Sustainability Case Study Review of Using Recycled Aggregate in Road Structure

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ABSTRACT
Many transportation agencies are working towards more sustainable infrastructure management practices. One way in which agencies are being sustainable is by using recycled aggregates in road structures. It is important to evaluate the sustainability of these alternative road construction methods compared to the sustainability of traditional road construction methods. This paper reviewed the sustainability of rehabilitated road structures constructed using crushed reclaimed asphalt and cement concrete rubble. Four key aspects of sustainability were considered – economic, social, environmental and technical.

A City of Saskatoon "Green Street" Infrastructure Program case study is presented in this paper. From an economic perspective, significant costs savings are observed compared to the use of traditional virgin road aggregate materials. From a social perspective, residents who use the rehabilitated road will see an equal or improved level of service compared to a traditional structure. This is observed through the use of non-destructive heavy weight deflection (HWD) measurements where the deflection measurements on the recycled structure were less or equal to a traditional structure. The cost savings with the use of recycled materials may also be reinvested into rehabilitating more roadways improving the overall performance of the roadway network for residents.

Environmentally, because recycled materials are typically locally available and aggregate shortages are forcing justiditions to haul virging aggregates from futher away, fewer emissions are generated due to shorter distances for trucking and less energy is required to be consumed. Less virgin materials are required to be extracted from the earth and less waste material is also generated by recycling construction rubble. Technically, the mechanistic properties of the recycled materials were found to be equal or superior when compared to conventional road building materials. Laboratory and field measurements indicate that under higher applied stress state field conditions, the recycled materials exhibit performance measures that exceed that of conventional granular materials. This study illustrates that recycled materials can be used effectively in sustainable road construction when applied within a framework of applied engineering computational mechanics for design and analysis.

1.0 INTRODUCTION

Many jurisdictions in Canada including the City of Saskatoon are facing an infrastructure crisis where significant amounts of infrastructure require rehabilitation however, the funds that are needed to complete all the rehabilitation that is required are not available (*1)*. To prevent new roadways and those that are being rehabilitated from adding to this crisis there is a need to ensure that roads are constructed in a sustainable manner.

A number of principles, definitions and various metrics have been developed by various groups and agencies to promote and encourage sustainable practices and development. For the roadway industry to move towards achieving sustainability, constructing a pavement that is structurally adequate for the traffic loading that is anticipated and the climatic *in situ* conditions is also a key to achieving a sustainable road.

1.1 Objective

The objective of this project was to conduct a case study evaluation of the holistic sustainability of a roadway rehabilitation project test section using recycled materials under the City of Saskatoon "Green Street" Infrastructure Program.

1.2 Sustainability Background

Sustainability and sustainable development have become key issues within the engineering profession. The most widely accepted definition of sustainable development was developed in 1987 by the World Commission on Environment and Development and defined it as, "meet[ing] the needs of the present without compromising the ability of future generations to meet their own needs *(2)*." Various principles and definitions have been developed by numerous parties to define and explain sustainability resulting in more than one hundred definitions (*3*). A number of definitions including the 'Triple Bottom Line' and 'The Three Pillars of Sustainability' incorporate the idea of having net benefits in economics, environmental and social areas (*4)*. The Natural Step (TNS) has developed a framework to assist businesses and governments to move towards sustainability. This framework consists of four principles, two of which can be specifically related to the construction of roadways with the use of recycled materials. These principles are that materials extracted from the earth's crust should be minimized and that concentrations of materials produced by society should not be accumulated (*4*).

Groups and agencies have developed metrics to rate and promote sustainability and sustainable development. For buildings, the U.S. Green Building Council developed the LEED (Leadership in Energy and Environmental Design) rating system. This rating system has been increasingly implemented and is the recommended building rating system by the U.S. General Services Administration (*5*). A number of rating systems for roadways have also recently been developed. These include Greenroads developed at the University of Washington, GreenLITES developed by the Department of Transportation of the state of New York, the Federal Highways Administration (FHWA) Self-Evaluation Tool and GreenPave developed by the Ontario Ministry of Transportation to name a few *(6, 7, 8, 9)*. There are more benefits to using rating systems then using them as just a metric. The other benefits of using ratings systems include developing baselines and tracking, encouraging participation, assisting to meet or anticipate new future requirements, rewarding excellence, communication of benefits and goals and developing best practices *(6, 8)*.

When applying the definition of sustainability to roadway construction, the concept of identifying benefits in the various aspects of economics, environmental and social areas related to the work is possible. However when reviewing the sustainability of a roadway one must consider a fourth critical component of sustainability that is overlooked with the traditional definitions. This component is a technical component. Technical understanding is critical to construction of roadways that will be able to perform to a desired level of service over its in-service life so that the desired economic, environmental and social aspects of sustainability can come to fruition. This concept is shown in the figure below.

