CASE STUDY

THE PETRONAS TOWERS, KUALA LUMPUR, MALAYSIA

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THE PETRONAS TOWERS, KUALA LUMPUR, MALAYSIA

International Cooperation and Information Transfer in the
Realization of the World’s Tallest Buildings

The international diversity of the Petronas Towers project teams had great effect on the innovative strategies employed throughout the design and construction. In addition to introducing new technologies and industries to the emerging nation of Malaysia, the project provided an opportunity for numerous construction professionals to share information that will undoubtedly influence the future of the global construction industry. Several key factors in the design and construction of the Petronas Towers make them particularly interesting: the engineering decision to challenge local industries by specifying higher-strength materials and lower tolerances than had previously been possible in Malaysia, contracting and bidding were set up with technology transfer in mind, the decision to award construction contracts for the twin towers to two competitive firms, one from Japan and one from Korea. In addition to the globalization issues associated with the Petronas Towers project, a number of innovative engineering and construction strategies were employed throughout the project’s development: the design and installation of the skybridge, the decision to frame a building of this scale using high-strength concrete, which had never been used in a Malaysian project, the technical challenge of how to pump concrete to this height also demanded an innovative response, highly irregular soil conditions demanded innovative engineering and construction strategies.
1. INTRODUCTION

The Petronas Towers in Kuala Lumpur, world headquarters for the Petroleum Nasionale (or iPetronasi) Corporation, were conceived and designed to be the symbol of an economically and politically advanced Malaysia. Vision 2020: The Way Forward was published by the office of the Prime Minister Mahatir bin Mohammad, clearly outlined an ambitious plan for the development of the country. In the opening section, the document states, "Hopefully the Malaysian(s) who (are) born today [and in the years to come] will be the last generation of our citizens who will be living in a country that is called developing. The ultimate objective that we should aim for is a Malaysia that is a fully developed country by the year 2020."  

International recognition and foreign investment are fundamental to this development plan. The modernization of infrastructure in and around the capital city of Kuala Lumpur is critical to assure the international presence of Malaysia as a stable and rapidly growing power. Aware that Malaysia’s manufacturing base was too narrow, the prime minister made it clear in his vision statement that new industries must be promoted and technological and managerial know-how developed. Large-scale investment in the physical environment, which would involve a wide range of foreign expertise, was a prime opportunity to import these technologies and skills as a way to diversify the local economic base.

It is within this environment of rapid growth and ambitious investment that the Petronas Towers were conceived. Although, it was never formally stated that the towers should be the tallest buildings in the world, the expansive program and limited footprint specified in the project description signaled from the outset that this structure would be a contender for the title.

Several key factors in the design and construction of the Petronas Towers make them particularly interesting in the context of the study of the globalization of the building industry.

• The architect decided to focus on the development of a building form expressive of the region instead of the more common transplanting of western models into developing countries.

• The engineering decision to challenge local industries by specifying higher-strength materials and lower tolerances than had previously been possible in Malaysia, allowing for more efficient building systems, required a high degree of trust and cooperation between foreign engineers and local trades.

• The secondary agenda of know-how transfer as a means of developing local industries permeated all levels of the design and construction process. Contracting and bidding were set up with technology transfer in mind: the care taken to organize teams of international and local firms was an important aspect of each group’s bid package.

1 Dr. Mahatir bin Mohammad, Prime Minister of Malaysia. Vision 2020, The Way Forward, Kuala Lumpur, Malaysia.
• Because of the large scale of the project, decision was made to award construction contracts for the twin towers to two competitive firms, one from Japan and one from Korea. This strategy divided the responsibilities, making the construction of each tower more feasible. The division of the contract also kept either team from setting the schedule for the project and brought together more groups with various skills, increasing the quantity of technical knowledge being introduced to Malaysia through the project.

• The large-scale mobilization of local and foreign fabricators needed to meet the continuous demand for high-quality materials and components required careful logistical planning by many contributing manufacturers. The development of an on-site high-strength concrete plant and of a local and international joint venture to supply highly specialized cladding system panels are just two examples of the scale of these operations. Many of the industries developed for this project plan to continue operation after the completion of the towers, adding diversity to the local economy.

In addition to the globalization issues associated with the Petronas Towers project, a number of innovative engineering and construction strategies were employed throughout the project’s development.

• The design and installation of the skybridge provided a number of interesting technical challenges to the teams involved. The link between the two tallest towers in the world required careful design and analysis to withstand the forces exerted by the differential movement of the towers. The lateral wind forces on the bridge and its legs were also a concern.

• The decision to frame a building of this scale using high-strength concrete, which had never been used in a Malaysian project, raises some interesting questions as well. The use of very high strength concrete in Chicago led the engineers to seek out ways to introduce it into Malaysia. After a careful search, an Australian supplier was chosen to set up a concrete batching plant on-site. Local production of the structural concrete helped avoid the delays that would have resulted given the congested streets of Kuala Lumpur, allowing for a higher level of quality control.

• The technical challenge of how to pump concrete to this height also demanded an innovative response. The race to the top included a test of two different concrete delivery systems. The Korean team, with the use of powerful German-engineered pumps, achieved the world record for the highest continuous pump. The Japanese team, making use of Jones International’s experience with concrete delivery systems, imported the technology of the high-speed hamper hoist from the United States to lift concrete to an intermediate pumping platform.

• Highly irregular soil conditions demanded innovative engineering and construction strategies. The use of detailed geotechnical studies to carefully size and position the friction barrettes (used to
support the two foundation mats for the towers) required teamwork among the foundation contractor, structural engineer, architect, and a variety of foundation specialists.

It is clear that most if not all of the innovative strategies employed throughout the design and construction of the Petronas Towers benefited in some way from the international diversity of the project teams. In addition to introducing new technologies and industries to the emerging nation of Malaysia, the project provided an opportunity for numerous construction professionals to share information that will undoubtedly influence the future of the global construction industry.

