DESIGN AND CONSTRUCTION OF CRUISE BERTH FOR COLON 2000, PANAMA

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ABSTRACT

Colón 2000 operates a one-berth cruise facility on the Caribbean coast of Panama. In late 2007, the owner decided to build another berth and terminal dedicated to serving Royal Caribbean Cruise Lines. The owner selected Intercoastal Marine Inc. (IMI) to furnish the berth within a year on a design/build basis. IMI selected BergerABAM to provide pre-award engineering, construction documents, and construction support services for the berthing structure, which was planned as a marginal wharf and mooring dolphins.

The main elements of the project included a 200-meter-long (656 feet) by 20-meter-wide (66 feet) marginal wharf, two 160-tonne breasting line dolphins, and two 120-tonne mooring line dolphins. After initial study, using a sheet pile bulkhead concept was eliminated due to weak soils above the bearing Gatun stratum, high cost, and schedule risk. An open pile-supported wharf concept that overcame the cost and schedule risks was selected instead, to be built over an engineered underdeck slope. The wharf option was made more viable by installing stone columns under the wharf footprint to improve the weak soils and increase the slope stability for both static and dynamic conditions.

The wharf structural system consists of precast concrete piles supporting a platform made of precast concrete transverse cap beams, precast concrete deck panels, and cast-in-place topping. This system, which resulted in a very durable structure, used locally produced components and expedited construction to complete wharf design and construction in only 10 months and allow IMI to meet the tight December 2008 deadline for berthing the first vessel. Construction challenges included stone column installation using a top-feeding system, close interaction with dredging activities, and slope dredging in presence of coral.

The Colón 2000 terminal became the first homeport for Freedom-class cruise vessels in the southern Caribbean that sail from Colón to other Caribbean destinations. Latin American tourists no longer need to begin their cruise at a U.S. port which requires obtaining a U.S. visa. The new berth supplements the existing terminal and allows more than double the vessel calls during the short cruise season.

BACKGROUND

Colón 2000 is a cruise facility located in the city of Colón, at Manzanillo Bay, on the Caribbean coast of Panama. In late 2007, the owner decided to build a second cruise berth and terminal building to serve Royal Caribbean Cruise Lines (RCCL), with the goal of becoming the first homeport for Freedom-class cruise vessels in the southern Caribbean. Cruise ships would sail from Colón to different Caribbean destinations, including Colombia, Jamaica, Aruba, and Curaçao. With this Panamanian homeport, Latin American tourists would no longer need to begin a cruise trip at a U.S. port, which requires them to obtain a U.S. visa.

The owner selected Intercoastal Marine Inc. (IMI) to furnish the berth within a year on a design/build basis. IMI, in turn, selected BergerABAM to provide pre-award engineering, construction documents, and construction support services for the berthing structures.

Based on the limited geotechnical information available, the owner also asked the team to evaluate a tied-back sheet pile bulkhead concept. The team performed supplemental borings and found the soils to be worse than the initial borings, which meant designing and building a combi-wall. IMI also discovered that procuring materials for the steel bulkhead concept would put the project schedule at serious risk. Based on these and cost considerations, the steel bulkhead option was quickly eliminated and a contract was signed to build an open, pile-supported wharf.

TERMINAL LAYOUT

Figure 1 shows the terminal site plan. The second berth was positioned north and 54 meters (177 feet) offset with respect to the existing berth. The main construction elements of the project included the creation of the underdeck slope and the construction of a 200-meter-long (656 feet) and 20-meter-wide (66 feet) marginal wharf and four mooring dolphins. The dolphins located at the north end of the site were connected to the terminal with a newly built rock dike. The dolphins on the south were built on land. A passenger and baggage processing facility (built by others) was set up west of the cruise berth.

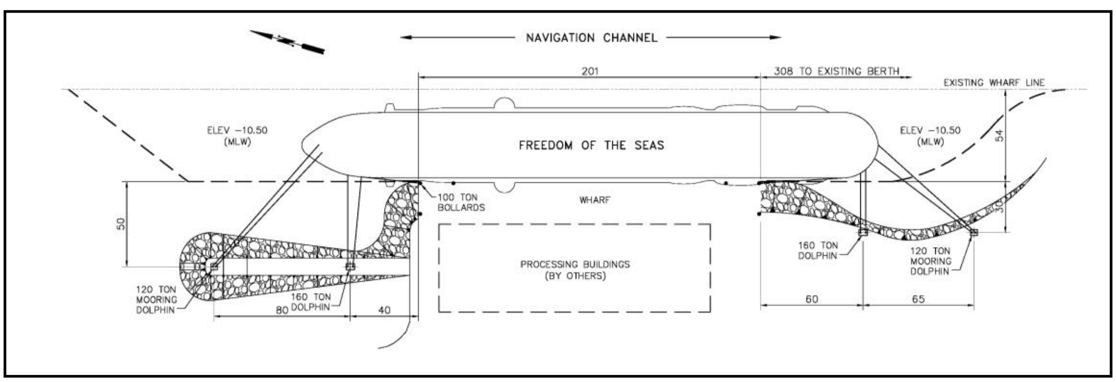

Figure 1. Site plan.

