2007 TAC SUSTAINABLE URBAN TRANSPORTATION AWARD SUBMISSION

DESIGN AND CONSTRUCTION OF CONCRETE PAVEMENTS WITH RECYCLED CURB AND GUTTER AND SIDEWALK

Organizations: Centre for Pavement and Transportation Technology (CPATT)-University of Waterloo, Cement Association of Canada (CAC), Natural Science and Engineering Research Council of Canada (NSERC), Region of Waterloo

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PROJECT DESCRIPTION

The Recycled Concrete Aggregate (RCA) Concrete Road was designed and constructed as a partnership with the Centre for Pavement and Transportation Technology located at the University of Waterloo, Cement Association of Canada (CAC), Natural Science and Engineering Research Council (NSERC) of Canada and Region of Waterloo, where the road is constructed. The road includes three sections which contain 15% RCA, 30% RCA and 50% RCA in the Jointed Plain Concrete Pavement (JPCP) structure and as well a control section with 0% RCA or 100% Virgin Aggregate. All RCA that has been incorporated into the road came from demolished curb and gutter and sidewalk from the Kitchener/Waterloo area. The approximate age of the demolished concrete varied from 30 years old to approximately 80 years old. The road has been carefully designed to examine if RCA can be used as a viable aggregate for incorporation into the concrete pavement structure. Preliminary results show not only the environmental benefits of recycling the old demolished concrete, reduced impacts to the ecosystem and avoidance of needing to landfill this material, but the preliminary economic estimates of using RCA can provide a savings as high as 60%.

BACKGROUND

There is a dramatic decline in good quality aggregate available for construction use. World wide aggregate use is estimated to be ten to eleven billion tonnes each year. Of this, approximately 8 billion tonnes of aggregate (sand, gravel, and crushed rock) is being used in concrete every year [Naik 2005] [Mehta 2001]. In central Canada, 14 tonnes of aggregate are consumed per person each year. However, for every three tonnes of aggregate that is produced only one tonne is replaced by opening new aggregate sources or through recycling [McNaughton 2004]. Ontario is currently using aggregate faster than it is being made available resulting in an aggregate shortage [APAO 2004].

The current state of aggregate resources in Ontario alone is not fully known since the last detailed study was carried out in 1992 by the Ministry of Natural Resources (MNR) in the “State of the Resource Report” [Miller 2005]. From 1992 to 2003, Ontario’s annual consumption of aggregate was approximately 170 million tonnes. More than 16 tonnes of aggregate are used per person in Ontario each year [APAO 2004]. To construct one kilometre of 6-lane expressway, 51,800 tonnes of aggregate are used. Aggregate production in Ontario is currently produced by 2800 licensed pit and quarries and it exceeded 160 million tonnes in 2001 [Miller 2005]. Aggregate consumption in Ontario over the next 25 years is estimated at four billion tonnes [APAO 2004]. Ontario is facing an aggregate shortage. It is estimated that some urban areas will run out of aggregate by 2010 [Miller 2005].

The project described herein, is an example of an innovative sustainable urban transportation initiative because it provides many social, economic and environmental benefits. More specifically, concrete structures that are designed to have service lives of at least 50 to 100 years need to be reconstructed once they have reached the end of their life. The environmental impact of waste concrete is significant. Not only is there the environmental impact of transporting the waste concrete away from the site but the waste concrete will ultimately need to be placed in a landfill. Furthermore, from an ecosystem/sustainability perspective, the continued demand for aggregate to maintain existing and new transportation infrastructure is significant as noted earlier. The ability to recycle this waste material into the paved road surface in a sound, engineering way would achieve many sustainability objectives, especially in the urban environment where curb and gutter and sidewalk can be re-incorporated back into the project to achieve zero waste management. Of course this also opens the opportunity to utilize waste concrete from other sources as well. In short, the societal, economic and environmental benefits would be vast. In effect, the once wasted concrete can essentially reduce the need to utilize virgin material. Not only are benefits achieved by RCA replacement but also there are reductions in emissions associated with mining new aggregate sources and there are large costs associated with reduced transportation costs, etc.

PROJECT OBJECTIVES

The overall scope of this initiative is evaluate the use of Recycled Concrete Aggregate (RCA) in roadway infrastructure with particular emphasis on incorporation into the concrete pavement surface layer. The research which is being carried out by the Centre for Pavement and Transportation Technology (CPATT), located at the University of Waterloo, involves an integrated laboratory and field study whereby four full scale road sections have been placed in June 2007 to examine traffic and environmental impacts on using RCA in Jointed Plain Concrete Pavements (JPCP). Preliminary outcomes provide material and design guidelines for optimal RCA percentages for use in typical JPCP, and valuable insight into the cost and benefits of using RCA. Note, because this is still small scale, it is further anticipated that these results will provide the necessary basis for engineered utilization of RCA by Canadian cities, municipalities and provincial Departments of Transportation and economies of scale will further provide a strong rationale for using RCA in a similar way that Recycled Asphalt Pavement (RAP) has been adopted.

