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Engineering Challenges of Dubai's Palm Jumeirah

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ABSTRACT

Dubai is the largest city in the United Arab Emirates (UAE) and is quickly developing into a worldwide cultural and business hub. Its economy is driven by the oil and gas industry, and since the country first began to export oil in 1962, the UAE has morphed from a series of modest fishing communities, to a major economic centre. The financial boom of the oil and gas industry has contributed to the construction of the world's tallest skyscraper and the world's largest shopping mall, as well as a flourishing tourism industry.

Dubai is constantly pushing the limits of design innovation, which undoubtedly contributes to its touristic appeal. One feature in particular is Palm Jumeirah, which is the first of a series of artificial islands located off the coast of Dubai, in the Persian Gulf. The island is formed in the shape of a palm tree with a protective crescent-shaped breakwater partially enclosing it. The island and breakwater house commercial and residential infrastructure, and adds 78 kilometres to the Dubai coastline.

Government owned Nakheel Properties is responsible for the concept and construction. The island was designed by a team of over 40 consultants providing solutions to coastal, material and transportation related concerns. Construction was undertaken by European dredging and marine contractors and began in June 2001. Part of the rock breakwater was created first to protect the sand constructed island inside. The island landmass was built using a dredging technique which sprayed sand precisely in a rainbow-like arch using GPS technology. Approximately 7 million tons of rock and 100 million cubic meters of sand were used in construction. A sub-sea tunnel was also built to transport people and goods between the inner "palm" and outer "crescent" sections.

The Palm Jumeirah project came with controversies and problems. Some residents were displeased with reduced lot sizes and a less luxurious experience than advertised. The original breakwater design prevented natural tidal movement which led to stagnant seawater within the palm space requiring a re-design. As well, despite the vibro-compaction process used, reported survey data has shown that the islands are sinking at a rate of 5 mm/year, much quicker than anticipated.

The following report provides an overview of how Palm Jumeriah was constructed, challenges faced by designers and contractors and post-construction issues.

INTRODUCTION

Dubai, the United Arab Emirates most populated city, is an economic hub of the Middle East and is quickly becoming a top tourist destination, majorly due to its idealistic weather, sandy beaches, and luxurious venues; see Figure 1 for location. Only fifty years ago, Dubai was a small town perfectly

Figure 1: United Arab Emirates

situated in the Persian Gulf to support its trading and pearl exporting industries. Since oil and natural gas was discovered in the area in 1966, Dubai has developed into an infrastructural wonder. In the last 25 years, the change in Dubai's landscape has been dramatic as buildings and roadways have steadily been developing; see Figure 2.

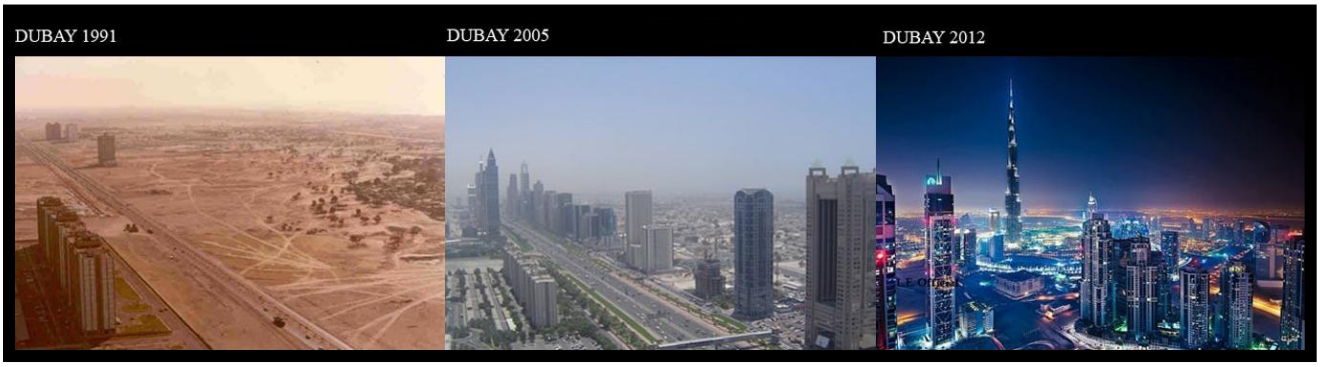

Figure 2: Dubai skyline in 1991, 2005 and 2012

Despite current success, oil reserves in the region are expected to deplete by the year 2016. To assure that the country continues to grow and sustain itself in the future, Mohammed bin Rashid Al Maktoum,

the Prime Minister and Vice President of the United Arab Emirates and constitutional Monarch of Dubai, decided to focus his country's attention on tourism.

To maximize tourism potential, changes were necessary. The area would have to expand on its limited coastline to increase the number of villas, hotels and tourist attractions it was capable of supporting. Land reclamation specialists were consulted and motions to build Dubai's first manmade island in the Persian Gulf began.

