CONTAINER PORT DEEPENING IN CARTAGENA

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ABSTRACT

Manga Terminal, operated by SPRC in the heart of Cartagena, Colombia, expanded at a moderate pace through the late 20th century to incorporate products ranging from cruise to Ro/Ro, and the first container handling berths were retrofit in 1985. Growth surged in recent years, precipitated by the expansion of the Panama Canal and consequent demand for nearby, deep water berths and container transshipment terminals. The two terminals operated by SPRC in Cartagena, Manga and Contecar, are now one of the top five container handling entities in Latin America.

After Berth 9 was constructed in 2011, the terminal could not expand significantly due to land constraints, so operators turned to modernization projects to increase throughput capacity. This paper discusses port improvements which will allow docking of New Panamax vessels alongside four berth segments, totaling 700m in length, originally designed and equipped for Panamax class ships. The increase in mooring and berthing load required upgrades to fenders and localized strengthening of the mooring hardware and berth structures. Dredging at the berth face was enabled through installation of toe walls to retain the existing under-wharf slope – a particularly challenging design for one segment with an existing toe wall. Ship to shore operations will be improved through procurement of larger gantry cranes in the future.

Innovative engineering allowed cost-effective upgrades which maximized reuse of existing infrastructure, with the constraint of maintaining container throughput during the construction period.

This discussion will be of interest and benefit to port planners and design engineers, specifically those adapting existing infrastructure to the ever-larger needs of the shipping industry.

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INTRODUCTION

The Manga Marine Terminal is located within Cartagena on the northern coast of Colombia, approximately 650 miles north of the Capital at Bogota and 330 sea miles east of the Atlantic mouth of the Panama Canal. Sociedad Portuaria de Cartagena (SPRC) owns, operates, and maintains this terminal in conjunction with nearby Contecar to the southeast. Together, they are one of the top five container handling entities in Latin America.

The Manga Marine Terminal was originally constructed in 1934 and expanded at a moderate pace through the late 20th century to incorporate products ranging from cruise to Ro/Ro, with the first container berth retrofits in 1985. Port operations are now focused around container transshipment along the marginal wharf and cruise ship services at two piers.

Growth in container handling has surged in recent years, precipitated primarily by the expansion of the Panama Canal and consequent demand for nearby, deep water berths and transshipment terminals. As the Manga Marine Terminal has reached its expansion capacity, SPRC is turning to modernization projects in response to increase throughput capacity. This paper discusses structural improvements which will allow docking of New Panamax vessels alongside four marginal wharf segments, totaling 700 meters in length, originally designed and equipped for Panamax class ships.

EXISTING CONDITIONS

The container wharf at the Manga Marine Terminal is 700 meters long and is comprised of three berths, designated as Berths 7, 8, and 9. Berth 8 is further subdivided into two sections, Berth 8 East (8E) and Berth 8 West (8W) which were constructed in different time periods using substantially different structural sections. The locations of these berths are shown in Figure 1. Each is a marginal, pile-supported wharf.

Berths 7 and 8, together totaling 538 meters in length, were designed and equipped for Panamax ships with a dredged depth of 13.2 meters, overall vessel length (LOA) of 295 meters, and vessel displacement of approximately 75,000 metric tons (MT). Mooring bollards at each berth were rated to 100 metric tons. Berth 7, part of the original terminal expansion, was converted to a container wharf in 1985; this retrofit included an outboard sheet pile toe wall and crane beams supported by concrete piles for the transition to container use. Both segments of Berth 8 were constructed for container vessel use.

Berth 9, completed in 2011 and 162 meters in length, was designed to accommodate Super Post-Panamax ships with a dredged depth of 16.5 meters, LOA of 366 meters, and vessel displacement of approximately 200,000 MT, on the assumption that Berths 7 & 8 would be upgraded in the future to allow full utilization of this capacity. Berth 9 was equipped with the same fender system as the adjacent Berths 7 and 8 to maintain a straight berthing alignment, but was designed to accommodate higher reactions and larger mounting surface required for a future upgrade to all fenders. Similar to the other berths, 100-MT bollards were provided along its length, with the exception of three (3) 225-MT bollards located at the west end. Again, these high strength bollards anticipated future upgrade to Berth 7 & 8.