2. THE SITE AND THE LOCAL ENVIRONMENT

Malaysia has developed as a major economic force in Southeast Asia. The country has a significant supply of natural resources, including coal and petroleum. A booming textile industry and the rapid growth of the local electronics manufacturing base, both fueled by Malaysia’s wage-based comparative advantage, have provided the economic support for the fast-paced modernization of the country. Forty-three percent of the official population of 19.7 million lives in urban areas. Although the official religion is Islam and Moslem traditions are strongly felt, Malaysians represent a diversity of religions, including Buddhism (17 percent of population), Confucianism and Taoism (11 percent), Hinduism (7 percent), and Christianity (7 percent). Jon Pickard, a senior associate from Cesar Pelli and Associates, noted that, “Malaysia is a pluralistic culture which has historically been at the crossroads of Asia.”

Located just north of the equator, the country is warmed by southwest winds from April to October and by northeast winds from October to February. The temperature consistency and high humidity brought by monsoon winds makes Malaysia an ideal climate for the rapid growth of vegetation. The swampy coastal plains rise quickly into jungle-covered hillsides and mountains at the interior. The existence in Kuala Lumpur of a subterranean porous limestone cliff, rising from beneath a sandy and stiff soil formation known as “Kenny Hill,” would have a major impact on the siting and foundation design of the Petronas Towers project.

The continuous rapid growth of Malaysia’s economy over the past decade has led to a major construction boom. Projected yearly growth rates of 8 percent through the year 2000 send a clear message about Malaysia’s economic strength and stability. Many large-scale projects, such as a new international airport, are currently under way in Kuala Lumpur, and new cities and modernized infrastructure are being planned and constructed across the country (a description of some of the larger projects is found in the appendix).
The most highly publicized of Malaysia’s recent large projects, the Kuala Lumpur City Center (KLCC), occupies the most central location in downtown Kuala Lumpur on the former site of the Selangor Turf Club, at the heart of what has been called the “Golden Triangle.” This prime location had remained relatively unbuilt throughout the development of the center city. Originally the location of British cricket fields, the site was later developed as a horse track. More recently, this site had been reconfigured into a major gambling center. The prime minister was concerned about having one of the most central and influential spaces in the rapidly developing downtown associated with gambling, and negotiations ensued that resulted in the relocation of the complex to an outlying region.
The Petronas Towers are the centerpiece of the Kuala Lumpur City Center project (*Fig. 1*).

![Fig. 2. Model for the Petronas twin towers.](image)

The 100-acre site for the tower complex occupies the northwest end of the KLCC development at the intersection of two of the most important streets in Kuala Lumpur, Jalan Ramlee and Jalan Ampang. The two towers, each with 2.35 million sq. ft. of office space, will house the world headquarters of the Petronas Corporation. In addition to the Petronas Towers, the first stage of construction for the KLCC project, called the North West Development, includes a variety of other smaller buildings. The fifty-story
Ampang Tower and thirty-story Esso Tower together will provide 1.3 million sq. ft. of office space, while a 1.5 million sq. ft. shopping center will bring retail activity to much of the ground area of the development. A 1 million sq. ft. hotel will occupy another thirty-eight-story tower in the North West Development. The National Symphony Hall will occupy a space immediately beneath the towers. An 80,000 sq. ft. mosque, a utility plant that will service the entire district, and more than fifty acres of park space are also included in this first phase of construction.

In September 1992, the site for the Petronas Towers was moved 200 ft. to the southwest after the results of more thorough geotechnical studies were known. The existence of a subterranean porous limestone cliff, which dropped in elevation from near the surface to a depth of more than 395 ft. over the span of the site, made the location of piles extremely difficult in the original location. The questionable composition of the limestone cliff was also of concern. The decision was made to move the project back from the important intersection to a location where none of the piles would reach the limestone. This move saved an estimated $20 million on the cost of the foundations and resulted in a more favorable location for the project. Jon Pickard, one of two project architects from Cesar Pelli and Associates, noted, “The move which was necessitated by the soil condition problems allowed us to resolve the traffic issues and redesign the area around the towers. The move provided space for a five-acre garden, which meant that the building could be entirely surrounded by green space. This had a very positive effect on the project.”

3. THE ORGANIZATION OF THE PROJECT

Because of the tremendous scale of the Kuala Lumpur City Center project and its secondary agenda of technology transfer, a complex organizational structure was developed and followed throughout the course of the project, and local counterparts were assigned for nearly every foreign professional. The local project managers, architects, engineers, and other construction professionals provided a wide range of local expertise to the international teams, while they in turn benefited tremendously from intensive on-the-job training.

The towers were designed to be the world headquarters for the Petronas Corporation. Petronas’s vast knowledge about bidding processes in the petroleum industry transferred quite directly into their contract strategies for the towers.

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2 Jon Pickard. Excerpt from phone interview, February 14, 1997
The Kuala Lumpur City Center Bhd. (KLCC Bhd.) acted as the local project manager and coordinated the early phases of the project's development. Initial project decisions, including the choice of the site, were made locally and involved the prime minister directly. The firm of Collegis, Carter, and Vail, was awarded the master planning study for the new urban development.

KLCC (Holdings) Sdn. Bhd., a group consisting of Petronas and a handful of other investors, then organized an invited international competition for the design of the building that would house the national headquarters of the Petronas Corporation. Firms were invited based on their experience with large
projects and their international reputations. They included Kohn Pederson Fox, John Burgee, Aldo Rossi, Helmut Jahn, KKS from Japan, and Cesar Pelli and Associates. In September 1991, Cesar Pelli won the design competition and was chosen as “design consultant” for the project. A team comprised of many of the top architects in Malaysia had been organized by KLCC Bhd. to be the local “architect of record” for the Petronas building. This temporary firm was made up of roughly sixty architects and was named the Architectural Division KLCC Bhd. In addition to their responsibility as local project architects, members of this team rotated into the office of Cesar Pelli and Associates in New Haven, Connecticut, to help with the initial design phases, and they later joined Adamson Associates, the production architect, to help produce the construction documents for the project.

