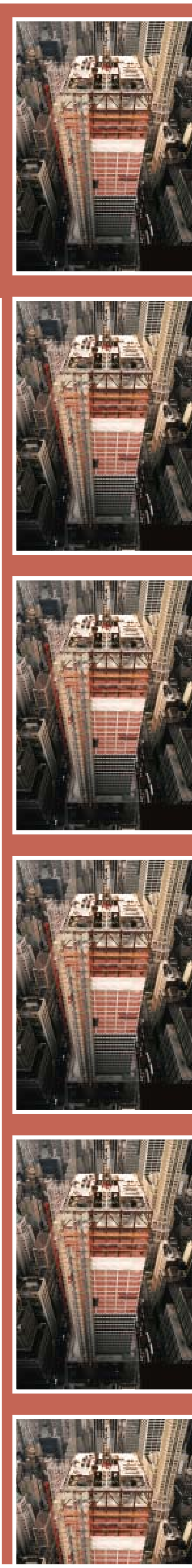
300 Madison Avenue

Practical Defensive Design Meets Post 9/11 Challenge

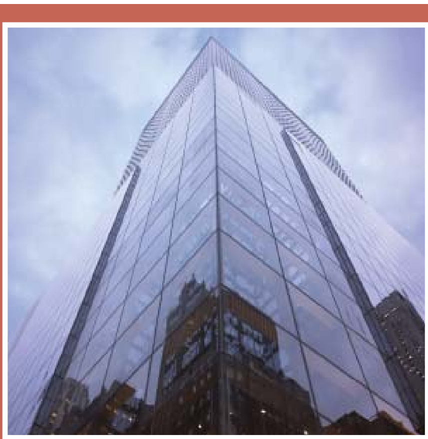
By Victoria Arbitrio, P.E., and Karl Chen, P.E., S.E.



Looking west across Madison Avenue
Belt trusses at the 36th floor.
Photo courtsey of Turner Construction Company

The newly completed 40-story office tower between Times Square and Grand Central Station in New York City consists of some unique structural features including some areas of blast-resistant design, a reduced potential for progressive collapse and connections that are stronger than required by the building code.

This 575-foot-tall steel-framed structure is located at the south west corner of 42nd Street and Madison Avenue. The 1.1 million square foot tower was designed to house CIBC World Market U.S. headquarters. Brookfield Financial Properties developed the site and also owns the World Financial Center and 1 Liberty Plaza, each across the street from the World Trade Center site. Both of these buildings were damaged by the debris from the Trade Center collapse. At the time, the 300 Madison construction team was excavating rock for the two basement levels. Although the building structure was almost fully designed and drawings were out to bid, the design team was asked to study the impact to the new building in the event that Grand Central Station or the subway station under this building was attacked.



East and north facades reflect their neighbors
Photo courtesy of Brookfield Properties

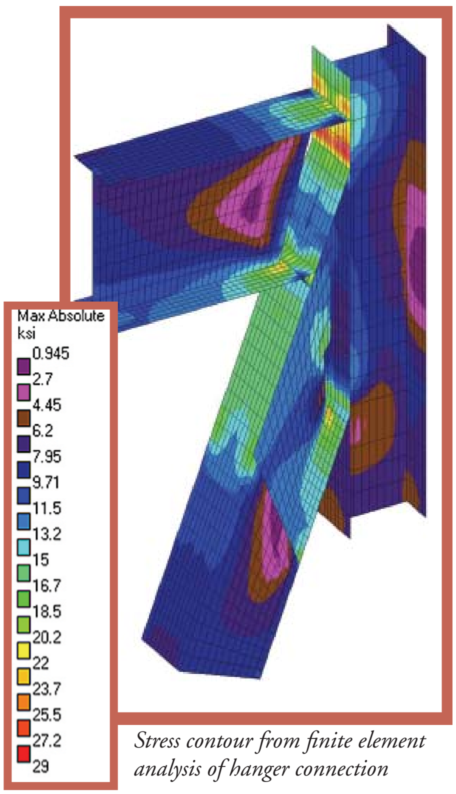
Innovations

Gilsanz Murray Steficek (GMS) designs and practices achieved cost efficiency, while adhering to the client's needs, at 300 Madison Avenue. Cost savings occurred through the use of 65 ksi steel, belt trusses, reinforced flooring and other structural innovations. The design was thorough, as it considered several different schemes and even carried two core schemes (concrete core vs. steel core) to the bidding stage. The steel core was the eventual winner, thanks partially to use of high-strength steel and simplicity of construction. The design was also flexible enough to handle the removal of a tower column without affecting safety or aesthetics. However, quality was not sacrificed as the design provided simplicity in construction, clear architectural floor space and an elegant curtain wall.

