ROLLER COMPACTED CONCRETE

DESIGN AND CONSTRUCTION FOR INTERMODAL TERMINALS

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ABSTRACT

Roller Compacted Concrete Design and Construction for Intermodal Terminals

With the tremendous growth in intermodal traffic, railways need to fast track the expansion or replacement of existing intermodal transfer facilities. This report describes the pavement design and construction for Canadian National’s (CN) new intermodal terminal in Edmonton, Alberta that opened on time and on budget, October 2nd, 2001.

The new terminal is strategically located between two mainline subdivisions and is adjacent to excellent highway truck access. The location can also accommodate extensive future expansion.

To support the significant wheel loads generated during container transfer operations, various pavement structures were evaluated. The use of roller compacted concrete (RCC) was selected to meet structural requirements and balance design economy with an extremely tight timeline to construct. The pavement structure consists of 2 – 8 inch lifts of RCC over a 10 inch compacted granular base. The paper will also describe the previous field-testing undertaken to evaluate and improve surface bond between RCC layers. As a result of these tests, a light surface scarification of the base layer of RCC was incorporated into the construction sequence with excellent results. In total, over 110,000 square yards of RCC pad was placed in just under 30 days.
INTRODUCTION - PROJECT OVERVIEW

Intermodal traffic comprises containers that move from origin to destination by a combination of truck, train and ship. With significant ongoing and projected growth in intermodal traffic, CN’s existing intermodal terminal in Edmonton, Alberta, Canada had essentially reached full operating capacity with no viable option for further expansion.

In 1999, CN embarked on a 3 phase, 30 year strategic plan for the staged development of a new intermodal rail terminal to be located in northwest Edmonton. The new facility is strategically located to provide excellent roadway and rail access, with the Yellowhead Highway to the south and the terminal situated between two mainline subdivisions. In addition, the development of this facility presented an opportunity to relocate the existing terminal from a developed area, resulting in a reduction in truck traffic and related operational noise through an adjacent residential community. In consideration of this, the design of the new terminal incorporated a depressed terminal grade line as well as berming along the east side of 184 Street to mitigate potential future noise and visual impact concerns.

The terminal layout consists of a central roller compacted concrete (RCC) pad between 7,500 feet (2,300 m) long pad tracks that connect to the mainline tracks at each end of the terminal. The RCC pad accommodates the rail stacker crane used to transfer containers between rail cars and trucks. To support the significant wheel loads from the stacker crane operation a 16 inch (400 mm) RCC pad thickness (placed in 2 – 8 inch (200 mm) lifts) over a 10 inch (250 mm) granular subbase was
selected. To enhance the bond between lifts an innovation developed by UMA incorporated a light surface scarification immediately in advance of the second lift.

Site drainage utilizes an on-site stormwater management pond that collects all drainage from the site for pre-treatment through an oil/water separator prior to a controlled release (to maintain desired water levels) into the adjacent Kinokamau wetland.

Terminal Notes

Roller Compacted Concrete: 92,500 tons (94,000 tonnes) covering an area of 111,230 square yards (93,000 m²) placed over a period of roughly 30 days between June 15, and July 14, 2001.

Track: Approximately 12 miles (19 kms) of new track constructed between April 15 and September 15, 2001.

Facility: The terminal facility built within a $25 million (CAN) overall budget included property acquisition, environmental permitting, detailed design, site engineering, grading, drainage, RCC pad, trackage, asphalt roadways, automated entrance gate, operations center, maintenance facility, communications, yard air and lighting.


ROLLER COMPACTED CONCRETE

Overview

Roller compacted concrete (RCC) consists of the same material components, i.e. Portland cement, fly ash (optional), coarse to fine aggregate and water, and is designed to achieve equivalent or higher compressive and flexural strengths to that of conventional concrete pavements. The RCC is placed at zero-slump through a paver and is compacted in place with a vibratory roller (similar to an asphalt paving operation). This method of placement allows for a large amount of concrete to be placed quickly without the need for forms, dowels or reinforcing steel. Significant cost savings can be realized by combining the inherent efficiencies of this paving technique with the final product of a rigid, high strength Portland cement concrete pavement. The RCC pavement surface however is generally rougher than conventional concrete pavement which has tended to limit its application to terminals and load out facilities accommodating heavily loaded vehicles travelling at low speeds. RCC pavements have been used for streets and highways but these applications generally require an asphalt overlay to improve surfacing and ride quality characteristics.