GEOTECHNICAL CHALLENGES AND SOLUTIONS

Figure 2 shows the typical soil stratigraphy along the wharf footprint. The soil profile shows a fill crust up to 4 meters (13 feet) in depth, underlain by a layer of relatively loose, medium dense silty and clayey sands (Atlantic muck) with coral fragments, down to a depth of 17 to 19 meters (56 to 62 feet). Below the muck layer, there is a thin layer of weathered rock, underlain by the Gatun rock formation.

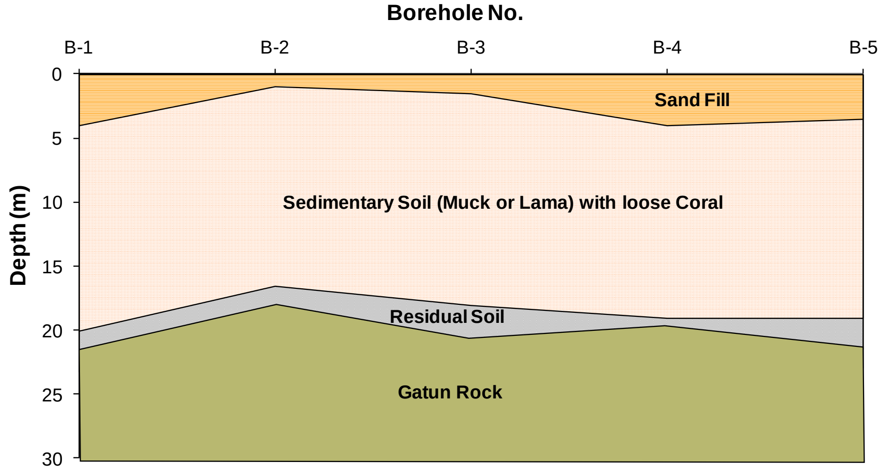

Figure 2. Stratigraphy along wharf

The desired water depth was -10.5 meters (-34.4 feet) mean low water and deck elevation was +2.0 meters (6.6 feet). The owner wanted to have a marginal wharf no more than 20 meters (66 feet) wide. This meant that the underdeck slope needed to be 1.67H to 1.00V. The results of the geotechnical slope stability analysis rendered a low factor of safety against slip circle rotational failure of the slope, even for gravity loading conditions. Hence the team recommended a ground improvement program, and vibro-replacement was selected, with stone columns installed in part of the wharf footprint. Target soil replacement was defined at 15 percent volumetric replacement.

Stone columns were 0.9 meter (3.0 feet) in diameter, evenly distributed in a 2.0-meter-square (6.6 feet) grid plan, and top-fed down to elevation -14.0 meters (45.9 feet). Although the length of the stone columns was limited by the installation equipment that was locally available, their length was deemed satisfactory because it reached down close to the weathered rock layer. The material used for the stone columns met project-specific gradation requirements established by bracketing the minimum and maximum limits of ASTM C33, size 467 and 57, gradation curves. All the stone column work could be done from existing ground elevation to the desired depth, which optimized construction costs. After the stone columns were installed, the soil in front of the improved soil prism was excavated to yield the desired stable slope (see Figure 3 for the extent of the stone column work).

BASIS OF DESIGN

The wharf was designed for Freedom-class cruise ships (339-meter [1,112 feet] length overall, 38.6-meter [127 feet] beam, and 8.5-meter maximum draft) with a displacement of 70,000-plus tonnes. Water depth at berth face was defined as 10.5 meters (34.4 feet). Fenders were installed based on a 1,100 KN reaction requirement, an approach velocity of 0.1 meters (0.3 feet) per second, and an approach angle of 6 degrees.

The wharf piling was designed based on a working load of 225 tonnes. The deck was designed for a uniform live load of 1.2 tonnes per square meter or those associated with an AASHTO HS-15 truck. Because Colón is located in an area of intermediate seismic activity, the wharf structure was also designed for an operational level earthquake (OLE) of 0.1g peak ground acceleration (PGA) and a contingency level earthquake (CLE) of 0.15g of PGA. Mooring dolphins were designed for ultimate loads of 160 tonnes (inner dolphins) and 120 tonnes (outer dolphins).

