Summary of City of Saskatoon "Green Street"Infrastructure Program

Prepared by:

Curtis Berthelot, Ph.D., P. Eng.:
Professor and Director of Saskatchewan Centre of Excellence in Transportation and Infrastructure, University of Saskatchewan, Saskatoon, SK Canada S7H 0A5
Phone: (306) 966-5427, Fax: (306) 966-7014, Curtis.Berthelot@usask.ca

Rielle Haichert, E.I.T., PSI Technologies Inc., 221 Jessop Ave., Saskatoon, SK Canada S7N 1Y3
Phone: (306) 477-4090, Fax: (306) 477-4190, rhaichert@pavesci.com

Diana Podborochynski, E.I.T., University of Saskatchewan, Saskatoon, SK Canada S7H 0A5
Phone: (306) 966-5427, Fax: (306) 966-7014, dep119@mail.usask.ca

Colin Wandzura, E.I.T., University of Saskatchewan, Saskatoon, SK Canada S7H 0A5
Phone: (306) 966-5427, Fax: (306) 966-7014, cmw394@mail.usask.ca

Duane Guenther, P.Eng., City of Saskatoon, 222 3rd Avenue North, Saskatoon, SK Canada, S7K 0J5, Phone: (306) 975-7894, Fax: (306) 975-7651, Duane.Guenther@saskatoon.ca

Brian Taylor, P.Eng., PSI Technologies Inc., 221 Jessop Ave., Saskatoon, SK Canada S7N 1Y3
Phone: (306) 477-4090, Fax: (306) 477-4190, btaylor@pavesci.com

Sheri Praski, P.Eng., City of Saskatoon, 1030 Avenue H South, Saskatoon, SK Canada S7M 1X5, Phone: (306) 975-2487, Fax: (306) 975-2553, Sheri.Praski@saskatoon.ca

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ABSTRACT
In 2009, the City of Saskatoon implemented the "Green Street" Infrastructure Program. The "Green Street" Program employed on-site recycling methods and off-site recycled materials to construct five test sections during the 2009 construction season. The purpose of this paper is to summarize the use of recycled hot mix asphalt concrete (HMAC) and Portland cement concrete (PCC) materials in the construction of City of Saskatoon test sections.

Pre construction, all "Green Streets" test sections were exhibiting severe surface and structural deterioration. Test sections were full depth rehabilitated using a structural design that incorporated both recycled HMAC and PCC as structural layers. Pre construction characterization showed all sites had severe sub-structure moisture problems. Mechanistic characterization of the recycled materials showed significant structural improvement in the recycled material structural design. The structural benefits were validated through pre and post construction non-destructive heavy weight deflection testing.

Based on the findings of this research, it was found that using recycled HMAC and PCC in the rehabilitation of urban roads provides a cost effective alternative to using virgin granular base materials. In fact, if processed to a high performance mechanistic specification, recycled materials were shown to provide improved mechanical behaviour over conventional aggregates. Structural asset management measurements showed full depth reclamation significantly improved the structural asset value of the urban streets rehabilitated.

(222 words)

INTRODUCTION

The City of Saskatoon, like many urban centres, is challenged with rehabilitating, maintaining, and operating several thousand lane kilometers of roads. First and foremost, much of the City's urban road network is ageing and has been in operation past its intended design life. A history of reduced preservation budgets and maintenance has increased the City's infrastructure deficit (1). Keeping up with the rehabilitation and maintenance of existing road assets in combination with the expansion and construction of new roads in the city has proved to be a difficult task for the City of Saskatoon.

The City of Saskatoon has seen an increase in the amount of road infrastructure rubble available at the landfill in recent years. To illustrate, over the past 5 years, it is estimated that the City of Saskatoon has generated 500,000 metric tonnes (MT) of hot mix asphalt concrete (HMAC) rubble and Portland cement concrete (PCC) rubble through road infrastructure renewal operations (2, 3). The cost of landfilling general waste materials is significantly increasing as the City's landfill approaches its service life. As a result, the City diverts whatever material possible from the City's landfill and stockpiles HMAC and PCC rubble at the City of Saskatoon's rubble stockpile yard.

In addition, road construction and rehabilitation costs have increased substantially over recent years (2, 3). This is primarily due to a reduction in the availability of quality construction materials, specifically locally available high quality virgin aggregates resulting in long haul distances, energy consumption, and road damage due to concentrated hauls. In fact, in Saskatchewan, high quality aggregate pits have been depleted in many regions of the province, particularly near urban areas (2, 3, 4). In particular, quality aggregate sources in the Saskatoon area have been exhausted and are now being transported from pit sources up to 100 kilometers from the City limits (1, 2, 3, 4,).

