THE PETRONAS TWIN TOWERS

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For two decades, the 110-story Sears Tower stood as the tallest building in the world. Topping out at 1,454 feet above ground level—almost as tall as a string of five football fields would be long—the bundle of nine steel tubes standing just outside Chicago’s Loop could be said to have cast a shadow over all other skyscrapers since its completion in 1974. New York’s World Trade Center, the 1,368- and 1,362-foot-tall twin towers completed only a year earlier, held the record as tallest buildings for only a brief time. Before that, the Empire State Building, at 1,250 feet tall even without its broadcasting towers—which, like those of the Sears Tower, do not count as part of the building proper—held the world height record for over four decades. Completed in 1931, the Empire State then surpassed the one-year-old Chrysler building, which at 1,046 feet tall had been the first to break the magical 1,000-foot mark. Before then, the Woolworth building, a 792-foot-tall Gothic cathedral of commerce paid for in cash by the profits from its namesake’s chain of five- and ten-cent stores, had stood as the world’s tallest building for almost two decades.

Skyscrapers—so named since the 1880s, when Chicago’s 100-foot-tall buildings were marvels of contemporary structural engineering—seem to have sprouted up in temporal and spatial clusters, with Chicago and New York proving especially hospitable to the form and its financing. Throughout most of the 20th century, the skyscraper was considered a particularly American genre, growing with the economy and optimism of cities such as Atlanta, Houston, Los Angeles and Seattle. In the last decade of the century, however, the frontier of the skyscraper has moved across the Pacific Ocean to the Far East. Today, most of the tallest buildings in the world are being proposed for locations such as Tokyo, Taiwan, Hong Kong and mainland China. And they are not only being proposed; they are being built, with the tallest building in the world recently being topped out at 1,482 feet in Kuala Lumpur, Malaysia.

The Federation of Malaysia is a southeast Asian country of about 20 million people, the vast majority of whom live in West Malaysia, located just above the equator on the Malay Peninsula, between Thailand to the north and Singapore to the south. (As established in 1963, the federation included Singapore, but it seceded in 1965.) The two states of East Malaysia are situated to the east, across the South China Sea on Borneo, the third largest island in the world. Kuala Lumpur, the capital of Malaysia, is served by a modern North-South Expressway that puts Singapore within a five-hour drive. The city’s Subang Airport has direct flights throughout the world and hourly flights that depart for and arrive from Singapore, and passengers get a bird’s eye view of lush golf courses among rubber trees—a sign of the changes that have been taking place in Malaysia, which has been described as “predominantly a Malay Islamic state with strong Chinese and Indian influences.”

A Vision of the Future

In the 1980s, the Malaysian economy was based on commodities such as palm oil, rubber and tin. However, with the rise of a government headed by the strong-willed and powerful Prime Minister Mahathir bin Mohammad, by training a medical doctor, Malaysia began to assert itself as a country on the move. The prime minister is said to have “reinterpreted Islam as allowing the pursuit of wealth and technical knowledge,” and the government’s official objective came to be articulated, in Bahasa Melayu, the native language of the ethnic Bumiputra population, as Wawasan 2020—or Vision 2020 in English, the country’s accepted language of commerce and industry. The vision has Malaysia transformed into a fully developed industrialized nation by the year 2020, with manufacturing and construction becoming the main driving forces of the country’s economy. The Kuala Lumpur City Centre project is helping in a big way to make the Malaysian vision a reality.

Kuala Lumpur City Centre is a 100-acre development on the site of a former racetrack, the Selangor Turf Club, and is described as among the largest real estate development projects in the world. As the result of an international competition held in 1990, a master plan—“an ideal city-within-a-city”—was defined by the U.S. firm of...
Klages, Carter, Vail & Associates of Cosa Mesa, California. It comprises a 50-acre park, which will include a lake, much of which will be accessible to the public, and a complex of 20 or so surrounding buildings that will contain office space, apartments, hotel rooms, recreational facilities, restaurants, shops, banks, a convention center, a civic center, a mosque and a plant to provide chilled water for cooling all these buildings in the subtropical climate. The first phase of the $2 billion project includes the pair of buildings known as the Petronas Twin Towers, themselves costing approximately $800 million, most of which was to be provided by Petroleum Nasional Berhad, Malaysia's national oil company and the source of the towers' name, and the government. As they have risen to become the world's tallest buildings, these striking towers have already become Kuala Lumpur's most significant landmark.

Back in 1991, with the master plan in hand, a separate international design competition was held to determine exactly what kind of structure would provide a significant focal point and monumental entrance to Kuala Lumpur City Centre. The competition was won by the architect Cesar Pelli & Associates of New Haven, Connecticut. According to Pelli, the client wanted a Malaysian image but could not say exactly what that meant. Existing tall buildings in Kuala Lumpur were of the boxy international style. With no indigenous structural models to inspire him, Pelli looked to Islamic art and adopted a multipointed star pattern as a footprint for his building design. His early scheme called for a 12-pointed star layout, but this was changed to a modified 8-pointed floorplan with intermediate arcs when the prime minister observed that the former geometry was more Arabic than Malaysian.