Following the selection of Cesar Pelli and Associates, KLCC Bhd. chose Lehrer McGovern, a subsidiary of the London-based Bovis International, to join them as their international counterpart in the role of project managers. Lehrer McGovern had recently completed the Canary Wharf project in London with Cesar Pelli and Associates. Because the developer on the KLCC Bhd. team had very little experience with projects of this scale, Lehrer McGovern stepped in and took control of the early stages of the project. To this point, there had been no formal contracts. Even Pelli’s office had been working under an informal letter of agreement. The Lehrer McGovern team’s first task was to draft and prepare contracts for all parties.

Bruce Schlaitzer, the project manager from Lehrer McGovern, noted, “We’d learned from our experience with the Canary Wharf project that it was prudent for an aggressive developer to step in and reevaluate the initial consultant teams and then take an active role in the reappointment of consultants and suppliers.” Pelli’s team, which had been assembled for the competition, remained largely intact at the end of this reorganization. KLCC’s desire for highly computerized elevator testing capabilities led to a change in the elevator consulting team, and the contract for the production architect was reawarded. The process of selecting a production architect for the project involved inviting several firms to present proposals for production services. According to Schlaitzer, the selection of Adamson Associates from Toronto resulted from the unusual nature of the work environment. The fact that KLCC Bhd.’s architectural division, as project architects, would be taking responsibility for the stamping of the drawings while at the same time looking for a “mentoring” relationship meant that flexibility would be required of the production architect.

4. THE ARCHITECTURAL DESIGN

Despite the initial stated desires of the local design team to look to western precedents as symbols of the modernity that Petronas, KLCC, and the prime minister wanted to convey in the project, Cesar Pelli’s office attempted to define a new typology more closely linked with the specifics of the tropical climate and the richness of the Malaysian culture. Pickard notes, “The project brief was confusing. They said they wanted a modern tower. What was not on the piece of paper were the real goals of the project. They wanted an identity for Malaysia. They wanted a symbol and they wanted that symbol to somehow distill
their culture. That is a very difficult task, especially for an architect from Connecticut, and I have no idea if we did that successfully." It was noted that much of what was generally considered to be Malaysian architecture was instead an architecture of British colonialism. The more recent large-scale projects were typically versions of western modernist models, often British in origin as well.

To try to define a more purely Malaysian design sensibility, members of Pelli’s team, including senior associates Jon Pickard and Lawrence Ng, traveled extensively throughout the region to gain experience and exposure to Malaysia's people and their crafts. Among numerous discoveries, the delicacy of local wooden screens and the richness of traditional weaving methods offered inspiration for the design of the buildings. In addition to the importance of these elements in the conceptual development of the project, these discoveries can be clearly perceived in the detailing of the lobby and public spaces of the towers. Wooden screens hang behind the large windows of the lobby, acting as sun protection and helping to define scale. Tile patterning and wall stenciling refer to these local sources. The ancient songket weavings, cherished for centuries and worn by royalty for special occasions, were also a notable inspiration. A large pewter sculptural element, which draws its patterning and formal logic from the delicacy of the silk and golden threads of songket weavings, hangs above the main space of the towers’ entry hall. (Fig. 2)

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The use of the rotating Islamic eight-pointed star as a formal generator for the buildings’ plan created a repetitive patterning in the curtain wall that is reminiscent of the geometrical forms of Islamic art. This also increased the surface area of the towers, maximizing views from the interior while simultaneously using the texturing to break down the perceived scale from the exterior. Pickard noted, “There is an Islamic fascination with things that on the surface seem extraordinarily complex, but on closer inspection reveal a great deal of order and purity. These buildings read that way. At a first glance, they are perceived as columns of light, then the complexity of the secondary levels of detail emerge and, finally, the logical simplicity of the underlying structure becomes evident.”

The use of reflective glass, which had become the standard for large projects throughout Asia, was to be avoided. As Pickard observed, “The office believed strongly, and the prime minister agreed with us, that buildings talk to people. Mirrored glass has an anonymity which was not consistent with the concept.” The glass that was used, which had a slight green tint because of its low-E coating, allowed the tower to become quite transparent. This transparency allowed the human scale to be perceived from outside the building. According to Pickard, “From the exterior, you can see the window shades. It’s a more humane building. We were very concerned about placing two towers of this scale into what is still quite a delicate environment.” He went on to remark, “Many people who have seen the towers in person have the same response: You know, they’re really not that big. This is not a bad thing.”

In direct contrast to the desire in the northern United States to always seek out the sun, the tradition of shading and avoiding the direct sun was very strongly felt in this tropical city. Given the decision to avoid using mirrored glass, it was imperative that the design incorporate another method for reducing solar gain. Stainless steel louvers that projected past the surface of the building were carefully engineered to shade the window surfaces while maximizing views from the interior (Fig. 3). In a tropical setting, the sun would be nearly directly overhead during the hottest hours of the day. This meant the issue of blocking low sun angles, an important consideration for projects in New York or Chicago, was not as much of a concern. The existence of the external louvers has also reportedly improved the psychological character of the interior spaces by offering a level of reassurance to inhabitants.

