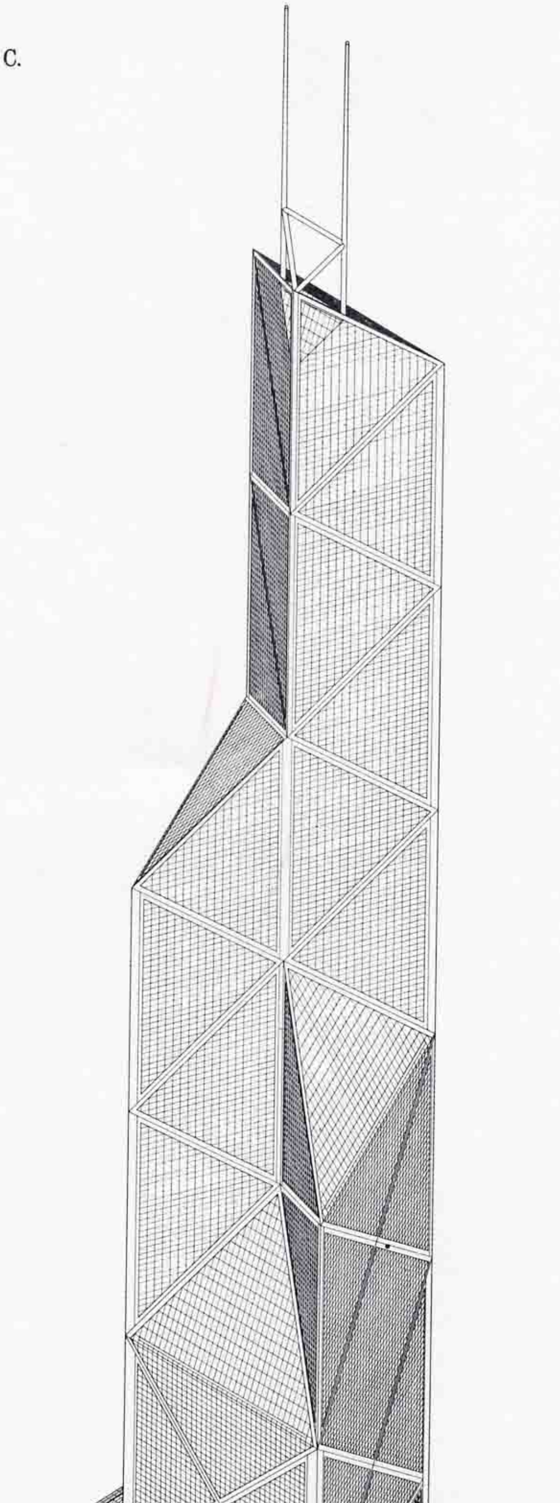
The Bank of China
Hong Kong
I. M. Pei & Partners, Architects
Robertson, Fowler & Associates, P. C.
Structural engineers



The logic of eccentricity

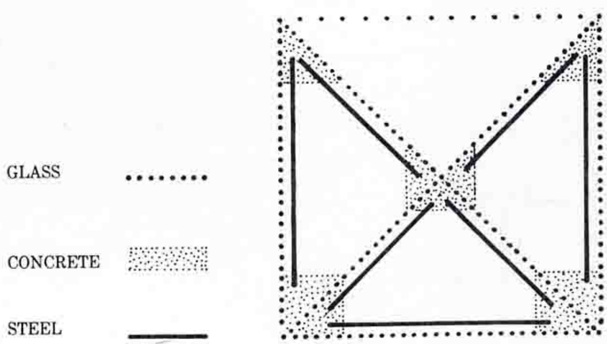
The Bank of China photo-montaged onto the Hong Kong skyline.

The Bank of China Building, currently under construction in Hong Kong and scheduled for completion in 1988, is a stunning exercise in architectural geometry. The tower was conceived by I. M. Pei as a cube, rising out of the ground, and divided diagonally into quadrants (see diagram below). As the structure moves upward, the mass is diminished one quadrant at a time until it is reduced to a single, triangular prism 70 stories, or 1,028 ft above grade. Pei intended the architectural partition to fall precisely on the geometry of the form: a crystalline Euclidean vision in reflective glass and aluminum. Maintaining the purity of that geometry was the challenge around which the very structural feasibility of the project turned.