**Architecture and Engineering**

The final design of skyscrapers, especially those that are to be the tallest in the world, does not evolve wholly from an architect's drawings. How a structure will stand against the forces of nature—whether the ground motion in an earthquake zone, the wind at hundreds of feet above the ground or the heat of the sun beating down on the ground—requires the insight and calculation of a structural engineer. (The exposed structure of Chicago's John Hancock Tower, for example, was the result of a collaboration between architect Bruce Graham and structural engineer Fazlur Khan of the firm of Skidmore, Owings and Merrill.) Pelli wished the "cosmic pillars" in Kuala Lumpur to be joined by a skybridge to form a welcoming portal to Kuala Lumpur City Centre and to have as few structural columns as possible blocking the view outward from the office floors. Such features were easy to render on the drawing board but no small task to

Figure 1. World's tallest buildings, the Petronas Towers are in Kuala Lumpur City Centre, Kuala Lumpur, Malaysia. (Except where noted, photographs courtesy of Thornton-Tomasetti Engineers.)

Figure 2. Building design evolved to incorporate Islamic themes. (Illustration courtesy of Cesar Pelli & Associates.)
realize in concrete and steel. For the Kuala Lumpur project, Pelli sought the structural expertise to accomplish such objectives in the international engineering design firm of Thornton-Tomasetti Engineers, based in New York City. Charles Thornton, chairman and principal in the firm, had long wanted to design the tallest building in the world, and had indeed designed with Pelli a 125-story Miglin-Beitler building for Chicago that for financial reasons did not come to fruition. He was thus well prepared to work again with Pelli on the Petronas Twin Towers, equivalent in height to 95 stories.

The challenges associated with designing and building a skyscraper begin in the ground. If the foundation is not firm, the building will be susceptible to settling, which, in the worst case, can lead to tilting and collapse. Underground conditions are not often fully known, however, until extensive, albeit usually still only sampling, exploration takes place, and this may not proceed until the design is defined enough for engineers to set the locations and types of tests needed. As it turned out, the Kuala Lumpur master plan had sited the showcase buildings over an underground cliff. To found piles in the rock, which sloped very steeply and contained caverns, every pile location would have had to be surveyed before proceeding. Thus the location of the towers was moved about 200 feet to the southeast, where the generally fissured limestone was sufficiently deep so that all piles could terminate in the soil above the rock and thereby ensure a more uniform foundation. This alluvial ground, known as Kenny Hill, is a weathered sandy shale that is considered relatively sound. The challenging foundation conditions necessitated drilling some piles almost 400 feet deep, more than three times the depth of the foundation beneath the Sears Tower. Even then, the foundation of the buildings are expected to settle as much as three inches under the weight of the completed structure.

Innovative Concrete

Designing the superstructure of the building presented another set of challenges. Among the first decisions facing structural consultant Thornton and his associates at Ranhill Bersekuta in Malaysia was the choice between steel and concrete. Although the tallest skyscrapers are steel structures, that material was not readily available in Malaysia, where prohibitively high tariffs on imported steel make concrete the construction material of choice. Furthermore, steel buildings tend to be more flexible than concrete ones and sometimes have to be fitted with mechanical devices known as tuned mass dampers to ameliorate the effects of vibrations induced by the wind. Concrete structures, on the other hand, although they tend to be stiffer and have qualities that damp out quickly any vibrations that do begin, often are bulkier-looking than steel. Since the architect wished the Petronas Towers to be slender-looking and have columns spaced rather far apart, conventional concrete columns would have been too aesthetically broad and struc-
turally heavy. To overcome this objection, an extremely high-strength concrete was developed, with bearing capacities as much as three times that of concrete conventionally used in Malaysia, or elsewhere for that matter. Special concrete mixes, using local materials, were developed to produce compressive strengths as high as 10,000 pounds per square inch, with quality control provided by state-of-the-art computerized systems.

