

DESIGN OF CONTAINER YARD AT PORT OF BALBOA

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ABSTRACT

Committed to converting the Port of Balboa into a major transshipment hub, Panama Ports Company (PPC) launched in 2006 a \$300-million expansion program to increase berthing and stacking space that would almost triple the port capacity. The site's history of marine-related activities, deteriorating facilities, buried structures, and poor soils mandated significant investment in clearing and preparation. Of the 25-hectare container yard to be built, about 15 hectares were dredged to remove poor soils and reclaimed by filling/compacting with imported sand. Ground conditions in a 5-hectare area were also improved by a wick drain and surcharge program.

Most container yards in North America are built with continuous asphalt or jointed portland cement concrete (JPCC) pavement. However, the Balboa yard features a discrete paving system for container stacking that is suited for rubber-tire gantry (RTG) crane operations. It consists of narrow reinforced concrete (RC) beams (serving as container bases) with a thin asphalt sealed crushed rock base around them. Support for the RTGs consists of continuous jointed RC strip footings, with JPCC pavement provided at yard tractor lanes and other roads for circulation of reach stackers and empty container handlers. In addition to providing savings relative to the continuous PCC solution, this discrete system eliminates container stacking on sloped planes, which is undesirable for very high stacking.

This paper describes the design and construction processes associated with site improvement and the pavement system. Traffic demand on truck and passing lanes was evaluated based on estimated throughput including the effects of container type, size, block size and dwell time. The design followed the 1993 AASHTO Guidelines. Load equivalency factors were used to account for non-linearity of axle load effects from different yard equipment. Finite element modeling was used to determine short-term load demands on pavement elements to account for complex loading conditions.

BACKGROUND

In 2006, Panama Ports Company (PPC), a division of Hong Kong-based Hutchison Ports Holdings, embarked on a \$300-million expansion program at the Port of Balboa, Panama. The main features of this project, known as the “Phase 4 expansion,” were the construction of a 440-meter (1,443 feet) marginal wharf and the development of approximately 25 hectares (62 acres) of container yard (CY). The Phase 4 expansion project followed CY reclamation (Phase 1); Berth 16 construction (Phase 2); and the southbound extension of Phase 1 and the construction of the Berth 15 yard and Berth 17 (Phase 3).

The design of the Phase 4 CY expansion had to deal with challenges stemming from deteriorated marine facilities built almost 100 years ago, buried utilities and structures, and, most importantly, unsuitable soils. Site preparation involved a combination of dredging to remove poor soils, land reclamation by filling with sea sand, vibro-densification to increase the sand fill density, and a ground improvement program involving wick drains and surcharge.

Unlike most North American container terminals, where either asphaltic concrete pavement (ACP) or continuous jointed portland cement concrete (JPCC) pavement are the preferred choices, the pavement system at Balboa is a discrete system, comprised of a series of long, narrow reinforced concrete (RC) strip footings serving as runways for rubber-tire gantry (RTG) cranes, with isolated narrow RC strip footings (set perpendicularly to the RTG runways) serving as bases for containers, and a thin asphalt sealed crushed rock base between container bases. This pavement system was used in the CY areas completed earlier.

Because the Phase 4 CY expansion would be a longitudinal extension of the Phase 1 CY, PPC chose to maintain the discrete system pavement solution with modifications related to drainage and container stacking and truck and passing lane surfaces. In Phase 1, RTG runways were set up at different elevations and drainage was provided at every two container blocks with inlets located along passing lanes. In Phase 4, RTG runways were at the same elevation with the leveled container bases, which eliminated stacking containers on sloped planes. Under this scheme, drainage inlets were located within the stack. Additional modifications of the new yard involved the use of JPCC pavement in truck and passing lanes—ACP had been used in Phase 1.

This paper describes the different pavement elements used in the Phase 4 CY, the analysis to estimate load demands, and the design and construction of the CY.

PROJECT BOUNDARIES AND PHASING

Figure 1 shows the area to be reclaimed and the boundaries of the Phase 4 CY expansion area. To hand over CY space gradually, the 25-hectare CY expansion was divided into two areas: CW1 (10 hectares [25 acres]) and CW2 (15 hectares [37 acres]).

Figure 2 shows the CW1 and CW2 CY layouts, including the project boundaries.