Because the tower's structural lines are pulled just inside the building envelope, and because the shape of the envelope changes dramatically, the position of the five major columns must joggle out-of-plumb as they make their way down to the ground while maintaining the structural steel in a true and plumb, repeating geometry. The result is eccentrically loaded columns. Common practice says it is not possible to make such a building stand because the off-center loads would cause excessive stresses in the columns. Common practice aside, the engineers at Robertson, Fowler & Associates hit upon a system that accepts the radical eccentricities inherent in the architecture.

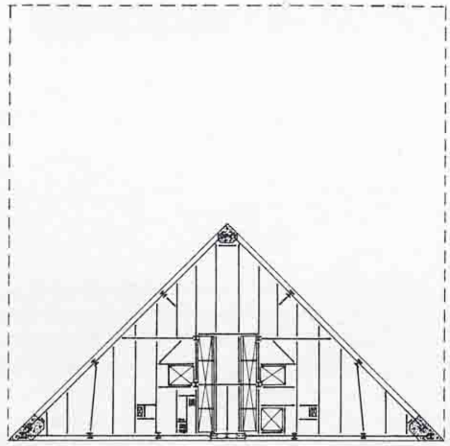
The structural designer, Les Robertson, based the system on what he refers to as, "a 'truism' not obvious in practice to most engineers." A single eccentricity in a column will cause bending; but two or more lines of eccentricity, *joined by a uniform shear force mechanism,* will counteract and therefore eliminate the bending. This principle was applied to the Bank of China in the following way. The five composite columns of the system support the braced-frame of structural steel that spans them. The centroid, shape, and position of these columns change as they move down the building—the source of eccentricity. But because the concrete "glues" the steel to itself, bending is eliminated. The concrete, then, serves as the uniform shear force mechanism. Dynamic eccentricity is arrested with creative engineering logic.

The result is a structural configuration equal in its own right to the eloquence of the architectural design. Furthermore, the system is outstanding for its economy of material. Compared to buildings of the same height and area, the Bank of China will use approximately 40 per cent less structural steel (a remarkable achievement considering that both the wind and live loads for Hong Kong are twice that for buildings constructed in New York). Exemplified in practice, Les Robertson's remembered "truism" should pave the way for a new generation of super-tall structures. *Darl Rastorfer*

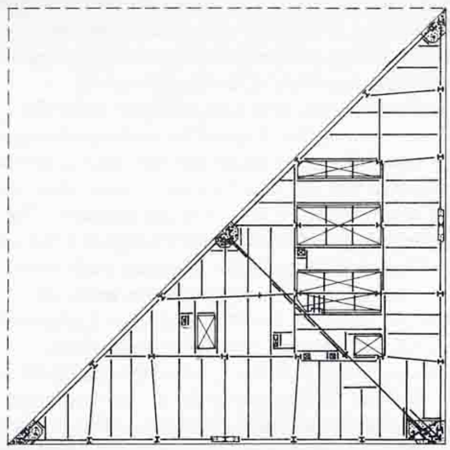


The conceptual plan diagram, at left, of the 25th story shows the two major partitions of the architectural geometry. The line of the glass curtain wall falls on the pure geometry of the square divided diagonally into quadrants. The structural line for steel and the positions of concrete columns are held within the pure geometry, forcing shifting alignment. The potential bending problem caused by misalignment is solved by the concrete when used as a uniform shear force mechanism.

