PETER HYATT

The World's Tallest Buildings

Malaysia's Petronas Twin Towers serve as both a cultural and an economic symbol

by Cesar Pelli, Charles Thornton and Leonard Joseph

The urge to build as high as possible appears to be a common trait of human culture. From the Great Pyramid of Cheops to the Tower of Babel, many civilizations tried to craft structures that stood above their surroundings. Mesopotamian ziggurats, Chinese pagodas and Moslem minarets became symbols of religious belief, towers that reached toward heaven.

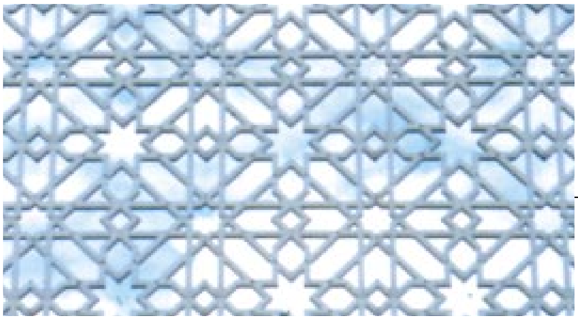
Today the modern obelisk is the skyscraper. For more than a century, architects and civil engineers have applied practical and theoretical knowledge about vertical construction techniques to transform the look of cities. Early skyscrapers borrowed ideas from the shape of Greek columns and Renaissance towers. The modernist movement that predominated after World War II avoided symbolic qualities: these flat-roofed, rectangular structures were even called high-rises, not skyscrapers. In recent years, architects have again revived interest in the tall building as cultural emblem. Preeminent examples of the trend are the world's tallest buildings, the Petronas Twin Towers, which soar above Malaysia's capital city of Kuala Lumpur.

The pinnacles of the 88-story structures reach 451.9 meters. The edifices, connected by a skybridge at the 41st and 42nd floors of both buildings, are more than simply an office complex. These recently completed buildings stand as a symbol of Malaysia's economic growth, while emphasizing the distinctly Islamic traditions of this southeast Asian nation of 19 million people.

Each floor plan is a star shape with alternating round and square-cornered points, after a design drawn from Islamic art. Faceted outside walls repeat the same pattern. The project is a centerpiece of what Mahathir Mohamad, the prime minister of Malaysia, calls Wawasan ("Vision") 2020, a blueprint for the country's development, which also includes a variety of other large infrastructure projects.

Each of the tower buildings contains 213,750 square meters of floor space (equivalent to 48 football fields). Besides offices, the space is used for a petroleum exhibit center, an art gallery and state-of-the-art multimedia conference rooms. The two buildings themselves are part of a much larger complex, Kuala Lumpur City Centre Phase I, and are constructed on one corner of the former site of a racetrack, the Selangor Turf Club. The complex also encompasses a 140,000-square-meter retail and entertainment facility; a 2,600-square-meter, 850-seat concert hall; 251,000 square meters of below-grade parking for 5,000 cars; and two smaller office towers with approximately 186,000 square meters of space.

The owner of the development complex is Kuala Lumpur City Centre Holdings Sendirian Berhad, a partnership that includes Petronas, the national petroleum company, which is also a key tenant. The project developer is Kuala Lumpur City Centre Berhad. What follows is an account of the architectural and engineering decision process that began with a design competition in 1991 and moved through to the completion of the towers' pinnacles.


J. MITSUI Cesar Pelli & Associates

ISLAMIC MOTIFS influenced the architectural design of the Petronas Towers, seen in the bottom photograph from a nearby lake.

ARCHITECTURAL DESIGN
Gateway for Malaysia


P. FOLLETT Cesar Pelli & Associates

The architectural design of the Petronas Towers began, as most large-scale projects do today, with an international competition. Eight firms from Asia, Europe and the U.S. responded to the invitation from the owner and developer. All architects worked from a relatively short brief that described the project requirements—a general design for a shopping center and public spaces—and a more detailed prospectus for two towers to be occupied by Petronas in the northeast corner of the 40-hectare complex.

The towers, according to the brief, would define a gateway into this new city center. They would create "a place that people can identify as unique to Kuala Lumpur and Malaysia." It was never specified that the towers should become the tallest buildings in the world, just that they be beautiful.

The competition lasted only a short time during the summer of 1991. Within three weeks, each design firm had to prepare drawings, models and rendered perspectives to send to Kuala Lumpur. The developer's technical staff spent two weeks reviewing the proposals. Then, in August, each competitor had to make multiple presentations of its designs to audiences that included the developer and Prime Minister Mahathir. These sessions addressed technical and economic concerns as well as aesthetic and philosophical questions.

Later that month Cesar Pelli & Associates, the New Haven–based architectural firm, received notice that it had been chosen to design the first phase of the Kuala Lumpur City Centre project, which included the Petronas Towers. One never knows with certainty why one design proposal is selected. In this case, the client indicated that, as architects, Cesar Pelli & Associates had answered all the practical concerns and, most important, that the proposal met the desire for a uniquely Malaysian design.

