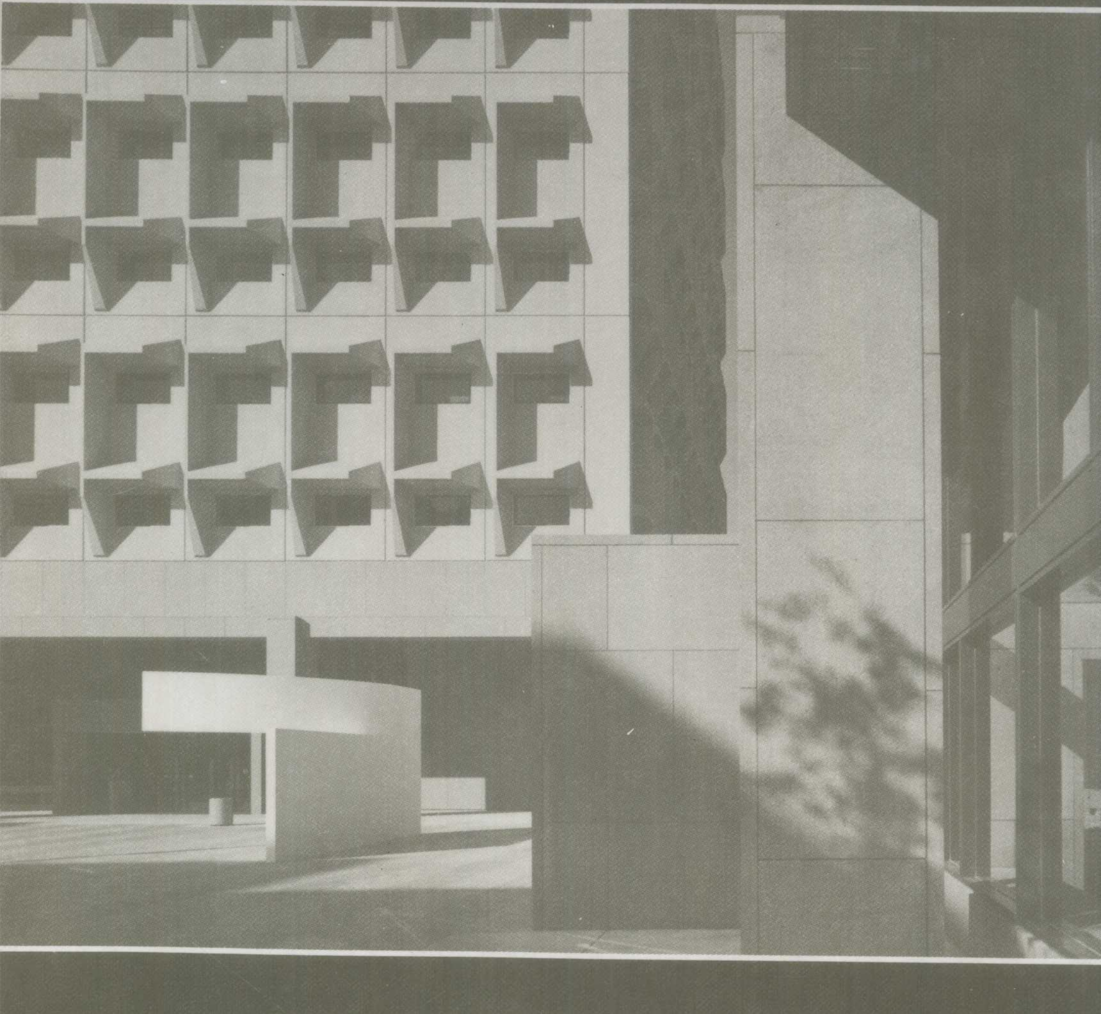
EXTERIOR WALL SYSTEMS

Glass and Concrete Technology, Design, and Construction



BARRY DONALDSON, *Editor*

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Foreword

This publication, *Exterior Wall Systems: Glass and Concrete Technology, Design, and Construction,* contains papers presented at two separate symposia on Exterior Wall Systems. The first was held in New York in 1988, and the second was held in Chicago in 1989. The symposia were sponsored by ASTM Committee E-6 on Performance of Building Constructions (see Overview for names of cosponsors and other contributors). Barry Donaldson, Tishman Research Corp., was symposia chairman and was editor of this publication.