RECYCLED CONCRETE AGGREGATE

In Canada there is very limited use of RCA. For example, the Ministry of Transportation of Ontario (MTO) currently is recycles old concrete by blending it with virgin granular material for use as base and subbase [Gilbert 2005]. The MTO focuses on cost savings rather than on recycling. However, competitive bids in some areas of the province where virgin aggregate is very expensive usually include recycling the existing pavement [Gilbert, 2005]. However, this in general relates more to asphalt pavements as opposed to concrete pavements. RCA is not currently considered for incorporation into the concrete layer of the pavement structure yet, it certainly provides many beneficial engineering qualities particularly in terms of strength. Should the RCA be effectively incorporated into the concrete layer of a concrete pavement structure, this could improve performance, depending on the source of the RCA, mix designs, placement techniques, etc.

In general, it is still necessary that various issues be addressed before RCA can be utilized, in the concrete layer of the pavement structure. This initiative attempts to address the following questions:

1. Is the RCA a viable aggregate source for use in concrete pavements, with particular emphasis of utilizing it in the surface, concrete layer? How does it contribute structurally and how does it compare with virgin aggregate that is traditionally used?
2. How should RCA be monitored for quality and what are the most suitable sources (i.e. old bridges, sidewalks, curb and gutter, etc.) of RCA?
3. What are the typical material properties for RCA and how do these impact the mix design and constructability of the pavement?
4. What are the typical pavement performance values for concrete pavements constructed with RCA?
5. Is RCA concrete cost effective? What are the technical and economic benefits of using RCA in the pavement structure?

KEY DESIGN FEATURES

In an attempt to address these several and various issues, the CPATT, in partnership with the Cement Association of Canada (CAC), Natural Science and Engineering Research Council of Canada and the Region of Waterloo has carried out several laboratory tests first to determine the best mix design and to optimize the roadway performance based on both structural and functional considerations. This also accounts for potential contamination of the RCA. Once this analysis was completed and the materials/design was optimized, the full scale road sections were constructed in June 2007. One section is a control section constructed out of the conventional 100% Virgin Material or 0% RCA with material properties that are typical for a typical JPCP located in Ontario. The remaining three sections consist of a percentage replacement of virgin coarse aggregate with RCA in the quantities of 15%, 30% and 50%.

In order to ensure this could be transferred to other Canadian communities and organizations, the selected percentages of RCA are based in part on typical current asphalt recycling limits and other engineering data for many Canadian Cities, Municipalities and Provincial Departments of Transportation. For example 15% RCA would be considered to be a very conservative recycled component and relatively low risk in terms of failure. Consequently, it would be a suitable percentage for initial introduction. Overtime, assuming that the performance with 15% RCA was satisfactory, a 30% RCA in the coarse aggregate percentage might be considered and would be a reasonable progression. Practically speaking, by this point in time, the test section would already be a few years old and demonstrate performance. A 50% replacement would be considered somewhat risky and would likely only be practically considered after medium to long term successful field performance was observed and would likely be best suited for collector, arterial and local facilities. However, with heighten prices associated with current paving materials combined with limited aggregate sources this may ultimately move current practice into higher percentages of recycling and the 50% section would provide this information. In short, the RCA percentages where selected from a realistic design and constructability perspective. All of the RCA, was obtained locally and crushed locally to specification. The RCA material was donated by Steed and Evans Limited. Figure 1 shows the crushed RCA used on this project. Dufferin Construction in partnership with Dufferin Concrete supplied the pavement materials and services for the construction.