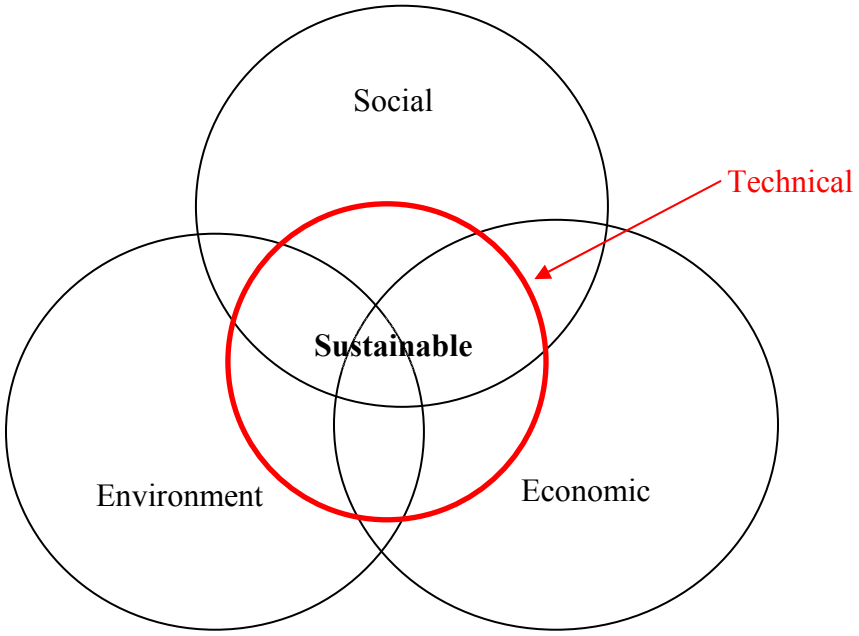


Figure 1: Roadway Construction Sustainability Venn Diagram

1.2 Green Street Infrastructure Program Background

For many years, the City of Saskatoon has stockpiled rubble hot mix asphalt cement (HMAC) and Portland Cement Concrete (PCC) that is generated through infrastructure repair and rehabilitation projects. The city experimented with crushing this rubble material with its own forces and using it as a low quality fill material. The City realized that developing engineered specifications would significantly improve the effectiveness of the use of the rubble material that was available and the "Green Street" Infrastructure Program was subsequently created.

This paper presents the rehabilitation of a section of 8th Street in the City of Saskatoon which was constructed using recycled materials under the "Green Street" Program. Prior to construction, the road was exhibiting fatigue cracking and experiencing sub-surface moisture issues. This case study focuses on a holistic sustainability review of the rehabilitation of 8th Street looking at the specific economic, environmental, social and technical benefits of using recycled materials in roadways. As part of the sustainability review, the City of Saskatoon's specified conventional design *(10)* was used as a baseline for comparison of the proposed recycled road structure.

1.3 Project Scope

The scope of this review includes:

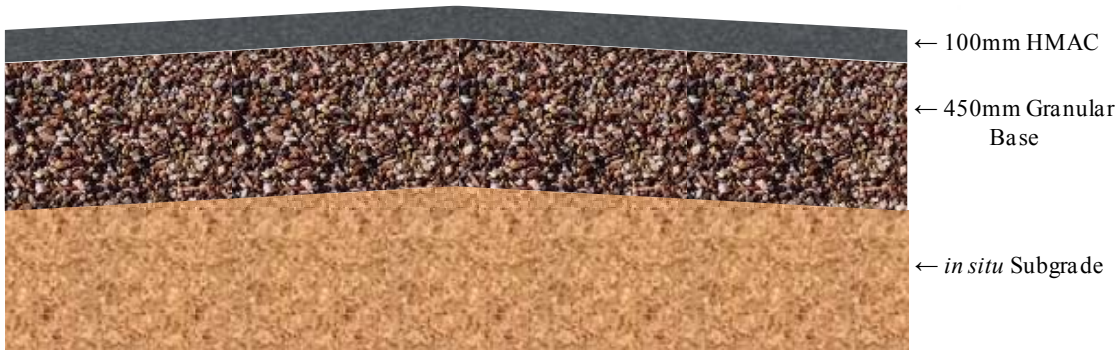
- A holistic sustainability review in terms of economic, social, environmental and technical considerations with the use of recycled materials compared to conventional granular materials.
- A comparison of the 8th Street "Green Street" test sections to theoretical conventional design for the same road considering the economic, social, environmental, and technical aspects of the project.
- Case study evaluation and material characterization of the reconstruction of the 8th Street "Green Street" Project within the City of Saskatoon involving the use of recycled materials.