Following the decision, a team was assembled that included Thornton-Tomasetti, structural engineers; Flack & Kurtz, mechanical engineers; Adamson Associates, production architects; Balmori Associates, landscape designers, among others.

In total, 16 firms collaborated in the design effort. This number is not unusual for a project of this size, given that the taller the building the greater the design demands of function, structure, efficiency and economy. The large complement also responded to a requirement that Western firms experienced in design and construction practices for very tall buildings should work closely with Malaysian professionals to share their technological expertise.

ENGINEERING DESIGN

Islands in the Sky

The basic engineering principles for tall building design look deceptively simple. Floor slabs and beams span from one column to another, creating open space that can then be partitioned into defined work areas. Columns carry the building load all the way down to the foundation. Parts of the structural systems must also provide lateral stiffness for stability. A shear wall, for instance, can rise through multiple floors to brace against wind and other dynamic forces, such as earthquakes.

Demands on the structure, however, increase rapidly with height. In a 40-story building, an average column carries a load equivalent to 23 floors. At 80 stories, a column in the lower 40 stories absorbs an average load equivalent to 80 floors. Doubling the height more than triples the load because of the compounding effects of the building's own weight.

As height increases, the area exposed to wind forces—a critical variable in tall building design—also expands. The lateral deflection of upper floors must be controlled. Doubling a building's height multiplies wind sway 16-fold unless the structure's stiffness is increased dramatically.

Providing upper floors with air, water, electricity, communications lines and sanitation takes up precious interior space, and the room needed for these services can grow disproportionately. Large pumps are needed in the basement to push water to the top. The bottom sections of water and air-conditioning pipes experience great pressure. Some relief from this pressure buildup comes from water storage tanks and heat exchangers dispersed throughout the building.

Firefighting and evacuation cannot be performed above 30 meters (100 feet) from ladder trucks on a street. Sprinklers, alarms, smoke-control systems and fire refuges (areas with a separate air supply) consequently become vital. Ground-based construction methods are unsuited for tall buildings: cranes, working platforms and forms (steel boxes into which concrete is poured) must climb with the building as construction proceeds. The time needed to lift workers, concrete, steel and glass can affect the project schedule. The contractors must, in effect, plan the project as if working on an island in the sky.

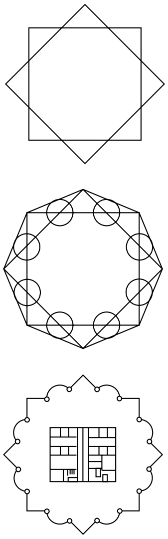
Despite impediments, buildings continue to grow taller and have yet to approach practical height limits. High-strength concrete can form compact structural members, thereby reducing constraints on building design imposed by column size and weight. Stronger steels now under development might also be used where weight limitations are critical. Wider bases are needed to provide stability against wind. Many new towers, in fact, are megastructures covering several blocks.

The main limit on height is human physiology, not structural constraints. Pressure changes and travel times in ever higher elevator runs impose a "vertical commuting" cost on occupants. The financial burden involved in building tall also sets a practical limit. These barriers, nonetheless, keep moving slowly upward.

PETER HYATT

ARCHITECTURAL DESIGN

A Multifaceted Star



Linking the Petronas Towers to Kuala Lumpur and Malaysia required rethinking the character of the traditional skyscraper to unburden it of American or European connotations. The buildings were connected to their place in several ways. The shape of the towers has its origin in Islamic tradition, in which geometric patterns assume greater symbolic importance than in Western culture.

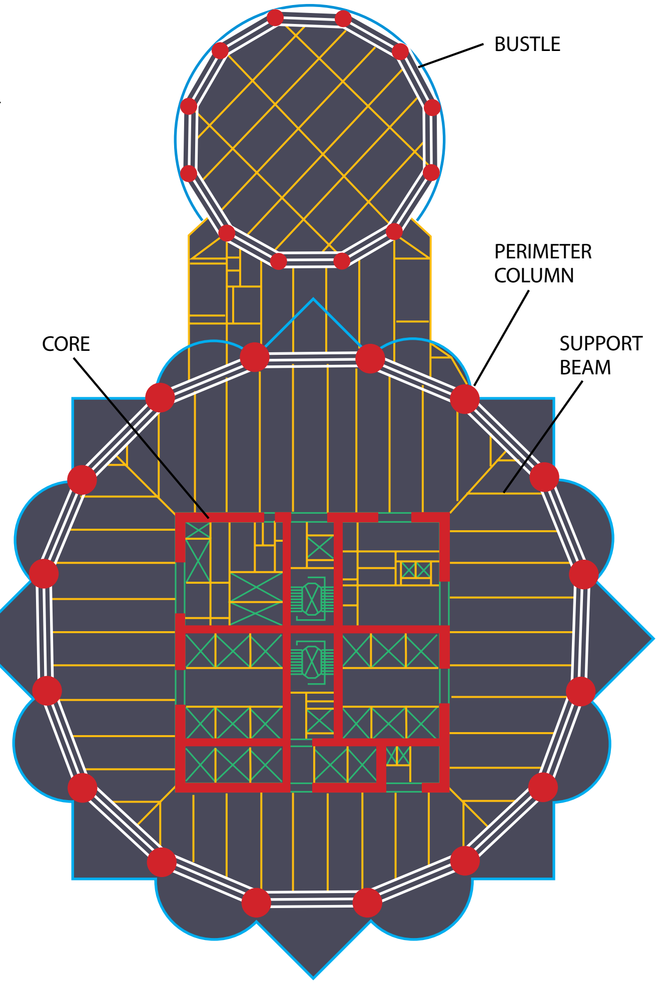
In the competition, Cesar Pelli & Associates proposed a 12-pointed star as the shape of the building perimeter, giving the building both a graceful form and very usable floor space. Prime Minister Mahathir suggested that other patterns might prove more representative of Islamic design. After being awarded the contract, we researched traditional motifs and concluded that the most common design is an eight-pointed star—achieved by superimposing two rotated squares. Further confirmation came from a drawing suggested by Mahathir, who proposed two interlocked squares. But an eight-pointed star results in an unsuitable floor plan; the exterior wall comes too close to the building core, reducing flexibility in the use of the floor space.

