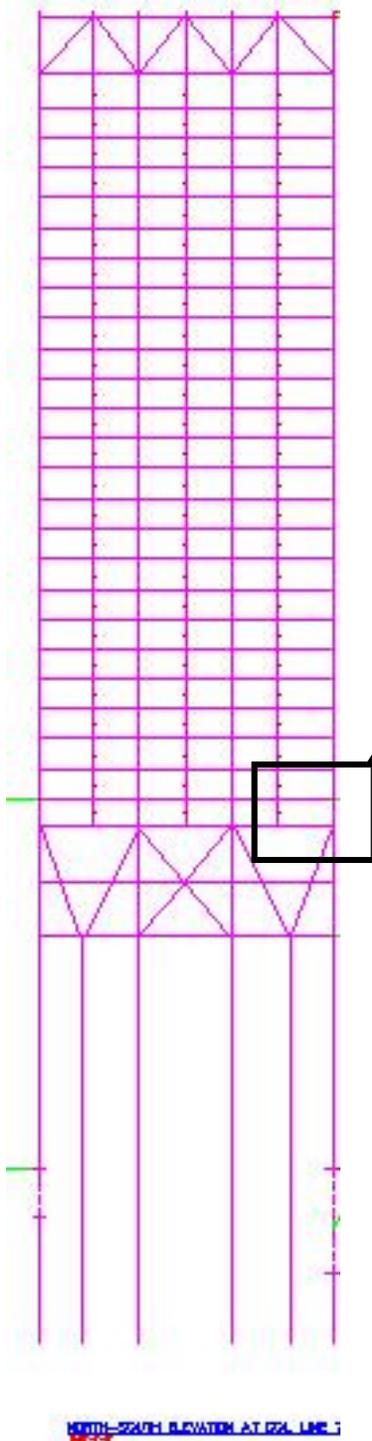


Figure 9 – Omitted columns with hanger

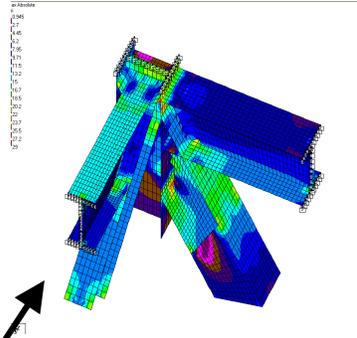


Figure 10 – Finite element analysis of hanger

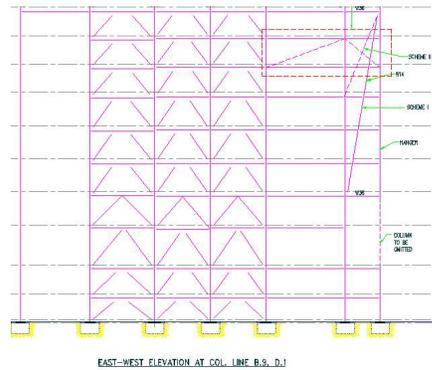


Figure 11 – Skewed columns

- Hanger (Fig. 9 and 10)
 The hanger up to the 9th floor (mechanical floor) shifted gravity to adjacent columns through the belt trusses, which were located on the 9th to 11th floors. However, a problem arose because the removal of a column would cause the structure to lean to the side due to the additional moment from gravity. The solution was to remove another column on the opposite side of the building to balance gravity and also to reduce building deflection. In this way the transfer was integrated as part of the belt truss, hence serving two different purposes. The connection at the transfer, hanger and truss joint was studied with a finite element analysis (see figures 9 and 10).

FABRICATION AND ERECTION OF GR. 65

Canron fabricated and erected the steel structure. Sawing, drilling and flame cutting of Grade 65 shapes were performed using the same procedures as for Grade 50. No change in saw blades and drill bits was necessary.

Since 1996, A913 Grade 65 and Grade 50 have been pre-qualified in the Structural Welding Code AWS D1.1; therefore, weld procedure qualification tests are not necessary. Moreover AWS D1.1 allows welding of A913 Grade 65 without preheating, for temperatures above 32 degrees, provided low hydrogen (H-8) electrodes are used. If low hydrogen electrodes are not used, the Welding Code requires the same preheating temperatures for A913 Grade 65 as for regular Grade 50. The very lean chemistry and low maximum permitted Carbon Equivalent value (0.43%) of A913 Grade 65 explain the reduced preheating provisions.

Besides reduced preheats, A913 was welded in shop and field using the same procedures for Grade 50 with the exception that for the few connections with complete joint penetration welds in tension, an E80-type filler (matching Grade 65 properties) had to be used, as required by AWS D1.1. All other welded joints, which were either partial penetration welds, fillets welds or welds to Grade 50, were carried out with the same filler used for Grade 50. The only available E80 self-shielded electrode was the self-shielded flux-cored wire NR-311-Ni, which is classified as E70 and respects properties of E80 but not H-8. The typical shop welds were made with a gas-shielded flux-cored wire classified as E70-T9. The heavy longitudinal welds between the W shape and the reinforcing plates were made using the submerged arc process with a wire/flux combination classified as F7A4-EM12K-Ni1-H8. It should be noted that the extra cost for NR-311-Ni (approximately 10%) used for the field welded column splices was offset by welder appeal – nice smooth arc with very little spatter and easy slag removal.