DESIGN CRITERIA

The primary design criteria for the deepening project was the safe mooring and berthing of New Panamax container vessels at either end of the wharf. These two positions were selected in order to maximize operational flexibility, without the need to upgrade every bollard or the accompanying disruption to terminal throughput. The increased ship size, approximately 250% increase by displacement over the Panamax class, necessitates the following works:

- Dredging of the berth pocket and toe walls to support existing slopes and structures in place
- Fender upgrades for added berthing energy
- Mooring bollard upgrades to maintain operational wind criteria with larger vessels at berth
- Future upgrades to ship-to-shore (STS) cranes for additional outreach

Figure 1: Manga Marine Terminal & Berth Locations

Design Vessels & Dredge Depth

The MSC Beryl was identified as a suitable design vessel in the New Panamax class, as described in Table 1. Design dredge depth was set to 16.5 meters for the required underkeel clearance (UKC) for both New Panamax and Super Post-Panamax classes. Based on berth geometry and vessel proximity limitations, the largest ship which can be berthed concurrently is a 200-meter LOA feeder vessel.

Vessel Parameter	Units	MSC Beryl
Length Overall (LOA)	m	366
Length Between Perpendiculars (LBP)	m	350
Width/Beam (B)	m	48.4
Moulded Depth (D)	m	23
Design Draft (T)	m	13.5
Displacement at Design Draft	MT	182,665
Loaded Lateral Wind Area	m^2	11,500
Loaded Frontal Wind Area	m^2	1,550
Number of Mooring Lines	-	16
Mooring Line Type	-	Double Braid
Mooring Line Material	-	Nylon
Mooring Line MBL	MT	135

Table 1: Design Vessel Parameters

Environmental Limits for Operations

The design wind speed of 90 kilometers per hour (30-second average) was considered, in accordance with United Facilities Criteria (UFC) 4-159-03 *Type IIA, Standard Moorings* and the existing operational criteria. Hurricanes do not occur in Cartagena, and this design wind occurs with a return period greater than 1 year. Winds from the northeast to northwest quadrants cause the largest mooring loads and vessel motions, as the wind acts to push the vessel away from the berth. Due to the sheltered location, analysis demonstrated that the wave and current loads were not controlling criteria.

Fender Design Criteria

Berthing energy requirements were calculated in accordance with the recommendations of PIANC Maritime Commission Working Group Report No. 33, *Guidelines for the Design of Fenders Systems*. Maximum allowable hull pressure was limited to 200 kilopascal (kPa) for design of the steel fender panel. Results are shown in Table 2.

Design Parameter	Value
Abnormal Berthing Energy of New Panamax (kN.m)	1430
Recommended Fender	Trelleborg SCN1600 E1.2 or Equivalent
Rated Energy Absorption (kN.m)	1618
Rated Reaction Force (kN)	1955
Maximum Allowable Hull Pressure (kPa)	200
Minimum Required Fender Panel Area (m^2)	10.8

Table 2: Recommended Fender Parameters

Mooring Point Design Loads

A dynamic mooring analysis was conducted for the design vessel using aNyMoor software. 225-MT single bitt mooring bollards were selected for New Panamax bow and stern line locations, matching the type and capacity of the larger bollards installed at Berth 9.

For structural analysis of a mooring system, designers typically consider an allowable pull on each bollard equal to the safe working load (SWL). This ensures that the weakest link in the load path is the mooring line, followed by the bollard, then the structure. For the existing berths at Manga, the mooring points were envisioned as a closely spaced cluster of three bollards to reduce construction footprint, with approximately 6m between bollards in lieu of more conventional 18 to 24 meter spacing. Simple addition of the SWL for each bollard proved unrealistic and unmanageable for the existing structure with such close proximity between bitts.

In general accordance with PIANC Maritime Commission Working Group Report No. 153, *Recommendations for the Design and Assessment of Marine Oil and Petrochemical Terminals*, the total allowable bollard pull on each mooring point was ultimately determined by the following equation:

Mooring Load, $M = SWL\ [1 + 0.6\ (n-1)]$

$M = 495\ MT$

Where:

SWL = *Safe Working Load of individual bollard, 225 MT*

n = *number of bollards in cluster, 3*

While this method was conceived for quick release hooks, it has similar application to the Manga upgrades as it presumes that all three bollards in a mooring point will not experience maximal loads concurrently. The individual anchorage for each bollard was designed for the full SWL, maintaining the standard design practice of the mooring line being the weak link in the system.