Also, with an expanding commercial economy and significant urban housing developments, traffic volumes in the City of Saskatoon have increased significantly. The overall volume of personal light-weight vehicles, commercial truck traffic, and construction truck traffic has increased with Saskatchewan's recent influx of commercial and housing development (2, 3, 4). Heavy construction truck traffic loads related to new housing subdivision construction has also led to the premature structural failure of relatively new subdivision roads (2, 3, 4).

With a clear need to establish more sustainable solutions to account for the City of Saskatoon's structural road deterioration, the City of Saskatoon established the "Green Street" Infrastructure Program in early 2009. Overall, the "Green Street" Infrastructure Program was initiated with three specific objectives:

1) To implement crushing and processing protocols to recycle HMAC and PCC rubble materials and provide mechanistic-climatic material properties that exceeded those of conventional granular base materials by at least thirty percent.
2) To characterize recycled HMAC and PCC rubble materials as structural base course layers utilizing mechanistic material characterization and directly compare them to conventional granular base.

3) To use reclaimed and recycled HMAC and PCC rubble materials in several road reconstruction field test sections projects as engineered structural base course layers and to evaluate their subsequent field performance.

BACKGROUND

In early 2007, the City of Saskatoon began stockpiling HMAC and PCC rubble materials to save landfill space; however, it was soon recognized that there was an opportunity to reclaim, reuse, and recycle these rubble materials. Initially, by public tendering, conventional aggregate processing jaw and cone crushing equipment was employed to crush the reclaimed HMAC and PCC rubble. This resulted in reduced crushing efficiency, low production rates, and overall poor quality of the final crushed product.

In 2008, an impact crusher was implemented by PSI Technologies to reclaim HMAC and PCC rubble at improved production rates and end-product quality. Initial crushing and materials testing performed in early 2008, coined first generation crushing, showed that crushing and screening production rates were economically sufficient and generated quality materials. Under the "Green Street" Infrastructure Program, the impact crusher was modified to further improve the quality of the crushed HMAC and PCC rubble.

As part of the "Green Street" Program, crushed HMAC and PCC materials were characterized in the laboratory using conventional as well as mechanistic laboratory protocols and were compared to conventional granular base. In addition, these materials underwent a full factorial stabilization analysis using slow-setting (SS-1) emulsion and cementitious stabilization materials. Based on mechanistic characterization, various structural designs were selected for City of Saskatoon "Green Street" test sections.

One of the objectives of this research was to pilot the field application of reclaimed and recycled HMAC and PCC in a typical City of Saskatoon road reconstruction application. In the summer of 2009, 18,000 m² of City roads were structurally rehabilitated using the recycled HMAC and PCC materials crushed in both 2008 and 2009. All these roads were exhibiting substructure moisture problems and structural failure. Therefore, these field test sections posed a significant challenge from a structural design perspective. Approximately 30,000 MT of crushed HMAC material was used as an engineered black base layer and approximately 70,000 MT of crushed PCC material was used as a stress dissipation drainage layer in rehabilitated road structures. In addition, in-place reclaimed asphalt pavement was remixed and/or stabilized and reused in the rehabilitated road structure of each test section.

OBJECTIVE

This paper presents a summary of the "Green Street" rehabilitation of 8th Street in Saskatoon, Saskatchewan. The purpose of this paper is to summarize the design and construction of the 8th Street "Green Street" test sections as well as the non-destructive structural integrity assessment to validate its mechanistic materials design.

SCOPE

This paper discusses the rehabilitation of one of the "Green Street"test sections, 8th Street in Saskatoon, including validation of the material constitutive properties obtained in the laboratory and a comparison to the end-production structural value obtained from the road systems constructed. A heavy weight deflectometer was used to assess the pre and post construction structural integrity of rehabilitated "Green Street" roads. This paper includes the pre and post construction results of all the "Green Street" test sections.

Further documentation of this Program may be found elsewhere (2, 3, 4, 5). In addition, a paper further discussing the crushing and processing of City of Saskatoon recycled and crushed HMAC and PCC is included in these conference proceedings (5).

8TH STREET REHABILITATION USING RECYCLED HMAC AND PCC MATERIALS

A segment of 8th Street from Boychuk Drive to Tamarid Place was selected as a "Green Street" test section. The limits of the 8th Street test section are from the intersection of Boychuk Drive (km 0.000), west to the intersection of Tamarid Place (km 0.540). As an arterial road in the City of Saskatoon, 8th Street serves as a significant connector route for the east side of the city. The westbound 8th Street test section was comprised of three lanes: the right lane, the passing lane, and the median lane.