Reinforcing in slab to connect
belt trusses to core bracing
Photo courtesy of Turner Construction Company

For this significant building, the goal was flexibility and strength of the design. Not surprisingly, Brookfield wanted to keep costs down and have a building with adequate interior space and a tasteful curtain wall. The Architect wanted small columns and no braces across the office floors. The Contractor wanted a simple design to build. GMS wanted to ensure the safety and integrity of the building. To achieve all these goals, GMS took into consideration a range of materials and a range of designs, and produced a building that was relatively easy to build within an accelerated construction schedule.

Initially, GMS worked with 50 ksi structural steel, but internally discussed the use of 65 ksi steel in order to reduce the weight of the steel to be transported and positioned, and reduce the total weight of the building. The special fabrication and erection procedures required when using 65 ksi steel, such as selected flame-cutting and welding techniques, were outweighed by better weldability and a lower pre-heat requirement. However, New York City Building Code seismic provisions (based on UBC 1991) prohibited using 65 ksi steel for lateral force resisting systems. GMS felt that there were significant advantages to the project by using 65 ksi steel, so they applied for, and were granted, a variance from the New York City Building Department to build with the high-strength steel. The 65 ksi steel was mainly used in construction of the columns. The average weight savings of using 65 ksi steel over standard 50 ksi steel was approximately 24%, or 135 lb/ft for most columns, and about 10% of the total weight of steel.



Stress contour from finite element analysis of hanger connection

The core of the building was of utmost importance to the strength and cost of the structure, and the architectural layout of the space. GMS provided several core schemes, including several steel, concrete and hybrid core systems, in a three-phase process. Ultimately, an all steel core was selected aided with belt trusses, which shared the shear and moment loads. These belt trusses were located at the mechanical floors (9 through 11) and the 36th floor, and worked with the reinforced floor slabs. The owner and construction manager determined that an all-steel core would minimize coordination between the concrete and steel sub-contractors, and ensure adherence to the construction schedule.

The costs and schedule impacts analyzed in each comparison were not limited to the structural elements, but included all other trades affected by the core design. Items such as elevator shaft wall construction were almost non-existent with a concrete core scheme, but were essential to the steel scheme; this added cost to the steel version, but did not impact schedule as greatly, since shaft walls can be built simultaneously with many other trades.

Column Removal Study

The architect requested that a column be removed in the lobby, which posed problems with the load path. GMS considered several methods to resolve this issue.

- The Transfer Method required a few large transfer girders, which meant high cost and reduced headroom at the 10th floor.
- The Skewed Column Method would skew 4 columns, from the 8th to the 2nd floor to shift the load diagonally. This scheme generated irregularities in the architectural layout.
- The Hanger Method, hanging down from the 9th floor (a mechanical floor), shifted gravity to adjacent perimeter columns through the belt trusses, which were located between the 9th and 11th floors. However, the removal of one column would cause the structure to tilt unsymetrically due to the additional moment from gravity. By removing another column on the opposite side of the building, GMS balanced the gravity forces and reduced the overall building deflection. The connection at the transfer, hanger and truss joint was studied with a finite element analysis to verify the design of each component.

Table 1

For typical column B2, with column effective length ~ 13 feet

Capacity	Size		Wt/ft diff	% Save
	65 ksi	50 ksi		
7300	W14x730	W14x730 with cover plates		
5452	W14x550	W14x730	180	25%
2756	W14x283	W14x370	87	23%
1698	W14x176	W14x233	57	24%

Average weight/ft savings = **135 lb/ft**
Average percentage of steel savings = **24%**

Defensive Design

While the specific measures taken to harden the structural system cannot be specifically discussed for security reasons, an overview of the general approach taken by GMS can be discussed. GMS had already completed the design of this structure when the events of September 11, 2001 unfolded. Faced with the fears and emotions evoked in the aftermath, the owner asked GMS to re-evaluate the structural design with defensive design considerations in mind.

Three options were presented to the owner: (1) accept the usual redundancy and robustness levels inherent in steel framing without change; (2) evaluate and upgrade the structural system to meet the prescriptive requirements, such as those provided by GSA guidelines; or (3) perform a risk assessment to establish the likely threats, and evaluate and upgrade the structural system to meet the resulting design criteria. After careful consideration, the owner chose option three.