GEOTECHNICAL ANALYSES & STRUCTURAL UPGRADES

Toe Walls

It was critical to preserve the existing slope under each wharf after dredging to maintain bearing pile support conditions and preclude lateral forces from downslope soil displacement. A toe wall was therefore required, both to accomplish the change in grade between existing and proposed mudline and for global stability of the existing wharf structure.

Slope Stability

Each section of wharf was evaluated for the existing and future dredge depth, including analysis of the existing cutoff wall, where applicable, and proposed toe wall. The effects of surcharge loads on the wharf structure and in the container yard behind the wharf were also investigated. Results show that the proposed deepening to 16.5 meters could be safely accomplished through installation of a toe wall at each berth with suitable embedment into the Cartagena Formation, the bearing stratum in this locality which is comprised primarily of hard clays.

Existing Foundation Capacity

Analysis showed that the existing pile foundations, especially the critical waterside crane beam (WSCB) piles, were embedded almost entirely in the active wedge of the retained soil mass and provide negligible restraint to the soil mass for small deflections. As such, the new toe wall would be the stiffest element in the global system and dictate the slope stability under the structure. To determine required toe wall moment of inertia, which in turn determines slope displacements, idealized deflections from bulkhead models were entered in the finite difference model of the WSCB piles as soil displacements. The resulting design moment and concurrent axial demand on the bearing piles were compared to the interaction diagram of the existing concrete piles to determine the maximum allowable toe wall deflection equal to 6 centimeters.

Retaining Wall Design

Improvements to the Berth 7 berth to accommodate the New Panamax vessel loads included addition of a new toe wall, landward of the existing toe wall, and a supplementary deadman system. The new toe wall at Berth 7 replaced an older generation of sheet piling (which was demolished and removed) and retains substantially more soil than Berth 8 toe walls. To maintain stability, it was determined the limits of the toe wall should extend from the active mudline to EL -29.0 meters at the tip, which is approximately equal to the tip elevation of the existing piles. A king pile wall system was selected to obtain appropriate stiffness; however, even the largest commercially available sections exceeded the soil deflection criteria of the existing bearing piles (6 centimeters) when used as a cantilever retaining wall. Consequentially, alternatives were investigated to anchor the bulkhead.

Ultimately, the king piles were extended to the deck elevation and incorporated into the fascia beam to provide lateral restraint to the bulkhead. Intermediate sheet piling was cut off at the active mudline to save material costs. This design allows for king pile installation fully above water. Intermediate sheet piling is also threaded into the interlock above water, then driven to grade using a follower. Subsea soil anchors were considered as an alternate anchorage method but were ultimately discarded due to capital cost and equipment availability. Overall lateral capacity of the wharf was augmented with new tie rods and landside deadman pile pairs. See Figure 2 for a typical Berth 7 section view.

Further complicating the toe wall installation, the Berth 7 structure included existing batter piles, with the pile inclining toward the waterside and penetrating the toe wall alignment at approximately the design dredge depth. Soil exfiltration at the penetration was minimized by arranging bulkhead elements to frame each batter pile with minimal tolerance. This was accomplished using AU 20 intermediate sheet piles, which are nearly equal in width to the existing batter pile, and alternating single/paired HZM king piles. This unique arrangement, as shown in Figure 3, also fits the existing structure bent-to-bent spacing of 6.0m exactly, allowing uniform detailing down the length of the wharf.