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Overview

In recent years the design of exterior walls has incorporated more diverse materials and complex building technology than ever before. Metal and glass, stone, concrete, and masonry are being combined in ways that offer rich architectural variety in the color, texture, and overall articulation of building exteriors. The integration of such diverse materials in the building facade is challenging the abilities of architects, engineers, manufacturers, and contractors and leading them towards a greater understanding of materials and systems.

The papers included in this publication reflect these trends in the building industry and present the observations of a number of experts who have spent their lives intimately involved with the design and technology of exterior wall systems. The papers have been compiled and edited from two separate symposia held in New York in 1988 and Chicago in 1989. The first of these focused on metal and glass curtainwall systems and the second dealt with concrete and masonry systems. Each of the presentations deals with specific building projects and examples of exterior wall systems to illustrate solutions based on actual experience. The use of case studies is important because they go beyond a theoretical understanding to the experience of successes and failures on real buildings. The work of architects, engineers, manufacturers, and fabricators is all included to bring a breadth of experience and a variety of viewpoints. The first section describes design concerns of exterior wall systems by architects who are familiar with the entire process of making buildings from initial design through final construction. The second section deals with testing and analysis, focusing on structural performance, thermal performance, and weather integrity. The remaining sections focus on specific materials and systems, ranging from glass and glazing technology to stone, precast concrete, and composite concrete wall systems. Many of the presentations on masonry and stucco that were intended to be printed in this book were never transcribed by the authors into papers. Therefore, these have not been included.

In an industry that brings together an enormous variety of expertise and experience from many individuals and companies, it is my hope that this document will further a more integrated approach towards buildings in general. It is essential that architects and engineers and manufacturers and contractors begin to speak a common language with a common purpose of bringing this age old process into the 21st century.

This publication and the two symposia from which these papers were developed could not have happened without the enormous help of many individuals and organizations. I would like to thank the following organizations, who cosponsored the two symposia, for their support:

American Society for Testing and Materials
Building Design & Construction
International Masonry Institute
Prestressed Concrete Institute
The Ornamental Metal Institute of New York

In addition, I would like to thank many friends and colleagues who participated in this effort. I would like to thank Myron Wander, who was a primary cosponsor and editor of the first symposium on metal and glass curtain walls, and Phil Schreiner, editor of *Building Design & Construction,* whose insights and good humor have contributed greatly to a more integrated view of the building process and whose sponsorship of both symposia was greatly appreciated. A special thanks to Kathy Greene and all of the staff at ASTM, whose perseverance made this publication possible.

Barry Donaldson
Tishman Research Corp., New York, NY;
editor

Design Concerns of Exterior Wall Systems

Joshua M. Horowitz[1]

The Interrelation of Exterior Wall and Structural Systems in Buildings

REFERENCE: Horowitz, J. M., **"The Interrelation of Exterior Wall and Structural Systems in Buildings,"** *Exterior Wall Systems: Glass and Concrete Technology, Design, and Construction, ASTM STP 1034,* B. Donaldson, Ed., American Society for Testing and Materials, Philadelphia, 1991, pp. 5–23.

ABSTRACT: The object of this paper is to discern recurrent interactions between the exterior wall and structural systems in buildings. A general discussion in which the reader is introduced to the basic structural imperatives of high rise construction is presented first. Dynamic building movement due to gravity loads, wind loads, and thermal expansion/contraction are examined next so that an understanding can be gained regarding the performance requirements for exterior wall systems. Each of the basic design approaches to exterior wall construction (conventional masonry, panel systems, aluminum-framed systems) are discussed with emphasis placed upon their interrelation to the building structure. Various case studies are analyzed which demonstrate how these issues are handled on specific projects. Conclusions are drawn and correlations observed which can help the architect and structural engineer become sensitive to one another's goals.