WHARF FRAMING

Figure 3 shows a cross section of the marginal wharf, including the extent of the stone columns. Figure 4 shows a partial plan of the wharf framing. The wharf structural system consists of a series of 21 bents, spaced every 10.0 meters (32.8 feet), with 0.51-meter sqaure (1.67 feet) precast prestressed concrete piles supporting a platform composed of 0.7-meter-deep (2.3 feet) precast concrete transverse cap beams; 0.35-meter-thick (1.15 feet), 9.2- to 9.4-meter-long (30.1 to 30.8 feet) precast concrete deck panels; and a 0.125-meter-thick (0.41 foot) cast-in-place (CIP) concrete topping.

The tip elevation of the longest pile was set at -23.3 meters (-76.4 feet) to ensure proper penetration into the Gatun formation. The precast transverse beams were positioned on top of the CIP concrete subcaps and integrated to each other through a closure pour. Top deck elevation was set at 2.0 meters (6.6 feet), to be compatible with the vessel's door elevation. Using the precast transverse beams instead of more conventional CIP pile caps was done to expedite the overall construction schedule.

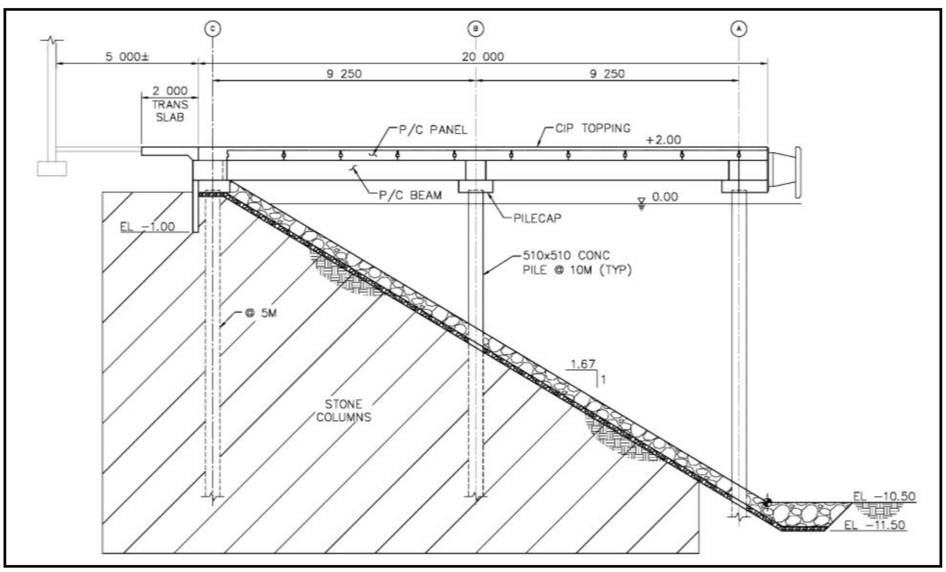

Figure 3. Wharf cross section.

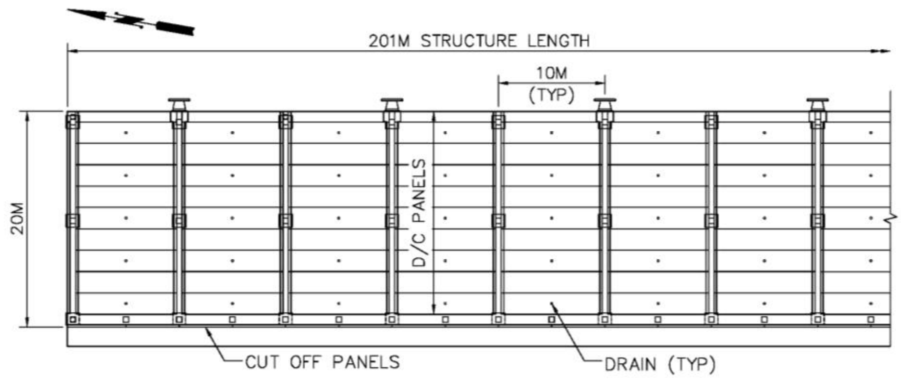

Figure 4. Partial plan – wharf framing.