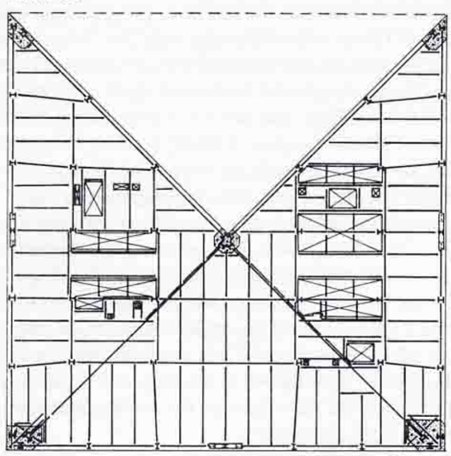
The structural plans at right represent the four fundamental floor configurations of the building as it rises from the ground to the aerial structure at its summit: they are, from bottom to top, the fourth, 25th, 38th and 52nd stories. Floor slabs are stone concrete, 4-in. thick, on a steel deck. The primary columns are composite concrete and steel. The framing pattern for the steel floor structure is noted in the plan, as are the trusses used in the lateral force system, which fall on the diagonal and orthogonal planes. Below the 25th floor (bottom plan) the central column has been terminated. The load, as it builds in that column from the 70th story down flows to the outer columns between the 51st to 25th floors. The additional downward force from the transfer increases the effective stance of the building to resist lateral loads. At the fourth story, well below the height where the column disappears at the 24th floor, the prismatic tower joins the granite base of the banking hall level. Here, I. M. Pei has designed an unobstructed space with expansive views in all four sides (see section, opposite page, far right). At the center of the hall, an open atrium rises 15 stories to a skylit enclosed garden, providing spatial continuity to all the bank's activities and natural daylight to the center of the hall. The lateral diagonal bracing at the surface of the tower (see north and south elevations) was given a direct architectural expression in the facade. The transfer trusses that wrap around every 13th story (see bracing elevation, following page) were originally expressed in the facade, but were concealed in the final design at the client's request for the following reason: with the horizontal bracing, the facade appears as a ladder of X's. The X is a negative symbol in Chinese iconography. Therefore, the horizontal expression was removed. The revised facade treatment was presented by Pei to the client as a tower of "diamonds"—a symbol happily embraced by the bankers.