KEY WORDS: interstory differential movement, creep, head receptor, thermal expansion and contraction, unitized curtain wall, wind tunnel, weather barrier, torsion, eccentric loading

An intimate relationship exists in buildings between facade detailing and structural framing systems. The designer's effort is realized not only in the perception of the finished product, but in the economy and simplicity of the detailing methods. Curtain walls are exterior wall systems which support only their own dead weight; they transfer vertical gravity and horizontal wind loads to the building structure. How this is achieved impacts on the design of both systems. When these issues are not adequately addressed, the resulting problems and associated costs can be substantial. Many times the designer fails to comprehend the full interaction of the exterior wall design with the building structure. The owner thus finds himself forced into a schedule- and budget-threatening redesign mode. To avoid this, dialogue should begin early between architect and engineer so that reasonable assumptions can be made by both. Architects should find it unconscionable that dollars be unnecessarily wasted to resolve a problem when the value of that expenditure is never perceived by the users of the building.

Although economics and availability play a large role in selecting the structural design (steel or concrete) for a project, certain building types lend themselves more easily to a given structural system. For example, high-rise residential buildings are well suited to flat plate concrete design because a system which resists relatively small loads carried over short 16 to 20 ft (4.9 to 6 m) spans is required. Since residential spaces are generally heated and cooled with incremental units which do not require overhead duct work, the underside of

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a concrete slab can be used as the ceiling of the space below (not usually possible with steel). Office buildings can be designed in either steel or concrete; however, steel buildings traditionally handle long span conditions more easily. Many special mixed use, hospital, or hotel projects combine both types of systems using steel for the long span spaces (such as showrooms, casinos, operating theaters, meeting and ballrooms) and concrete for the residential towers.

Detailing methods for exterior wall components are influenced to varying degrees by the building structural design. All high-rise structures, whether steel or concrete, will transfer movement to the building facade. Steel structures can be more flexible than concrete (which by virtue of its greater weight and dampening characteristics is inherently stiffer than steel), while concrete framing imparts movement to the exterior wall due to long-term shrinkage (creep). When the building insulation is placed inboard of the perimeter columns and beams (as with conventionally set masonry), the differing coefficients of expansion for steel and concrete similarly affect movement within the facade. This is in addition to the actual movement of the wall components themselves due to thermal expansion and contraction. The inability of some exterior wall systems to handle these dynamic forces has led to many curtain wall failures in the past. The design criteria for live load deflection, elastic shortening, creep (if applicable), and drift of the structural frame must be addressed by the proper design and sizing of joints in the exterior wall. A structural analysis should be performed which aggregates all the applicable quantities of displacement, so that for each structural frame a range of total anticipated interstory differential movement can be established for vertical and horizontal directions. Once this is accomplished, the thermal movement of the curtain wall materials themselves should be factored in, at which point a complete design criteria can be determined for movement within the facade.

Conventional Masonry Designs

From a technical point of view, conventional masonry designs demand the most involvement of the design professional. Since walls of this type are built by numerous trades (masons, waterproofers, ironworkers, caulkers), none of whom are "system" oriented (like curtain wall contractors), the inner workings of the attachment and flashing systems must be addressed by the architect's details. Unit masonry has always worked well in residential buildings because its application is consonant with residential design methods. Buildings of this type are vertically repetitive, but unlike office buildings, need not repeat horizontally and are designed from the inside out. The floor layout as a whole is never perceived by the user in an apartment house; one experiences only the succession of apartment spaces, which are arranged like a jigsaw puzzle of functioning units. Masonry is ideal for this type of building design because its small elemental size can modulate easily. This enables a placement of openings within the wall which can respond almost entirely to what happens within the living unit, without the imposition of rigid horizontal repetition as required for glass and aluminum systems. A condominium apartment project in upper Manhattan, shown in Fig. 1, exemplifies this characteristic. The different masonry pier dimensions can barely be perceived, but are essential to the balanced placement of window openings from within the rooms of the apartment units.