2.0 HOLISTIC SUSTAINABILITY REVIEW

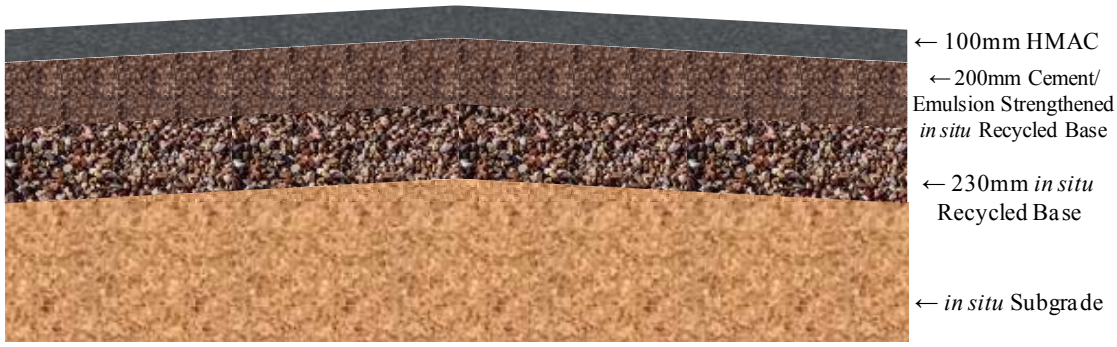
A review of the reconstruction of 8th Street in the City of Saskatoon (COS) was completed to compare the holistic sustainability of the use of recycled construction rubble materials to the use of traditional

materials. This holistic review addresses four key areas of sustainability related to roadway construction which are economic, environmental, social and technical.

A 540 m section of 8th Street on the southeast end of Saskatoon was rehabilitated with a structure of 430 mm of *in situ* recycled granular material with the top 200 mm stabilized with cement and emulsion overlaid with 100 mm of virgin hot mix asphalt concrete (HMAC). If this rehabilitation had been completed using conventional materials, the specified structure used by the COS would have been 450 mm of virgin granular base overlaid with 100 mm of hot mix asphalt concrete. These pavement structures are shown in Figure 2. Based on mechanistic testing as detailed in the technical section of this paper, the recycled structure is deemed to have equivalent or superior design capacity to the traditional structure.



(a) Conventional COS pavement structure



(b) Recycled "Green Street" pavement structure

Figure 2 Constructed 8th Street roadway structures.

2.1 ECONOMIC SUSTAINABILITY EVALUATION OF 8TH STREET

The economic evaluation of the "Green Street" Project was reviewed based on areas in which the City of Saskatoon was able to reduce costs in comparison to the traditional road rehabilitation method of remove and replace of the existing structure. Savings were realized through the reduction of hauling distances, reduced virgin material quantities, and elimination of landfill fees for the disposal of waste materials. The 2010 projected costs saving for the City of Saskatoon over the entire Green Streets Program based on initial capital for the aggregate materials is $1.81 million (*11).*

Based on unit costs of conventional roadway materials from other concurrent rehabilitation work and the actual construction cost using recycled materials on 8th Street, the total construction cost for the recycled structure and alternate conventional design were determined. As shown in Figure 3, the total cost for the rehabilitation of 8th Street with the use of recycled materials in 2009 was $350,306. Had conventional

materials been used the cost would have been $618,516. This is a cost savings of approximately $268,000 for the rehabilitation of 8th Street using recycled materials. The costs presented include all of the labor, equipment, and material supply to construct the roadway. In addition, based on the improved mechanistic properties of the recycled materials relative to the conventional materials, the lifecycle costs of the recycled pavement structure are expected to be the same or lower than the conventional structure.

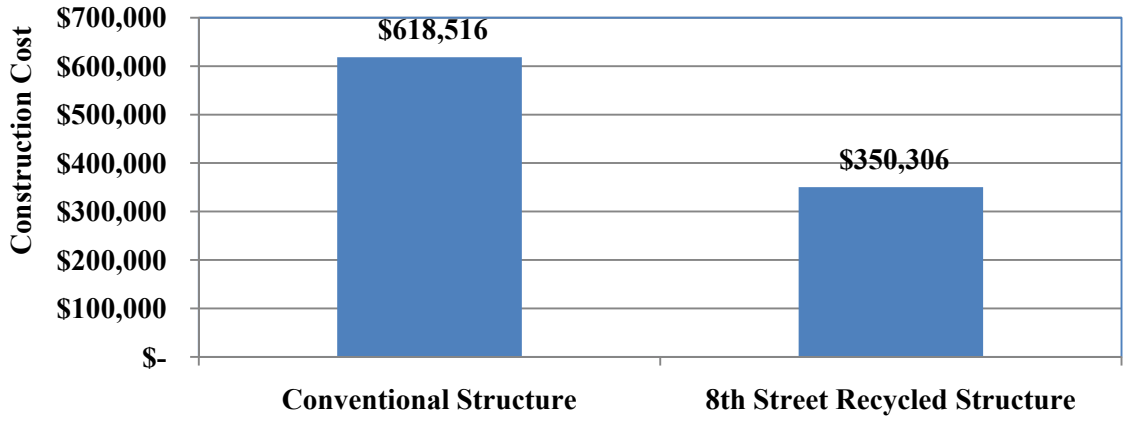


Figure 3 Estimated cost of construction for conventional and recycled pavement structures.