The decision to celebrate the space between the twin towers became very important to Cesar Pelli. “The space in between is my greatest interest in this project,” he stated. The eighty-eight story towers, connected by the skybridge at levels forty-one and forty-two, define a space that Pelli describes as a portal that “symbolizes the threshold between the tangible and the spiritual worlds.” Pickard connected, “He (Pelli) sees that space is talking about things which are difficult to talk about. It is about the

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4 Jon Pickard. Excerpt from phone interview, February 14, 1997
5 ibid.
relationship of human beings to their God, whatever name you want to put on it. It's a space which is infinite and looks to the heavens. Never before has a tall building defined such a space.”

Figure 5. The interior during construction, showing the big round columns on the perimeter

The use of stainless steel as a cladding material was also unique for a project of this scale. Pickard noted, “By manipulating the surfaces and then cladding them in stainless steel, you have in essence created a building that always seeks out light.” The towers, which Pelli refers to as “cosmic pillars” and Pickard has called “columns of light,” owe much of their lightness to the integrated use of clear glass and stainless steel in the cladding system.

Throughout the initial design phases, members of the KLCC architectural division rotated into the New Haven office of Cesar Pelli and Associates, some staying for as long as a year. Despite the differences in

7 Jon Pickard. Excerpt from Presentation at Harvard University GSD Symposium on International Construction. February, 1997
8 ibid.
decision-making methods, the two teams complemented each other well, and, according to Pickard, “It was very much a back-and-forth design process.”

5. THE ENGINEERING OF THE TOWERS

The structural system of the building, designed by Charles Thornton and the team from Thornton-Tomasetti Engineers, was integrally connected with the architect’s vision for the towers. Thornton noted, “It started with a phone call from Jon Pickard in the summer of 1991. He said, ‘Do you want to join us for a competition? I’ve got this idea. It’s going to be two tall buildings with a bridge at the forty-third floor. Can we do it?’ and I said, ‘Yeah, sure.’”9 The long-standing professional relationship between the two offices provided a high level of trust and cooperation. The desire to minimize material and maximize views was expressed by Pelli’s office, and together the architect and engineer developed a strategy that involved the use of widely spaced high-strength concrete columns periodically tied back to a structural core. (Fig. 4)

Fig. 6. Core Wall Layout (Lower Floor Shown)

9 Charles Thornton, Ph.D., P.E. Excerpt from Presentation at Harvard University GSD Symposium on International Construction. February, 1997
Thornton remarked, “This project is about two things: drift and information transfer.”\(^{10}\) The height and slenderness of the towers made dynamic behavior a large concern. Furthermore, the desire on the part of the client and the prime minister to use this project as a means for developing local expertise affected both the makeup of the engineering teams and the tower’s design. According to Thornton, six or eight Malaysian engineers were actively involved in the project at Thornton-Tomasetti’s New York office throughout the design phase.

The collaboration between Thornton-Tomasetti Engineers and Cesar Pelli and Associates on the Midland Bixler tower in Chicago in the mid 1980s had provided the teams with a good bit of insight into towers of this type. Thornton noted the importance of this project: “What we learned about tall buildings was that when the height to width ratio is around 8, 9, or 10, you can’t make it work in an all-steel building. The mass is too low, the damping is too low, and the acceleration is too high.” So-called performance concrete, which could be purchased from two suppliers in Chicago, had demonstrated a consistent strength of 14,000 psi. High-strength concrete, made available by the introduction of new materials like silica fume and superplasticizers and made affordable through the use of automated batching equipment, was to have a tremendous impact on the development of the structural system. Strict quality control was required on-site to ensure its reliability.

Regarding his firm’s first trip to Kuala Lumpur, Thornton recalled, “So when we went down to Malaysia we said: Let’s look at the culture, let’s look at import duties, let’s look at indigenous materials, let’s look at what’s available and what’s not available.”\(^{11}\) This research provided the design teams with a number of interesting insights. The group from Thornton-Tomasetti discovered that there was a 42 percent import duty on fabricated steel. They experienced the traffic congestion of downtown Kuala Lumpur first-hand. They noted that although Malaysian construction companies had no experience with high-strength concrete of this type, there was a long history of local concrete construction. Despite his acknowledgment of a noticeable increase in the use of steel in Malaysian projects, Pragasa Krishnasamy, general manager of KLCC Bhd., said, “We are not a steel country.”\(^{12}\) The space available on-site made it possible to construct a batch plant where the required aggregate and other components could be stockpiled. This was important to assure a high level of quality control and also to keep supply constant in a city increasingly characterized by traffic jams.

The relative simplicity of the structural system of the towers may have been the key to their success. The core and columns are constructed of high-strength concrete, while the floor framing, which extends from the core and cantilevers past the outer column ring, is constructed of lighter weight steel. The skybridge and pinnacle were prefabricated of steel and installed on the towers.

\(^{10}\)ibid.

\(^{11}\)ibid.

For the structural frame of the Petronas Towers, Thornton-Tomasetti saw many benefits deriving from the use of high-strength concrete, including economy of cost and space, efficiency and flexibility of construction, simplification of joints, avoidance of secondary fineproofing, effective lateral stiffness, and the damping associated with its high mass (Fig. 5).\(^\text{13}\)

**Fig. 7.** Graph showing the column sizes and concrete strength along the height of the towers.

The structural frame for each of the main towers consists of sixteen cylindrical high-strength concrete perimeter columns connected by a haunched ring beam at each level. This haunching allows for the passage of mechanical systems at the center span of the beam. This frame is tied back to the structural elevator core at the thirty-eighth and fortieth floors by concrete outrigger beams. The core is constructed with added strength at the corners to help resist the moment created by lateral wind forces. (Fig. 6) Two essentially solid sheer walls cross within the core to further increase its stiffness. The grade of concrete is consistent between the perimeter columns and structural core and ranges from 80 MPa at the base to 40 MPa at the top. (Fig. 7)

![Fig. 8. Skybridge isometric and leg plan.](image-url)

The decision to design the floor as a steel system took into account a number of concerns related to site, project, and schedule. The fast-paced schedule required a system that could be quickly constructed. The flexibility, simplicity, and light weight of steel construction made it ideal for the floor systems. The lightweight steel members could be quickly placed, often without the assistance of a crane. It was important that the erection of the floors could occur independently from the "form and strip" cycle of the concrete frame to avoid projectwide delays resulting from problems with either process. It was possible, with the use of steel, to work out of sequence when necessary to accelerate erection schedules. The
design of the members as simple-span infill beams linking the structural core to the column ring sought to keep the members relatively simple to facilitate local fabrication.