In addition to expediting construction to meet the tight schedule, the staged construction system provided a very durable structure using locally produced 42 MPa concrete for precast elements and 35 MPa concrete for the topping. Precast products, except cut-off wall panels, were produced in Panama City and trucked more than 90 kilometers (56 miles) to Colón. The cut-off wall panels were produced by the contractor on site. The entire wharf footprint was covered with slope protection to guard against a vessel's bow thruster and waves generated by the northeasterly wind.

SEISMIC DESIGN

The wharf was designed for the load effects associated with an OLE with 0.1g PGA, and a CLE with 0.15g PGA. The PGA value for the OLE is approximately two-thirds of the PGA associated with the 475-year return period (CLE) spectrum defined by the Panamanian Code REP-2004.

The team conducted a pushover analysis to estimate the lateral displacement demand on the structure associated with the design earthquake. The wharf structure was modeled as a stick model with plastic hinges at the tops and bottoms of the piles, with moment and rotation capacities defined based on the results of sectional analyses accounting for the benefits of transverse reinforcement confinement on pile ductility. A capacity protection design approach was implemented for the shear design of all piles. Because the highest shear force demands occur at bulkhead piles, an additional pile was placed between bents along the bulkhead.

Figure 5 shows the pushover analysis results for the OLE event. The expected lateral displacement demand of the wharf is approximately 3.8 cm (1.5 inches). The expected lateral displacement demand for the CLE event (not shown) was 6.4 cm (2.5 inches).

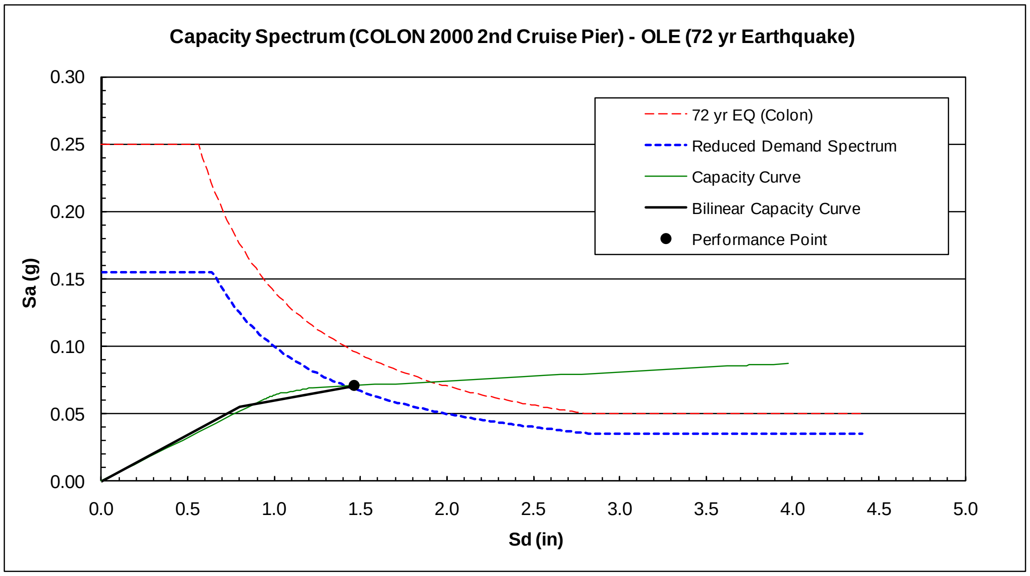

Figure 5. Pushover analysis results (OLE event).

The team also conducted a series of time history analyses using seismic records consistent with the OLE and CLE events to examine the wharf torsional response due to earthquake loads. Because the locations of the center of rigidity and mass of a marginal wharf do not coincide in plan, the lateral loads associated with an earthquake may induce significant deck torsion in plan with the subsequent increase in torsional demand on piles located close to the wharf corners. Corner piles were designed for those effects.

To ensure proper bending strength at pile/cap joints, the precast pretensioned piles were provided with longitudinal non-prestressed dowels. To account for the effects of earthquake reversals, non-prestressed bars were also placed at the bottom of the transverse precast pile caps and extended towards the longitudinal bulkhead cap.

MOORING DOLPHIN DESIGN

Working loads on mooring dolphins were established from mooring analysis results obtained through mooring analysis software (OPTIMOOR) runs. The results rendered values lower than the ultimate load requirements established by RCCL. The mooring dolphin posed a tricky problem. Traditionally, a batter pile system using steel piles is the scheme of choice to optimize the number of piles. However, in this case, the weak soils did not provide the needed tension capacity and the Gatun formation would not allow any penetration of piles. Hence, a concrete plumb pile sytem working primarily in a bending mode was selected. The two dolphins to the south and the first dolphin to the north were already on land and provided adequate passive resistance for the piles. However, the northernmost dolphin was in water 5 meters deep and plumb piles would have been too flexible. After much deliberation, it was decided to build an engineered rock dike with an enlarged end through which the dolphin piles were driven and the dike and dolphin piles were effective in providing the necessary lateral capacity.