Figure 1 illustrates the typical surface condition of the 8th Street test section both pre construction and post construction facing west. Pre construction, 8th Street was composed of a conventional hot mix asphalt concrete (HMAC) road structure. The road was exhibiting varying degrees of raveling, fatigue cracking, and rutting. The poorest surface condition was observed in the right lane.

The rehabilitation of 8th Street consisted of two pavement rehabilitation systems. Pre construction, the right turning lane of 8th Street was exhibiting the poorest surface condition due to increased moisture in the pavement structure. Therefore, the rehabilitation of the right lane included a drainage system as illustrated in Figure 2 and as pictured in Figure 3. As seen in Figure 2, a woven geotextile was place on the subgrade to separate the crushed PCC drainage layer. Geotextile and a reclaimed asphalt pavement (RAP) base layer were then placed on top of the reclaimed PCC drainage layer. City of Saskatoon offsite impact crushed RAP and PCC was used in the drainage system.

As seen in Figure 4, the entire right turn lane and sections of the median lane and the driving lane were rehabilitated by rotomixing the HMAC and granular base layers and adding offsite impact crushed RAP to top up the remixed base layer. The top 200 mm of this remixed base layer was stabilized with one percent SS-1 emulsion and one percent cement. The entire 8th Street test section was surfaced with typical City of Saskatoon Type A2 HMAC.

In situ remix material consisting of HMAC surfacing and *in situ* granular base materials was retrieved from 8th Street during construction and characterized using conventional and mechanistic laboratory tests. The loss on ignition of the *in situ* remix material was 5.0 percent, indicating a relatively high residual asphaltic content of the RAP. As seen in Figure 5, when subjected to mechanistic triaxial frequency sweep characterization, both the stabilized *in situ* remix material (utilized as a black base course) and the HMAC surfacing materials showed good mechanistic structural material constitutive behaviour. The stabilized *in situ* remix material yielded end-product mechanistic material behaviour that exceeded that of the City of Saskatoon Type A2 HMAC.

STRUCTURAL INTEGRITY OF "GREEN STREET" TEST SECTIONS

The City of Saskatoon employs structural primary response measurements as part of its internal structural asset management system. Therefore, non-destructive heavy weight deflectometer measurements were collected pre and post construction. Dynamic surface deflection measurements were obtained using a heavy weight deflectometer, as seen in Figure 6, under a load spectra of typical commercial truck loadings experienced in Saskatoon from secondary legal load limits to primary legal load limits. Peak surface deflection and PSIPave structural index profiles were calculated based on the collected primary deflection profiles. Heavy weight deflection surveys were conducted pre construction and post construction. On-going non-destructive structural monitoring of all "Green Street" test sections will also be performed in spring and summer 2010.

Peak surface deflections were calculated based on the collected primary deflection profiles and are presented in Figure 7. As seen in Figure 7, the City of Saskatoon recycled road structures all met the target structural peak surface deflection of less than 0.75 mm across load spectra of secondary load limits to primary plus 50 percent, with the exception of 115th Street which utilized conventional pit run rock as the drainage layer, and the Arlington back lane which could not be a full pavement structure due to shallow gas utilities.

As seen in Figure 7, this project demonstrated the ability to construct roads utilizing recycle materials, and showed that significant structural integrity can be obtained from the use of recycle road materials when compared to conventional road structures. This was widened based on the field structural integrity results from the 115th Street test section where pit run rock was used as the drainage layer. When compared to Kenderdine Road, it was also shown that crushed PCC rubble provided improved end-product structural capacity. This is believed to be the result of increased fracture faces resulting from the crushing process of PCC rubble materials.

As seen in Figure 8, under primary weight limits plus 50 percent pre construction, 8th Street test section rated poor with significant *in situ* structural variability. The outside wheelpath of the right turn lane was exhibiting especially high peak surface deflections and very high variability in deflections. Post construction, the structural rehabilitation of the 8th Street test section significantly improved the average structural primary response of 8th Street and significantly reduced the variability of the structural primary response. One month post cure, all deflections and variability in deflections reduced significantly.

SUMMARY AND CONCLUSIONS

Since inception, the "Green Street" Infrastructure Program realized numerous significant accomplishments, many of which have been published and are presented elsewhere (2, 3, 4, 5). The City of Saskatoon commissioned the "Green Street" Infrastructure Program to investigate the potential to use recycled RAP and PCC rubble as structural road layers. The objective of this study was to employ mechanistic based materials characterization and structural asset management testing to validate the field performance of these road structures. When subjected to mechanistic triaxial frequency sweep characterization, both the cement-emulsion stabilized *in situ* remix material (utilized as a black base course) and the HMAC surfacing materials showed good mechanistic structural material constitutive behaviour. The stabilized *in situ* remix material yielded end-product mechanistic material behaviour that exceeded that of the HMAC surfacing.