An analysis of the damping needs of the towers indicated that the additional weight of a structural concrete floor was not necessary. In addition to increasing the speed of construction, the light weight of the steel floors allowed for time and cost savings in the construction of the foundations for the towers. The repetition of cantilevered triangles resulting from Pelli’s design made the use of flying concrete forms impractical. If concrete had been chosen as the material for the floors, the effects of the long-term creep deflection would have made the design and construction of the facade-to-floor joint detail more extensive. The predictability of steel in this situation provided significant cost savings.

A special profile of corrugated decking, not commonly used in the United States, was rolled in a Malaysian plant created for the project. This profile, which incorporates dovetail ribs, allowed for high levels of fire rating with thin layers of normal-strength concrete. In addition to the above-mentioned qualities associated with the metal frame and decking system, the use of these materials allowed the tenants of the towers a high degree of flexibility for future customization of their work environments.

The engineering of the skybridge, critical to Pelli’s design intent, was recognized as a significant challenge. Preliminary hopes that the bridge might actually be used to help stiffen the two towers were quickly abandoned, and the difficult problem of separating the bridge from the differential movement of the towers was addressed. Expansion joints, located at both ends of the bridge structure, were designed to isolate the motion of the two towers from the bridge. (Fig. 8)
The addition of four 3.6-ft.-diameter wishbone legs, although not needed to support the midspan, helped to minimize deflection and maintain the centering of the bridge structure. Lateral wind loading on the bridge itself had to be studied as well. Tuned mass dampers were designed to be installed in the wishbone legs to alleviate vibrations resulting from vortex shedding associated with the lateral wind loads (Fig. 9).

Fig. 10. Tower Profile with Foundations
6. THE BIDDING PROCESS

The client, the Petronas Corporation, had a tremendous amount of knowledge about bidding processes in the petroleum industry that they transferred quite directly into their strategy for selecting contractors and suppliers for the project. Although the appointment of the architectural team, prior to the arrival of Lehrer
McGovern, had involved a relatively informal negotiating process, the competitive bidding for the big-ticket contracts was a highly formal and controlled undertaking.

Every bidding company was asked to submit two entirely separate and highly detailed bid packages. The first package, called the “technical proposal,” was used to determine the capability of the company to complete the work satisfactorily. A highly organized process set out the guidelines for this technical review. After signing in, the members of the review board were given the equipment they would need to analyze the technical proposal. The technical review board then submitted a technical review booklet to the steering committee with its recommendations. Any firms that were judged incapable of the work were then omitted from the second stage of the bidding process. To determine this, about ten questions were asked, including: Do they have the necessary experience? How have they organized with a local partner? Is this a good pairing? Are they financially stable and capable of carrying out the work (verified by a letter from their lending institutions)? Do they have the technical capability to complete the contracted work?

After the first round, the second package, called the “commercial proposal,” was evaluated. Because all technical questions had been asked in the first review, this round could focus entirely on the numbers. Very strict guidelines structured the commercial bids so that they could be fairly and efficiently judged. Although compliance with these guidelines was mandatory, the committee conducted a preliminary “normalizing process” to ensure that the numbers made sense prior to their review. The steering committee was presented with the final results of the review board’s investigation of the commercial proposals, and contracts were awarded accordingly.

Perhaps the most interesting of the bidding processes involved the construction contract for the two towers. The initial request for proposals gave a very strict set of guidelines for contractors that were planning to submit bids. The teams were instructed to prepare three separate sets of bid documents. They were asked to submit a bid for the entire project and then a separate bid focused specifically on the construction of one tower. According to Bruce Schlaitzer, the project manager from Lehrer McGovern, the makeup of the international teams and the care with which local contractors were integrated into the group was an important factor in the final decision. Of the nine international teams that submitted bids, two were eliminated after the review of the technical proposals. The evaluation of the commercial bids revealed that there were only nominal benefits from contracting the entire project to one team. The project management team decided that they didn’t want one really large contracting group setting the pace and quality level for a project of this scale. In addition, concerns about the depth of financial resources that the project would require supported their decision to split the contract. The Tower One contract was awarded to a team that included Hazama Corporation and Mitsubishi Corporation from Japan, J.A. Jones Construction Company, Inc. from Charlotte, North Carolina, and the local Malaysian MMC Engineering and Construction Company. This would come to be known as the Japanese team. The contract for Tower Two and the skybridge was awarded to SKF, a joint venture of three firms,
Samsung Engineering and Construction, Kuk Dong Engineering and Construction from Korea, and the local construction company Syarikat Jasatera Sdn. Bhd. In addition to these three companies, Turner Construction from the United States played a limited role on what came to be known as the Korean team.

This bidding process was used to evaluate competitors for a wide range of other contracts. The long-lead items, like the elevators and curtain wall panels, were contracted out using this type of bidding process. The “sitewide buys” of these important components allowed for the necessary consistency between the towers and also provided cost savings for the owners. Lehrer McGovern was careful to avoid putting themselves in the critical path between the contractors and their suppliers for the shorter lead time items like the structural steel and concrete.