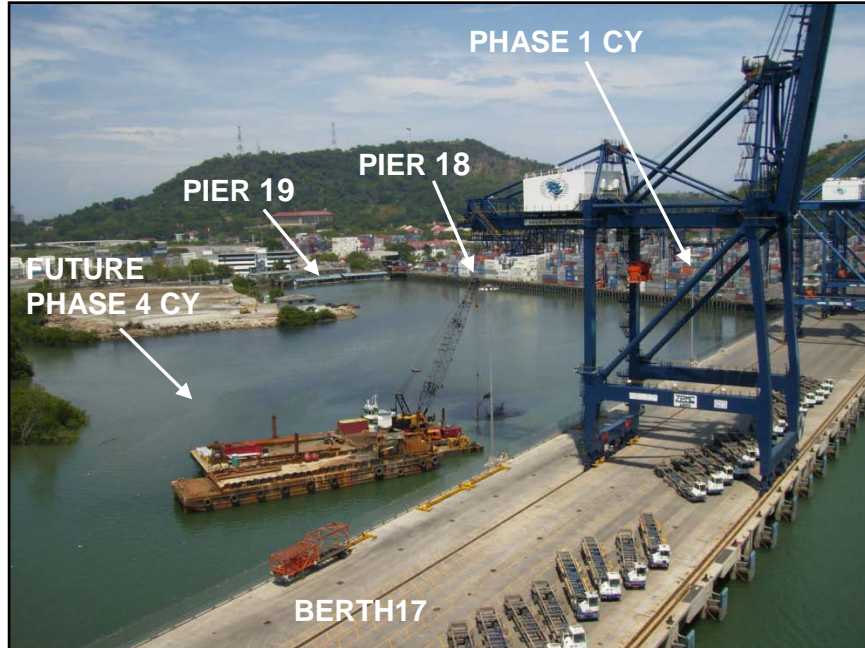


Figure 1. Project Site.

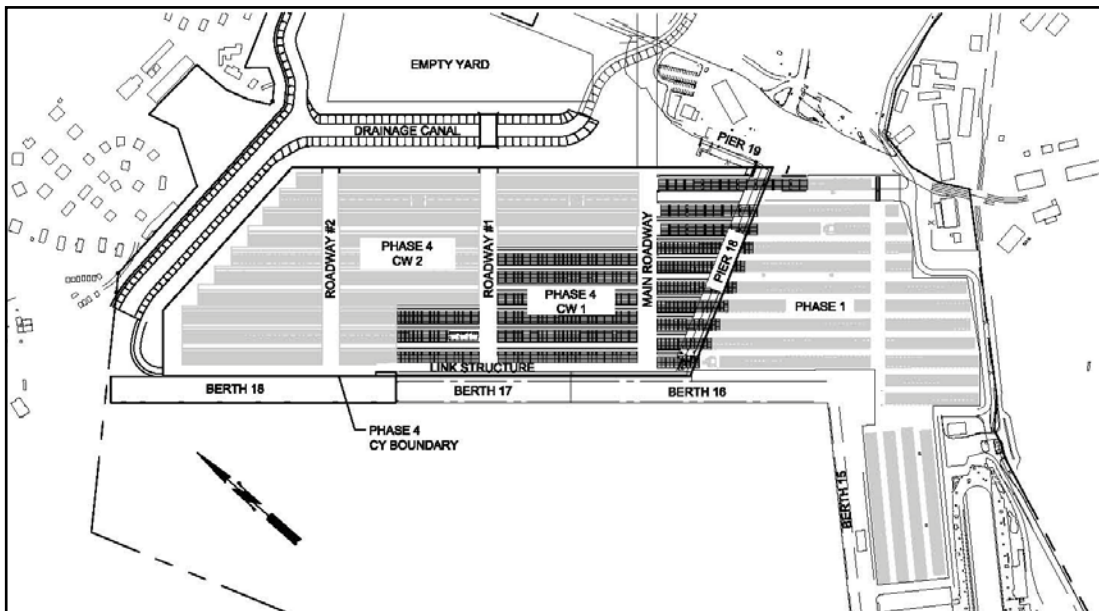


Figure 2. Project boundaries and phasing.

The stepped interface between CW1 and CW2 was dictated by the land reclamation sequence and PPC’s desire to maximize the availability of yard stacking near the operating berths as paving construction progressed. The CW1 area is surrounded by an operating finger pier (Berths 16 and 17) and two 1914 vintage piers (Piers 18 and 19). A 20-meter-deep (66 feet) rock dike was constructed along the back of the finger pier to contain the sand fill. The CW2 area is bounded along the west side by the new Berth 18 wharf and along the east side by an open channel built as part of an existing

river diversion. About 60 and 40 percent of the CW1 and CW2 areas, respectively, are reclaimed from the bay.

