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O-Cell Testing for Singapore's Marina Bay Complex

Longfellow Installs Drilled Shafts for Transmission Lines

Foundation Challenges at Harris Gully Methodist Center

Drilled Shaft Seminar Coming to Denver

Singapore's Marina Bay Sands Development:

O-Cell® Drilled Shaft Testing Addresses Tight Schedules in Challenging Subsurface Conditions

by William F. "Bubba" Knight, P.E., and Fitri Johari; Loadtest, Inc.

Three towers dominate the area skyline. Photo provided by Timothy Hursley.

Dramatic photos of the Marina Bay Sands Hotel appeared on the internet in the fall of 2011. The eye-popping photos of roof top gardens spanning three structures begged the question, "who built these amazing buildings? And, in that they were constructed in Singapore, perhaps an international ADSC Member might have been involved in the project?" A bit of research as to the parties involved led to the following article for which we thank ADSC Member firm Loadtest, Inc. and most specifically, Bubba Knight. (Editor)

Singapore's Vision

The city of Singapore began using forward thinking and planning with the creation of a master plan in 1952-55 and which was officially accepted in 1958. The plan looked closely at the future development in the city-state. With the Urban Redevelopment Authority (URA) established in 1974 further focus was placed on "development" meeting the visions of a master plan. The master plan, reviewed and updated eight times since inception, identifies five regions: the West, North, North-East, East, and Central. Marina Bay is itself an important development within the Central Area, which is part of the Central Region.

The vision for a seamless extension of the downtown district to support the city-state's continued development into a major financial and business hub in Asia goes back over 40 years. This vision included the transformation of Singapore's southern tip into a 890 acre waterfront business district that eventually lead to the Marina Bay Development. Along this artificial bay land reclamation efforts occurred in phases between 1969 and 1992. These reclamation efforts had a major impact in the planning and construction of the Marina Bay Sands Development.

With the vision of a "Garden City Environment by the Bay," Marina Bay was intended to be a 24/7 location for vibrant

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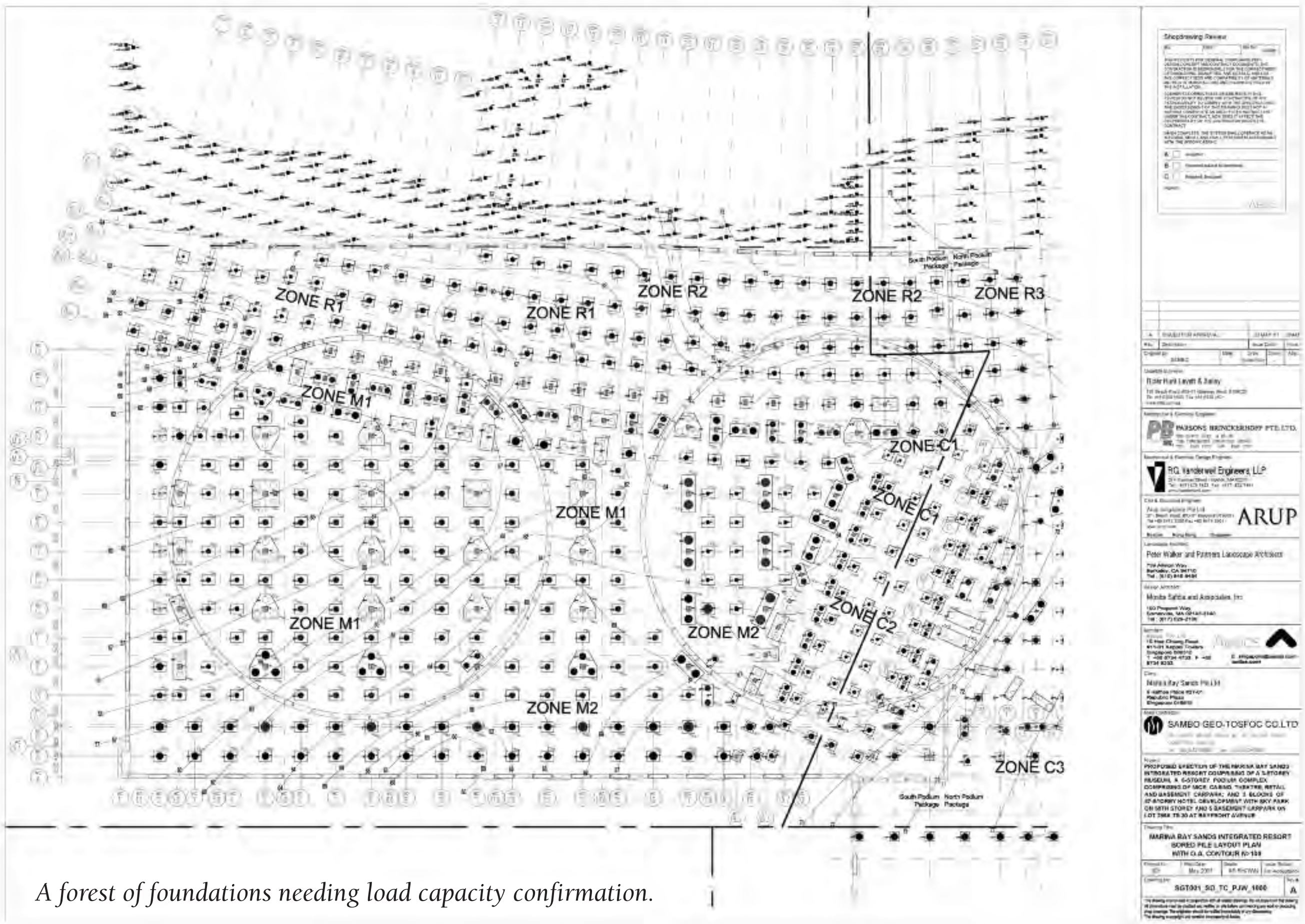
Rooftop garden spanning the three buildings creates a feeling of a ship floating above the structures. Landscape design by Peter Walker & Partner (PWP) Landscape Architects.