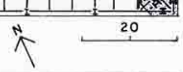
STORYS 51 AND 52

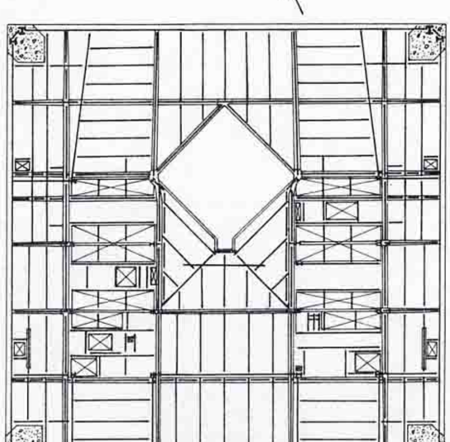


STORY 38

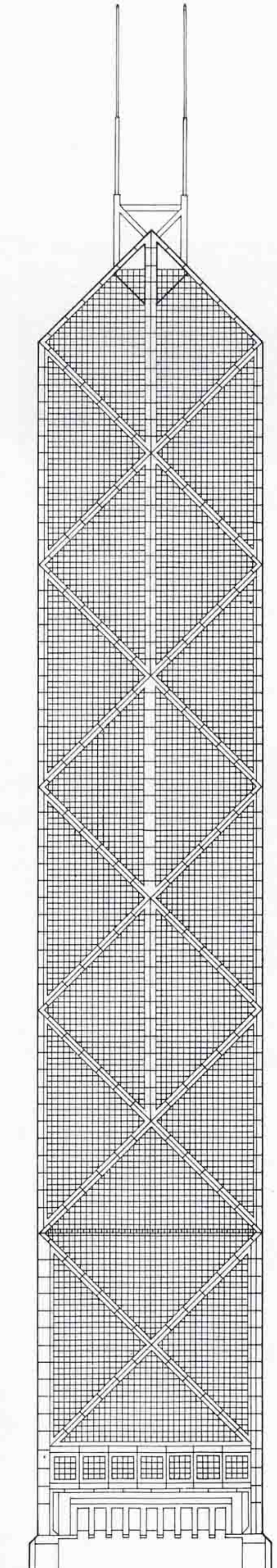


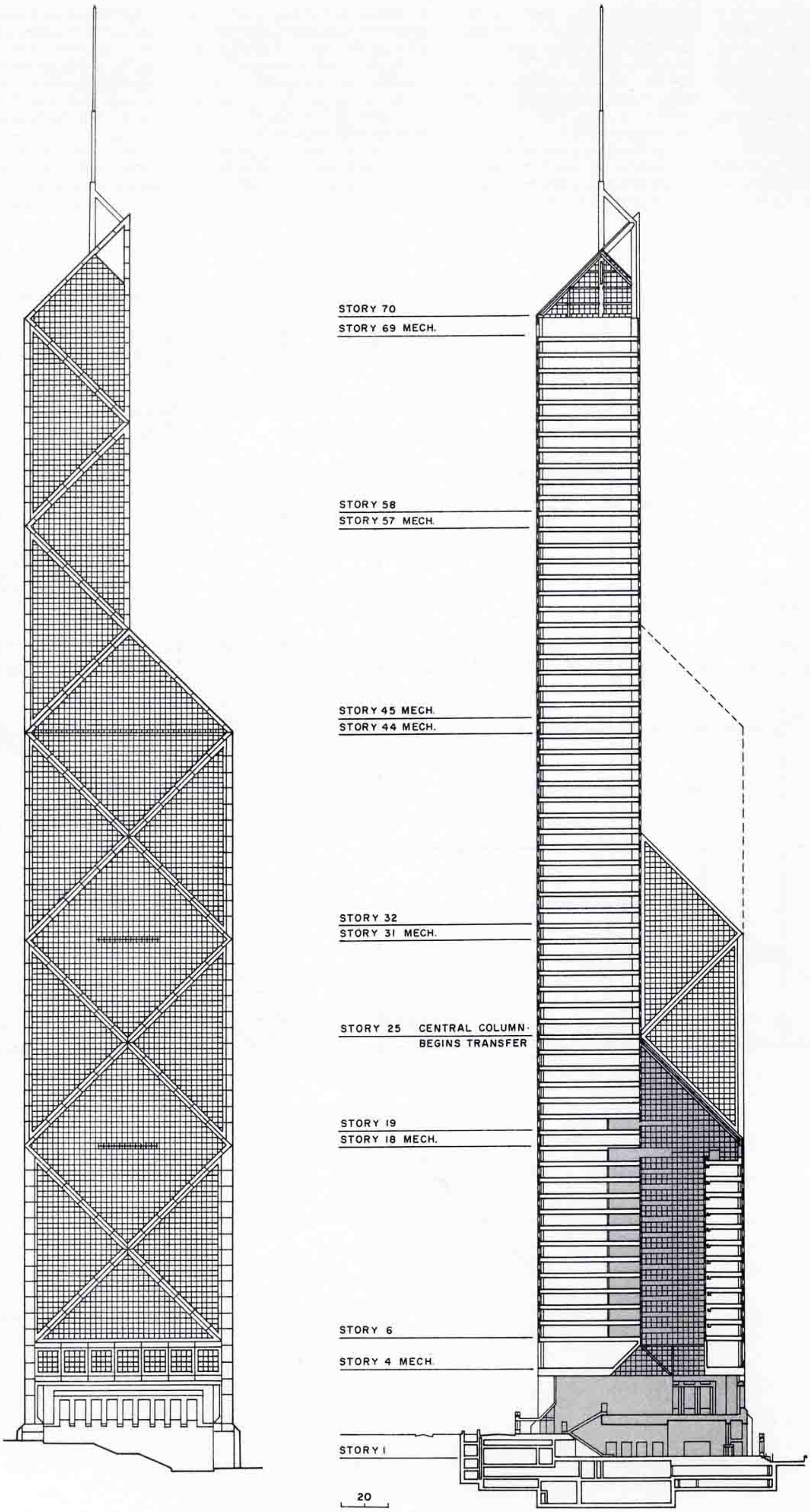
STORY 25





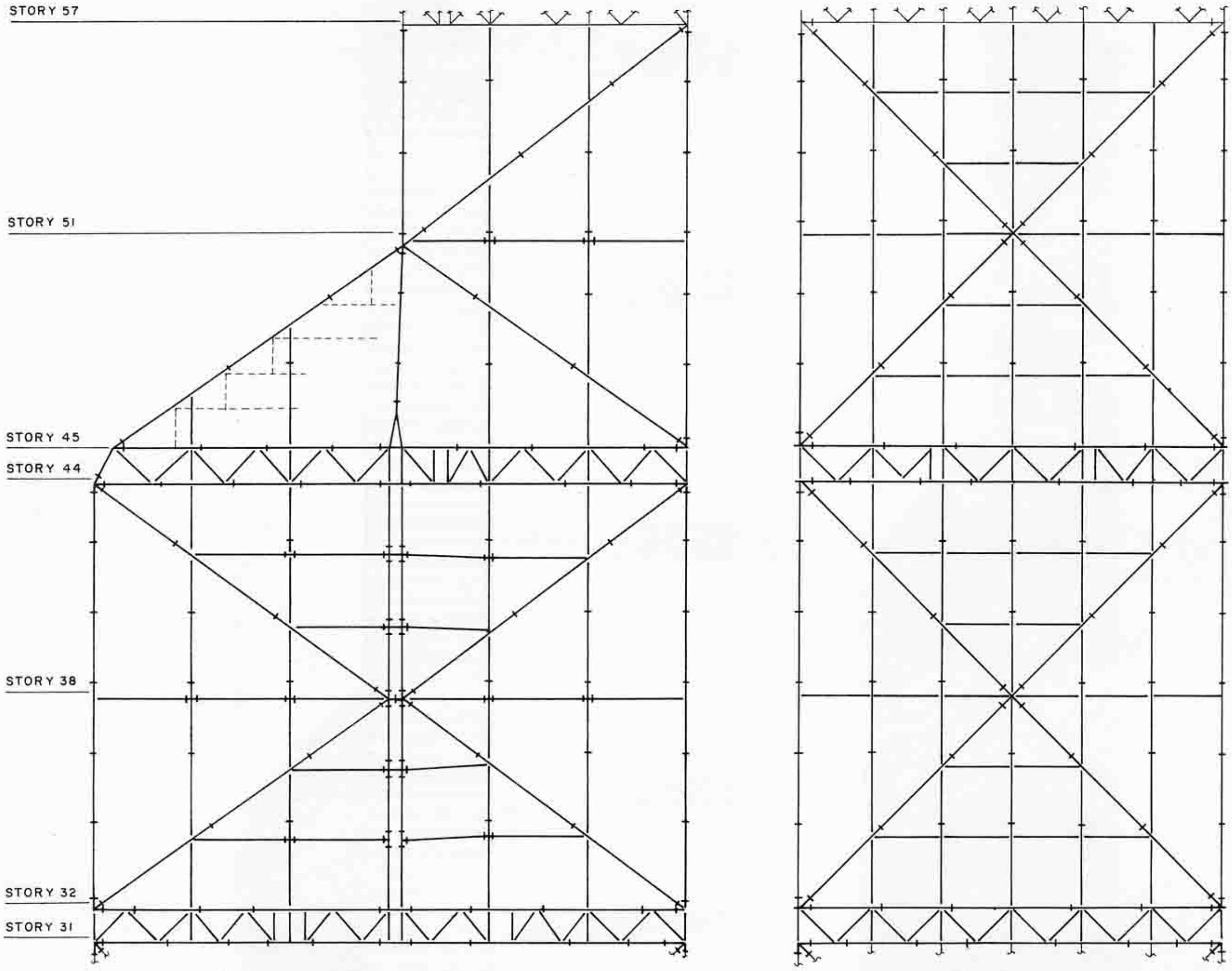
STORY 4

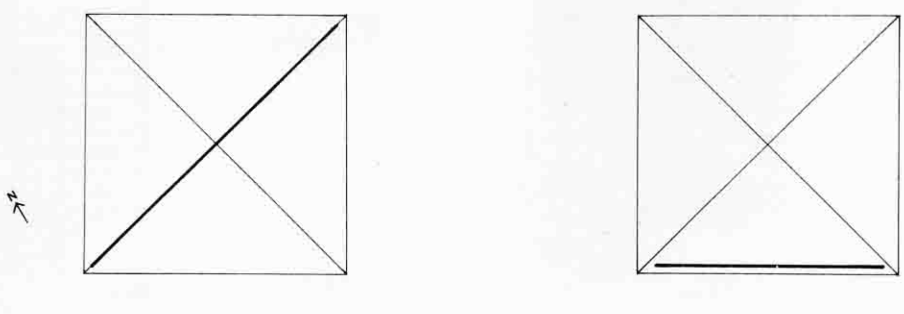




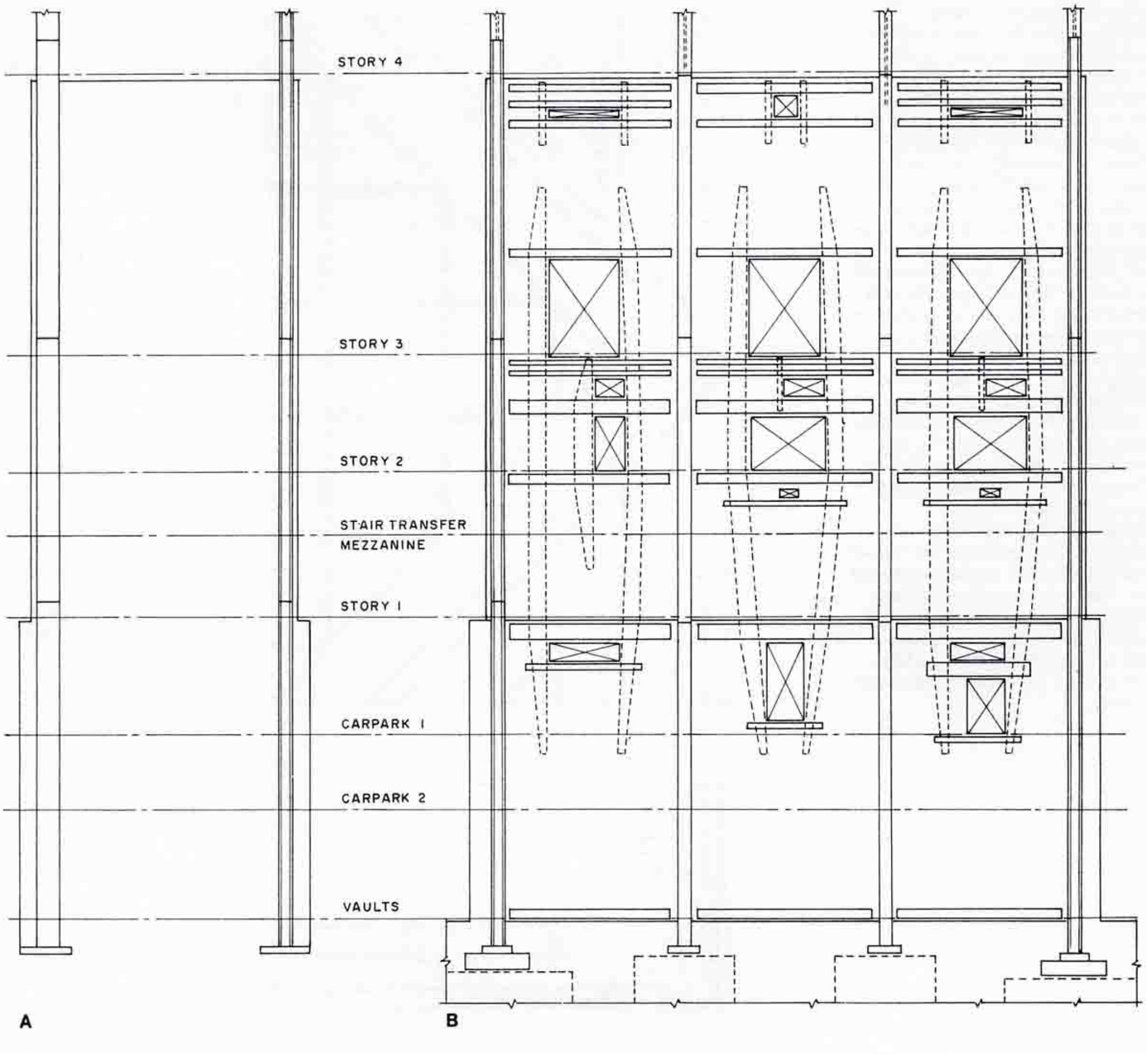
STORY 70
STORY 69 MECH.
STORY 58
STORY 57 MECH.
STORY 45 MECH.
STORY 44 MECH.
STORY 32
STORY 31 MECH.
STORY 25
CENTRAL COLUMN
BEGINS TRANSFER
STORY 19
STORY 18 MECH.
STORY 6
STORY 4 MECH.
STORY 1
20

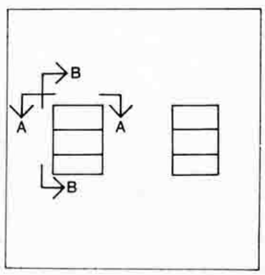
Never has a building as tall as 70 stories been built in such an adverse environment. Hong Kong is in a typhoon zone. With wind loads twice that for New York City, and equal to four times the earthquake load for San Francisco, lateral forces were a primary concern to the engineers. Their solution is a light, efficient megastructure of braced frames that tie into the composite columns of the gravity-transfer system. The steel plane-frame system rises upward from the fifth story, following the geometry of the square plan partitioned diagonally. The frames are organized in 13-story modules with a major transfer of the internal columns at every 13th floor (illustrated in the framing elevations below of stories 31-57 for the diagonal and south frames as shown in the plan diagrams). The stiffening trusses on the perimeter, working with the 12-story-high major bracing configuration, transfer interior and exterior column loads to the four corners. Thus, only a small portion of the loads carried to the service cores in the lower floors flows directly to the foundations. Assisted by the transfer level and making use of the X configuration above and below, both the vertical and the lateral loads are absorbed into the concrete-and-steel columns. While three-dimensional in its action, the megastructure is composed of true plane-frame braces, as they are simply connected to a single steel column at the corners. Each plane-frame, then, has its own steel columns, but the plane-frames share the composite concrete/steel columns. This planar technique is simpler and less expensive and allows for more rapid construction than a three-