Pier 18 provides a transition between the existing Phase 1 and CW1 CYs. This pier, built circa 1914, displays deterioration in the RC stringers and slab deck and structural evaluation revealed its condition was adequate for stacking only empty containers or, at best, single stacks of laden containers. This situation meant that transitioning from the Phase 1 CY to the new Phase 4 CY had to address the deficiencies of Pier 18 so that yard equipment could operate safely.

GROUND IMPROVEMENT PROGRAM

The extent of unsuitable soils, namely OH and SM type, triggered an extensive dredging program to remove and replace them with marine fill sand. Nearly 15 hectares (37 acres) across the Phase 4 expansion area were dredged. The sand was imported by a trailer suction hopper dredge. The CW1 area was subjected to a vibro-densification program with target relative density set at 65 percent achievable by poking in a 3-meter (10 feet) triangular grid. Target densities were verified through extensive cone penetration testing (CPT). Five hectares (12 acres) of land within the CW2 area were improved through a supplemental program of wick drains and surcharging. Settlement of this area is being monitored. Reclaimed CW2 areas will also be vibro-densified.

CONTAINER YARD LAYOUT, OPERATIONS, AND EQUIPMENT

In the Phase 4 CY, the typical arrangement of container stacks is six wide and six high—one higher than in the Phase 1 CY. Figure 3 shows a cross section of the CY north of the main roadway. The layout features enough space for hatch cover laydown and traffic lanes east of Berth 17 and along the new Berth 18.

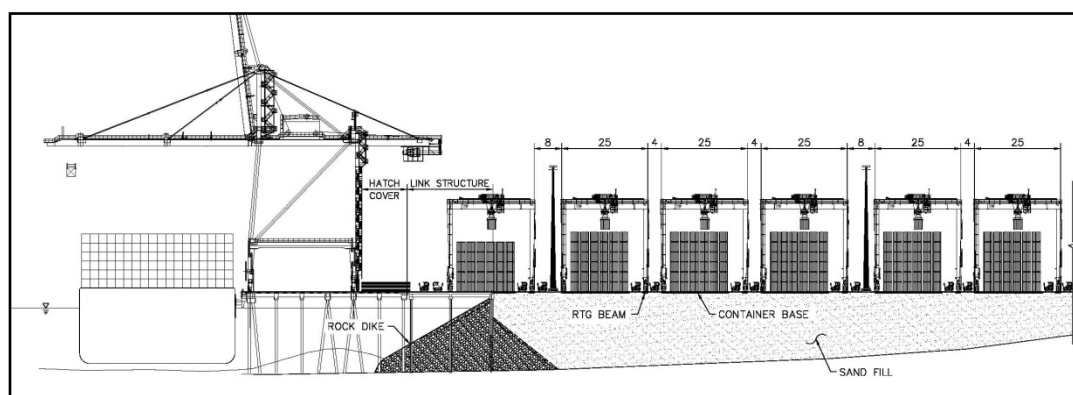


Figure 3. Yard cross section – north of main roadway.

The basic stacking plan shown in Figure 4 highlights the unique features of the Balboa container yard: the container bases are laid discretely and modularly in plan to enable the stacking of either 20- or 40-foot containers, with some stacks dedicated to reefer containers. RTG crane runway support is provided through longitudinal strip footings for all stacks.