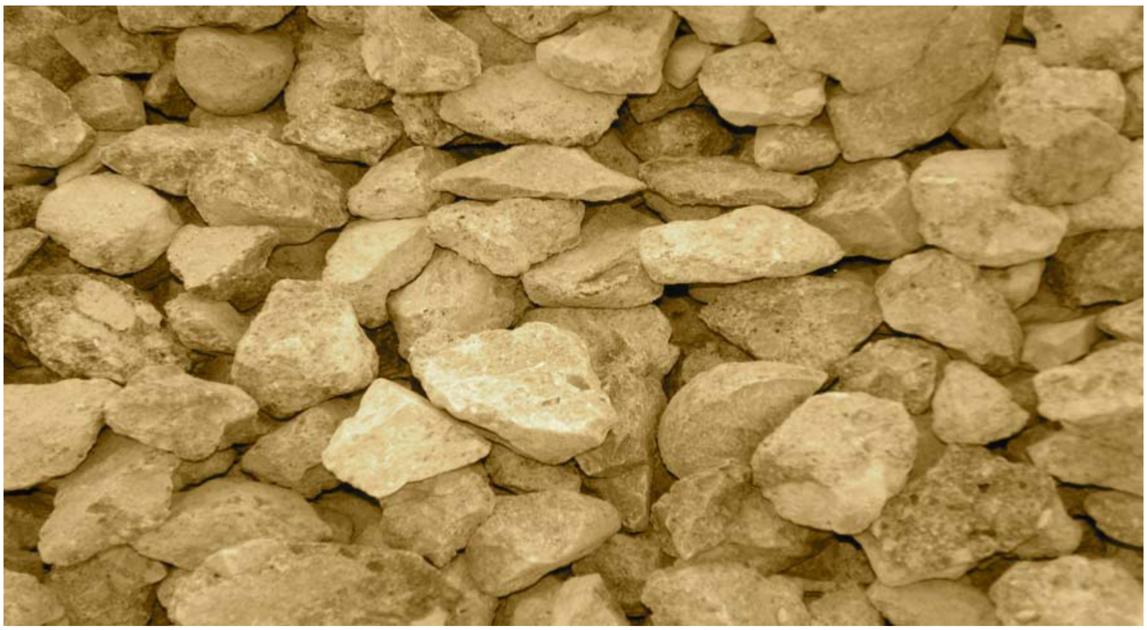

Figure 1 Close Up of Crushed Recycled Concrete Aggregate

PAVEMENT MATERIALS AND DESIGN

The pavement design for the RCA test sections was consistent throughout the four sections and consists of 250mm of Concrete, over 100mm of Open Graded Drainage Layer (OGDL) over 450mm of granular base as shown in Figure 2. As noted earlier it is a JPCP and contains load transfer devices as noted in Figure 2.

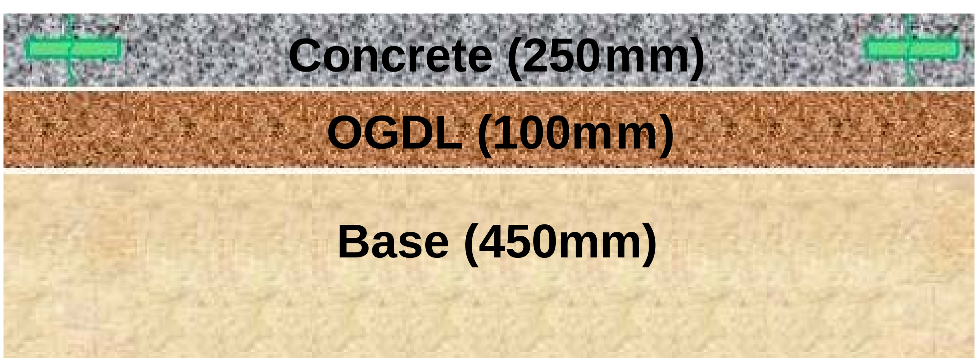

Figure 2 RCA Structural Pavement Design

The base layer is a typical Granular A, which is commonly used in Ontario. The Open Graded Drainage Layer (OGDL) is an asphalt bounded drainage layer consisting of 16 mm to 4.75 mm aggregate. It is a total thickness of 100mm and it is placed using a conventional asphalt paver over the Granular A. It is intended to act as a permeable layer to allow any ingress water to quickly filter through the design. Dowel baskets where used in this study and they were pinned in place directly prior to concrete placement. Each load transfer basket has 13 dowels that are approximate 45 cm long and 3 cm in diameter. The distance between two dowels is approximately 30 cm and the basket is designed so that each dowel is approximately 13 cm above ground, so that it is located at approximately one half of the thickness of the concrete pavement. The concrete layer surface was placed with using a slipform paver. The total width of the roadway is 8.5m and it was placed in two lanes. Figure 3 shows the RCA stockpile and the placement of the RCA Test Sections.

Figure 3 Clockwise from Top Left: RCA Stockpile, Concrete Pavement Placement, Finished Concrete Pavement Surface, Finished Concrete Pavement

INNOVATIVE ASPECTS

The design and construction of this RCA road demonstrates that RCA can be a viable aggregate. Long term performance of the road will provide a definitive answer to the questions raised earlier. This monitoring will include regular deflection, pavement distress, roughness, skid and noise surveys over time. Several surface textures on the roadway have also been constructed at this site to evaluate impact of texture on pavement performance properties. In addition, the joint cutting has been skewed to examine this impact on overall pavement performance.