Concrete Structures

Conventional masonry integrates well with concrete structural systems. A minimum of ironwork is required for support of the facade material (usually only the lintel angle or clip),

FIG. 1—*Manhattan condominium exhibits the balanced placement of window openings from within the rooms of apartment units.*

which is attached to the structure by load-bearing inserts cast in the concrete slab or spandrel beam. Horizontal masonry ties can be fitted easily into dovetail slots and also cast into concrete beam and column faces. Continuity of flashing is aided by the ability to hold a consistent nominal dimenison from the face of the building to the face of the structure, and cast-in or surface-mounted reglets can be used to vertically terminate the spandrel flashing. It is this ease of attachment, coupled with concrete's intrinsic ability to be formed into a variety of profiles, that makes its interaction with masonry detailing so harmonious.

In examining a theoretical wall section of stone and block masonry on a concrete frame, the concrete is set on line with the face of the backup block [usually 6 in. (15 cm) from the face of building]. Beams and slab edges always maintain this relationship. Columns can also be set in this manner or moved inboard. The stone rests on a discontinuous clip directly bolted to the bottom of the concrete slab edge or beam. If large window openings occur, and in all cases at parapets, vertical dowel reinforcing ties the back-up material to the structure. Metal flashing (usually stainless steel) is used and returned horizontally into the back-up masonry. If a deep, continuous edge beam is part of the structural design, a cast-in reglet can receive the spandrel flashing. A soft joint must be included to allow interstory differential movement whenever masonry walls are unbroken from floor to floor. A compressible rubber pad and joint sealant is used under the lintel of each floor for this purpose. Materials such as low-modulus silicone can be used as a sealant. Horizontal expansion joints should be included at regular intervals (more frequently at parapets) and are also constructed of expandable/compressible materials. In addition to the dynamic movement of structure which all buildings transfer to the facade, it is important that wall systems supported on concrete frames must also accommodate long-term shortening due to creep.

Window systems that are built within masonry openings also need a means of accommodating structural frame and thermal movements. This can be achieved by a variety of techniques, the most common being a two-piece head frame. The fixed portion of this

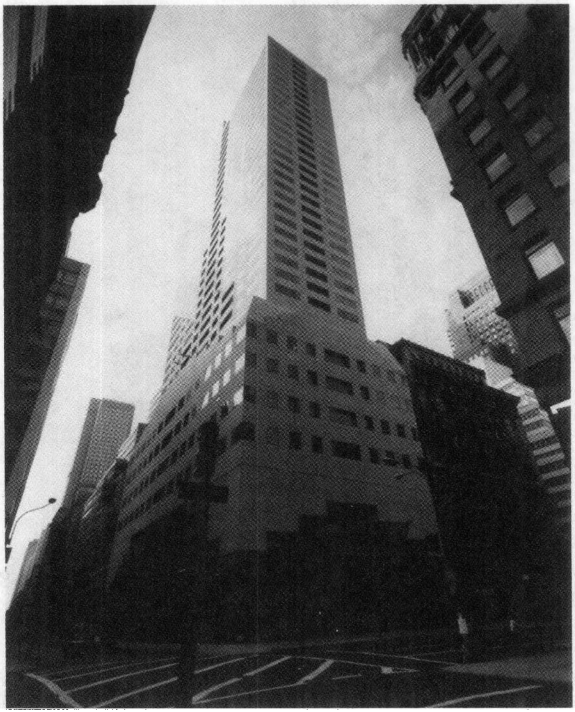

FIG. 2—*This building is an example of conventional stone masonry on a concrete frame.*

assembly, also known as the head receptor, is a channel-like member which can be directly fastened to the underside of the adjoining construction along the top of the window opening. It is designed to interlock and overlap the window head member and will allow movement within the plane of the wall without compromising the weather tightness of the window construction.