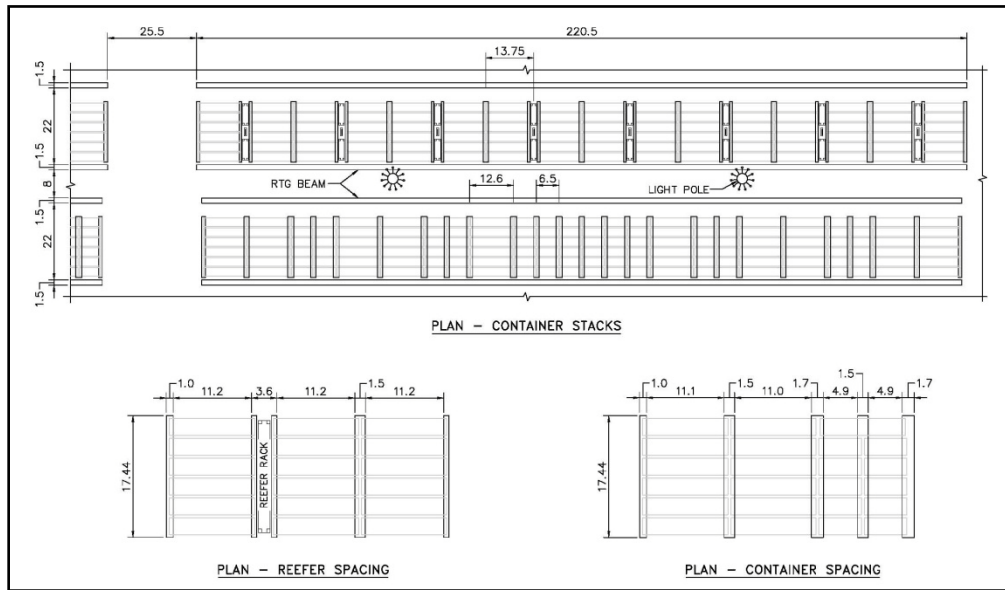


Figure 4. Basic container stacking plan.

Important CY equipment includes 1-over-6 RTG cranes (six containers wide plus truck lane), yard tractors, reach stackers, and empty container handlers. The latter two are intended to transit using only the main roadway. Design axle loads associated with the different equipment are reported in Table 1. Container corner loads for different stacking heights were adopted from the guidelines of the British Ports Association (1996). Corner loads associated with a 40-foot container (30-tonnes rated load) were, respectively, 75, 135, 180, 210, 225, 265 and 310 kN (1kN = 0.225 kips) for stacking 1, 2, 3, 4, 5, 6, and 7 high. The values for stacks higher than one include a reduction coefficient.

Table 1. Yard Equipment Wheel Loads

Axle	Load				
	Yard Tractor (tonnes)	Empty Handler (tonnes)	Reach Stacker (tonnes)	RTG	
				Transiting (tonnes)	Operating (tonnes)
Front	7.9/20.0 *	46.1 (24.4)	100.0 (30.0)	23.0	37.2
Back	37.0**	(12.7)	(29.0)	-	-

Notes: 1. Numbers in parenthesis refer to unloaded condition
 2. RTG loads are loads per wheel (four wheels per side)
 *Front and middle axles, respectively
 **Tandem axle

DESCRIPTION AND DESIGN OF PAVEMENT COMPONENTS

The main components of the Phase 4 CY included RTG concrete runway beams at same elevation, discrete concrete bases for container support at the same level as the RTG runways, and JPCP pavement on truck and passing lanes, with a compacted crushed rock base with single asphalt seal between container bases. A subbase was not required because of the good characteristics of the compacted fill sand subgrade.

Figure 5 shows these elements in typical pavement cross sections at and between container bases.