Each of the construction teams had their own suppliers and local fabricators for structural steel. Import duties on prefabricated steel could be avoided by importing the raw materials and performing the required fabrication locally. There was an inspection of the fabricators’ operations to assess their capacity to meet the quality and quantity expectations of KLCC, Lehrer McGovern, and Thornton-Tomasetti. In most cases, some alterations were made as a result of these inspections to assure that expectations could be met.

Lehrer McGovern’s experience from the Canary Wharf project as well as their assessment of the congestion of local roads which only appeared to be worsening as the project progressed led them to realize that it would be necessary to produce the required concrete on-site. The grade 80 high-strength concrete specified for much of the buildings’ structural system had never been produced in Malaysia. It was therefore important that the engineers and project management teams be able to maintain a high level of quality control. KLCC and Lehrer McGovern put the concrete supply job to bid and Pioneer, a concrete company from Australia, in partnership with a local firm, was chosen. Instead of a contract a licensing agreement was drawn up. Lehrer McGovern set up an agreement that the contractors could use any supplier of concrete as long as they could demonstrate cost savings exceeding 5 percent by not using the on-site facility. Both teams were supplied by Pioneer.

7. THE CONSTRUCTION OF THE PETRONAS TOWERS

7.1. The Foundation System

The contract for the foundation work was awarded in March 1993. The foundation contracting team consisted of Dragages et Travaux Publques, a French-owned company located in Hong Kong, and the local firms, Bachy-Soletanche Sdn. Bhd. and First Nationwide Engineering Sdn. Bhd. The $52 million, twelve-month contract for the foundation of the entire project mandated a $120,000 per day fine if completion deadlines were not met. To meet the strict schedule, vertical borers were flown in from France and the excavation of the foundation mats was started.
The discovery of a steep limestone cliff beneath the surface of the original site for the Petronas Towers necessitated the movement of the buildings away from the busy intersection of Jalan Ramlee and Jalan Ampang. At the new location, all 208 piles would be above the limestone, relying largely on surface friction in the stiff sandy layer known as the “Kenny Hill” formation. This meant that friction barrettes, rectilinear piles with heavily textured sides, would be needed. To maximize the coefficient of friction of the piles, grout tubes were used to force concrete from the edge of the pile out into the surrounding soil. Careful three-dimensional studies of the contours of the limestone cliff below the piles allowed for the precise design of the barrettes to minimize the differential settlement of the foundation mats. Each tower was to be supported by eighty-five barrettes of varying lengths, extending to a maximum depth of 377 ft. from the bottom of the excavated mat. Nineteen shorter barrettes were needed for each of the bustles, which were to be smaller cylindrical towers that would climb forty-five stories up the side of each of the taller towers. A 3-ft.-thick slurry trench wall wrapped the 1.6-mile-long perimeter of the building site, dropping 84 ft. from grade to the depth of the foundation mats (*Fig. 10*).

*Fig. 12.* The assembly of the curtain wall.
Several problems occur from specific conditions of the site. The high silt content of the surrounding soil was mixing with the Bentonite slurry used in the boring of the piles, and a desilting machine from Europe was flown in to alleviate the problem. The soil composition of the Kenny Hill formation was also tough on the drilling equipment and required frequent replacement of cutting edges. An underground cavern in the porous limestone cliff caused a portion of the perimeter wall to collapse, causing a two-week delay in the pouring of this element.

The pouring of the mats commenced in January 1994 and consisted of two continuous pours, employing the use of eight pumps for more than fifty hours for each pour. The mats, located 84 ft. below grade, are 15 ft. thick. Each pour used 466,092 cubic ft. of 60 MPa high-strength concrete. Concerns about the problems associated with the high temperature differentials led Dragages et Travaux to use chilled water in the mix. After the pours were completed, each mat was wrapped in an insulating layer to prevent thermal cracking.

7.2. The Structural System

Despite the fact that two separate construction teams were employed for the construction of the two towers, many involved with the process have noted the similarity of the construction methods employed by the two teams. Bruce Schlaitzer, commenting on the differences between the two teams, remarked, “Really, the two teams used very similar building processes and at the end of the day, the two buildings are almost identical.” Alan Naspinski, scheduling engineer for Jones International, observed, “The two towers are identical. I think at the beginning there were some fundamental differences concerning issues such as crane locations. The two teams watched each other and were always analyzing their strategy in comparison to that of the other team. As the project progressed, the two teams became noticeably more similar in their processes. The Korean team had the marked advantage that they started behind us due to the scheduling of the foundations.”

Throughout the construction of the towers, members from each team were permitted to enter the construction site of the other team only during scheduled tours, which took place every Wednesday. These tours were always well attended and, according to Naspinski, a tremendous amount of information was exchanged during these encounters. Comparisons between the two techniques were also made by the management teams from KLCC Bhd. and Lehrer McGovern. The extensive construction supervision provided by the engineers, architect, and management teams was also an acknowledged conduit for information transfer between the towers.

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Fig. 13. The main components of the skybridge.

The removal of the mat insulation in March 1994 marked the beginning of the construction of the structural frame. The perimeter columns, cast in reusable steel forms, would be exposed to the interior at most levels. The self-climbing forms, used by both teams, allowed for a very fast construction schedule from a twelve-day-per-floor to a three-day-per-floor schedule as both teams streamlined their operations. The use of self-climbing forms was necessary because of the lack of space for crane placement. The tapering of the columns from a diameter of 7.87 ft. at the base to 3.94 ft. at the top floor was segmented into five size increments to minimize the cost of formwork reconfiguration (Fig. 11).