The architects studied many variations and proposed a form with eight semicircles superimposed in the inner angles of the eight-pointed star, creating a 16-branched form. A structural column occupies each of the 16 inner angles of the building, producing floor space that is otherwise free of columns.

Almost at the same time, development work began on the core, the hollow square of walls at the building's center that provides much of the structural support. The core, which also contains elevators, stairs, mechanical shafts, fan rooms and toilets, is the key to a well-functioning tall building. Its design must work with anticipated users' needs and floor layouts. The goal was to meet these demands with high "efficiency"—a measure that describes the ratio of usable-to-gross floor areas. The average efficiency of a typical office floor in the Petronas Towers is between 76 and 77 percent, a good ratio for a very tall building.

Achieving a compact core required a series of careful decisions. To provide efficient elevator service, each shaft accommodates multiple cabs. The number of express shafts that bring passengers to upper floors is reduced by a shuttle/skylobby system, similar to the one in the World Trade Center in New York City. Visitors to the upper half of the buildings transfer at midheight to two "local" shafts that are stacked one on top of the other. Capacity at peak hours is further increased by double-decker elevator cabs, as used in the Citicorp building in New York City and the Bank of Montreal building in Toronto.

Detailed design of the exterior wall and the public spaces started a few months later. Drawings and study models tested every element in the building. For example, the choice of glass for the windows and the design of the sunscreen—steel pipes that act as shields from the tropical sun—affect the building's overall appearance, the type of office lighting, the mechanical cooling equipment requirements and, ultimately, annual operating costs. Tentative solutions for these and other design features had to be resolved with local consultants and submitted to the client for approval.



THORNTON-TOMASETTI ENGINEERS

STAR SHAPE characterizes the floor plan of the Petronas Towers. The original concept for the plan consisted of two superimposed squares (*top left detail*), creating an eight-pointed star. It was modified—placing eight semicircles in the inner angles of the star points (*middle detail*)—to create more usable floor space. The final design contained 16 protrusions: eight points and eight lobes (*bottom detail*). The core, which consists of a hollow square of walls containing elevators, mechanical shafts and other services (*above*), connects to support beams that extend out to perimeter columns. A smaller building, or bustle, shown as a top appendage in the plan, reaches the tower's 44th floor.

H. YOUNG *Cesar Pelli & Associates*

ENGINEERING DESIGN

Building on Kenny Hill Soil

Kuala Lumpur is ringed by low mountains, but within the city only a small hill interrupts the level terrain. The site, on a space occupied by the former Turf Club, is a flat greensward. But the geotechnical and structural engineer of record, Ranhill Bersekutu Sendirian Berhad, knew from experience that the bedrock below could be very irregular.

Exposed to millions of years of weathering, limestone bedrock in this region contains caverns, spires, ravines and steep-shouldered mountains that, if above grade, would resemble a landscape from classic Chinese art. Sediment from erosion filled the valleys. These lower strata had metamorphosed to weak rock that weathered back into a type of stiff soil found in Malaysia called Kenny Hill.

The 300,000-metric-ton weight of each tower could be spread over a large concrete slab called a mat. But each tower would exert 1,140 kilopascals of pressure, more than twice the weight-bearing capacity of Kenny Hill soil and enough to cause the foundation to fail. To avoid such a possibility, the initial concept for the foundation used massive concrete-filled piers, two holes filled with concrete under each column. And more piers would also sit underneath core walls. The piers would pass through the soil before bearing down on bedrock.