Mixing, Placement, Compaction and Curing

RCC is typically mixed on site in a continuously mixing pugmill plant. The aggregate and cement is proportioned on conveyor belts and fed into the pugmill where they are mixed with the relatively small amount of water necessary to produce a stiff, zero-slump concrete. The freshly mixed RCC is collected into a small hopper and deposited into end-dump trucks for transport to the paver.
The RCC is placed with a paving machine onto a compacted base course over a prepared subbase surface. Immediately after placement, the RCC is compacted to specified densities with a dual-drum vibratory steel roller. The maximum thickness of a lift of RCC is generally limited by the paver capacity and the ability of the rollers to effectively compact through the full depth of the layer. The maximum uncompacted thickness is therefore usually about 10 inches (250 mm), with a compacted final thickness of between 8 to 9 inches (200 – 225 mm). For thicker pavements, 2 or 3 layers or lifts of RCC may be required. Placing RCC in layers unfortunately creates a horizontal joint or plane between the layers. Sufficient bond needs to be developed between these layers in order to produce a monolithic RCC pavement structure. To achieve this, the time between placement of the next layer needs to be as short as possible (generally less than 60 minutes, depending on ambient conditions of temperature and humidity) so that the underlying layer is still relatively fresh and has not set up before the next layer is placed. It should be noted that although this timeline was adhered to on an earlier project, core samples extracted showed a poor bond between layers. This initiated a test program to evaluate alternate methods to enhance the bond between layers of RCC (discussed in more detail in a following section).

Once placed, compaction of the RCC is accomplished by self-propelled vibratory steel wheel and rubber tired rollers. Rolling generally commences within 10 minutes of spreading and should be completed within 45 minutes. A rolling pattern needs to be established that will achieve the required density with a minimum number of roller passes. The required wet field density for RCC should be between 98-100% of the maximum wet density obtained by ASTM D1557, with no individual test below 95%.
Once compaction has been completed the RCC pavement should be cured for a period of 7 days or until the concrete has reached a minimum strength of 2,900 psi (20 MPa). Water curing or the application of a specified asphalt emulsion or membrane-forming curing compound can be used to ensure proper curing. The RCC pavement should be allowed to more fully cure, typically for 28 days to reach design strengths before being placed into service.

**RCC Pavement Design**

In order to accommodate the heavy wheel loads associated with container transfer crane operations, a rigid pavement structure is generally recommended. As indicated, the use of RCC was selected to meet these structural requirements and balance design economy with an extremely tight timeline to construct. The proposed stacker crane used for this design is a Fantuzzi RS-50 (RS-70 also evaluated) with a front axle weight of 254,000 lbs (1131 kN) when fully loaded.

The RCC thickness design was undertaken using the method described in “Structural Design of Roller-Compacted Concrete for Industrial Pavements” developed by the Portland Cement Association. This design was compared with results obtained using software developed for Concrete Thickness Design for Airport and Industrial Pavements, also developed by the Portland Cement Association. The results varied somewhat based on the parameters used but were generally found to be consistent. The WinPAS Pavement Analysis Software (based on the 1993 AASHTO Guide Procedure for the Design of Pavement Structures) was also investigated but this procedure was not used, as the results are not considered to be valid for rigid pavements greater than 12.5 inches (320 mm) thick.
The design considered a subgrade California Bearing Ratio (CBR) of 3.5% with a ¾ in (20 mm) minus well graded crushed gravel base course compacted to 100% Standard Proctor Density at or near optimum moisture content. The RCC was required to have a minimum flexural strength of 700 psi (4.8 MPa), equating to 5,000 psi (34.5 MPa) compressive strength concrete.

With due consideration to paver and compaction depth limitations and to avoid the extra cost associated with a third lift, an RCC final pavement thickness of 16 inches (400 mm) made up of 2 – 8 inch (200 mm) lifts, over a 10 inch (250 mm) compacted granular base on the prepared subbase was ultimately selected.

**Site Specific Cost Comparison**

Once the RCC pavement design had been established, a cost comparison with other equivalent pavement structures was undertaken prior to proceeding with the final recommendation for RCC pavement (see Table 1). Although it should be emphasized that these cost comparisons are only valid for this specific project (owing to local material costs, aggregate availability and subgrade conditions), the RCC pavement was found to be the least cost alternative as compared with equivalent pavement structures using asphalt pavement or conventional cast-in-place concrete.
Construction Summary

With the required environmental permitting in place, initial site grading commenced in September of 1999. The site grading also included the stockpiling of alumina and silica rich clay for use in the manufacture of cement (part of the property acquisition arrangements with the previous landowner). Site drainage construction followed, incorporating on-site storage for stormwater management with pre-treatment (through an oil/water separator) prior to discharge into the adjacent wetland. A control structure was also constructed for ultimate discharge into the City’s storm sewer system.

With preliminary site work complete, the bulk of the terminal construction was undertaken between May and September 2001. Work completed during this period included:

- final site grading and subbase preparation;
- roadbed and track construction;
- RCC pad, granular storage areas and asphalt access roads;
- office and equipment garage facilities; and
- utility installation, yard air, power, lighting, water and communications.