Fig. 14. The installation of the skybridge
Perhaps the most notable difference between the two teams was their strategy for pumping the concrete used for the core and perimeter columns. The Tower Two team used two large German-made pumps to raise concrete to a world record setting height of 1,247 ft. The Korean team ran into some problems with this technique around floor sixty, but with the help of several pumping specialists, the system was fixed and construction continued. The Japanese team, making use of Jones International’s experience with concrete delivery in the United States, utilized a high-speed hamper hoist in conjunction with more localized pumping. Traditional concrete pumps were used up to the fifty-fourth floor. A pump was then installed at the fiftieth floor. This new pumping location was supplied from below by a concrete hoist.

7.3. Mechanical Systems

In addition to the innovative uses of materials and construction techniques throughout the buildings, the mechanical systems incorporated in the Petronas Towers are unprecedented in Malaysia. An advanced "cool recovery" system is used to save energy. Advanced fiber-optic networks are in place to facilitate data transmission. A carefully organized elevator system was needed given the height of the towers. A unique fire control system was also developed to respond to the specific needs of such a tall building and the limitations of the Kuala Lumpur infrastructure.

The consistent heat and humidity of this tropical city necessitated an innovative cooling system for the Petronas Towers. To maintain a high level of air quality within the project, the consulting mechanical engineering firm of Flack and Kurtz stressed the importance of a high turnover rate of fresh air. The exceedingly warm climate of Kuala Lumpur made this an expensive proposition. To minimize the cost of cooling the inflow air, Flack and Kurtz incorporated energy recovery wheels into the air handling system. Norman Kurtz, a principal of Flack and Kurtz, noted that although this technology had been available for almost twenty years, “its application in an office building near the equator is unique.”15 The 12-ft.-diameter wheels rotate slowly as the supply and exhaust air streams pass over them. The heat from the incoming exterior air is transmitted through the wheel into the cooler exhaust air. Simultaneously, a dessicant in the wheel absorbs humidity from the inflow air and discharges it into the exhaust air to help minimize the load on the building’s dehumidification equipment. This system reportedly drops the humidity of the supply air from 90 percent to 70 percent and reduces the fresh air cooling load by as much as 50 percent.

The fire control system needed to be developed in accordance with the highly specific demands placed upon it by the height of the towers and the congestion of downtown Kuala Lumpur. The inability of fire apparatus to navigate the traffic of the city center made it essential that any fire in the complex could be controlled locally. To meet this demand, extensive sprinkler, pressurization, and smoke exhaust systems

have been integrated into the building. Because of the difficulty of egress in towers of this scale, it was important to incorporate pressurized safe zones throughout the complex. In the wake of the Oklahoma City terrorist bombing, a number of changes were made to the buildings' security and safety systems that were already under construction. Emergency generators, located on the premises of the towers, were relocated away from the building. All parking was removed from beneath the towers and more backup fire controls were added. The skybridge came to be seen as a key path for emergency egress between the towers.

7.4. The Cladding System

The fabrication of the exterior cladding system was carried out locally by a limited partnership organized by Harmon, a curtain wall fabricator from Minnesota. The large-scale investment in machinery and personnel that Harmon had already committed to projects in Malaysia made the company a clear choice for the curtain wall contracts. This commitment aligned with the secondary goals of information transfer, and a number of facilities organized and constructed for the Petronas project have continued production following the completion of the towers.

The locally manufactured stainless steel curtain wall system consisted of large low-E coated glass panels held in a stainless steel frame. Stainless steel louvers projected out from the surface of the panels to help eliminate solar gain from high sun angles. The panels were designed and produced to navigate three slope changes that occur because of the stepping back of the tower profiles. Interstory drift, calculated to be as much as 0.4 inches per floor, had to be accommodated by the panel connections. Before the production of the 31,000 panels to be used in the towers, three full-scale 65.6-ft.-square panels were tested extensively at Construction Research Laboratories in Miami, Florida (Fig. 12).

7.5. The Skybridge

The skybridge was installed in August 1995, eighteen months after the beginning of frame construction by the Korean team. The 191.6-ft.-long, two-story, glass-enclosed bridge would connect the functions of the two towers at the forty-first and forty-second stories. Coordination between the two construction teams had been particularly crucial in preparation for the installation of this prefabricated element. Anchors in each of the towers had to be carefully aligned to receive the connections from the box-beam support of the bridge at level forty-one and the paired supporting steel tubes that meet the towers twelve stories lower at level twenty-nine. Lifting the main section of the skybridge by crane from ground level to a height of 600 ft. was a dramatic undertaking, performed in the midst of lightning storms and a barrage of media attention; despite a variety of unanticipated problems, the attachment to the towers was executed smoothly over the course of three days (Fig. 13).
The original design of the skybridge had specified that it should be constructed in position, using a temporary bridge as a staging area for the assembly of smaller prefabricated pieces. Terry Sullivan, consultant for the Korean team, remarked, "We were concerned about safety and impact on the schedule..."
[so] we asked them to vary the design.”16 With Lehrer McGovern’s approval, the bridge was redesigned to be prefabricated by Samsung in Korea. The 493 discrete pieces of the bridge were manufactured, tested, assembled, and disassembled in Korea before being shipped to the site. A location between the towers on the first level of the unfinished parking structure was prepared as a staging area. Eight hydraulic lifts, each with a capacity of 125 tons, were mounted on the adjacent towers.

The assembly of the bridge involved several key steps. The 134.5-ft. main section of the bridge was assembled on the ground. The exterior cladding and concrete roof were included in this center portion of the bridge assembly. The 27.23-ft. long end sections were built separately. To facilitate the connections between the pieces, only the primary frame of these two components was preassembled. These two end pieces were hoisted to the forty-first floor, where they were temporarily attached to each of the towers. After the assembly of the main section of the bridge was completed, this structure was hoisted by the eight jacks to a height of 36 ft. above the staging area. The top 33-ft.-long sections of the supporting legs were bolted and welded into place on the underside of the box girder. The lower sections of the four wishbone legs were then assembled on the ground and lifted to the twenty-ninth floor of the towers, where they would eventually be bolted into place to help minimize deflections at the center span of the bridge (Fig. 14).