EARLY DEVLOPEMENTS

Al Maktoum contracted real estate developer Nakeel Properties to execute the project. Upon hearing the land reclamation idea, Sultan Ahmed Bin Sulman, chair of Nakheel, proposed a circular island that would increase Dubai's coastline by 7 km. Al Maktoum was not satisfied with this design and instead had his own idea of an island in the shape of a palm tree. This design would not only double the length of Dubai's existing coastline, but would also be internationally recognizable and unique to Dubai, a definite lure for potential tourists and local buyers.

Nakeel consulted Dutch land reclamation experts to provide advice on the design of the island. Al Maktoum wanted the island to blend in with the natural surroundings, so only natural rock and sand materials were to be used. The engineering team developed a preliminary design that included a sand palm tree island section, complete with 16 fronds and a connecting trunk, which would be built inside of a rock breakwater. Due to short timelines and pressure from government, construction on the breakwater began before the final design and analysis were completed. Two dredging companies were hired; one to build the breakwater and another to build the palm shaped island.

BREAKWATER CONSTRUCTION

Design of the breakwater was undertaken by Royal Haskoning while the construction was completed

Figure 3: Breakwater Construction

by Archirodon. The breakwater would serve as a protective barrier to the inner palm section of the development and was constructed in a semi-circle crescent shape since protection was only required where water depths were greater than 10m. Construction began in the summer of 2001 with a fleet of 9 barges, 4 dredgers, 40 pieces of heavy equipment, 10 floating cranes and 15 tugboats. The core of the breakwater was built with seabed sand from areas near the site. Dredge boats would deposit sand in specific locations in layers up to 7.4 meters thick. To prevent wearing down of the sand core, an erosion-preventing, water permeable geo-textile material and a layer of one-tonne filter rocks were added on top.

To provide the majority of the protection, two layers of armourstone caped the breakwater. The contractor sourced rock from 16 quarries in the Dubai area and blasted day and night to recover the 7 million tons required. A steady fleet of haul trucks delivered approximately 40 tons of rock per day to a barge which then transported the material to the breakwater. It took less than 24 hours between blasting and placement. All boulders were graded by size and weight and only stone that met the dimension and density requirements was used. All rocks were placed individually by cranes to assure sufficient sturdiness and divers checked the breakwater's progress daily for signs of fatigue and to guarantee there was no movement.

The breakwater faced its first test of strength in the winter of 2001 when it experienced the annual Shamal, a strong northwesterly wind which affects the Persian Gulf states. The breakwater was plummeted with large waves and sand and construction was delayed by 3 weeks. Despite this, the breakwater held firm throughout and progress resumed afterwards.
One major design concern was discovered when engineers realized that water within the breakwater was not circulating as desired. To resolve this, two-100 meter wide, 3 meter deep channels were cut out of the breakwater about a quarter of the way into either side to allow circulation and prevent stagnant water within the palm area. Following the improvements, environmental water samples were taken and tested every day to assure that the conditions were improving. This redesign bettered the water renewal time to about 15 days.

By April 2002, the first 550 meters of breakwater was 3 meters above sea and the area was protected enough so the second dredge contractor could begin work on the inner palm fronds section. The breakwater construction continued and both teams worked simultaneously to complete the work. The 22 kilometre long, 100 meter wide breakwater was completed by the end of 2003.

FROND CONSTRUCTION

The frond section of the development would provide the impact that the developers desired. It would house the majority of the villas, hotel and tourist attractions. Desert sand was too fine to be used for its construction, so materials engineers sourced an ideal supply of sand, 6 nautical miles from the site, which was coarse enough to be packed densely. It took three hours for contractor Van Oord's barges to be towed to this site, pick up sand in their 8000 ton tanks and return to the development to deposit it. Sand was sprayed in a rainbowing fashion at 10 m/s into to gradually build up the island.

To assure that the palm leaves were being constructed to design specifications, 5 surveyors walked the edges of the fronds everyday with GPS technology to assure all was on track. Information from the surveyors was relayed back to the ships for guidance. All work required great precision, not only for the specific placement of sand, but the slope of the beaches as well.

It was critical that both the sand and breakwater crews worked together to assure that they were in sync. If the breakwater progressed too quickly, it would cut off the land reclamation team's access to their site. If land was being built too quickly, there was a risk that storms would erode land. In October 2003, two months following the breakwater completion, the land portion of the project was completed. A total of 70 million cubic meters of sand was used in the construction of the fronds. The truck section was about 5 km long and 457 meters wide while each of the 16 palms were about 5km long. The

Figure 4: The process of rainbowing sand to create Palm Jumeriah's fronds

original seafloor was approximately 10.5 meters below sea level and the final elevation ranged between 3.5 m and 4.2 m above sea level.

The sand island required compaction so it could withstand the extreme loading of the structures to be built on it. Additionally, the sites close proximity to a major earthquake zone also drew concern. Vibro-compaction was used to increase the density of the "shelly fine to medium sand." 15 machines, drilled 200,000 holes into the manmade island. Jets injected high pressure water and air into the holes and probes vibrated the sand to compact it. More sand was added as the existing sand settled and the process was repeated until the sand island became essentially solid rock. Following this 8 month long process, the island's tremendous infrastructure undertaking could begin.