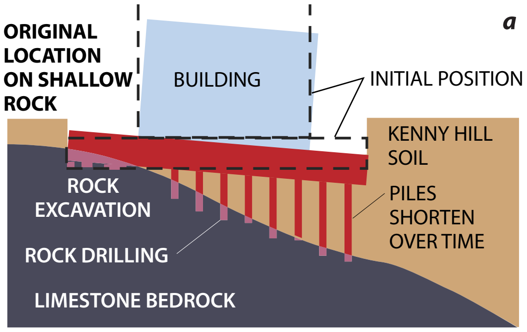
As results by soil probes came in, the design team faced a quandary: bedrock under both towers started shallow, 15 meters down, but sloped steeply to deeper than 180 meters. Excavation to a depth of 21 meters was needed for the basement, which would penetrate into rock at one end. At the other end, more digging would sink piers down through the soil until they reached bedrock. Pier installation at the deep end would be risky, slow and costly, exceeding normal construction practices. And the piers' inevitable shortening could be different for each foundation support, producing unacceptable tower tilting. (Pier length diminishes from the extra loads imposed by adding upper floors and the weight bearing down as tenants move into the buildings.) Any shortening could be evened out, but the process would require extra digging and other measures that would increase cost.

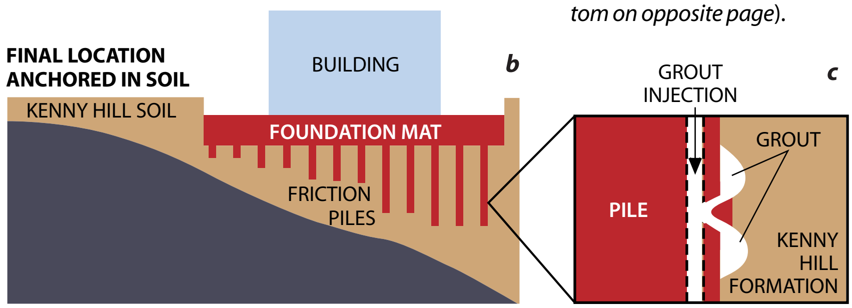
Fortunately, the site was large enough for the design team on the project to consider moving the foundations. Shifting both towers 60 meters southeast put at least 55 meters of soil below each tower basement. Instead of resting on bedrock, they would anchor within the soil. The new location provided more room between the towers and nearby streets, which improved traffic flow and left room for off-street drop-off lanes and parking entry ramps.

At the new site, the towers were to sit over opposite banks of a filled ravine, with bedrock 80 to more than 180 meters below. The plan called for an entirely different foundation system. A concrete mat would spread building weight to drilled 1.3-meter-diameter piles, structures narrower than piers. These piles would transfer the weight of the tower to the soil more gradually than a mat alone would. Friction between the surface of a pile and surrounding soil would prevent the foundation supports from sinking, much as a nail stays firmly rooted in wood. Settlement would then occur in the zone of soil between the pile tips and bedrock. Varying the pile lengths so that all the supports remained at about the same distance above the sloping rock would result in even settlement, avoiding tilt of the foundation.

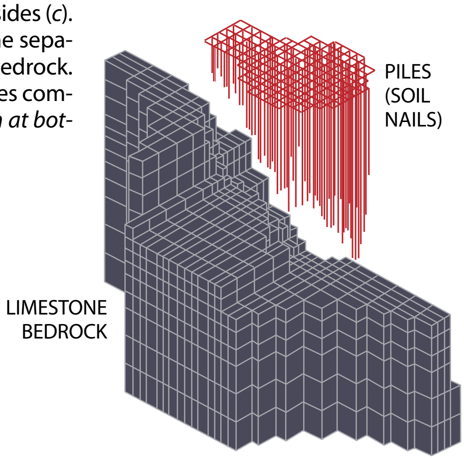
The use of this type of support brought a new concern. The solidity of Kenny Hill soil depends on interlocking grains of sediment, whose sand and silt had once been rock. The soil in an excavation bed normally swells as digging proceeds and the weight of the soil above is removed. The interlocking grains of soil would decouple as the soil expanded. To avoid reducing soil solidity, we decided to sink the piles from near ground level. The piles then would act as "soil nails" to restrain the excavation against swelling.

Each final foundation consisted of 104 barrettes (rectangular cast-in-place piles up to 1.2 by 2.8 meters) dug as deep as 125 meters. Barrette construction proceeded with crews lowering a cage of steel reinforcing bars into each hole, which was then filled with concrete. Friction between the piles and the soil was enhanced by injecting grout—a sand-and-cement mixture that was pumped down embedded pipes and out the side of the piles. Once hardened, the bumps of grout on the outer surface of the barrette increased soil friction. Finally, each foundation was completed by casting a concrete mat atop the barrettes. Each 4.5-meter-thick mat required 13,200 cubic meters of concrete. Casting each mat took place in a short, intense burst of activity: a concrete truck arrived to deliver its contents continuously every 90 seconds for two days.





