Overview

• Location

• Balboa Phase 4 Expansion Project

• Container Yard
  – Operations
  – Equipment
  – Traffic Demand Evaluation

• Pavement Design and Construction

• Conclusions
Location
Balbo Phase 4 Expansion Project

• $300M project. One of the largest in the western hemisphere amidst a worldwide recession.

• Goal: More than double current terminal throughput.

• Main Components:
  – 25 Ha Container Yard (CY) (15 Ha to be Dredged/Reclaimed)
  – 400 m Berth 18 construction
  – Extensive dredging

• Master Planning described by Zinserling et al (2010)

• Challenges
  – Tight Schedule; Construction in active terminal
  – Dredging of Organic/Unsuitable materials
  – Buried structures and deteriorated infrastructure
  – Diversion of 2 rivers
  – Staged CY construction and hand over of finished CY areas
What’s Unique in the Balboa Container Yard?
Project Boundaries and Phasing
Container Yard

Note: Dimensions in meters
Building on the Past, Respecting the Future

CY Pavement Components

Note: Dimensions in meters
## CY Equipment and Container Loads

<table>
<thead>
<tr>
<th>Axle</th>
<th>Yard Tractor (tonnes)</th>
<th>Empty Handler (tonnes)</th>
<th>Reach Stacker (tonnes)</th>
<th>RTG Transiting (tonnes)</th>
<th>RTG Operating (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front</td>
<td>7.9 / 20.0 *</td>
<td>46.1 (24.4)</td>
<td>100.0 (30.0)</td>
<td>23.0</td>
<td>37.2</td>
</tr>
<tr>
<td>Back</td>
<td>37.0**</td>
<td>(12.7)</td>
<td>(29.0)</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Notes:**
- Numbers in parenthesis refer to unloaded condition
- RTG loads are loads per wheel (2 wheels per corner)
  * Front and middle axles, respectively
  ** Tandem Axle

- Container corner loads: 7.7 tonnes (laden 40’ box; use reduction coeff. for high stacking)
**Traffic Demand Evaluation**

- Goal: estimate number of truck passes through CY service life and convert into standard equivalent single axle loads (ESALs).
- Port of Balboa is a trans-shipment facility. Most of the traffic is generated by on-terminal movements. Some off-terminal movements to and from rail yard.
- Key aspects:
  - Premium CY areas see more traffic than others.
  - Number of truck passes depends on:
    - Container stacking layout and height
    - Density, Shuffling of boxes
    - Dwell Time
    - Load distribution in containers
    - Ratio of 40’/20’ boxes
- No. of truck cycles in 20 years = 200,000 to 1,000,000
- How to convert this number into ESALs?
ESAL Conversion Example: Assume 500,000 cycles (2 trips/cycle)

\[
LEF = \left( \frac{P_i}{P_{ref}} \right)^4
\]

\[
\begin{align*}
7.9 \ T & \quad 20 \ T & \quad 18.5 \ T & \quad 18.5 \ T \\
\bigg( \frac{7.9}{8.2} \bigg)^4 & = 0.9 & \bigg( \frac{20}{8.2} \bigg)^4 & = 35.4 & \bigg( \frac{37}{14.5} \bigg)^4 & = 42.4 \\
\end{align*}
\]

\[
TF = \frac{(0.9 + 35.4 + 42.4)(500,000) + (0.3 + 0.004 + 0.002)(500,000)}{1,000,000} = 39.5
\]

\[
ESAL = 39.5 \times 1,000,000 = 39,500,000 \text{ passes} !!!!!
\]

LEF = Load Equivalency Factor
TF = Truck Factor
Pi = Axle Load
Pref = Reference Axle Load

What are the implications on pavement design?
Pavement Design and Construction

• Design
  – Traditional Approaches:
    • Nomographs
    • Design Tables
  – Codes:
    • British Ports Association (BPA) Pavement Design Guidelines
    • AASHTO

• Construction Challenges
  – Coordination with marine contractor
  – Staged handover of finished CY areas
  – Existing yard constraints
  – Drainage issues
  – Location of utilities; Manholes outside trafficked areas
• Design Considerations:
  – Subgrade Modelling (Spring Constant Evaluation)
  – Boundary Conditions of Discrete Pavement Elements
  – Loading Conditions
    • Static
    • Dynamic
  – Load Combos
  – Design Checks
    • Serviceability
    • Strength
    • Fatigue of Concrete
    • Fatigue of Steel Reinforcement
  – Joint Detailing

Impacted by large ESALs
• RTG Runways:
  – Beams on springs
  – Finite Elements

Thin runway. Poor reaction distribution

Deeper runway. Better reaction distribution

Shrinkage/Restraint Crack

Tensile stress distribution
• Container Bases: Stacking variations are endless!
• Container Bases: What can Finite Elements do for you?

- FEA used to evaluate flexural and shear stresses for wide variety of stacking scenarios
- Stress evaluation essential for fatigue control
• JPCC Slabs (Thickness verified with old AASHTO equation)

\[
\log_{10} w_{18} = Z_R S_o + 7.35 \log_{10} (D + 1) - 0.06 + \frac{\log_{10} \left[ \frac{\Delta PSI}{4.5 - 1.5} \right]}{1 + \frac{1.624 \times 10^7}{(D + 1)^{8.46}}} + (4.22 - 0.32 P_t) \log_{10} f_c C_d \left( D^{0.75} - 1.132 \right) \\
215.63 J \left( D^{0.75} - \frac{18.42}{\left( \frac{E_c}{k} \right)^{0.25}} \right)
\]
• RTG Runways:

• Container Bases:

• JPCC Slabs:

CY Pavement – Typical Sections and Joint Details
Building on the Past, Respecting the Future

CY Pavement Construction

PORTS 2010
CY Pavement Construction
Operations Under Way
Conclusions

• The discrete pavement system at Balboa involves the use of concrete strip footings for container stacking and RTG transiting, and JPCC paving for yard tractor traffic. More important than costs, the operator is used to it.

• Traffic demand evaluation for design of truck lanes, passing lanes and roadways can be as sophisticated as desired.

• Finite Element Analysis is a powerful tool for analysis of this type of pavements.
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