Roller-Compacted Concrete Pavement, An Industry Perspective

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Abstract

This paper presents a summary of findings and experiences in implementing Roller-Compacted Concrete Pavement ("RCC Pavement") at industrial distribution facilities. The author's experiences in RCC Pavement involved defining and taking complete responsibility from concept to completion, including but not limited to, material selection, mixture design, structural design, production, transportation, placement and curing. Using ten-plus years of experience and incorporating pertinent research findings, processes and tests lead to the development of Quality Assurance ("QA") Processes and Quality Control ("QC") tests/observations. Continuous improvement has been made on developing a QC program. The author's experiences involved the use of RCC Pavement as a finished surface and dictated a high performance RCC Pavement (compressive and flexural strength as high as 40 MPa and 5MPa, respectively after only 7 days); therefore, all placement utilized an ABG paver and vibrating screed with dual tamping bars to obtain high density RCC Pavement while minimizing roller displacement and maximizing smoothness and riding characteristics of the final RCC Pavement surface. Size of the projects has limited these experiences to production of RCC Pavement through the use of either a wet-batch concrete plant or a dry-batch concrete plan in conjunction with a horizontal shaft mixer.

Significance

The goals of this paper are to identify the significance of specific research to the practitioners in the development and acceptance of RCC Pavement as a pavement choice, to present findings and experiences in the implementation of RCC Pavement within the industry, and, to help identify what additional research tools and information would aid in furthering the acceptance of RCC Pavement.

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Introduction

Some features and benefits used in the consideration of RCC Pavement are as follows:

- Speed of Construction (placed without forms, finishing or surface texture).
- Decreased downtime (due to early strength gain RCC Pavement can obtain 20 – 25 MPa compressive strength in 36- to 48-hours).
- Economics (taking into account the life-cycle costs and little, if any, long-term maintenance costs of RCC Pavement over its life).
- High strength and increased durability.

Present applications of RCC Pavement have been limited to high-load storage yards, intermodal container terminals, low-speed drive and parking lots. It is the opinion of the author that with advances in mixture development that permits the design of RCC Pavement with optimum packing densities (Marchand, Gagne, Ouellet and Lepage, 1997), research demonstrating RCC Pavement frost durability and de-icer salt-sealing resistance (Portland Cement Association RD-135, 2004) and recent fatigue test results of RCC Pavement (SEM Report 20213, Canadian Cement Association, 2003), that many more applications for RCC Pavement will be considered in the near future. Performance based specifications on design-build projects should allow for the consideration of RCC Pavement for more road applications.

RCC Pavement Material Selection. Binder contents around 12%, approximately 300 kg/m^3, generally ensure a sufficient paste volume to fill voids between aggregate particles in addition to providing the mortar necessary to obtain a closed surface. Experience demonstrates that it works best to use conventional aggregates generally used in concrete or asphalt production as the supply consistency is verified and can be monitored to maintain consistency in accordance with established procedures. Sufficient fine particles (*i.e.* passing 75um or the #280 sieve), generally in the 6% to 8% range, are needed for workability of the final RCC mixture and subsequent density of consolidation of the RCC Pavement. If additional fine particles are needed, very successful projects have been completed using limestone screenings or mineral admixtures, such as fly ash, as partial sand replacement. Chemical admixtures were not utilized in any RCC mixtures in which the author was involved.

Using marginal aggregates and industrial wastes can not only causes significant strength reduction (Hague, 1981), but can also reduce the durability of RCC Pavement in general. The author has used marginal aggregates and industrial waste in the structural base of large industrial floor slabs. In this application the structural base is not subject to saturation in conjunction with freeze-thaw cycles or de-icer salts, therefore abrasion resistance is not necessary. Once the facility is protected from the weather, the slab is finished by covering with a bonded overlay using

conventional concrete to obtain the smoothness and flatness requirements needed for a high-storage, industrial facility.

In the author's experience, more research effort is needed to develop alternate structural base mixtures to be used in lieu of the gravel utilized in typical roadway construction, particularly when mixtures that use industrial by-products are developed. In addition to the improved structural performance and environmental benefits of this type of roadway base, covering the sub-base with an impervious surface would greatly enhance the constructability of the final roadway pavement.