The 575 Fifth Ave. New York City building detailed in Fig. 2 (architect's drawing shown in Fig. 3) is an example of conventional stone masonry (Taivassalo and Rosa Porrinno granite) on a concrete frame. The stone is supported on clips located at the centerline of the vertical stone joints. This enables each stone to share two clips (one on each edge) and reduces the total amount of hardware and leveling required for installation. Two wedge-type inserts are cast into the concrete spandrel, centered about the vertical stone joint to support the clip device. Because the granite facing is thicker than 2 in. (5 cm), it is possible to cut a slot into the back of the stone about 6 in. (15 cm) from the edge. The clip then fits into the slot, eliminating the need for a liner or cleat on the back of the stone. The clip is a two-piece device with a stainless steel plate and angle. *Vertical* adjustability is provided by the wedge insert, *in and out* adjustment is achieved with shims, and *right and left* adjustment is provided by the sliding of the two components of the clip assembly. Lateral resistance is provided by stainless steel strap anchors, fit into slots in the stone edges, and attached to the structure with drilled-in fasteners. To divert any water penetrating the caulk joints, stainless steel flashing is provided in the stone piers at the horizontal joint coinciding with the window head and is turned down into the dammed trough at the window construction. This flashing terminates vertically into a reglet cast into the concrete beam or column