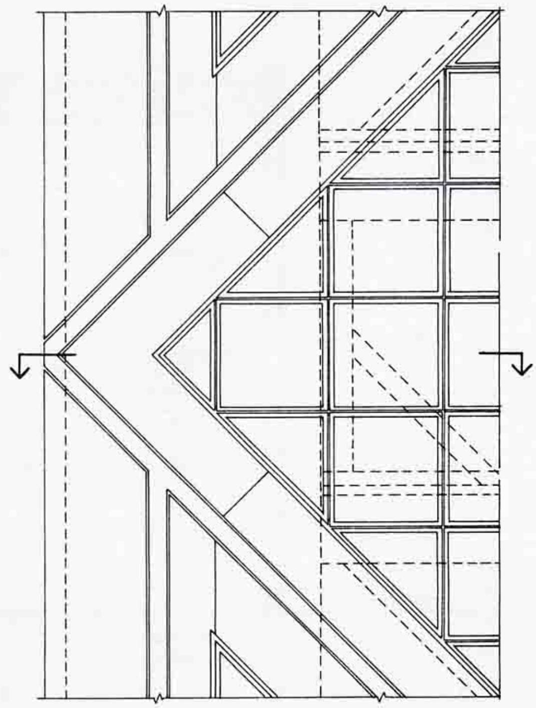


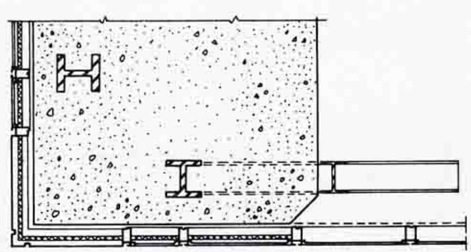
dimensional connection joining out-of-plane steel diagonals to a single steel column. Lateral loads are carried down the building through the diagonal system to the fourth floor where they are coupled to the two service towers. These towers, designed as shear tubes, reach up and stabilize the building at the fourth floor (see shear tube elevations and plan diagram below). When the wind comes, the overturning moments stay in the four corner columns on the outside walls. Shear is carried down from the fourth floor to the first floor in the shear tubes. At the first floor, shear force is transferred out through the concrete floor to the slurry walls that surround the building. The tubes are made of steel columns braced by horizontal and verticle steel plate stiffeners generally 1/2 in. thick. The entire shear tube is laminated with 10 in. of reinforced concrete to allow for unstiffened areas; to add to the strength and rigidity of the tube; and to provide a solid backing for granite facing. The entire fourth floor is a steel-plate diaphragm covered with concrete. At the base of the tubes, the concrete covering over the solid-steel plate is increased to a thickness of over 3 ft to form the highest-security vaults of the bank.