SOIL NAILS, or friction piles, keep the foundation from sinking. If piles driven into the bedrock had settled differently, the building would have begun to tilt (*a*). Instead, at a new location (*b*), friction between the piles and the soil was enhanced by forcing grout out the sides (*c*). A computer model (*right*) shows the separation between the piles and the bedrock. Casting a concrete mat atop the piles completed the foundation (*photograph at bottom on opposite page*).



THORNTON-TOMASETTI ENGINEERS

ENGINEERING DESIGN

Concrete Monoliths

The earliest tall buildings had to be made of stone, brick or conventional concrete, which creates unacceptably large and heavy walls and columns. Steel overcame this limitation at the beginning of the skyscraper era. But advances in concrete technology have again made concrete attractive. Adding microsilica and other compounds to basic concrete can greatly increase its strength. (Microsilica is a superfine dust that is a by-product of electronics manufacturing.) This high-strength concrete can be used to form more compact structural elements. Other materials also give concrete superior properties. Superplasticizing agents make it easy to pump. When water reacts chemically with cement particles and other components to form concrete, heat is released. Excessive heat can crack the concrete. Partially replacing cement with fly ash from coal power plants avoids the problem.

Concrete is ideal for the columns and core walls of the Petronas Towers because of its familiarity to local contractors. It can be lifted into place using buckets or pumps rather than massive cranes, and it is easy to mold into complex shapes. Concrete also helps to damp the natural tendency of any tall structure to move back and forth slightly in the wind; its ability to attenuate vibrations is twice that of steel. These back-and-forth oscillations—one cycle of which occurs every nine seconds in the towers—are slower because of the concrete's mass. Both characteristics reduce the building's response to wind to a comfortable level.

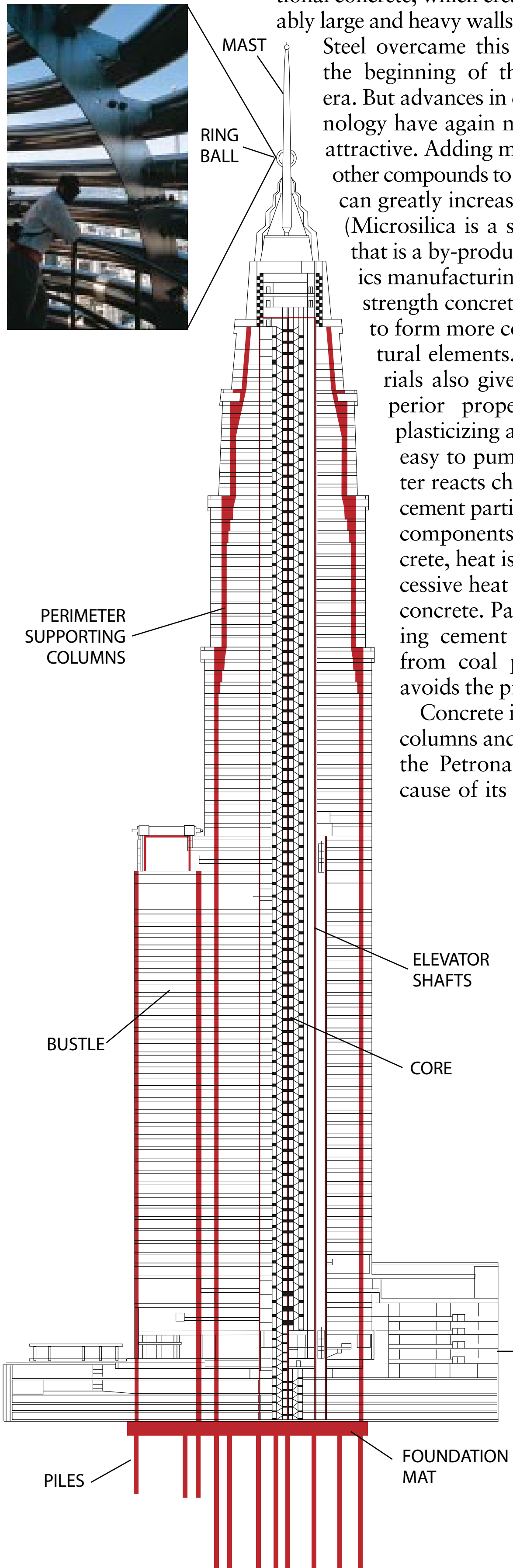
Lateral strength and stiffness is essential to tall buildings. Shorter structures use the central core alone as their spine, but the compact core of the Petronas Towers would have only half the strength and stiffness needed to resist deflection from wind and other forces. The necessary strength comes from a combination of the core walls and a frame of concrete beams and columns along the perimeter as well as outriggers (stiff beams reaching from the core to the perimeter). Steel-framed cantilevers reach beyond the perimeter columns to form star-like protrusions, which offer the added advantage of giving tenants unobstructed views.

The facade uses one-story-tall modular panels, each four meters tall by 1.4 meters wide, with interlocking tongue-and-groove joints for rapid installation. Stainless-steel and tinted glass panels with self-cleaning teardrop sunshades adapt well to the tropical setting and provide a lightweight enclosure with strong visual texture.