A forest of foundations needing load capacity confirmation.

leisure and cultural experience all back-dropped against Singapore's city skyline. It was felt that this development should fulfill the "vision" as a source for the exciting exchange of ideas, and for business information coupled with an opportunity for new living and lifestyles that would burgeon in Singapore.

Night sky provides a dramatic perspective of these iconic buildings.

The Marina Bay Area

In order to ensure around-the-clock area vibrancy, the Marina Bay master plan focuses on mixed use. Value was sought through providing commercial, residential, hotel, and entertainment space. Building heights for the key open spaces and waterfront areas were to be kept low so as to maximize views from individual developments located further inland from the waterfront. This was intended to enhance structural attractiveness and to create a dynamic stepped-profile with pedestrian-scaled areas.

The overall Marina Bay Development area is supported by transportation links including the iconic Helix Bridge, other bridges linking Marina South and Marina Centre, roads directly linking it to the city and airport, five underground MRT stations, and includes a data-telecommunication cable and sewer system located in a common tunnel. All these link and support the 250 acre Gardens by the Bay and over 5,400,000 sq ft of grade 'A' office space.

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A drill rig excavating one of the test shafts.

The Safdie Marina Bay Sands Design

In May 2006 the U.S. based Las Vegas Sands Hotel organization was awarded Marina Bay Sands following a highly competitive proposal-bidding process The proposal was based on the "Safdie Architect" firm's design of the business-oriented and totally integrated resort.

The Moshe Safdie design for Marina Bay Sands was deemed superior due to the hotel tower placement which was set back from the waterfront and featured open views of the city and Marina Bay, all enhancing the distinctive skyline. Devotion to pedestrian access that fit within the Marina Bay landscape made the design a "winner." In addition, providing for 1,200,000 sq ft of convention space, (half the desired amount for downtown Singapore), as well as the inclusion of the ArtScience Museum, two performing theaters, and six celebrity chef restaurants netted the design top marks for convention and tourism appeal. Adding to the tourism appeal the three hotel towers, inspired by decks of cards placed upright and as shuffled by a casino croupier, include 2,560 rooms and suites, a shopping mall, skating rink, the world's largest atrium casino, and a three acre Sands SkyPark terrace sitting atop the three hotel towers.

The Site Condition Challenges

As noted earlier, the Marina Bay area has undergone several reclamation phases since the late 1960's, with the latest being completed in the mid-1990's. The majority of the development is sitting on the 1990's reclamation zone, with the eastern side of the development located within the 1970s reclamation zone.

> ***This soft marine clay, coupled with the proximity of the East Coast Parkway highway and the Benjamin Sheares Bridge, posed significant challenges to the design of the excavation works.***

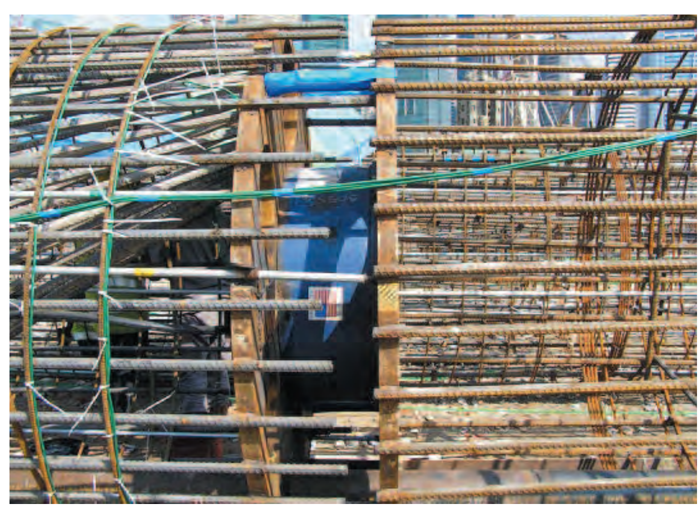
A general soils profile is described as 39 ft-49 ft of sand reclamation fill overlying 16 ft-115 ft of soft marine clay deposits known as the Kallang Formation. This predominately soft marine clay has interbedded firm clay and fluvial-origin medium dense sands. This is underlain by a layer of very stiff-to-hard Old Alluvium (OA).