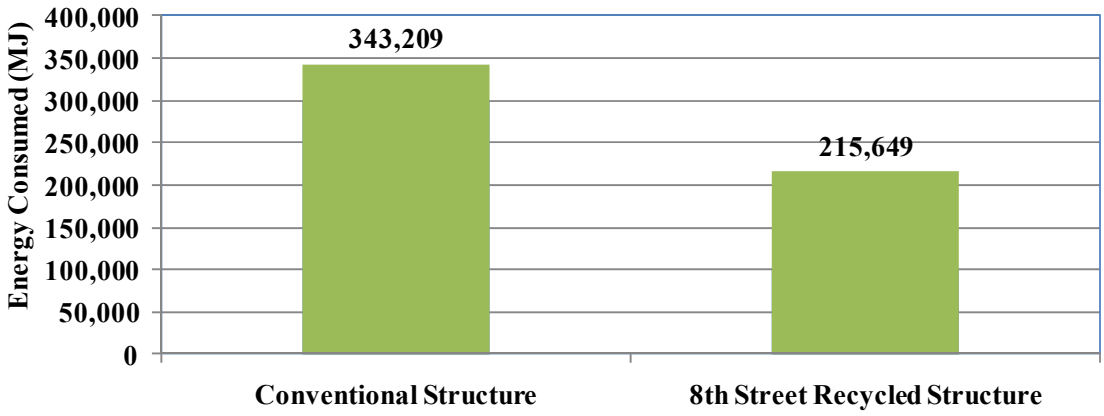
2.2 ENVIRONMENTAL SUSTAINABILITY EVALUATION OF 8TH STREET

Environmental benefits that are achieved through the use of recycled rubble materials include: fewer emissions and energy consumed due to reduced haul lengths, less virgin materials required, and a reduction in waste generation (*11, 12)*. Haichert et al. developed the Eco-Streets energy consumption model which determines energy consumption of road construction or rehabilitation based on the fuel consumed during construction and transport of materials (*12*). The scope of the model is limited to the transportation of materials and on-site construction activities. Therefore, the additional energy savings associated with the recycled structures with regards to the reduced need for extraction and processing of virgin materials is not captured in the eco-streets energy consumption analysis. However, due to field observation of the reduced processing effort associated with recycled materials it can be inferred that an energy savings is also associated with the processing of recycled materials though this energy usage has not been quantified at this time.

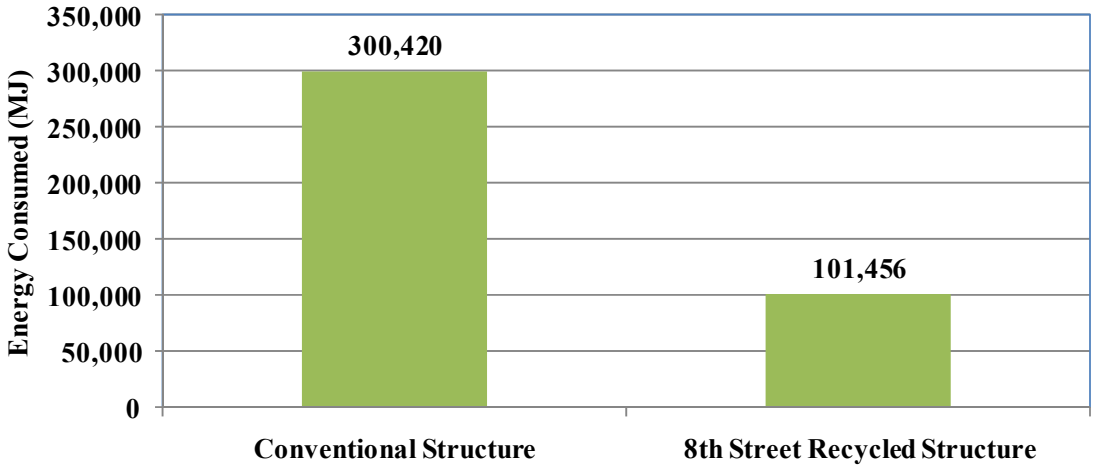
Conventional aggregates are a non-renewable natural resource; by using recycled materials the natural deposits of conventional aggregates can be maintained. Therefore, by recycling construction rubble, these materials can be diverted from the landfill, thus reducing the amount of waste that is returned back to the earth. The use of recycled materials in roadway construction closely follows two of TNS principles by minimizing the extraction of natural resources and by avoiding the building of concentrations of unnatural materials.

As seen in Figure 4, by applying the Eco-Streets model for the 8th Street project it was found that 215,649 MJ of energy was consumed for the construction of 8th Street using recycled materials, including 101,456 MJ of energy for the transportation of materials. If conventional materials had been used for the construction, 343,209 MJ of energy would have been consumed including 300,420 MJ of energy for the transportation of materials. This results in a savings of 127,560 MJ for the reconstruction of 8th Street using recycled materials.