Being made of high-strength concrete, the columns around the periphery of the towers could be smaller in diameter and lower in mass, thus reducing their dead weight. Still, at the base of the towers, the columns are nearly eight feet in diameter. The towers are not purely concrete structures, however, and the floor beams spanning between each building’s core and ring of columns are made of steel. This was done to speed construction, minimize the floor height and better accommodate such mechanical equipment as cooling ducts. The tapering at the top of the building demanded some especially tricky structural engineering, and its geometry necessitated the installation of a wide variety of different-size glass panels. The record height of the towers is achieved through the pinnacles at their tops, which are part of the basic architecture and structure proper, unlike the broadcast antennas erected after the fact on such buildings as the Empire State Building and the Sears Tower. (The official arbiter of skyscraper records, the Council on Tall Buildings and Urban Habitat, confirmed at an executive committee meeting in April that the Sears Tower had indeed been surpassed as the tallest building on Earth.) The pinnacles, with designs based on minarets rather than Gothic cathedral spires, were erected by jacking them skyward from within the uppermost part of the hull of the towers. The pinnacle design was the result of detailed studies including many options. The final design is a scaled-up version of one originally proposed to provide a more graceful tower top and, coincidentally, reach a record-breaking height. Thornton, an avid sailor, likens the structural support for the pinnacles to that of the mast of a sailboat.

Among what makes extremely tall buildings viable investments is the amount of usable, rentable or saleable floor space they contain relative to their height. As buildings grow taller, more and more of their volume must be devoted to elevators to transport the tens of thousands of occupants up and down. In the Petronas Towers, the usable floor space was increased considerably by the addition of smaller 44-story structures, referred to as “bustles,” to each tower. With the bustles, which are to be topped by prayer rooms for the Muslim occupants who will be called to prayer twice each working day, each tower has about 2 million square feet of office space. The internal transportation system that moves people vertically in the towers will include double-deck express elevators to optimize the use of the shafts. Passengers will transfer to and from double-deck local elevators in sky lobbies about halfway up the buildings, on the 41st and 42nd floors.

Figure 5. Pinnacles atop towers were jacked into place.

The towers will also be connected to each other at the level of the sky lobbies by a sky bridge, a 190-foot-long steel walkway that not only will facilitate movement between one tower and the other but also will serve as an alternative escape route in the event of a fire or other emergency, such as occurred when the terrorist bombing forced the evacuation of one of the towers of the World Trade Center. But the sky bridge’s design presented additional and unusual structural problems. Since the two towers can sway in the wind both in phase and out of phase, as well as twist in independent directions, the sky bridge could not be attached rigidly between the vertical structures. Thus special bearing connections had to be devised to allow for as much as 12 inches of horizontal movement each way at each end, as well as the twisting. Because such a long, unsupported sky bridge would have to have been of very heavy construction if it were not to sag in the middle, a set of slender steel legs was designed to angle up from supports on each tower about 160 feet below to the center of the sky bridge. To prevent such slender struts from vibrating excessively in the wind, thus presenting the potential for uncontrollable motion or at least the accelerated growth of fatigue cracks, tuned mass dampers were designed to be installed inside the legs. (Each mast-like pinnacle also has a damper in the form of an energy-absorbing, rubber-sheathed chain.)

The Petronas Twin Towers and all the buildings planned for the Kuala Lumpur City Centre will be what are known as intelligent buildings, employing automatic controls and communications systems to minimize energy consumption and
maximize the comfort of occupants and the convenience of use. The concept of an intelligent building dates from the 1980s, when costs associated with installing and retrofitting environmental and communications systems were escalating. There also came to be recognized clear advantages in incorporating networking capabilities into a new building, rather than providing tenants with a structural shell that they themselves have to wire. In the Petronas Twin Towers, each floor or pair of floors has its own local area network for air conditioning and lighting, as well as a general-purpose controller for unspecified future use.

Technology Transfer

Although the record-breaking height of the Petronas Twin Towers will be their most immediately visible and talked-about feature, that notoriety is likely to be short-lived, since taller buildings already are being planned for Shanghai, China, and Melbourne, Australia. Among the more long-range benefits of the Petronas Twin Towers to the Malaysian economy is the considerable amount of technology transfer that has accompanied their design and construction, with the direction and input of the prime minister. For example, the development of the high-strength concrete used in the towers has in four years doubled the strength of concrete now produced in Malaysia. This means that buildings can be built in less time and for less money.

Another by-product of the Twin Towers project has been the establishment of new local industries. The Twin Towers required about a million and a half square feet of stainless steel cladding and glass, in the form of 32,000 windows, to form a so-called curtain wall. This was the largest such job that Harmon Contract, the Minnesota-based participant in the cladding contract consortium, had ever tackled, and to win the job, Harmon prepared an 800-page bid to meet the Malaysian expectation that proposals be both educational and business instruments. Furthermore, as a condition of receiving such a large contract, the American specialist was required to set up shops in Malaysia to fabricate the components of the curtain wall and thereby introduce a new industry to the country.

The experience gained by local engineers and contractors in designing and building the world’s tallest buildings has prepared them well to complete the rest of Kuala Lumpur City Centre by the year 2020. By demanding local participation in the project, the Malaysian government, led by its strong-willed prime minister, has ensured that the Petronas Twin Towers project will leave a legacy that will serve the local economy and society long after taller buildings are erected elsewhere in the world.

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Bibliography