In summary, the design, construction and demonstrated performance after 9 months in service, with heavy truck traffic, open the opportunity for many Canadian agencies to incorporate this waste product into roads. In fact, the preliminary laboratory and field data indicate that the concrete pavement with 30% RCA is showing better performance as compared to the conventional, control section with 0% RCA, 15% RCA and 50% RCA sections respectively. Another innovative aspect to this initiative includes the design and incorporation of several sensors within the pavement structure to evaluate environmental and traffic loading impacts. Each sensor set contains two vertical extensometers for measuring the curling and wrapping of the pavement slab. Six embedment strain gauges were installed on two different elevations (actual elevation), and they will be used to measure the longitudinal and transverse strain of the pavement as well as the pavement internal temperature. Two inter-plane extensometers were installed to measure the joint movement between the two slabs. As shown in Figure 4, two vertical extensometers were both installed 300 mm inward from the pavement centre line and the edge of the pavement and are 300 mm offset from the pavement joint. This data will provide rationale and defendable data for future design, construction and management of RCA roads.

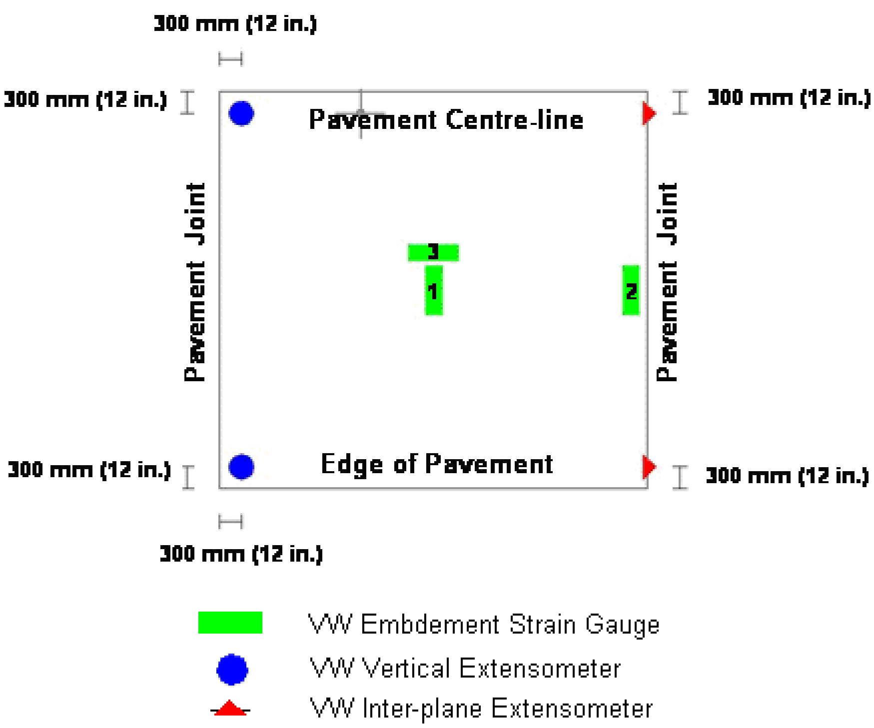

Figure 4 Plan View of Sensor Locations

FUTURE PROSPECTS AND OPPORTUNITIES

Realistically, this integrated laboratory and field RCA program will quantify the impact of RCA on concrete pavements and will optimistically result in several social, economic and environmental benefits. Future prospects for achieving the TAC New Vision for Urban Transportation will depend largely on realizing a number of opportunities, organized efforts and partnerships with the public and private sectors to promote and support sustainability throughout the Canadian Transportation Sector. This initiative will "Pave the Way" for future use of RCA use nationally and internationally.

The initiative has been recognized through acceptance of papers describing various aspects of the initiative. The work was featured invited article in the Canadian Civil Engineer Winter 2008 magazine, which is a publication of the Canadian Society of Civil Engineers and is presented in the attached. In addition, it has been accepted for presentation and publication at the 9th International Conference on Concrete Pavements (ICCP) to held in San Francisco in August, it was accepted to the Transportation Research Board Annual Meeting in January 2008 and has also been accepted to the 2008 TAC Annual Conference. Several other presentations have been invited including inclusion in the Ontario Good Roads Seminar on Green Pavements.

ATTACHMENTS

1. Canadian Civil Engineer Article, Winter 2008
2. Transportation Research Board Paper and Poster

REFERENCES

[APAO 2004]. Aggregate Producers Association of Ontario, "Importance of Aggregate," The About Aggregate Series, Aggregate Producers Association of Ontario, Mississauga, Ontario, 2004, pp. 1-4.

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[Mehta 2001]. P. Kumar Mehta, "Reducing the Environmental Impact of Concrete," Concrete International, V. 23, No.10, October 2001, pp. 61-66.

[Miller 2005] Gord Miller, "Running Out of Gravel and Rock," Toronto Star, January 6, 2005, p. A22.

[Naik 2005] . Tarun R. Naik, and G. Moriconi, "Environmental-Friendly Durable Concrete Made with Recycled Materials for Sustainable Concrete Construction," International Symposium on Sustainable Development of Cement, Concrete and Concrete Structures, Toronto, Ontario, October 5-7, 2005, pp. 277-298.