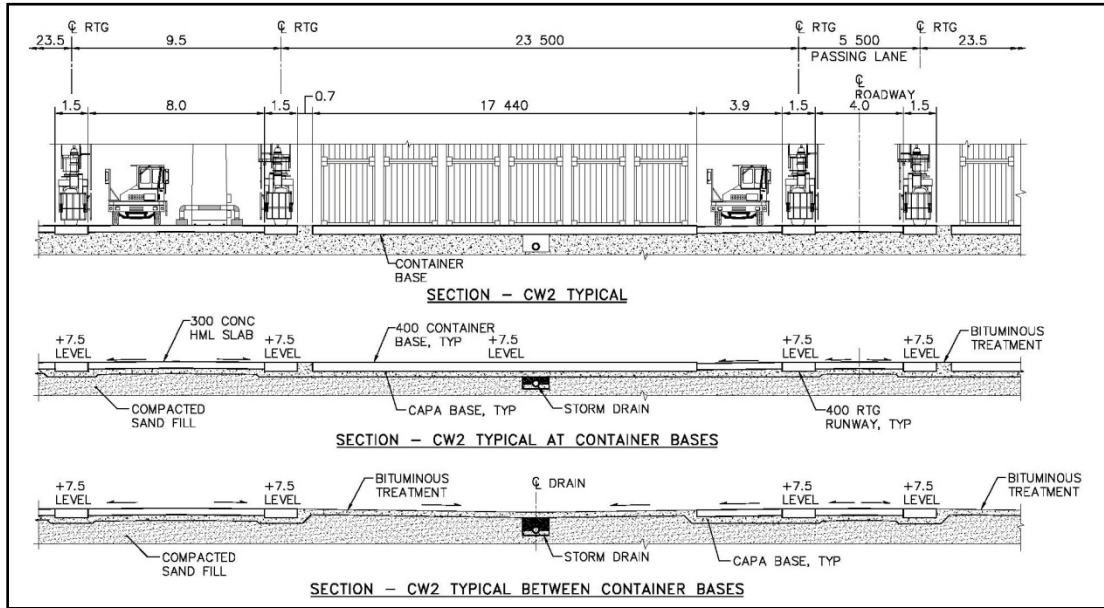


Figure 5. Typical pavement cross section.

RTG RUNWAY BEAMS

RTG runway beams were analyzed as long RC beams supported on springs assuming a subgrade reaction modulus, k_s , of 200 pci. The beams were subjected to loads associated with RTG cranes (see Table 1) and applied as either static (operating) or moving loads. Figure 6 shows loading conditions on an RTG runway beam. Loads simulate working and gantrying conditions.

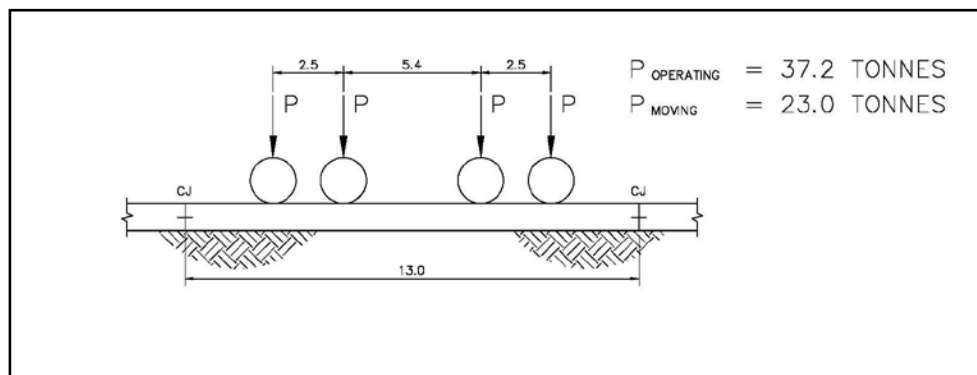


Figure 6. Loads on RTG runway beam.

RTG runway beams are 1.5 meters wide and 0.4 meter deep with control (doweled) joints spaced every 13 meters. A typical cross-section is shown in Figure 7. Heavier RTG cranes are used in the Phase 4 CY, and their runway beams are therefore deeper than those in the Phase 1 CY. The control joints in the Phase 4 CY were spaced to line up with the module of the container bases. The spacing also was chosen to avoid

cracking because of shrinkage—making the beam longer would have required more longitudinal steel to control shrinkage.

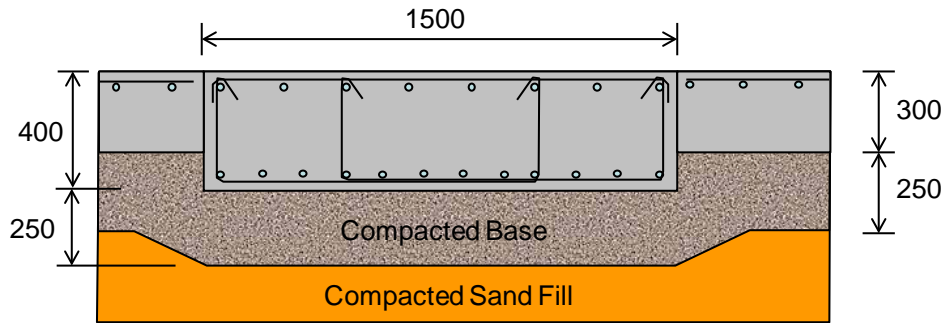


Figure 7. RTG runway beam detail.

The bottom reinforcement of the RTG runway beams was designed to limit the stress level to about 20 ksi (140 MPa). This stress level is intended to prevent fatigue problems in straight deformed reinforcing bars.