This soft marine clay, coupled with the proximity of the East Coast Parkway highway and the Benjamin Sheares Bridge, posed significant challenges to the design of the excavation works.

Beneath the southern end of the Sands Expo and Convention Center (MICE), casino, retail, theatres and ArtScience Museum, the Kallang Formation deposit is upwards of 115 ft thick with

A single level three O-Cell setup ready to assemble in a reinforcing cage.

thinning towards the north. To the east at the hotel location is the district's cooling system and Singapore Mass Transit Downtown Line 1 Extension. Here the soft marine deposit is generally 32 ft thick with deep valleys that occur at the southern and northern ends of the site.



An O-cell setup assembled in a reinforcing cage.

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Lifting a test shaft cage with O-Cell assembly.

ARUP Design Innovations

With an average basement excavation of approximately 65 ft, combined with over 40% of the concrete construction occurring 59 ft-115 ft underground, the construction timetable required innovative design approaches. ARUP, the project's structural engineer, took a design approach that allowed for removal of 3.66 million cubic yards of sand fill and marine clay in a two year span. This came to an average of 800 trucks per day. Additionally, a 115 ft deep cut-and-cover tunnel next to the Benjamin Sheares Bridge was engineered to connect the Downtown Line 1 Extension of the Singapore Mass Rapid Transit rail. It was necessary that the tunnel would be operational throughout the construction cycle.

ARUP's excavation design innovations include constructing four large cofferdams: two 393 ft diameter and a 328 ft diameter circular cofferdam, a twin-cell 246 ft diameter cofferdam, a 213 ft radius semi-circular cofferdam, a T-shaped diaphragm wall and a modification to the Benjamin Sheares Bridge to ensure the bridge could safely tolerate the horizontal movement imposed upon it by the excavation procedure.

Installation of test shaft cage with O-Cell assembly.

The Foundation Challenges

A forest of barrettes and 3.3 ft-9.8 ft bored piles installed into the Old Alluvium layer provided support for the buildings. The compressed construction schedule required construction of these bored and barrette foundations concurrently with the construction of the diaphragm walls and prior to the excavation of the cofferdams. In addition to the logistical challenges created, the issue of foundation load capacity confirmation had to be addressed.

O-Cell Technology Solves Foundation Challenge

With such a major project and the extremely tight piling works program, Sambo Geo-Tosfoc Co. LTD. engaged ADSC Member, Fugro Loadtest (Singapore) to conduct a working pile loadtest program using the Osterberg Cell bi-directional testing method. The tests were intended to confirm foundation load capacities.

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The O-Cell bi-directional technology was chosen for the following reasons:

- To confirm that the design loading requirements were being met
- For its ability to isolate and load the foundation bearing strata which was key to the schedule that required loading capacity confirmation prior to site excavation

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O-CELL DRILLED SHAFT TESTING Contd.

Strain gauge wiring and O-Cell hoses at the top of shaft.

- For its ability to separate the end bearing and skin friction components of foundation capacity
- For its ability to provide high test loads even with the deep foundation cutoff levels, 42.6 ft-83.6 ft below ground surface without need for reaction systems

A total of six working piles and one working barrette were tested. Test pile depths ranged from 228 ft-270 ft on the 6 ft and 9.8 ft diameter rotary bored piles and 9 ft x 3.3 ft barrette. As noted above the cutoff elevations ranged from 42.6 ft-83.6 ft.

The O-Cell test piles and barrette were constructed full-depth and were concreted to cut-off elevation levels. In order to maintain bore wall stability and for safety reasons the excavated borehole above was carefully backfilled with clean sand fill material up to platform level. The reinforcing cages and O-Cell related instrumentation was set at platform level so that testing could be conducted from the existing platform.

O-cell test setup; note the minimal logistical support required.

Testing of the rotary bored piles and the barrette were carried out using the ASTM quick test method but with a full 24 hour

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O-Cell testing in progress.

hold at test load. Bi-directional test loads reaching from 4,945 kips to 12,140 kips were applied to the test piles using a combination of 34 inch and 24 inch O-Cells in single and multiple configurations. In that the test piles were production piles intended to carry structural loading, the O-Cells and annular void created as a result of the expansion of the O-Cell were grouted to reinstate the structural integrity.

The flexibility of the O-Cell's bi-direction testing capability allowed for advance testing even though the site was reclaimed from the sea and was characterized by a substantial layer of sand fill overlying varying thicknesses of the soft marine clay Kallang Formation. O-Cell testing was able to confirm that foundation capacities meeting design loading requirements were derived from the Old Alluvium founding layer beneath the Marine Clay layer.

The Marina Bay Sands Development stands as a testimony to the value of load-testing as an integral part of foundation project execution.

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Project Team

Developer:	Las Vegas Sands, Inc Marina Bay Sands Pte Ltd
Architect:	Safdie Architects
Geotechnical Consultant:	Arup
Foundations Contractors:	Soletanche Bachy Singapore Pte Ltd/Sambo Geo-Tosfoc Co Ltd L&M Foundation Pte Ltd
Foundation Load Testing:	Loadtest, Inc.
Landscape Architect:	Peter Walker & Partners Peridian Asia Pte Ltd