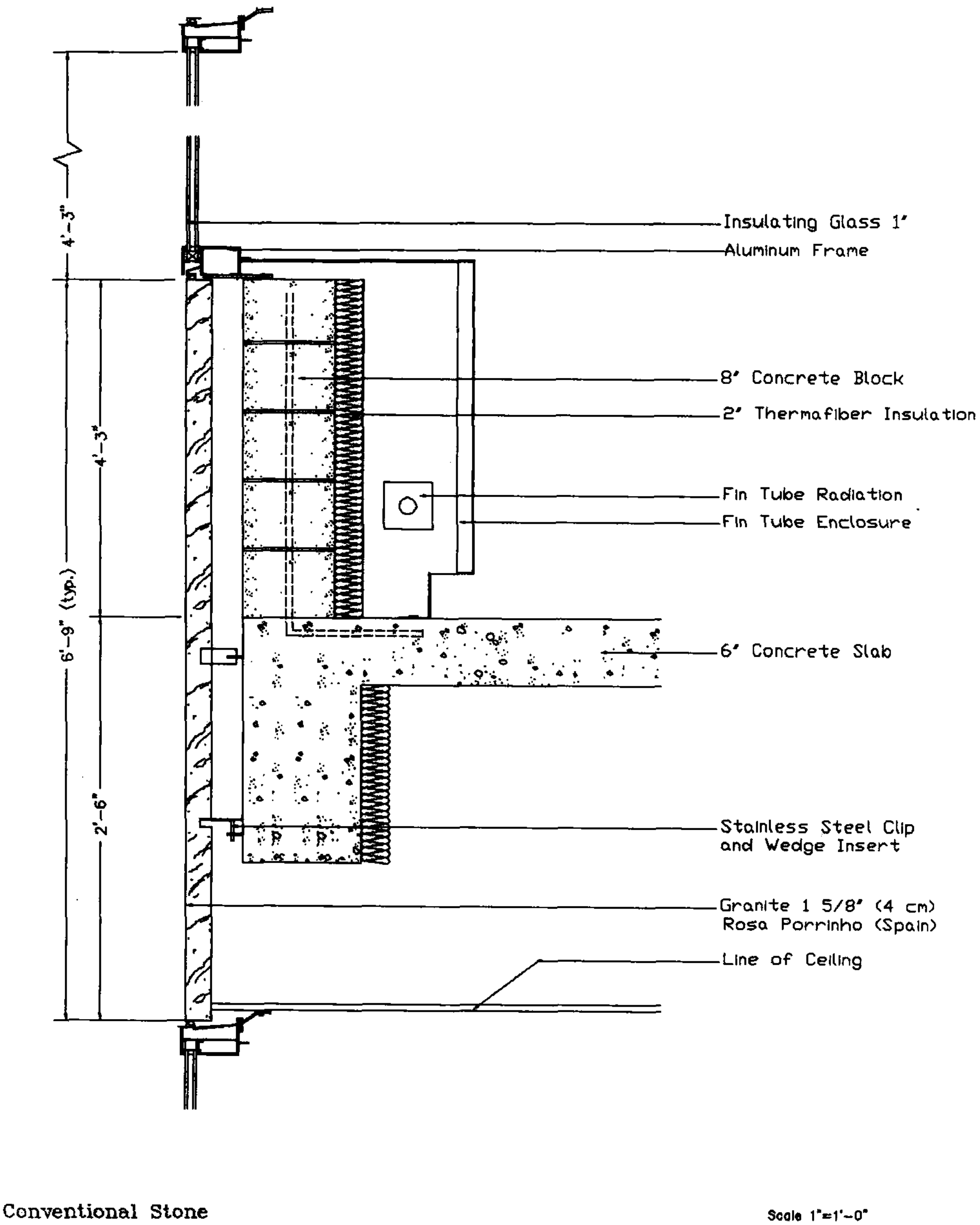

FIG. 3—*Drawing of the stone masonry building shown in Fig. 2.*

face. Within the masonry window opening, infiltrating water is allowed to drip down the back of the stone and into the window construction, which diverts the flow of water through an internal system and finally sheds it through the sill extrusion. In this manner, all requirements for a structurally sound, weather-tight enclosure are provided within a relatively simple detailing approach.

Steel Structures

Compared to concrete, steel frames create many problems which need to be addressed in the detailing of stone and brick masonry. Because steel sections are factory made and shaped for structural efficiency, but cannot be formed to suit detailing profiles like concrete, much greater thought must go into the design and coordination of the exterior wall attachments to the building structure. Frequently, a centerline connection is required between the perimeter spandrel beam and the column. When this is the case and the column is positioned so that it is not visually apparent on the exterior wall, i.e., set back 2 ft 6 in. to 3 ft (0.76 to 0.91 m), often only the metal deck and slab are available for the support of the facade materials. This may be acceptable when the building is clad in aluminum-framed curtain wall because its relative light weight is easily handled by the deck and slab alone. The *hidden* costs associated with heavier conventional masonry walls on steel buildings can include outriggers, double spandrels, elaborate steel hanger assemblies, and stiffening or increasing design criteria for torsion due to eccentric loading on spandrel beams. Also, steel costs are primarily a function of weight and complexity of fabrication. A good structural design will generally use the most efficient framing member for the given loading without regard for consistency of profile. It is not uncommon to have varying spandrel beam depths from floor to floor (shallower at the top of the building) or even varying beam depths on a single floor. This makes coordination difficult for detailing the attachments, since conventionally set masonry must be supported from beneath, not hung from above. A constant line of support (usually at the window head) has to be provided from a structural frame with large dimensional variations. As a result, back-up block as well as spandrel flashing design and installation may become complicated, with many changes in direction, terminations, and complex variations in profile. It is not uncommon to purchase spandrel flashing for masonry walls from the masonry contractor. Careful evaluation of this approach is warranted with steel-framed buildings where the scope of the work may require a more specialized contractor.

Steel fabrication is also a time-consuming process requiring many detailing considerations be made early in the project development, during the design of the structural steel. Steel attachments which are not anticipated and requiring field welding can be very costly. Devices such as grip-stay channels, deformed rods, etc. which can receive masonry anchors should be detailed and fabricated in the steel shop. Lead time for steel detailing and fabrication is critical. This additional time factor must always be considered with steel buildings.