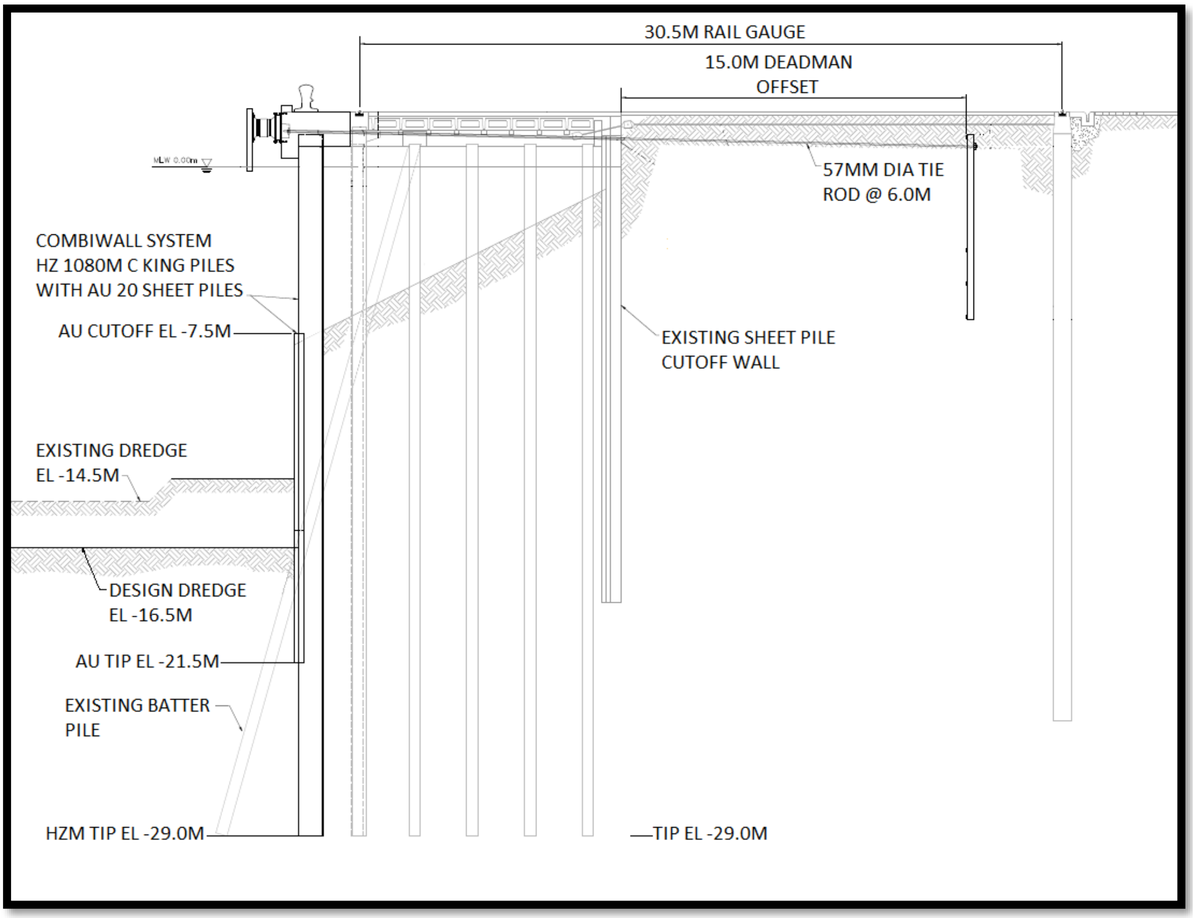

Figure 2: Berth 7 Section

Installing the toe wall landward of the existing berth face provided ancillary benefits in the form of additional vertical support to the WSCB, which may be required for future STS crane upgrades, and zero extension into the berth pocket – maintaining the same berth face as the current berth configuration. For a king pile toe wall in particular, the depth of the section is significant. Installation waterside of the fascia would have relocated the berthing line substantially, reducing the STS crane efficiency and relative reach.

Conversely, toe walls for Berths 8E and 8W were designed as conventional, cantilever steel sheet pile bulkheads, installed immediately outboard of the fascia beam. The difference in design section compared to Berth 7 was primarily due to the existing slope under these wharf segments, which was both steeper and dredged deeper, minimizing load imparted on the toe wall. The pre-existing toe wall at Berth 7 had a cutoff elevation of -8.0 meters, whereas the Berth 8 slope toe elevation was -13.5 meters.

Installation of the Berth 8 toe wall outboard of the fascia beam reduced disruption to wharf operations, requiring temporary removal of fenders but no additional work on the concrete wharf elements. See Figure 4 for a representative typical section view of Berth 8.

A toe wall was not required for Berth 9 by original design.