7.6. The Pinnacle

The two 150-ton stainless steel pinnacles were fabricated off-site and installed upon completion of the structural frame of each tower. The installation was a clear example of the competition between the teams as well as the opportunity for information transfer. Alan Naspinski compared the installation techniques employed by the two teams when he said, “We were concerned that having the mesh ball attached to the pinnacle as it was hoisted would complicate the installation. Therefore, we chose to install the ball after the pinnacle had been set in place. The Korean team installed the ball prior to hoisting. It seemed to us like they had no real difficulty hoisting the two together and in retrospect, I think it is pretty clear that their method was more successful in this case.”17

8. CONCLUSION

On January 27, 1997, the first 166 employees of the Petronas Corporation moved into their newly finished offices on the fifteenth and sixteenth floors of the Petronas Towers. A substantial amount of interior finish work was not completed at this point, but moving all 5,000 employees into the towers by August 1997 seemed an achievable goal. A number of the industries created particularly for this project had already spun off and were pursuing other work in the rapidly growing city and elsewhere in Asia. The expertise gained by local engineers, architects, project management teams, contractors, and fabricators was

already being tested on a wide range of other infrastructure projects throughout Malaysia that were being developed more independently by Malaysian nationals. These projects’ success will be attributable in large part to the knowledge gained through the know-how transfer that accompanied the Petronas project. Jon Pickard, commenting on the perceived success of the project, said, “The buildings appear to have been accepted by the people of Malaysia. They will, in fact, define their nation for at least this point in history.”

Many of the international relationships developed on the project will be maintained, adding to the noticeable globalization occurring throughout the construction industry. Pickard mentioned his desire to maintain close ties with the young architects of Malaysia by providing space in his office for visiting interns. Alan Naspinski said, that Jones was very interested in continuing ties with Hazama, which he characterized as a “very gracious host.” He remarked that the trend toward globalization had a number of benefits. Alignment with local firms opens previously inaccessible markets. The collaboration between large teams allows for a minimization of risk for any one party. Most important, increased globalization encourages construction companies to bring together the very best people and organizations to perform international projects with highly specific needs.

17 Alan Naspinski. Interview. March 13, 1997
Appendix: Other Major Construction Projects Currently Under Way in Malaysia

In addition to the Kuala Lumpur City Center project, a large number of other public and private developments have been planned or are under way in Malaysia. The scheduling of Kuala Lumpur to host the prestigious Commonwealth Games in 1998 has put increased time pressure on a number of infrastructure projects now in progress. The international attention the games will bring to the country will help promote the image of Malaysia as an emerging economic and political power in Southeast Asia.

The new Kuala Lumpur International Airport plans to accommodate 25 million passengers a year with its first stage of development, which has been budgeted at U.S.$4.9 billion and is expected to be completed by early 1998. A second-stage plan would expand the airport to handle a passenger capacity of 90 million passengers per year. The project is being designed by Kisho Kurokawa Associates of Japan, in association with the local firm Akitek Jururancang.

The newly conceived administrative capital city of Putrajaya is perhaps the most ambitious of these mega-projects. At a cost of U.S.$7.5 billion, the new city will house 76,000 government employees. The hope is that this will remove much of the pressure on the infrastructure of downtown Kuala Lumpur. The project’s adjacency to the new airport and accessibility to the downtown makes it strategically well placed as an internationally recognized governmental location. The design of the city includes the construction of an artificial lake. The first stage of construction, begun in August 1996, includes housing, infrastructure, and the prime minister’s department complex.

Fueled by international interest, the “multimedia super corridor” promises to become a major hub of high-technology production and research. The 290-square-mile area linking the new administrative capital city of Putrajaya and the new airport will be inhabited by a wide variety of international high-tech companies, including Microsoft, Nippon Telephone and Telegraph, and more than 100 other large international firms. To draw this diversity of companies, the government has committed U.S.$18.5 billion to develop the physical infrastructure of the region. Part of this project involves the establishment of a completely digital 2.5-10 gigabit fiber-optic information network.

Another city project, the Kuala Lumpur Linear City (KLLC), is planned to be constructed over the top of the Klang River. The project, 7.5 miles long, will be built on arched structures that span the river and will include residential, office, hotel, restaurant, and entertainment functions. Although the architect for the project, the local firm Original Scope, will be in charge of the design of the project, a wide range of international design firms have been involved, including Santiago Calatrava, Peter Cook, Ove Arup, Ron Herron, David Gosling, and Anthony Hunt.

Other major projects include the development of infrastructure in downtown Kuala Lumpur, the U.S.$2.25 billion Johor Waterfront City project, the reconstruction of the bridge to Singapore across the Straits of...
Johor, as well as a second bridge connecting the town of Tuas in Singapore with Gelang Putah in Johor, Malaysia. This bridge will inevitably fuel growth in this region of Malaysia, and plans are under way to construct another major township, Nusajaya. By the date of its final completion, this new town should house roughly half a million inhabitants. The Italian company Agarta Universe has secured a ninety-nine-year lease on a property in the town of Seri Alam where it will build the largest theme park in the area. The first phase of construction will involve an investment of U.S.$345 million in addition to the U.S.$23 million lease price.

This brief survey of large projects offers a glimpse of the incredible optimism that exists in Malaysia at this stage of its political and economic development and helps frame the context of the Petronas Towers and Kuala Lumpur City Center project. Bruce Schlaitzer, project manager from Lehrer McGovern, remarked that one of the most challenging aspects of the early work on the Petronas Towers was “the difficulty in dealing with people who had grown to believe that running the universe was an easy task.”

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Bruce Schlaitzer. Excerpt from phone interview. February 17, 1997