RCC Pavement Mixture Proportioning Methods. Many RCC mixture-proportioning methods exist and examples are summarized in RD 135 (Portland Cement Association, 2004). The author's experience has been limited to designs of RCC Pavement mixtures using the soil compaction concepts method and with optimum packing density method (Marchand, Gagne, Ouellet and Lepage, 1997). The soil compaction concepts method fixes the fine to coarse aggregate proportions according to suggested graduation curves (ACI Committee 325, 1995). Development of a PC-based software that would allow the determination of optimum packing densities would be an invaluable tool as this model could not only be used for the initial design of RCC Pavement, but also used in the field to recalculate the optimum proportions of an RCC mixture. Using this optimum packing density model method has not only created mixtures that have made 98% to 100% compaction consistency achievable in the field, but RCC mixtures designed in this method have allowed for some very successful projects in which up to one-half of the binder used was Class C fly-ash. On future projects, the intent is to replace 7% – 10% of the cement with silica fume as recent studies have shown the use of silica fume contributes to improving the frost durability and de-icer salt-sealing resistance of RCC mixtures (RD-135 Portland Cement Association, 2004). This same report also summarizes tests of experimental pavements built more than 10 years ago in which non air-entrained mixtures have not suffered from internal cracking or surface scaling.

Structural Design. The structural design procedure follows the methodology used for concrete pavements. The thickness design procedure uses the subgrade support, vehicle loads, flexural strength value (test method ASTM C78) and fatigue stress relationships (Portland Cement Association IS 233.01P, 1987). More research is needed to confirm the fatigue stress results of SEM 2020-13 (Canadian Cement Association, 2003). As documented by Piggott, one of the most surprising observations in this study (Piggott 1999) is there is little evidence of "faulting" (loss of load transfer) at joints. Further study to document load transfer across saw-cut joints and uncontrolled cracks is needed. More research is needed to investigate a controlled cracking system deliberately inducing frequent cracks to minimize crack width and maximize load transfer capability by maintaining good aggregate interlock (Shahid and Tom, 1996).

Placement. All the procedures generally associated with concrete placement apply, but due to the low moisture content, RCC is much more susceptible to segregation

and loss of moisture to evaporation. The ability to achieve 98% to 100% in place compaction, obtain a closed surface to reduce permeability and obtain sufficient compaction air voids, necessitates that QA and QC procedures are more stringent than conventional concrete. Successful projects start with an RCC mixture design which results in a mixture that allows for 98% to 100% compaction consistently achievable in the field and uses high density paving machines to achieve 95% compaction through the paver so that when the field compaction is completed by the roller, surface deviations are minimized. Since the early 1990's, RCC Pavement with riding qualities equal to new concrete or asphalt pavements have been built (Piggott, 1999).

Attention to detail during placement and the sequential order of the process is essential to ensure a quality RCC Pavement project. Parameters that are critical to RCC Pavement placement are as follows:

- Minimizing segregation of the larger aggregates from the balance of the RCC mixture.
- Maintaining consistency of moisture content is vital to allow RCC Pavement mixtures to be placed by high-density pavers.
- Preventing loss of moisture to evaporation from RCC Pavement mixture at any point in the process, from the time the mixture is produced until the time the curing compound is applied.
- Recognition that even though RCC Pavement can support a 12-ton roller immediately behind the paver, that RCC Pavement is still a concrete that can easily be damaged in the early stages.
- Assure that subgrade is damp prior to RCC Pavement placement to minimize moisture loss from the RCC Pavement mixture to the subgrade.
- Dampen, and if practical, slightly disturb, any existing RCC Pavement surface prior to placement of new RCC Pavement against these surfaces.
- Prohibit placement of fresh RCC Pavement over the top of existing RCC pavement material, even if existing RCC Pavement material is fresh.
- Prevention of random shrinkage cracking in RCC Pavements by saw cutting with an early entry saw in the first 6 – 8 hours after placement.