As mentioned, RCC placement of 92,500 tons of material covering an area of 111,230 square yards was placed over a period of 30 days between June 15 and July 14, 2001.
The primary application of RCC has been for concrete gravity dam construction involving the placement of RCC in continuous 18 – 20 inch (450 – 500 mm) layers to a final height of 5 to 10 feet (1.5–3 m). The common method to achieve adequate bond between the layers in this mass concrete application is to clean the concrete by wet sandblasting, high-pressure air or water jet blasting prior to placing the subsequent lift. To avoid loosening aggregate and/or loosing good material, this cleaning operation is done after the initial concrete set (1 – 3 hours depending on temperature and humidity). For structural concrete like RCC pavement it is critical that the entire lift be fully consolidated through proper compaction and that adequate bonding between layers is achieved. Although pavers of today can accommodate placement of RCC in uncompacted layers of 10 – 12 inches (250 – 300 mm), core samples have shown reduced consolidation in the bottom couple of inches in these maximum depth lifts. It is generally accepted that sufficient bond can be developed at the horizontal interface providing the bottom lift has not reached initial set, however, this initial set time can vary from just a few minutes to up to 60 minutes, making it difficult to place the next lift before the bottom lift has started to set. If the top lift cannot be placed while the bottom lift is still fresh, it is recommended that a cement slurry be used as a bonding agent prior to placement of the next lift.

Although the time between lifts was limited to less than 60 minutes for a previously completed RCC project, core samples extracted still often came out in two pieces, with no appreciable bond between lifts. Segregation was also evident in the bottom 1 – 2 inches (25 – 50 mm). In light of this and
prior to undertaking the Edmonton Intermodal Project, a test program was initiated to evaluate various methods for improving RCC consolidation and bonding.

The test program undertaken in 2000 at CN’s Sarcee Intermodal Facility in Calgary, Alberta covered an area of 2,700 square yards (2,268 m²) and provided an opportunity to evaluate different RCC placement methods, with and without vibration through the paver, and investigate different techniques to improve the bond between lifts. In addition to the application of a cement slurry between lifts, a light surface scarification (less than one-half inch (5 mm)) on the surface of the base lift was also investigated. Figure 1 is a plan of the test locations and Table 2 is a summary of the core samples extracted from this pavement after 28 days.

Although the tests were far from conclusive, a number of observations were made that were beneficial in the development of the RCC specifications for the Edmonton Intermodal Project. The difference between areas where vibration was applied and where it wasn’t did not appear to effect the overall product; generally the concrete strengths were met or exceeded with good consolidation evident throughout. Vibration through the paver for each lift was subsequently specified for the RCC placement at Edmonton.

As for improving the bond between lifts, it was noted that although the bond was generally good where the cement slurry was used (with the exception of core #2), the difficulty in being able to apply the slurry in a uniform manner and the additional labour effort associated with this work was felt to limit its effectiveness. It was also noted that it was more difficult to rollout the top lift of RCC over the area with the cement slurry as the mat tended to slip along the surface of the slurry.
Alternately, good bond results were found where a light surface scarification was applied to the bottom lift prior to placing the top lift. For the test section this was achieved with the blade of a motor grader lightly scarping across the surface. It is believed that this light scarification tended to break the surface glazing caused by the roller, providing a roughened surface and opportunity for enhanced bonding. Although the method used to achieve this scarification was thought to require further refinement, the concept was adopted for the Edmonton Project with excellent results.
CONCLUSION

The use of roller compacted concrete is a viable alternative that should be considered when designing pavements for intermodal transfer facilities. Designs incorporating RCC pavement can be completed quickly and realize cost savings without sacrificing pavement strength requirements. For CN’s new Edmonton Intermodal Terminal Facility, a 16 inch (400 mm) thick RCC pavement was able to be placed over an area in excess of 100,000 square yards in roughly 30 days.

Although RCC pavements have been around for some time, additional research and development is still required to enhance and improve on this type of pavement structure. Results obtained from previous work revealed a problem with obtaining proper bond between layers. Once realized, a test was developed to evaluate different methods for improving this bond. As a result of these tests, the implementation of surface scarification between layers was incorporated into the construction sequence for the Edmonton project with excellent results.