The outer dolphins on both the north and the south were provided with eight piles (two rows of four) whereas the inner dolphins had six piles arrayed in two rows. The lateral capacity of the piles was determined by accounting for the benefit from passive pressures exerted on the piles by the surrounding rock dike material (on the north) or soil (on the south). Figure 6 shows mooring dolphin details. Fully embedded pipe bollards were used to attach mooring lines.

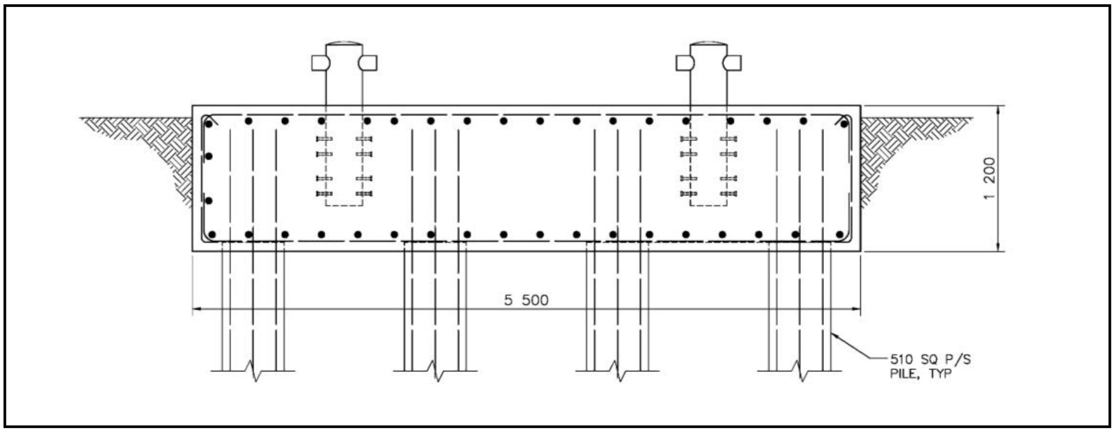

Figure 6. Outermost mooring dolphin detail.

CONSTRUCTION SEQUENCE AND ISSUES

Construction of the entire project was conceived as a land-based operation. Installing the stone columns required creating a variable depth sand platform over the wharf footprint at the beginning of the job. This platform was created by pushing sandy soils available at the site over the existing grade. Once the vibro-replacement was completed, the piles were driven bent by bent, starting from the north. Parallel to this activity, CIP concrete cut-off wall panels were installed along the back of the wharf.

As the pile driving progressed, the sand platform was either washed away by the sea or excavated out with a backhoe or clamshell. Once the bent beams were given continuity through CIP closure pours, dredging of the slips (between bents) took place with a clamshell. This activity required careful coordination between superstructure construction and dredging operations. Dredging of soft soils was further complicated by presence of coral in part of the slope. Where coral was found, it was not removed and slopeprotection was not placed.

The slope was dressed and riprap installed between bents before the deck panels were installed. Once the riprap was placed, the deck panels were set in position and the closure pours and CIP topping cast. Three 100-tonne bollards were installed at each end of the wharf to tie spring lines from the vessel.

POST-EARTHQUAKE PERFORMANCE

On the morning of 4 July 2009, a magnitude 6.0 earthquake hit the Caribbean coast of Panama. The epicenter was located 105 kilometers (65 miles) northeast from Colón at a depth of 38 kilometers (24 miles). The event was followed the next day by a magnitude 5.3 aftershock. When a team of divers inspected the berth, the results of the underwater reconaissence revealed that the pier behaved satisfactorily. No damage was observed in either the piles or the superstructure nor was slope failure observed.

CONCLUSIONS

Careful planning, engineering, and coordination with the construction contractor implemented an efficient wharf design successfully. This durable, economical structural system used locally produced precast concrete elements to meet an expedited schedule.

The new berth supplements the existing one and allows the owner to more than double the vessel calls during the short cruise season. Wharf design and construction, which took only 10 months, were completed in December 2008, a month ahead of schedule. Figure 7 shows an aerial view of the Colón 2000 terminal.

Figure 7. Colón 2000 cruise terminal with second berth completed.

REFERENCES

Panamanian Society of Engineers and Architects (SPIA). (2004). Structural Design Code for the Republic of Panama, REP-2004, 259 pp.