Several aspects of the towers' design reduce wind effects. Tapering toward the top diminishes the area exposed to faster, higher-altitude winds. The columns on upper floors are set back (shifted closer to the core) by sloping them inward. Wind drag on the towers' ribbed, rounded shape is less than for a rectangular tower, though more than for a smooth cylinder. The ribbing on the buildings' exterior also creates small areas of turbulence that break up larger vortices of air that could add to the buildings' swaying. It was discovered in wind-tunnel studies that air blowing through the gap between the structures does increase building movement, but not by very much.

Luckily, Kuala Lumpur also has a benign climate for tall buildings. It is not an area marked by seismic activity. And, close to the equator, it is not subject to hurricanes and typhoons. Tropical thunderstorms bring heavy rain and lightning strikes but not exceptional winds.

For high buildings, the time needed to build one floor dictates the schedule. Contractors sped up the schedule by implementing several strategies. For building core walls, jacks raised work platforms and forms (steel boxes for pouring concrete columns) as complete assemblies. The steps in building concrete-framed floors—forming, lathing (setting reinforcing bars), casting, finishing and curing—take longer than for building columns and so would have slowed the work pace. To avoid this bottleneck, construction crews fastened steel beams to the core and columns, placed a metal deck on them, then poured a much thinner layer of concrete. This process eliminated many of the steps required for an all-concrete floor.



EIGHTY-EIGHT STORIES terminate in a 63.2-meter-tall mast (*left*). Columns on upper floors are set back, allowing tapering at the building's top that reduces the area exposed to high-altitude winds (*top photograph*). The observer dwarfed by the mast's ring ball gives a sense of the building's scale (*bottom photograph*).

THORNTON-TOMASETTI ENGINEERS (*top photograph*); CESAR PELLI & ASSOCIATES (*bottom photograph*); CESAR PELLI & ASSOCIATES (*drawing*)

ARCHITECTURAL DESIGN

Highlighting the Void

Perhaps the most important architectural decision was to design the towers as skyscrapers with distinctive silhouettes. Cesar Pelli & Associates also took the unusual step of making the pair a symmetrical composition. In the modern movement, architects typically attempt to couple skyscrapers in asymmetrical arrangements. They usually do so by making the two structures of different heights. If equally tall, they are set diagonal to each other—the World Trade Center being a notable example. Like sculpture, the modernist building becomes a free object set in indeterminate space. As such, it avoids symbolic expression.

In the final design, which breaks from the modernist tradition, the towers are symmetrical. Their arrangement creates a distinctive space between them, adding to the symmetry. The separation constitutes the key element in the composition. Each tower has its own vertical axis, but the axis of the total composition is the intervening space. Through Frank Lloyd Wright, many architects have been influenced by Lao-tzu's teaching that the reality of a hollow object is in the void and not the walls that define it.

The space between the towers can be perceived as the most real element in the total composition. The visual power of the emptiness was enhanced by adding a midlevel skybridge not specified in the original client brief. The bridge and its supporting structure create a 170-meter-high portal to the sky, an element that can be seen as a door to the infinite. The Petronas Towers are thus unlike any Western skyscraper. This quality of the buildings is not derived from Malaysian tradition. But because it appears for the first time in Kuala Lumpur, it will be forever identified with its place. The Eiffel Tower is synonymous with Paris, for instance, although its structure and form were not derived from Parisian or French architecture.

J. PICKARD *Cesar Pelli & Associates*

ENGINEERING DESIGN

Bridging the Sky

THORNTON-TOMASETTI ENGINEERS

THREE DAYS were needed to lift the 325-metric-ton skybridge after lightning damaged control equipment.

The skybridge is an essential functional component of the Petronas Towers. Linking two skylobby levels in both towers permits easy access to meeting rooms, a *surau* (prayer room), an executive dining room and other offices. The skybridge is fire-resistant, so its midheight location provides an emergency exit from one tower to the other. This reduces the demand on other fire routes elsewhere in the building.

After various options were studied, an arched bridge supported from below was chosen. Other possible designs considered included a structure suspended from a cat's-cradle-like support and one held by cables above the bridge. The chosen arch configuration permits the use of thin walkway girders instead of trusses with crisscrossed members.