CONTAINER BASES

Container bases were modeled as beams on elastic foundations assuming a subgrade reaction modulus, k_s , of 200 pci. Container bases are 1.5 meters (4.9 feet) wide, 0.4 meter (1.3 feet) deep and 17.4 meters (57 feet) long. Container corner loads were modeled as static point loads along the base length on each side, applied at locations dictated by container casters. Container loads correspond to stacks of six-high 40-foot containers. Different container arrays were combined to determine loads that resulted in critical bending, transverse shear, and torsional demands. Figure 8 shows a typical cross-section of a container base.

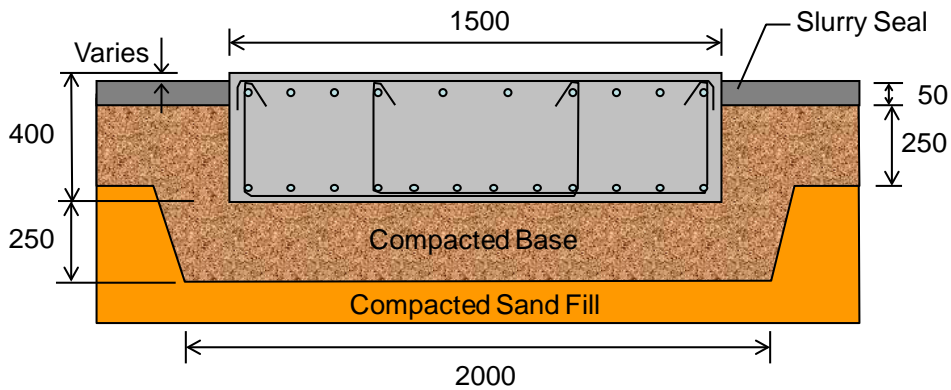


Figure 8. Container base detail.

As an example of the finite element analysis output that was obtained, Figure 9 shows bending moment intensities about the strong axis of a container base due to factored dead load plus container loads positioned close to the middle of the base. The depressed container base zones (blue color) show the critical location for this specific loading condition (bending moment close to 222 kN.m/m [50 ft.kip/ft]). Design

moments and forces were determined based on enveloped values resulting from all loading cases considered.

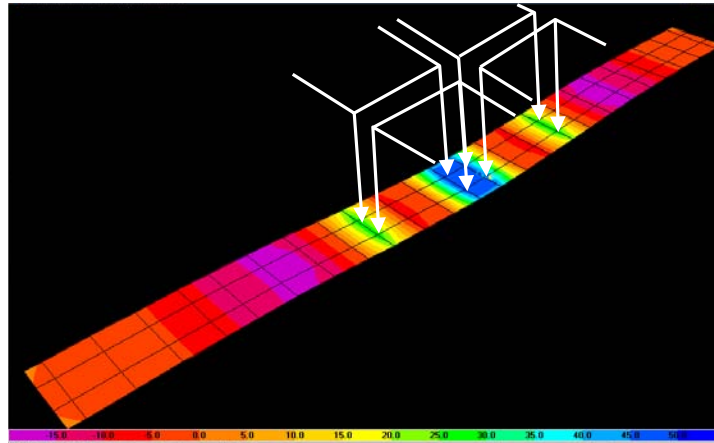


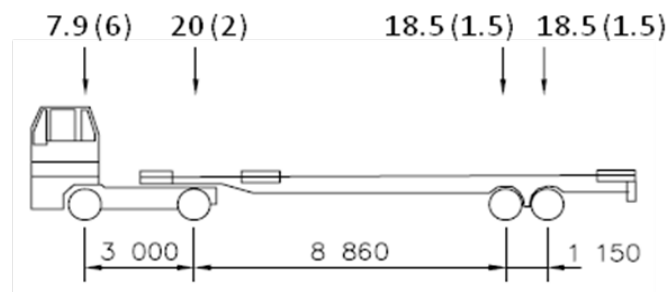
Figure 9. Finite element modeling of isolated container base.

JPCC PAVEMENT

Designing the JPCC slabs at truck lanes, passing lanes, and access roadways required assessing three major factors: traffic demand, pavement foundation characteristics, and the pavement design procedure.

Traffic demand (in cycles) on truck lanes was evaluated based on estimated container stack throughputs. The demand is a function of the distribution, density, dwell time, ratio of box size to that of a 20-foot box, and the type of containerized operations (trans-shipment, imports, and exports). The analysis also accounted for the fact that tractors are unloaded on half their route. The analysis was conservative and did not distinguish between container weights for import, export, or trans-shipment operations; instead, the wheel loads represented fully loaded containers.