Primarily, GMS assessed the prevention of the progression of collapse in a structure following the removal of a column. Extensive analyses for various conditions of column removal through-out the structure were performed. These analyses showed the benefits of the belt trusses and reinforced floor diaphragms–originally provided for other purposes–in redistributing the loads interrupted by column removal. Other structural components, those accessible to the public and slabs that separate public and private spaces were reinforced to resist blast loads. The overall effects on the structural framing were minimal, sometimes changing beams and columns by a few sizes. Since the cost of steel framing is dominated by fabrication and erection labor rather than material cost, these changes had a minimal im-pact on the cost of the building. We also reviewed the effects of a blast on the curtainwall system, and upgraded the panels along the streets between the curb and the setback at the ninth floor.

Summary

300 Madison Avenue will actually be the New York headquarters of Price Waterhouse Coopers, and CIBC will occupy the lower 6 floors. The major objectives of design were keeping to a schedule and budget while delivering a serviceable and strong structure to address the post 9/11 safety concerns of the tenant. GMS met this challenge with creative options that allowed the client and the contractor flexibility in construction and cost. The atypical use of 65 ksi steel and the deliberate design served to attain these objectives. 300 Madison Avenue is an elegant, lightweight office tower in the heart of Manhattan, constructed with the help of innovation and comprehensive design.▪

Victoria Arbitrio, PE is an Associate at GMS, LLP. She is also the Vice President of the National Council of Structural Engineers Associations, and a member of both the Structural Engineers Association of New York (SEAoNY) and the American Society of Civil Engineers.

Karl Chen, PE, SE, is an Associate at GMS, LLP and is a member of both the American Concrete Institute and Structural Engineers Association of New York (SEAoNY). He was GMS's project manager for 300 Madison Avenue.

LINK BEAM is that part of a beam in an eccentrically braced frame which is designed to yield in shear and/or bending so that buckling of the bracing members is prevented.

STRENGTH is the strength as prescribed in Section 2710 (d) 2.

V BRACING is that form of chevron bracing that intersects a beam from above and inverted V bracing is that form of chevron bracing that intersects a beam from below.

X BRACING is that form of bracing where a pair of diagonal braces cross near midlength of the bracing members.

(c) **Symbols and Notations.** The symbols and notations unique to this section are as follows:

M_P = plastic moment.

P_{DL} = axial dead load.

P_E = axial load on member due to earthquake.

P_{LL} = axial live load.

P_{sc} = compressive axial strength of member.

P_{st} = tensile axial strength of member.

V_s = shear strength of member.

Z = plastic section modulus.

(d) **Materials.** 1. Structural steel used in lateral-force-resisting systems shall conform to A 36, A 441, A 500, A 501, A 572 (Grades 42 and 50) and A 588. Structural steel conforming to A 283 (Grade D) may be used for base plates and anchor bolts.

> **EXCEPTION:** Other steels permitted in this code may be used for the following:
> A. One-story buildings.
> B. Light-framed wall systems in accordance with Section 2710 (j).

2. **Member strength.** Where this section requires that the strength of the member be developed, the following shall be used:

	STRENGTH
Flexure	$M_s = ZF_y$
Shear	$V_s = 0.55\ F_y dt$
Axial compression	$P_{sc} = 1.7\ F_a A$
Axial tension	$P_{st} = F_y A$
Connectors	
Full-penetration welds	$F_y A$
Partial penetration welds	1.7 Allowable
Bolts and fillet welds	1.7 Allowable

Members need not be compact unless otherwise required by this section.

(e) **Column Requirements.** 1. **Column strength.** Columns shall satisfy the load combinations required by Section 2303 (f) at allowable stress limits, with stress increases allowed by Section 2303 (d). In addition, in Seismic Zones Nos. 3 and 4, columns in frames shall have the strength to resist the axial loads resulting from the load combinations in Items A and B following.

NEW YORK CITY
DEPARTMENT OF
BUILDINGS

DEPARTMENT OF BUILDINGS

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April 10, 2001

Mr. Ramon Gilsanz, P.E.
Gilsanz, Murray, Steficek, LLP
95 University Place, 3rd Floor
New York, NY 10003

Re: 300 Madison Ave.
RS 10-5C
Seismic Design

Dear Mr. Gilsanz:

This is in response to your letter of February 12, 2001 and March 26, 2001 regarding application of Seismic Design to the above new structure.

The Department agrees that ASTM A 913 grade 65 steel may be permitted for columns. The Department also agrees that load and resistance factor design for all members of a structure, may be used per year 2000 edition of FEMA seismic recommendations, and 1999 edition of BOCA National Building Code, 1997 edition of Uniform Building Code, and 2000 edition of the International Building Code.

If you have any questions please contact me at 212/312-8324.

Sincerely,

Ronny A. Livian, P.E.
Deputy Commissioner

RAL:dw

c: Satish K. Babbar, R.A.
Nick Grecco, P.E.
Manher Shah, P.E.
Laura V. Osorio, R.A.