In addition due to the reduced haul of materials, the amount of damage sustained on surrounding road infrastructure is also reduced, mitigating the premature aging of the surrounding roads due to the concentrated haul.



(a) Construction activities and transportation of materials



(b) Transportation of materials only

Figure 4 Eco-street model energy consumption analysis results for transportation of materials and construction activities.

2.3 SOCIAL SUSTAINABILITY EVALUATION OF 8TH STREET

Many societal benefits are achieved through the use of recycled materials in roadways. Quantifying the monetary benefits of social sustainability is extremely complex and is outside of the scope of this paper. Social benefits that will be achieved through the use of recycled material in roadways include but are not limited to:

- More rehabilitation work that can be completed for the same cost,
- Less damage incurred on surrounding roads due to concentrated haul related to construction activities,
- Fewer disturbances to surrounding residents, and;
- Prolonged landfill life.

With the cost savings realized through the reuse of construction rubble within roadways more funds will be available to rehabilitate other roadways within Saskatoon. The superior mechanistic properties of the materials are also anticipated to extend the life of the road. With more rehabilitation occurring with high quality materials residents will benefit from a roadway network that will have an overall improved level of service.

Due to the lack of quality aggregate near Saskatoon haul distances for quality aggregate is reaching 100 kilometers (*13*). By crushing and reusing the construction waste that is generated in the Saskatoon area, the concentrated haul damage on roads adjacent to construction areas can be reduced and the life of these roads prolonged. Surrounding residents will also experience less disruption due to reduced construction time (shorter duration of road closures and construction noise) and haul trucks being on the road for shorter distances.

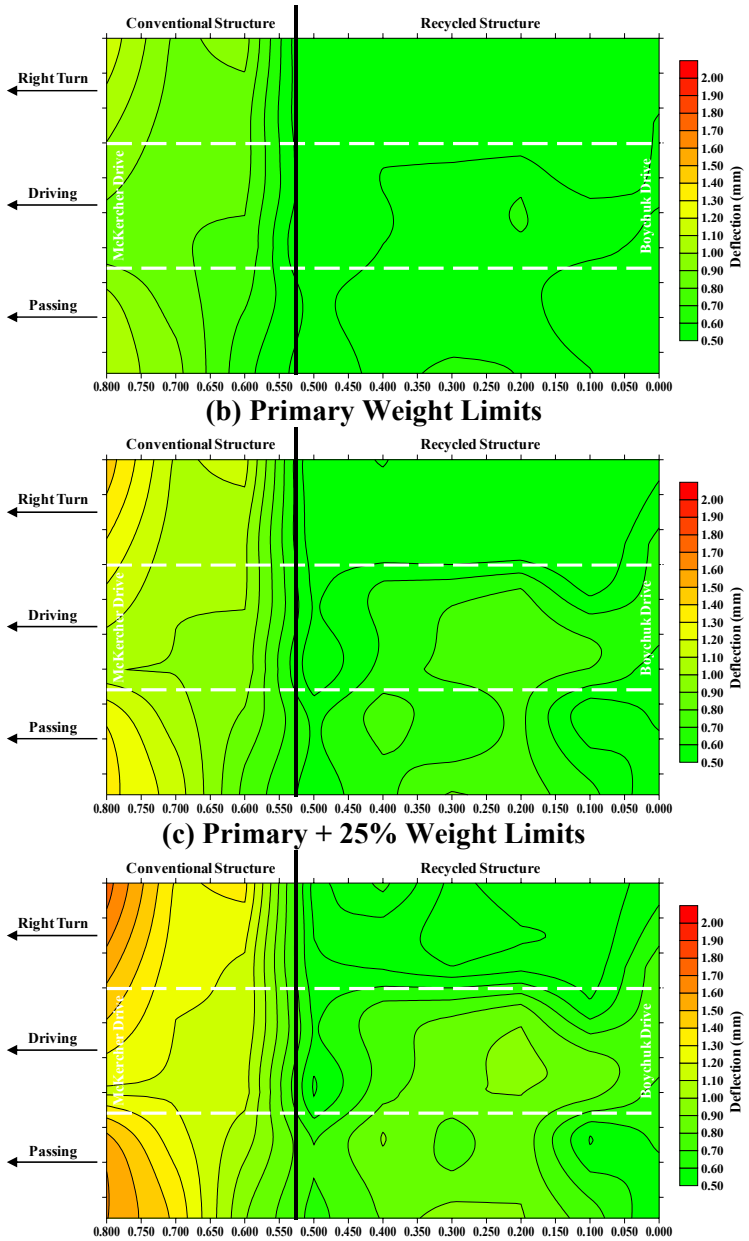
In the past, construction rubble has been disposed of in the landfill. As available landfill space is decreasing and the difficulties experienced in finding a new site for a landfill are increasing the cost for landfill space is becoming more expensive. By eliminating the need to landfill construction rubble not only is there significant costs saving by not landfilling the material but significant benefits for the residences are achieved by prolonging the life of the existing landfill for future use by the City.