The results indicated a demand of almost 2 million yard tractor cycles for the service life of the CY pavement in the busiest truck lanes (near the berth). Traffic loads were determined by converting wheel loads into 18 kip (8.2 tonnes) equivalent single-axle load (ESALs) repetitions. Figure 10 shows the axle load distribution in a yard tractor.



- Notes: 1. Axle loads in tonnes
2. Numbers in parentheses refer to empty tractor

Figure 10. Yard tractor axle loads.

Load equivalency factors, LEF , were defined to account for nonlinearity of axle load effects. Invoking the fourth power equation, LEF values for rigid pavements were

defined as $LEF = \left(\frac{P_i}{P_{ref}} \right)^4$ where P_i is the given axle load and P_{ref} is the reference load,

i.e., 8.2 tonnes. For tandem axles, the reference load is approximately 15.2 tonnes. For rigid pavements, this leads to LEF values of 0.9, 35.4, and 35.1, for front single, middle-single, and tandem axles, respectively, in a loaded tractor. In an unloaded tractor, $LEF = 0.3$ for the front axle. LEF values for the other axles are negligible. Because each of these axle loads is applied at every truck passage, the overall truck factor, TF , necessary to determine the equivalent total number of ESALs is evaluated as a weighted average of the different $LEFs$. Thus, the total ESAL per year is about 35.8 times the number of truck cycles. Although an estimate of terminal traffic growth could assess the ESAL evolution more closely through the service life of the pavement, for simplicity, this analysis assumed a constant ESAL for every year.

The calculation of the pavement thickness, D , for truck lanes was carried out per the AASHTO 1996 guidelines assuming a 200 pci subgrade modulus. The latter is a realistic value for a system combining a sand fill with 65 percent relative density and $N = 25$, and a compacted crushed base with $CBR = 70$. Setting both the directionality and lane factors equal to unity and based on previous experience, the concrete pavement thickness was designed as 0.3 meter in truck and passing lanes and 0.35 meter in main roadways.

JPCC slabs were designed as two-way slabs with a top steel reinforcing mat intended to control shrinkage cracking and miscellaneous slab deformations, and debonded dowels at control joints to transfer shear forces between the slab panels. Figure 11 shows a typical cross-section at a control joint.

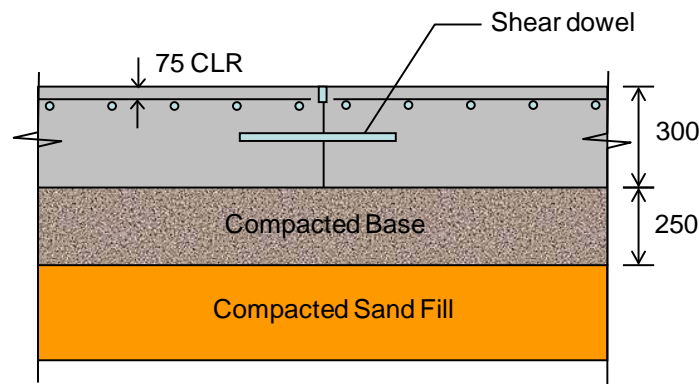


Figure 11. JPCC slab and joint detail.

TRANSITION BETWEEN PHASE 1 AND PHASE 4 CONTAINER YARDS

ACP of varying thicknesses and in lifts of 75-mm was placed south of Pier 18 as a transition surface for the yard equipment (including RTG cranes) from the Phase 1 CY to the Phase 4 CY and vice versa. At Pier 18, to avoid the impracticalities and high costs associated with an underside structural strengthening, a 0.28-meter-thick RC overlay was cast over the existing deck (see Figure 12 for CW1 south under

construction). This structural overlay spans from bent to bent as support for RTG cranes and truck transit from the Phase 1 CY to the Phase 4 CY and vice versa.



Figure 12. CW1 Yard Construction.

CONCLUSIONS

This paper describes the features, analysis, design and construction process of a remarkably useful pavement system implemented as part of the phase 4 container yard expansion at the Port of Balboa, Panama. The system, which is not used in North American container terminals, is made up of narrow RC strip footings that provide support to RTG cranes and container bases, and JPC slabs at tractor and traffic lanes. Different levels of complexity were adopted for the analysis and design of each pavement element. The CW1 project is close to completion. The entire project is expected to be complete by the end of year 2010.

REFERENCES

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