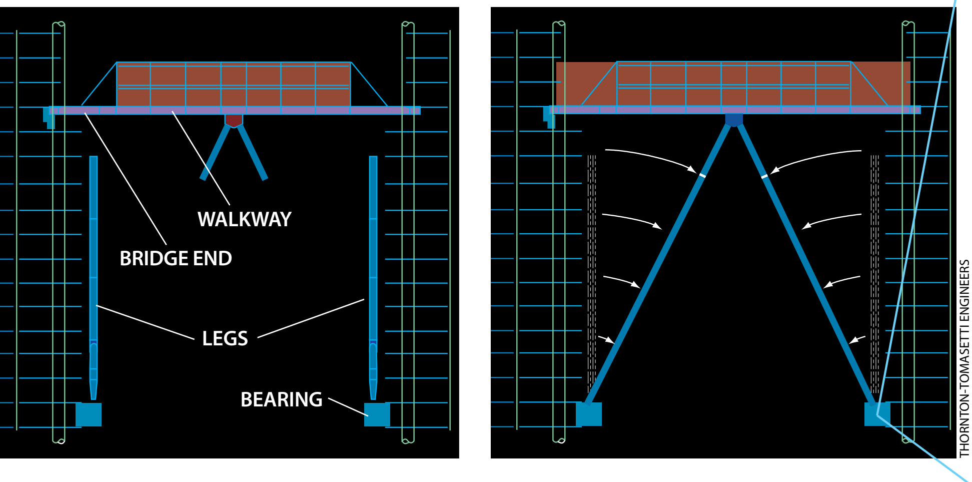
Bridge props made of 1.1-meter-diameter steel pipes rise diagonally from low supports on each tower, meeting at the middle of the bridge. The locations of the supports minimize rising or sagging of the bridge floor as the towers move. Wind-tunnel tests of a bridge model showed that the wind-induced vibrations of these flexible legs could cause fatigue cracking at some welded joints, so they were fitted with damping devices that reduce movement.

Bridge erection presented a special challenge. The structure was fabricated in South Korea and transported in pieces to Malaysia. The contractor who erected the bridge assembled most of the structure on the ground. Jacks then lifted the legs and the bridge ends. The biggest challenge was lifting the 325-metric-ton middle section, which comprised three quarters of the walkway length. Jacks that pulled eight high-strength cables could have lifted the structure in 20 hours, but the operation stretched to three days when lightning strikes twice burned out control equipment.

The pinnacles presented another hurdle. Considering the great height of and difficult access to the pinnacles, the client requested a low-maintenance structure that could be inspected easily inside and out, because rusting becomes a problem in the humid tropics. The top of the building consists of three elements: A drum-shaped garage on the top floor encloses a double-decker window-washing unit. From the wide garage, a cone tapers inward. Finally, a mast provides the visual transition from tower to sky. The 63.2-meter-tall mast has 14 meters of its length embedded in the cone frame, with the rest projecting above. The mast width tapers from 2.6 to 0.6 meter. At mid-height of the mast, a ball made of 14 pipes—each 300 millimeters in diameter that were curved into rings and attached together—symbolizes the 14 states of Malaysia, and a 1.9-meter ball sits at the top of the mast.

The window-washing garage and cone consist of a conventional steel-framed skeleton with attached stainless-steel facade panels. The narrow mast is made of stainless-steel panels, plates and bolts, which avoid corrosion and minimize maintenance. A single layer for both the facade and structural support eases inspection from inside ladders or external rigging. Using short panels facilitated lifting and assembly. The mast was assembled in small pieces within the building, then jacked up in two stages. This procedure protected workers and minimized the height of the crane required.

BRIDGE LEGS were lifted to their support bearings and strapped to each tower. Jacks then lifted the bridge ends to the skylobby floor. Next, workers elevated the bridge walkway (*left*). After welding these sections together, they swung out the bridge legs and attached them to the bottom of the structure (*center*). Bearings permit the bridge legs to flex as the towers move in the wind (*right*).



THORNTON-TOMASETTI ENGINEERS

Silhouettes against the Sky

As each tower ascends, it tapers in six gradations. In the upper sections the walls also tilt gently toward the center, completing the form and visually strengthening the *axis mundi*—the central vertical line of the skyscraper. The towers' pinnacles reach to the sky and reinforce the silhouette.

Throughout their development, the buildings maintained the basic form and image set out in the competition but also changed in many ways. The 12-pointed-star plan evolved into a 16-branched form; the towers acquired pinnacles and grew in height until they reached 451.9 meters, becoming the tallest buildings in the world.

The images that the towers create against the sky required detailed study. We proposed a pointed but pinnacleless design in the competition. The clients preferred a distinctly Malaysian top, one not derived from skyscrapers or church steeples. We experimented with many concepts, some of which were initially rejected, until the chosen pinnacle was developed.

From foundation to skybridge to pinnacle, construction is now complete, and occupants are moving in. At least for a while, the Petronas Towers will stand as the world's tallest skyscrapers. More significantly, the towers serve as worthy symbols of the culture and dynamism of this southeast Asian nation. SA

The Authors

CESAR PELLI, CHARLES THORNTON and LEONARD JOSEPH collaborated on the design of the Petronas Twin Towers. Pelli heads the architectural design firm of Cesar Pelli & Associates in New Haven, Conn., which, besides the Petronas Towers, designed the World Financial Center in New York City and the new Washington Airport terminal. He served as dean of the Yale University School of Architecture from 1977 to 1984. Earlier in his career, he worked in the offices of Eero Saarinen. In 1995 Pelli received the American Institute of Architects Gold Medal. Thornton is chairman and principal of Thornton-Tomasetti Engineers/LZA Group in New York City. He has spearheaded the engineering design of numerous projects, including One Liberty Place in Philadelphia, the United Center sports complex in Chicago and the United Airlines Terminal at O'Hare Airport in Chicago. He also assisted in the investigations into the roof collapse of the Hartford Civic Center and the Schoharie Creek Bridge failure. Thornton has taught at Manhattan College, Pratt Institute, Princeton University and Cooper Union. He co-authored with Joseph the book *Exposed Structure in Building Design*. Joseph is a vice president at Thornton-Tomasetti Engineers. He has been involved in the design of a variety of structures, among which are buildings, bridges, piers, parking decks, hangars and factories. His high-rise projects include the 50-story Chifley Tower in Sydney, Australia, and the 54-story One Mellon Bank Center in Pittsburgh.