Improved Level of Service for Road Users

Prior to the reconstruction of 8th Street the condition of the roadway was in very poor condition from a structural perspective. Because of the poor structural performance the ride quality provided to residents is also poor. Poor roadway conditions can cause unnecessary wear on residents' vehicles.

The section of 8th Street reconstructed with recycled materials was placed adjacent to a section that was previously reconstructed using a conventional structure. To validate the structural design performance, non destructive heavy weight deflection (HWD) peak surface deflections were measured on both sections after construction across a load spectra. Figure 5 illustrates the spatial distribution of the peak surface deflections of the recycled and conventional test sections after reconstruction. Deflection and stiffness are used by the City of Saskatoon as a performance and asset management measure. As seen in Figure 5, the conventional and recycled sections both exhibited good structural performance under the loadings. However, at the higher loadings, the deflection of the recycled test sections was slightly lower than that of the conventional structure.

This indicates that the recycled structure's performance is at least equal to that of the conventional structure. This will benefit the general public in terms of reduced incidents of premature failure of the road structure thereby improving the ride quality and reducing traffic delays due to the need for subsequent road repairs.



(b) Primary Weight Limits

(c) Primary + 25% Weight Limits

(d) Primary + 50% Weight Limits

Figure 5 Post construction peak surface deflection contour plots.

2.4 Technical Sustainability Evaluation of 8th Street

Traditional roadway pavement design is based on empirical observations of the performance of roadways *(10, 11)*. This method of design has allowed the industry to develop a knowledge base of how pavements behave, but the limitation of empirical design is that they do not account for changes in field state conditions or a deviation from traditional road construction materials.

Mechanistic design methods measure material properties in realistic field state conditions in order to predict life cycle performance and to compare various alternative or new materials where no empirical information is available. By using a mechanistic design approach, many uncertainties that are inherent to empirical methods can be avoided *(11, 13, 14, 15)*.

The key to the technical aspect of sustainability for roadway construction is to utilize materials that will perform well over the lifecycle of the roadway based on the anticipated *in situ* field state conditions including climatic and vehicle loading. When materials that have mechanical properties that satisfy the requirements for the *in situ* conditions of vehicle climatic loading, the other three key areas of sustainability – economics, social and environmental may be improved.

Designing roadway structures that are technically sound is a key to constructing and maintaining roadways in a sustainable manner. Understanding the mechanistic constitutive material properties that are being used and the field state conditions from a loading and climatic perspective will ensure that the cost of the pavement structure will be minimized and the level of service maximized over time. This will lead to more economic, social and environmental benefits for agencies, users and society not only at the time of construction but over the long term.

Within the City of Saskatoon, extensive testing of locally available recycle materials with and without stabilization additives was performed under the "Green Street" Infrastructure Program (*11,13)*. In previous studies, it was found that the structural performance of recycled materials were not adequately characterized using laboratory methods that were designed for conventional road materials (*13)*. Therefore, for the purpose of this structural design, triaxial frequency sweep testing was employed across realistic field state conditions to evaluate the performance of the recycled materials. Details on triaxial frequency sweep testing can be found in other sources (*14, 15*). For the purposes of this study, the recycled materials were compared to conventional City of Saskatoon specified materials.

This research only includes the mechanistic testing of materials below optimum moisture levels. However, in other research it has been observed that when subjected to moisture, the retention mechanical properties were significantly higher than that of conventional granular base (*11*). This is an additional benefit of the *in situ* recycled granular materials which is not quantified herein.

Dynamic Modulus

Dynamic modulus is a measure of relative stiffness of a material under dynamic loadings. It was found that stabilization of the *in situ* recycled materials with a low concentration of cement and emulsion resulted in an improved stiffness of 103 percent. The stiffness of the stabilized *in situ* granular was 59 percent higher than the conventional granular base. As seen in Figure 6, the dynamic modulus of the HMAC and stabilized *in situ* granular decreased with slower loading rates, which is a result of the viscoelastic effects of the asphalt cement. While there is also a decrease in stiffness at lower loading rates, the viscoelastic effects have added a benefit of increasing the fracture toughness of the materials.