After one year in operation, the RCC pavement is performing as intended under the heavy loading and service conditions that had been anticipated.
### TABLE 1 - Cost Comparison

<table>
<thead>
<tr>
<th>Pavement Structure</th>
<th>Estimated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alternative 1</strong></td>
<td></td>
</tr>
<tr>
<td>RCC Pavement</td>
<td></td>
</tr>
<tr>
<td>16” (400 mm) RCC Pavement @ $50/m²</td>
<td>$4,600,000</td>
</tr>
<tr>
<td>10” (250 mm) Crushed Granular Base @ $18/tonne</td>
<td>$950,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$5,500,000</td>
</tr>
<tr>
<td><strong>Alternative 2</strong></td>
<td></td>
</tr>
<tr>
<td>Conventional Asphalt Pavement</td>
<td></td>
</tr>
<tr>
<td>8” (200 mm) Asphalt @ $55/tonne</td>
<td>$2,400,000</td>
</tr>
<tr>
<td>12” (300 mm) Crushed Granular Base @ $18/tonne</td>
<td>$1,150,000</td>
</tr>
<tr>
<td>16” (400 mm) Granular Subbase @ $15/tonne</td>
<td>$1,300,000</td>
</tr>
<tr>
<td>30” (700 mm) Granular Subbase @ $10/tonne</td>
<td>$1,650,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$6,500,000</td>
</tr>
<tr>
<td><strong>Alternative 3</strong></td>
<td></td>
</tr>
<tr>
<td>Conventional Concrete</td>
<td></td>
</tr>
<tr>
<td>12” (300 mm) Concrete @ $230/m³</td>
<td>$7,000,000</td>
</tr>
<tr>
<td>10” (250 mm) Crushed Granular Base @ $18/tonne</td>
<td>$950,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$7,950,000</td>
</tr>
</tbody>
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Figure 1 - Consolidation and Bond Test Locations
<table>
<thead>
<tr>
<th>Core No.</th>
<th>Dia. (mm)</th>
<th>Length (mm)</th>
<th>Density (kg/m³)</th>
<th>Strength (MPa)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Top</td>
<td>100</td>
<td>210</td>
<td>2,457</td>
<td>26.2</td>
<td>Core came out in one piece with little to no segregation evident.</td>
</tr>
<tr>
<td>1 Bottom</td>
<td>100</td>
<td>225</td>
<td>2,475</td>
<td>35.6</td>
<td></td>
</tr>
<tr>
<td>2 Top</td>
<td>100</td>
<td>220</td>
<td>2,447</td>
<td>32.2</td>
<td>Core came out in two pieces, no bonding evident between lifts.</td>
</tr>
<tr>
<td>2 Bottom</td>
<td>100</td>
<td>220</td>
<td>2,466</td>
<td>37.1</td>
<td></td>
</tr>
<tr>
<td>3 Top</td>
<td>100</td>
<td>220</td>
<td>2,432</td>
<td>35.5</td>
<td>Core came out in one piece, some segregation at bottom of each lift.</td>
</tr>
<tr>
<td>3 Bottom</td>
<td>100</td>
<td>210</td>
<td>2,461</td>
<td>37.7</td>
<td></td>
</tr>
<tr>
<td>4 Top</td>
<td>100</td>
<td>230</td>
<td>2,442</td>
<td>37.0</td>
<td>Core came out in two pieces, no appreciable bond.</td>
</tr>
<tr>
<td>4 Bottom</td>
<td>100</td>
<td>240</td>
<td>2,398</td>
<td>34.5</td>
<td></td>
</tr>
<tr>
<td>5 Top</td>
<td>100</td>
<td>210</td>
<td>2,427</td>
<td>34.2</td>
<td>Core came out in one piece, very little segregation evident.</td>
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<tr>
<td>5 Bottom</td>
<td>100</td>
<td>255</td>
<td>2,488</td>
<td>49.3</td>
<td></td>
</tr>
<tr>
<td>6 Top</td>
<td>100</td>
<td>185</td>
<td>2,435</td>
<td>32.3</td>
<td>Core came out in one piece, very little segregation evident.</td>
</tr>
<tr>
<td>6 Bottom</td>
<td>100</td>
<td>255</td>
<td>2,463</td>
<td>33.5</td>
<td></td>
</tr>
</tbody>
</table>

Density Conversion: \(2,457 \text{ kg/m}^3 \times 0.06242 = 153.3 \text{ lb/ft}^3\)

Strength Conversion: \(26.2 \text{ Mpa} \times 145.04 = 3,800 \text{ psi}\)
Figure 2 - Edmonton Intermodal Terminal - Construction Sequence

Figure 3 - Rail Stacker Crane
Figure 4 - RCC Mixing Plant in Operation

Figure 5 - RCC Paving Operation
Figure 6 - RCC Base Lift Surface Scarification After Rolling

Figure 7 - RCC Top Lift Placement
Figure 8 - RCC Placement Adjacent to New Track

Figure 9 - RCC Surface Scarification Between Layers (foreground) / Roller Compaction (background)
Figure 10 - RCC - SS-1 Curing Compound Application

Figure 11 - RCC Surface with Tack Coat Curing