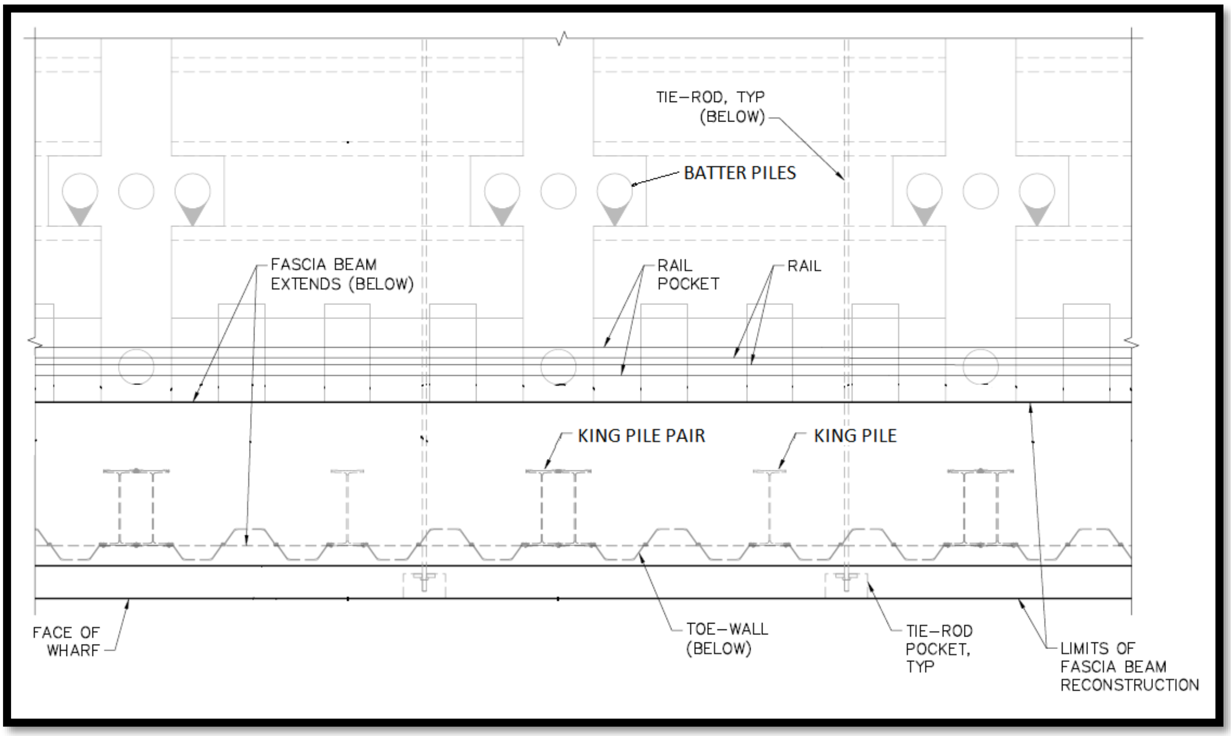

Figure 3: Berth 7 Toe Wall Arrangement

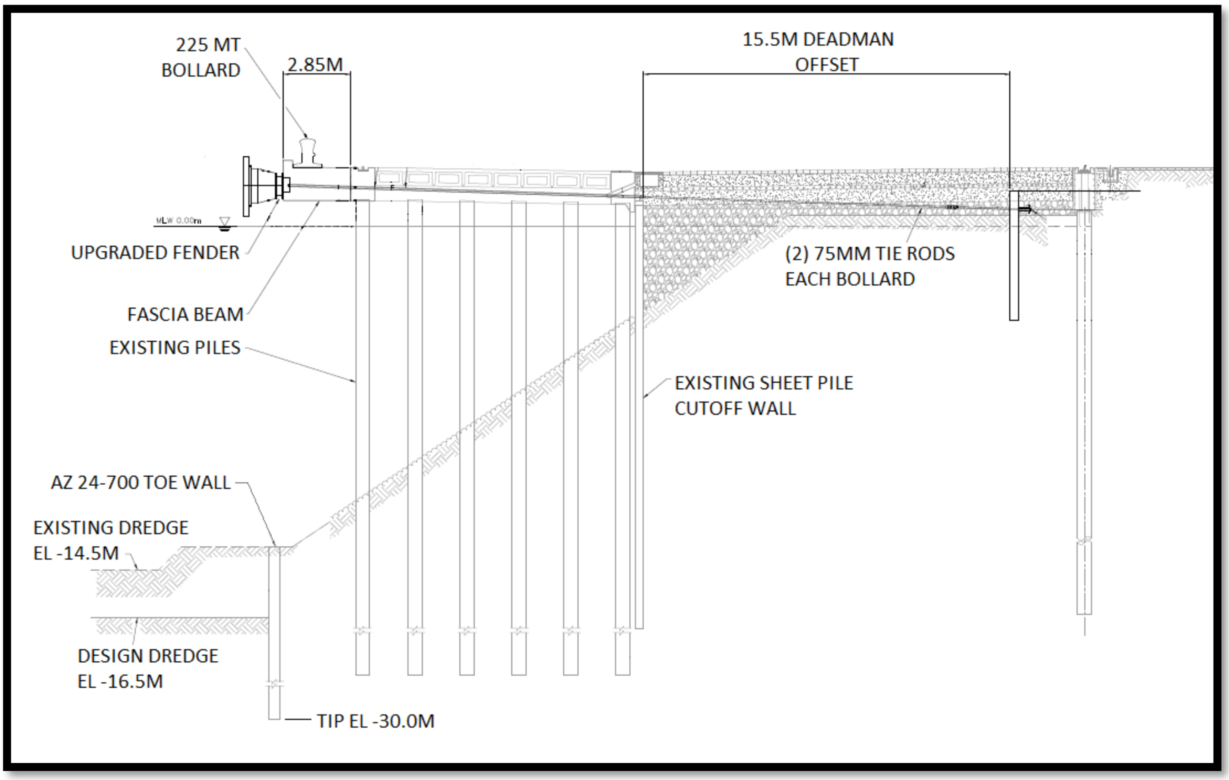

Figure 4: Berth 8 Typical Section after Upgrades

Fenders

Existing fenders were a combination of Bridgestone SUC 1000H and Marine International MCS 1000 cell fenders, spaced 6 to 18 meters on center typically. Based on the berthing energy calculation, the existing fenders do not have sufficient capacity to accommodate the New Panamax; therefore, a new fender program was selected for the berths.

To limit the required crane outreach, reduce fender submersion, and fit elements to the small existing fascia, a dual system was selected with two SCN 1100 fenders sharing a single panel, depicted on Figure 5. The existing cell fenders were removed and replaced with these cone fenders. The new fender systems were located approximately 18 meters on center. This was determined to agree with bent-to-bent spacing of approximately 6 meters.

The change in fender system type increased the load imparted on the structure from vessel berthing impact. Additionally, the dual system required individual elements to be located on either side of the existing bent caps, whereas existing fenders were located directly at transverse beams. Therefore, localized reinforcement of the fascia beam was also required.

Fender element design also included a small spool piece, which increases standoff and maintains safe ship clearance to the fascia and toe wall. This is especially important at Berth 8E and 8W, where the toe wall was driven immediately outboard of the fascia beam. The spool piece also permits slightly larger spacing between fender elements, thus reducing the total number required.