The bank building shown in Fig. 4 is an example of conventionally set masonry (stone at the base, brick above) on a structural steel frame. The window system for this building is a vertical strip design, fit between masonry piers. A full-story unitized curtain wall system that included a window and spandrel panel was used which could be erected entirely from the floors. The details of unitized systems will be discussed below, in **Aluminum Framed Curtain Walls.** Because the design included many changes in plane of the exterior wall, it was necessary to fabricate an elaborate steel girt system for the anchorage of the stone at the base. On the upper floors, where brick masonry was used, a variety of lintel and hanger assemblies were required to accommodate a constant support and flashing line on floors where the depth of the spandrel beam varied. Similarly, the flashing details had to work themselves around the dimensional variations of the steel sections, moment plates, hanger assemblies, bolt heads at splices, etc. The construction of the window mockup included typical portions of the surrounding masonry which proved to be of more value in learning about the construction of the brickwork and flashing than the actual window installation. A complex series of flashing dams and transition pieces prefabricated in metal were required to accommodate all the variations in the plane of the facade and structural frame in order to maintain watertightness.

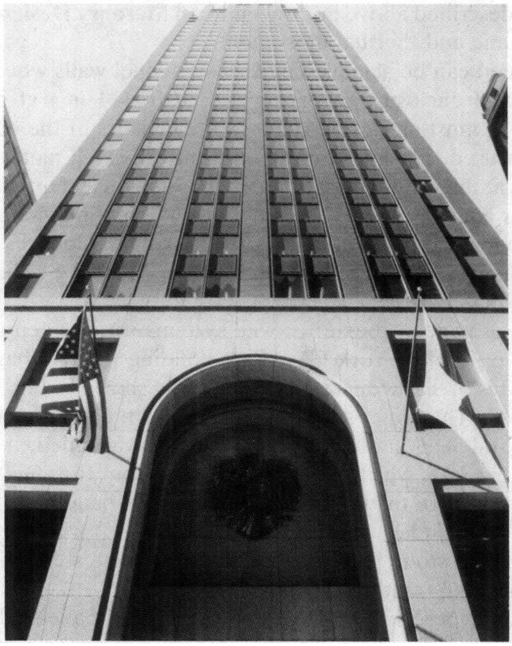

FIG. 4—*This New York City bank building is an example of conventionally set masonry on a structural steel frame. The window system is a vertical strip design fit between masonry piers.*

Panelized Wall Systems

Panelized wall systems (steel frame truss and precast), as compared with conventional masonry, can have a vastly different influence on the perimeter building structure. The points of attachment to the building structure are limited and the panel components are self-supporting. Therefore, the compatability of one structural design approach (steel or concrete) is not as apparent for panelized systems as it is for conventional masonry and concrete. In their most efficient form, panelized wall systems span from column to column and form a "beam" upon which the window sits. The gravity load (dead weight) of such systems is generally less than conventional masonry/backup block, especially with steel truss framed panels, and is concentrated at the columns. This eliminates the need for the spandrel beam to resist the vertical loads of the wall. If the structural system is a "tube" design with numerous columns on the building perimeter, lateral tiebacks can also be made at the columns, eliminating the transfer of wind load or dead load to the spandrel beam. When the panel is required to be tied back to the lower flange or web of the spandrel beam, torsional loads must also be factored into the structural design. Attachment points for these systems are limited and panel lengths are generally large—20 to 30 ft. (6.1 to 9.1 m) is not uncommon. Thus, the forces concentrated at these locations are much greater than those generated by conventional masonry walls, which are supported in smaller dimensional increments.

The sizing of joints between panels is a critical design element and has to take into account all the anticipated interstory differential movements, as well as thermal expansion and contraction of the exterior materials. Because cost-effective panel designs are often 20 to 30 ft (6.1 to 9.1 m) long, the accumulated movement within such a large area can be 3/4 in. (1.9 cm) or greater. Window systems placed between wall panels can use the split