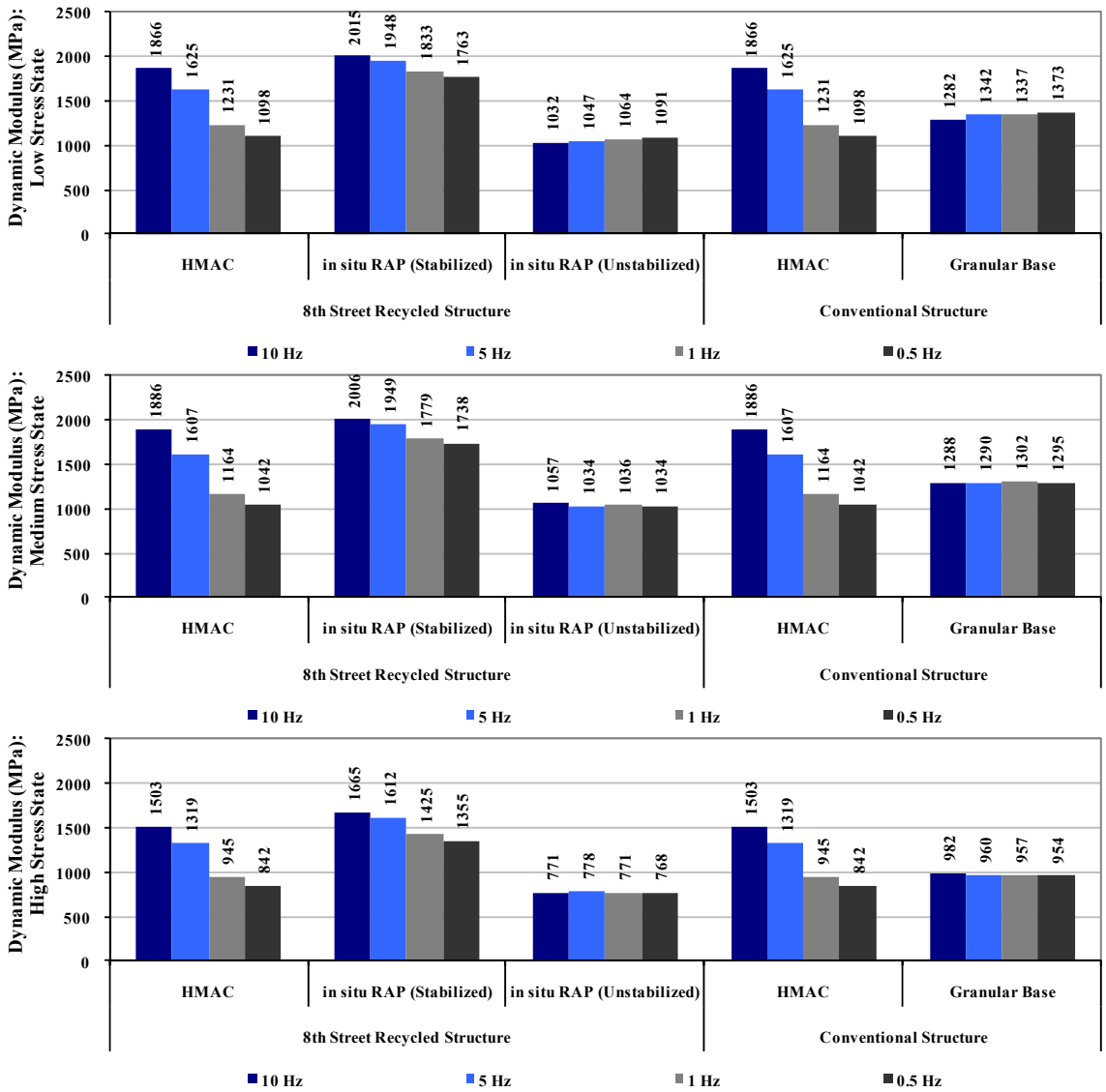


Figure 6 Dynamic modulus of materials for conventional and recycled pavement structures.

Radial Microstrain

Radial microstrain is a measure of the triaxial strain response of a material under a deviatoric stress state. As seen in Figure 7, the radial strain response of the stabilized *in situ* granular was 65 percent lower than that of the unstabilized *in situ* granular. This is evidence that there is a high structural benefit for the addition of a relatively low concentration of stabilizers into the recycled materials. Also, the stabilized *in situ* granular had a 29 percent reduction in radial microstrain in comparison to the granular base, which illustrates that the recycled materials, when stabilized have the potential to have superior mechanical properties compared to conventional granular base. It should also be noted that when looking at the high stress state alone, the stabilized *in situ* granular had a 47 percent reduction in radial microstrain in comparison to the granular base. This indicates that the stabilized *in situ* granular has even greater structural value under higher traffic loadings.