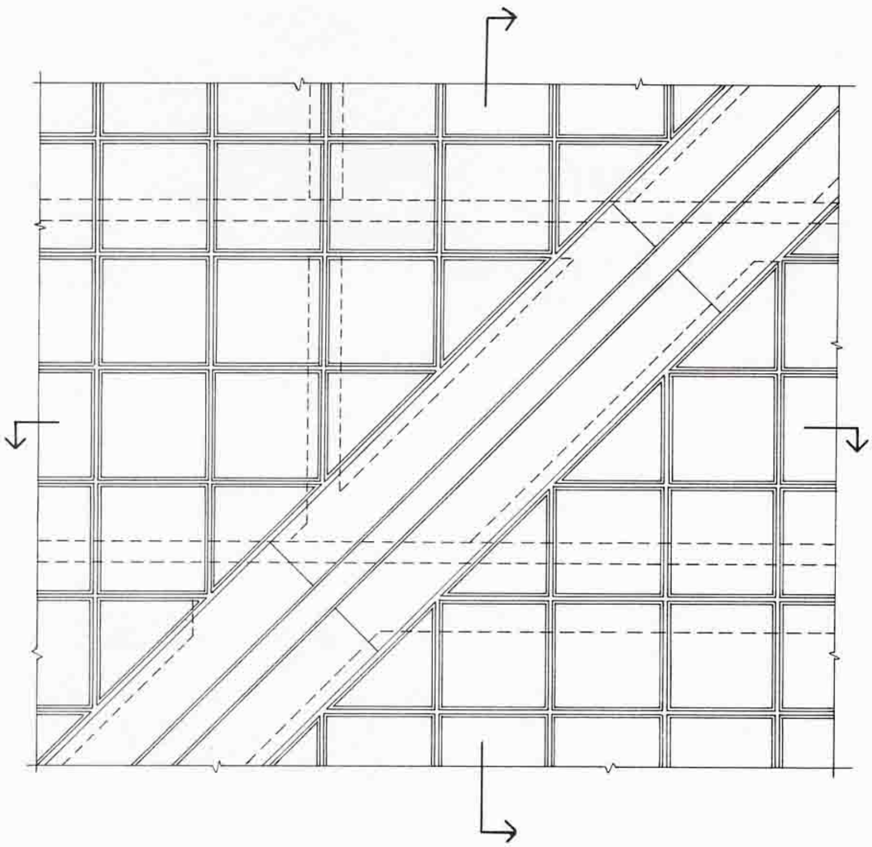


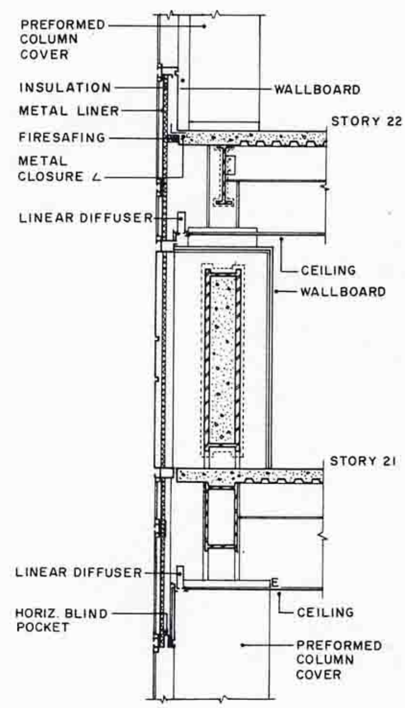


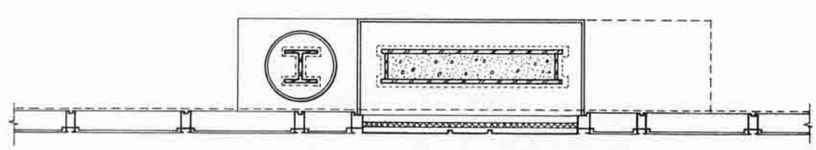
The expression of lateral bracing on the facade is essential to the building esthetic. Regarded by many architects as undesirable, the use of diagonal bracing and its graphic expression is considered by Pei as a natural way to build. Specifically referring to the Bank of China's outward appearance, Pei stated, "Form and decoration were not enough. The building must be structurally logical and elegant." And so it is. The bracing structure is expressed with an aluminum architectural cover that is flush with the plane of the facade and directly related in position and dimension to the diagonal structural members (see drawings at right and on opposite page). The corners of the reflective glass-and-aluminum curtain wall have also been sheathed with an aluminum cover. Though the corners' articulation marks the location of major columns, it does not always express the full dimension of those columns—an instance where the formal intentions of the architect demanded something other than a prosaic description of structural elements. The over-all result of the facade's handling is a crisp surface that appears tightly drawn across the faceted faces of the building.











The Bank of China
Hong Kong
Owner:
The Bank of China
Architects:
I. M. Pei & Partners
I. M. Pei, partner-in-charge; Bernard Rice, project architect; Robert Heintges, curtain wall; Abe Sheiden, project manager
Associate architects:
Wong/Kung & Lee, Architects, Hong Kong
Structural engineers:
Robertson, Fowler & Associates, P. C. Leslie E. Robertson, project designer; Harold D. Roet, project manager for the tower; Stanley L. Saffer, project manager for below-grade work; Vallentine, Laurie, Davies (associate structural engineers in Hong Kong)
Mechanical/electrical engineers:
Jaros, Baum & Bolles; Associated Consulting Engineers (associate mechanical/electrical in Hong Kong)
Wind tunnel testing:
University of Western Ontario Boundary Layer Wind Tunnel Laboratory