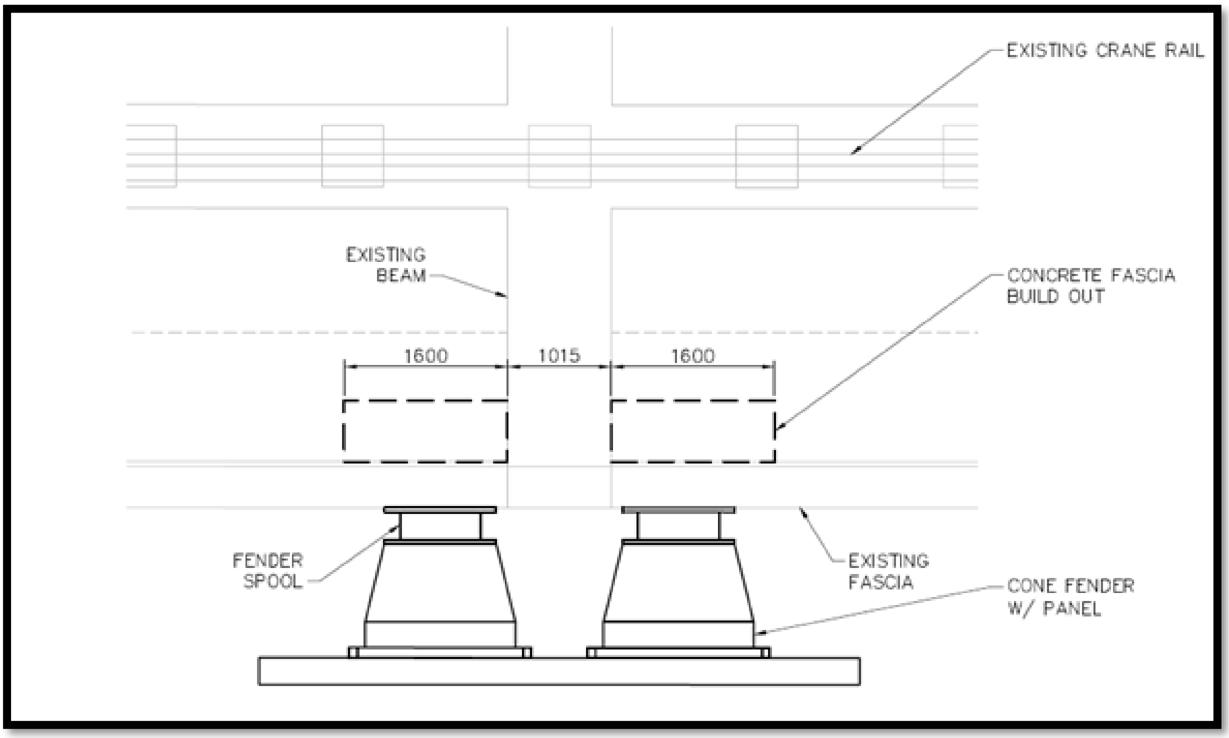

Figure 5: Fender System Layout

Mooring Points

To facilitate the plan for berthing of the New Panamax ships at either end of the terminal, additional 225-MT three-bollard groups were added at 3 locations (9 total new bollards). These larger capacity mooring points resulted in higher loads imparted on the wharf structures. To resist the lateral load, reconstruction of approximately 18 meters of the fascia beam and installation of additional anchors – tie rods and sheet pile deadman – was required at each cluster location. The existing plumb piles were determined sufficient to absorb the increased longitudinal loads at each cluster in Berth 8E and 8W.

Variations on the theme were required for each mooring point. At Berth 7, given the age of the structure and uncertainty in the as-built details and condition, cased drilled shafts were added to support the additional longitudinal loads. At Berth 8W, the existing pile caps run parallel to the wharf face, and short transverse beams were added to balance vertical loads and moments at the fascia beam.

The existing 100-MT bollards were left in place along the remainder of the structure as they were determined to be suitable for spring lines for the New Panamax vessels and as mooring points for smaller vessels utilizing the berths.

Future Gantry Crane Upgrades

Evaluation of the existing gantry crane rail foundation system was completed. Currently, each berth is outfit with crane rails at 30.5-meter gauge, suitable for the current generation of Post-Panamax STS cranes. Vertical capacity of the berths was originally designed considering 46 ton per meter crane wheel loads and 50 kilopascal (kPa) uniform live load. The larger container cranes required to serve the newest container ships have wheel loads ranging from 74 ton per meter to 97 ton per meter, depending on the manufacturer and specific operational requirements. As these higher wheel loads exceed the allowable capacity of the existing pile foundations, before larger cranes are employed at Manga, localized strengthening of pile foundations at each crane beam will be required.

Alternatives investigated for future crane rail improvements included additional piles and crutch bents or installing new steel pipe pile sleeves over the existing concrete piles. A determination of the optimal course will be made during final design.

CONCLUSION

The deepening project will greatly expand the operational capabilities of the Manga Marine Terminal and enhance Cartagena’s reputation as one of the top transshipment locations in Latin America. Through targeted structural modifications, the existing wharves will meet new demands economically and with minimal disruptions.

At the time of this writing, the upgrade projects are partially complete. Toe walls have been installed and the fascia of Berth 7 has been reconstructed and anchored. Since initial analysis and design, a mooring buoy has been installed approximately 40 meters west of Berth 9. Mooring point construction is pending, with potential layout modifications accounting for the additional buoy. Fender design will also consider reuse of fenders recently removed from the Contecar facility.

REFERENCES

PIANC (2002) Maritime Commission Working Group Report No. 33, *Guidelines for the Design of Fenders Systems*, PIANC, Brussels.

PIANC (2016) Maritime Commission Working Group Report No. 153, *Recommendations for the Design and Assessment of Marine Oil and Petrochemical Terminals*, PIANC, Brussels.

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