A few earlier experiences include use of asphalt personnel to place RCC Pavement and unauthorized aggregate substitution in production of RCC Pavement material. The details of the specific problems encountered are too long to list, but the corrective action of using an ultra-thin bonded concrete overlay to restore the surface with a durable and abrasive resistance surface has been used to successfully restore these pavements.

The owner should retain an engineer experienced with the design and placement techniques to achieve the best results for the intended project (Arland and Zamensky, 2000).

Quality Assurance and Quality Control. Common in-place density testing is through the use of a calibrated nuclear density meter. The moisture content of the aggregates and the RCC mixture should be monitored, when well calibrated these meters tend to give somewhat consistent and reliable wet density measurements. Generally an independent testing agency is recommended for the following:

- Oversee that aggregate supplier sampling procedures meet approved standard and tolerances (Arland and Zamensky, Table 44, 2000).
- Verify source of constituents matches those used to design RCC mixture.
- Assure that RCC mixture composition complies with design mixture.
- Before and throughout production, measure aggregate moisture content and adjust the volume of mixing water added accordingly.
- Monitor workability of consistency using the Vebe Test, as necessary.
- Establish Modified Proctor Compaction Test (ASTM D1557) relationship between moisture content and dry/wet density. Yields a maximum dry and wet density at optimal moisture content.
- Determine reference wet density of fresh RCC with modified Proctor Test. (NOTE: Using determined wet density, weigh a quantity of fresh concrete corresponding to the volume of the test specimen to be produced. If mold is either under filled or overfilled using this volume, then this is an indication that something in the mixture has changed.)
- Make test beams and carry out flexural testing in accordance with ASTM C78.

The snowball test is a quick and simple method of checking moisture level in fresh RCC material. The procedure is to pack RCC into a ball and then twist to shear the ball into two halves. If ball crumples, material is too dry. If ball sticks together and will not shear in half, material is too wet. If ball successfully shears into two halves, it indicates a good moisture level. Generally, keeping RCC material 1% or so above optimum still provides for a material that can be placed and rolled. If moisture level is too much above optimum, the material will not support the paver screed and additionally the material may stick to the roller drum and rolling to obtain the necessary consolidation will not be possible.

Curing. Given the low water content of RCC Pavement, it is essential to stop loss of surface moisture using proper curing techniques. Due to cost considerations, the author has never used wet curing, as this is recommended for seven continuous days. Conventional white pigmented highway curing compound works quite well, but dosage should be a least twice the dosage recommended by the manufacturer. It is

very important to mist the fresh joint and RCC Pavement surfaces to keep moist until the curing compound can be applied. Premature drying of the surface will subsequently reduce the durability of the surface.

Costs. Due to the all the facets of RCC Pavements based on the author's experience, it works best if performance criteria are used to define the pavement parameters. The owner should retain an independent experienced professional to define the QA processes and QC test/observations necessary to monitor the pavement process. Prior experience indicates the best scenario is for the owner to retain the independent experienced professional up-front to develop the RCC Pavement mixture using the available local aggregates. The verified RCC Pavement mixture mechanical properties can then be utilized in combination with the applied design loads and existing subgrade limitations to perform a structural design which will yield a pavement thickness. The up-front costs associated with the RCC Pavement mixture development and resulting pavement thickness will be more than offset by the cost that the project bidders would have to build into their quotations had this preliminary work not been completed. Over the years, the author has had numerous requests to bid on public projects in which the specification identifies all the RCC Pavement mixture specifics, states how and what equipment is needed to mix the RCC Pavement materials, identifies what equipment is acceptable to place the RCC Pavement and spells out the placement method in addition to identifying all the control variables, but yet this same specification defines the performance requirements and associated contractor penalties for noncompliant final product. Similar to providing a complete cookie recipe defining which ingredients and what proportion are to be used, stating the mixing and baking instructions, but yet this same recipe also defines the taste and appearance requirements expected for these cookies.