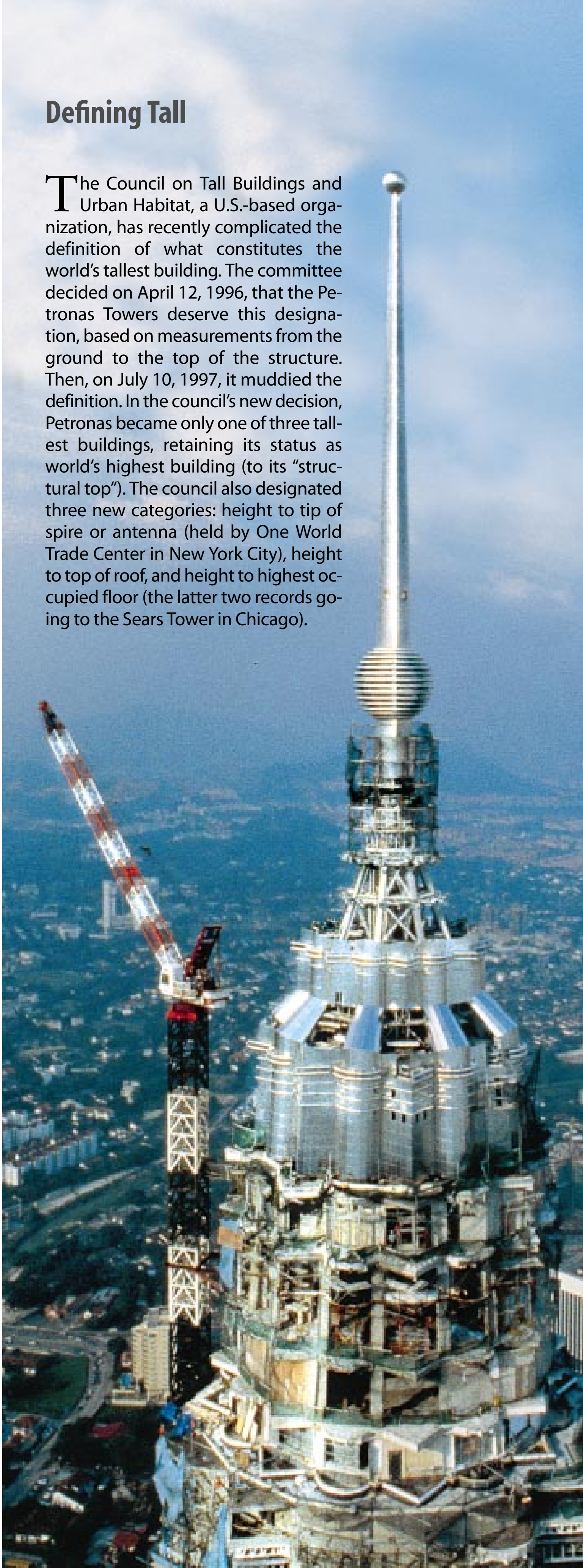
Further Reading

THE PETRONAS TOWERS—THE TALLEST BUILDING IN THE WORLD. Hamdan Mohamad, Tiam Choon, Tarique Azam and Stephen Tong in *Habitat and the High-Rise: Tradition and Innovation.* Proceedings of the Fifth World Congress. Edited by Lynn S. Beedle. Council on Tall Buildings and Urban Habitat and the Dutch Council on Tall Buildings, 1995.

COSMIC PILLARS: PHILOSOPHY OF TALL BUILDINGS. Cesar Pelli in *Collected Papers of Habitat and the High Rise.* Council on Tall Buildings and Urban Habitat, 1996.

Defining Tall

The Council on Tall Buildings and Urban Habitat, a U.S.-based organization, has recently complicated the definition of what constitutes the world's tallest building. The committee decided on April 12, 1996, that the Petronas Towers deserve this designation, based on measurements from the ground to the top of the structure. Then, on July 10, 1997, it muddied the definition. In the council's new decision, Petronas became only one of three tallest buildings, retaining its status as world's highest building (to its "structural top"). The council also designated three new categories: height to tip of spire or antenna (held by One World Trade Center in New York City), height to top of roof, and height to highest occupied floor (the latter two records going to the Sears Tower in Chicago).



J. APICELLA Cesar Pelli & Associates