In terms of erection, the weight savings of about 500 tons of steel resulted in direct savings in trucking and a reduction in the number of expensive field splices. In fact, because of the use of Grade 65 the shapes became lighter and the size of the shop-assembled portions could be increased – the limiting factor being the available crane capacity.

DESCRIPTION OF A913 GRADE 65

Specification

ASTM A913 / A913M – 01 is the current Standard Specification for Grade 65, but includes also Grade 50, 60 and 70. A913, which first appeared in 1993, covers structural steel shapes processed by the Quenching and Self-Tempering (QST) process. QST is an in-line process in which, immediately after rolling, the shape is rapidly cooled with water and reheats itself by a temperature equalization through a heat-flow from the inside to the outside of the material.

Properties

The optimal combination of strength and toughness results from the very fine grain size originating from the QST process. The outstanding weldability of the A913 steels, allowing in most conditions welding without preheating, is due to the very low amounts of alloying elements – and accordingly low Carbon Equivalent (CE) values.

$$CE = Mn/6 + (Cr+Mo+V)/5 + (Cu+Ni)/15$$

Figure 12 is a typical stress-strain curve (in MPa and %) from a uniaxial quasi-static tensile test (performed according to ASTM A370) of A913 Grade 65, measured on a coupon of a shape with a flange thickness of 0.88 inches (22.5 mm). The shape of the curve illustrates the good ductility of A913 Grade 65 and a comparable maximum elongation to A992.

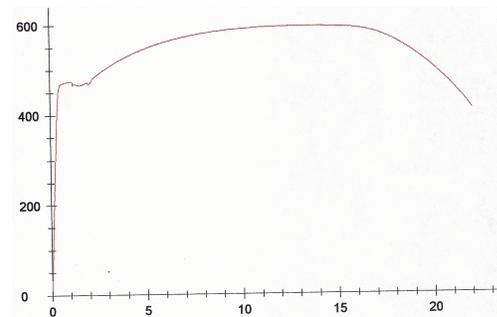


Figure 12: Typical stress-strain curve of Grade 65 (stress in MPa, strain in %)

Yield Strength (F_y):

- actual 68.5 ksi (473 MPa)

- required min. 65 ksi (450 MPa)

Tensile Strength (Fu):

- actual 86.4 ksi (596 MPa)
- required min. 80 ksi (550 MPa)

Elongation (A, 8'')

- actual 22%
- required min. 15%

A913 requires on a general basis a guaranteed minimum Charpy V-Notch impact value (CVN) of 40 ft.lbf [54J] at 70°F [21°C], measured in the flange (ASTM A673) location, whereas A992 contains no general requirement of a guaranteed minimum Charpy V-Notch impact value.

Table 2 shows the typical statistical distribution of Charpy V-Notch values of A913 Grade 65. It illustrates that even at a temperature of 38°F lower than the test temperature of 70°F specified in A913, the energy values exceed the specified 40 ft.lbf.

CVN test at 32°F [0°C]	A913 Grade 65 ft.lbf
Average	141
Stand. dev.	28
Min.	64
Max.	266

Table 2: Typical impact toughness of A913 Gr.65

A913 in the Codes

AISC Design Codes ASD and LRFD approve ASTM A913 / Grades 50 and 65. A913 is included as a referenced standard in LRFD Specification dated Dec. 27, 1999. The approval came in a letter ballot of the Specifications Committee in July 1995 and was confirmed at its meeting in November 1995.

AISC Seismic Provisions dated April 15, 1997, has A913 included in Part I – Chapter 2 as a referenced standard. In addition, A913 Grades 50 and 65 are included in Part I – Section 6.1. as follows: (...) the steel used in Seismic Force Resisting Systems (...) shall meet one of the following ASTM specifications: A36, A53, A500 (Gr.B or C), A501, A572 (Gr.42 or 50), A558 or A913 (Gr.50 or 65)(...). The specified minimum yield strength of steel to be used for members in which inelastic behavior is expected under Load Combinations 4-1 and 4-2 shall not exceed 50 ksi unless the suitability of the material is determined

by testing or other rational criteria. This limitation does not apply to columns for which the only expected inelastic behavior is yielding at the column base.

UBC 1997 includes ASTM A913 / Grades 50 and 65 through approval by the ICBO committee in September 1996.

Paragraph 2211.4.1 has been modified as follows: 2211.4.1 Quality. Structural steel used in lateral force-resisting systems shall conform to A36, A500, A501, A572 (Grades 42 and 50), A913 (Grades 50 and 65) and A588.

IBC 2000, cf. Chapter 22, approves by reference to the AISC Specifications the use of A913 Grades.