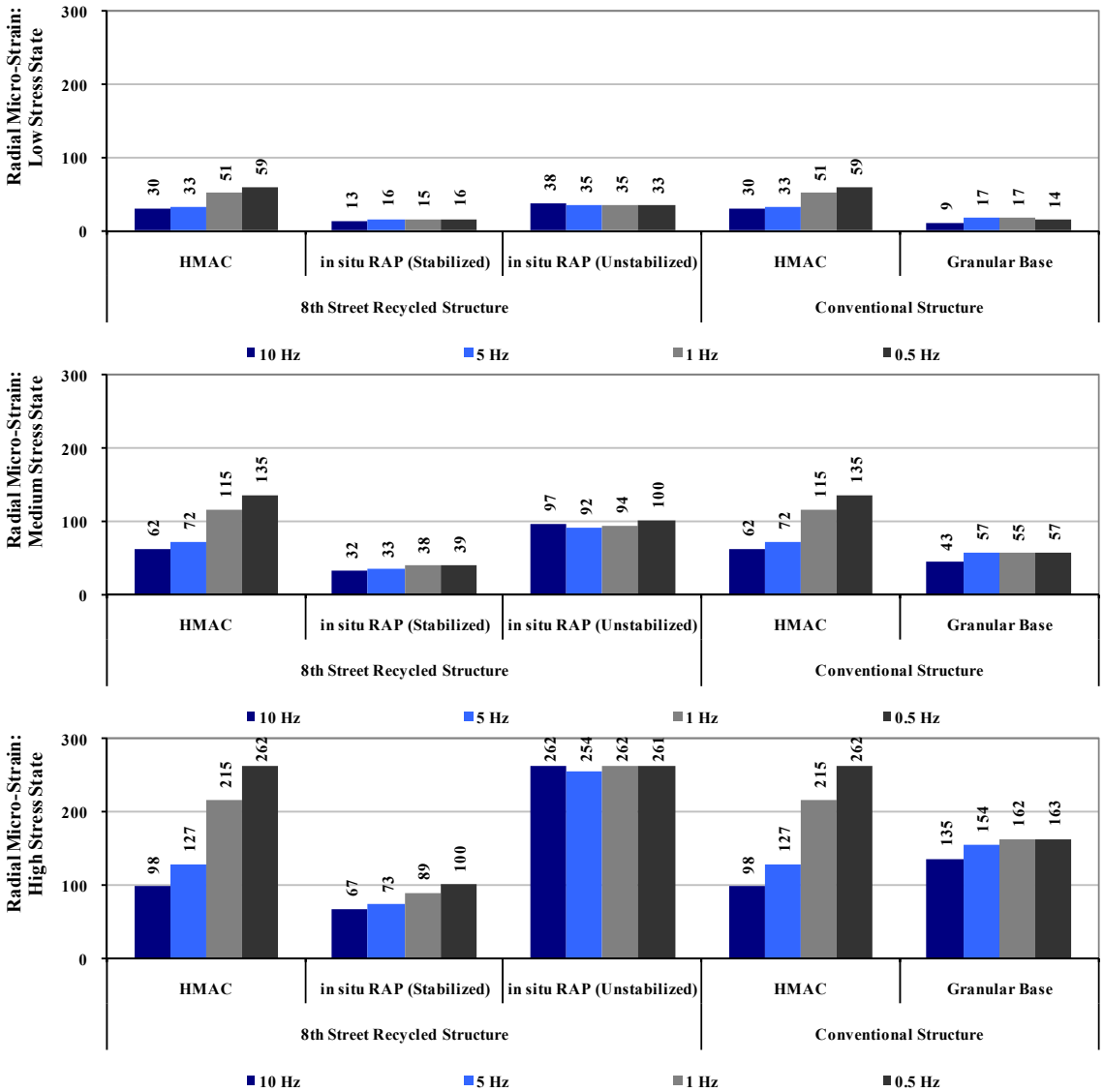


Figure 7 Recoverable radial microstrain of materials for conventional and recycled pavement structures.

3.0 SUMMARY AND CONCLUSIONS

This study evaluated the sustainability of a road rehabilitation project utilizing recycled aggregate materials under the City of Saskatoon's "Green Street" Infrastructure Program. The case study using the rehabilitation of 8th Street in Saskatoon, Saskatchewan was subjected to evaluation in terms of economic, environmental, social, and technical sustainability. Overall, the rehabilitation of 540 m of 8th Street, using recycled materials, found that approximately $268,000 was saved in comparison to the use of a conventional road structure. Environmentally, as per the Eco-Streets energy consumption model, 127,560 MJ less energy was consumed in comparison to the use of a conventional road structure.

Non destructive heavy weight deflection measurements of the 8th Street recycled structure were at the same level or better than the adjacent conventionally constructed section. This is an indication that residents will receive a comparable ride quality to the conventional structure. Furthermore, with the recycled structure reuse of in place aggregates, there was reduced damage to surrounding roads due to lower volumes of concentrated aggregate haul. Technically the recycled materials displayed equal or

superior mechanistic properties during triaxial frequency sweep characterization when compared to conventional materials. The use of a low concentration of stabilization materials greatly enhanced the mechanical properties of the recycled materials, which will further improve the pavement structure's life cycle performance and reduce the need for subsequent rehabilitation treatments.

This study illustrated that the recycled materials, when applied within a framework of a sound engineering mechanics perspective, can be effectively used in sustainable road construction providing benefits for all users economically, environmentally and socially. Furthermore, laboratory and field measurements indicated that under higher stress environments, the recycled materials exhibited performance that exceeded that of locally available conventional granular materials.

Acknowledgements

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