Given today's tools, a typical range of costs associated with RCC Pavement mixture development, associated tests to determine RCC Pavement mixture mechanical properties, and a structural design to determine pavement thickness requirements would be $3,000 to $6,000 U.S. dollars. The typical costs for a quality control program performed by an independent testing agency can vary greatly dependent on the defined QA processes and QC test/observation requirements specified and the project duration (i.e. up-front costs will be diluted over many more days in a large project), but prior experience in private work spending in the range of $1,500 to $2,000 U.S. dollars per day have been used to verify conformance with the performance requirements.

For budget purposes, it would generally be safe to assume RCC Pavement material costs to be the same as local ready mix concrete prices, but in many cases special plant and equipment mobilization are required. One time cost in the range between $25,000 and $40,000 U.S. dollars for this mobilization must be averaged into the material costs.

This range of placement costs can be quite large as these vary due to project constraints, project size, joint requirements, weather conditions, performance expectations, curing methods used etc., but generally these placement costs range between $3.00 and $5.00 U.S. dollars per cubic meter.

On a millimeter-per-millimeter basis, the author's experiences have shown that RCC Pavement can be installed at a cost approximately equal to asphalt. When a comparison in structural performance is taken into account, RCC Pavement performs much like conventional concrete pavements, therefore overall pavement thickness and subbase gravel base thickness will be thinner when compared to asphalt. The author's experiences have been limited to applications using rigid RCC Pavement with thickness ranging from 125 millimeters to 300 millimeters and in which all pavements were placed in a single pass.

Conclusions

Although RCC Pavement still has some open questions in regard to load transfer capability at joints and saw-cuts, freeze-thaw durability, de-icer salt-scaling resistance, and fatigue stress factors, working with the existing experiences and available data can still result in a very successful RCC Pavement projects. These RCC Pavements provide very desirable mechanical properties without all the unfavorable problems, such as load transfer across joints and curling generally caused by concrete shrinkage. Every effort should be made within the concrete industry to network and share experiences with RCC pavement to help assure successful projects and experiences. As a structural engineer, the author continues to be impressed by the mechanical properties of RCC Pavement. Experience in a successful use of RCC Pavement as the structure base for large distribution type facilities, in which an ultra-thin overlay is bonded to the RCC Pavement to meet the levelness and flatness requirements of high-rack storage, has demonstrated the structural adequacy of RCC Pavement.

Perception of RCC Pavement in the market should clearly be differentiated from conventional slip-form concrete pavements and in the author's opinion RCC Pavement should be defined with perception parameters as follows:

- A pavement in which a typical surface texture has the appearance of asphalt with exposed large aggregates.
- A pavement in which some level of raveling at the paver pass junction, much the same as asphalt, is expected. Furthermore acceptable degrees of raveling should be clearly defined.
- A pavement in which loss of some surface fines over time is expected.
- A pavement with rigid pavement load carrying properties much like concrete, which allows for use of the same structural design procedure as conventional concrete pavements.

Depending on the goals and objectives, RCC Pavement mixtures can be altered to improve appearance. For example, surface appearance can be improved by reducing the diameter of the maximum large aggregate size; however, this generally results in lower mechanical properties, including reductions in the flexural stress level to prevent fatigue failure.

Summary

To emphasize specific research and identification of tools/information that would aid in furthering acceptance of RCC pavement are as follows:

- Continued research on potential to use other waste by-products in RCC Pavement mixtures or in the soil cement subgrade mixtures.
- Investigation of any beneficial use of chemical admixtures in RCC Pavement mixtures.
- Development of a PC-based software that would allow for the determination of which material combinations would optimize the RCC Pavement mixture.
- Additional research on freeze-thaw durability and de-icer, salt-scaling resistance of RCC pavement mixtures.
- Continued tests to determine fatigue stress relationships for RCC Pavement.
- Testing to verify aggregate interlock and load transfer relationships in association with controlled cracking of RCC Pavement to minimize crack width and maximize load transfer.
- Development of industry accepted Quality Assurance and Quality Control procedures, including curing methods for RCC Pavement.
- Perception parameters developed to differentiate RCC Pavement from conventional slip-form concrete and asphalt pavement.

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