TUNNELS

Approximately 40,000 hired employees began work on building the villas, hotels and service infrastructure to make the island habitable. Seeing that the breakwater portion was designed to house property as well, an engineering solution was required to provide method of transporting goods, services and people on and off of this section without disturbing the aesthetic look of the development. To achieve this, designers developed a system of subsea service and traffic tunnels.

Service Tunnels: Naboodah Engineering Services was awarded the design/build contract to install 12 horizontal directional drilling crossings, 6 on both the eastern and western sides, to provide utilities to the breakwater. Magnetically guided drills penetrated the ground at an inclination of 15 to 16 degrees,

eventually levelling off and then angling again to the surface, to form holes approximately 250mm in diameter. The holes were enlarged using a series of increasing diameter reamers, and a high-density polyethylene (HDPE) sleeve was permanently installed for support. Inside of the sleeve were HDPE carrier pipes which held the various utilities, such as water, wastewater, treated sewage effluent and telecommunication cables, 10 meters below the seafloor. Naboodah also constructed two micro tunnels to feed electricity cables. Eastern and western launching and receiving shafts were built as well so the cables could reach the surface.

The main challenges of tunnelling were the close spacing between the crossings, challenging soil conditions and ground water. Mud levees were kept high to avoid collapse and polymers were added to the bentonite slurry (drill lubricant) to increase its viscosity. The guiding system for the drill often lost signal which required an immediate upgrade to the communication system.

Vehicular Tunnels: The vehicular tunnel was designed by Halcrow International Company and constructed by JV Taisai and Al Naboodah; construction began in March 2005. It was 1400 meters in

Figure 5: Tunnel during construction

length, 600 meters of which was completing underwater up to 25 meters below the seafloor. The design included room for three lanes of traffic in either direction and a central cell for emergency traffic. The external width and height of the tunnel was 37meters and 9.6 meters respectively. The concrete base slab was between 2 and 2.6 meters thick, while the roof and walls were 1.5 meters thick. A geo-membrane of HDPE was used to withstand the high water pressures.

The entire structure was built using a cofferdam method. Steel sheet piles were driven to a maximum depth of 30m and over 4.3 million cubic meters of water was pumped out in a multistage process to reduce the water level from +11m to -23m below sea level; the entire procedure took 45 days and contributed to 30% of the total vehicular tunnel's cost. The ground was then excavated and tunnel construction was carried out in a cut and cover method. The forming, reinforcing and concreting were completed using separate casting methods. The concrete work was done in 25 meter long sections and using a four cycle sequence, first the tunnel bottom, followed by the two sides and finally the roof slab. The vehicular tunnel was completed by April 2007 at a total cost of $145 million dollars.

POINTS OF CONCERN

Since the completion of the project, environmental experts are concerned about how the addition of Palm Jumeriah will affect the natural habitat and geology of the existing land. The project's quick delivery meant that proper studies were not conducted on how the island would impact the Persian Gulf's ecosystem. The island disrupted the natural current off the coast, acting as a giant jetty. With this disturbance, sand is being removed in certain areas of the natural beach and redeposited elsewhere. The erosion in some areas is up to 10 meters of shoreline per year. Additionally, the wave forces have been damped by the island so sediment deposition on the beaches has lessened. To deal with these effects, constant maintenance of the mainland coast is required and Dubai is currently spending millions of dollars annually to repair areas that have been eroded.

Natural marine life has also been affected. 1.2 square kilometres of coral was destroyed in dredging operations. Developers have begun to create manmade coral in the area to compensate for this. In addition, certain species of fish have not yet returned to the area post-construction and there are doubts that they ever will. It is not yet known how the absence of these species with affect the natural balance of aquatic life.

There are even greater concerns that the island is sinking into the water. Although natural settlement was expected, according to The New York Times, geologic survey data has revealed that the island is sinking at a rate of 5mm per year, much quicker than the expected 25mm over 100 years. Nakheel denies this claim, attributing the large number to the inaccuracy of satellite data.

Some homebuyers on Palm Jumeriah have also raised concern over Nakheel's decision to increase the number of residential units built on the island. With an increase in the number of properties, the average lot size has decreased, leaving some owners with the impression that they were deceived and not given what they were initially promised by the developer.

CONCLUSION

The total Palm Jumeriah program added an additional 78.6km of coastline to the naturally existing 72

Figure 6: Completed Palm Jumeriah

km of coast. The trunk section now holds 10,000 shoreline apartments and town homes, the fronds- 2000 villas and the crescent- 40, 5 star hotels. 105 million cubic meters of material was used to reclaim 25,000 square meters of landmass. It came at a cost of $12.3 billion US dollars and took 7 years to complete, from the first day of construction to the move-in date for some early villas. Construction is ongoing on Palm Jumeriah and it now functions as if it was always a part of Dubai.

Its success has lead to the construction of several other manmade island projects such as Palm Jebel Ali, Palm Deira and The World Islands. The entire project took a great amount of planning and coordination from a number of skilled designers and workers. The island and main utilities of the island were completed in a very short amount of time and it is possible that there were oversites and inefficiencies in the design. Time will tell how Dubai's islands succeed, however Palm Jumeriah will always be an amazing feat of construction and engineering.

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