AWS D1.1 (2002) lists A913 / Grades 50 and 65 as prequalified steels. In accordance with Table 3.2 of the structural welding code AWS D1.1, A913 Grades 50 and 65 are weldable without preheating (min. 32°F) when welded with low hydrogen electrodes (H-8). According to good workmanship practice, for welding of large material thicknesses and / or in highly restrained conditions, preheating may be necessary. AWS D1.1 requires for base metal temperatures below 32°F, a preheating to 70°F. Lastly, AWS D1.1 specifies that if electrodes have a higher level of hydrogen than H-8, A913 Grades 50 and 65 can be respectively welded like A992, A572 / Grades 50 and 65 with preheating.

FEMA 353 (July 2000) “Recommended Specifications and QA-Guidelines for Steel Moment-Frame Construction for Seismic Applications” approves and recommends the use of A913 Grades (cf. Part I, Chapter 2).

FEMA 350 (July 2000) “Recommended Seismic Design Criteria For New Steel Moment-Frame Buildings” approves and recommends the use of A913 Grades (cf. Chapter 2.6.1).

In addition to A913’s major code approvals, the New York City Building Department, granted a reconsideration of the **NYC Seismic Code** to allow the use of A913 Grade 65 in the columns of the lateral force resisting system. The request for this reconsideration was introduced by GMS for the 300 Madison Avenue project – and supported by all major SE firms of NYC.

Availability

Below table 3 lists the available W shapes in A913 Grade 65. It can be seen that beyond 12" and 14" shapes, the available shapes are mostly large and / or heavy -- where the weight savings can play a significant role.

Readily available	Available (check first)
W14 x 90 thru 730	W12 x 65 thru 230
W36 x 150 thru 439	W24 x 84 thru 370
W40 x 167 thru 503	W27 x 102 thru 129
W44 x 230 thru 335	W30 x 108 thru 148
	W33 x 130 thru 169

Table 3: Available sizes in A913 Grade 65

CONCLUSION

The major objectives of design for 300 Madison Avenue were keeping to a schedule and budget while delivering an aesthetic, serviceable office building in Midtown Manhattan. GMS met this challenge with options that allowed the client and the contractor flexibility in construction and cost. These objectives were met by the design and use of higher strength A913 Grade 65 structural steel shapes resulting in a lightweight office tower.

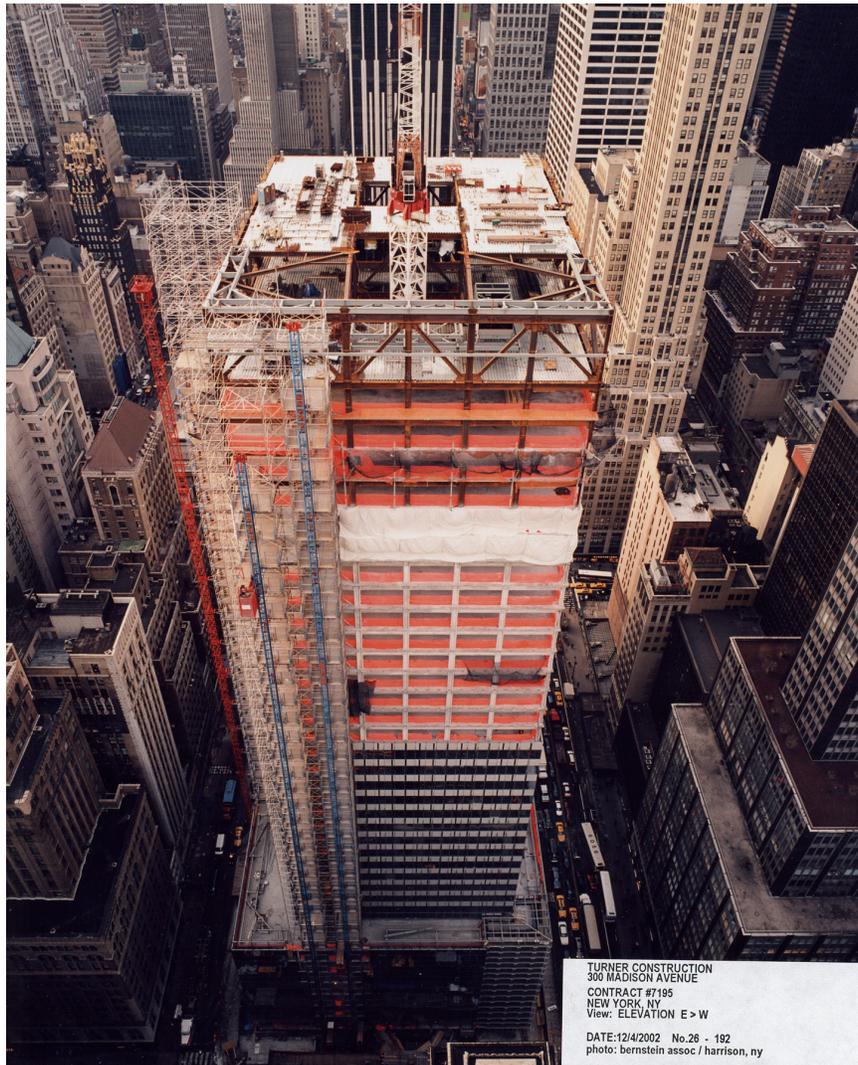


Figure 13 – Belt trusses at the 36th floor