Based on these results, the City of Saskatoon is now in the process of adopting mechanistic-based specifications for recycled HMAC and PCC for use in urban road rehabilitation. Based on the effective engineering use of recycled rubble materials, the potential exists for the City of Saskatoon to become 'aggregate neutral', such that urban recycled materials would provide all the City's aggregate needs for reconstruction and rehabilitation.

ACKNOWLEDGMENTS

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LIST OF FIGURES

a) Pre construction b) Post construction

Figure 1 Typical surface condition of 8th Street - km 0.480

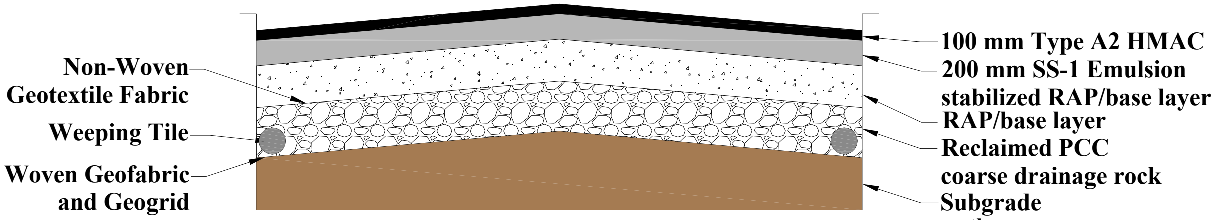


Figure 2 Typical cross section with drainage system installed on 8th Street right lane

Figure 3 Typical "Green Street" drainage system using reclaimed PCC drainage rock

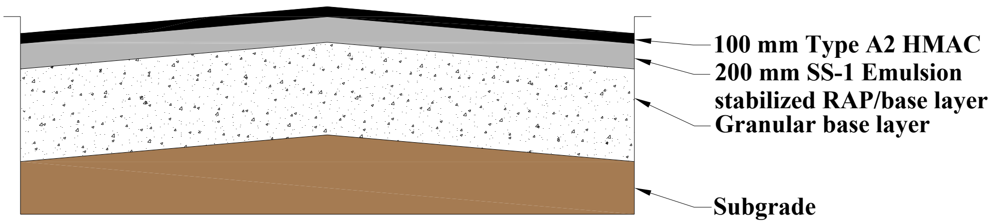


Figure 4 Typical cross section without drainage system on 8th Street passing and median lane

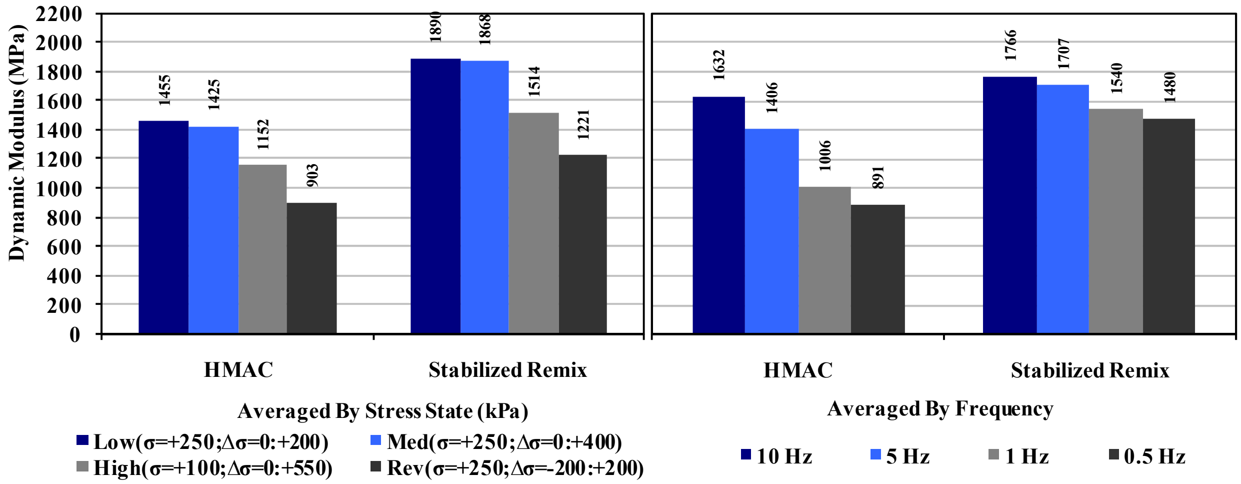
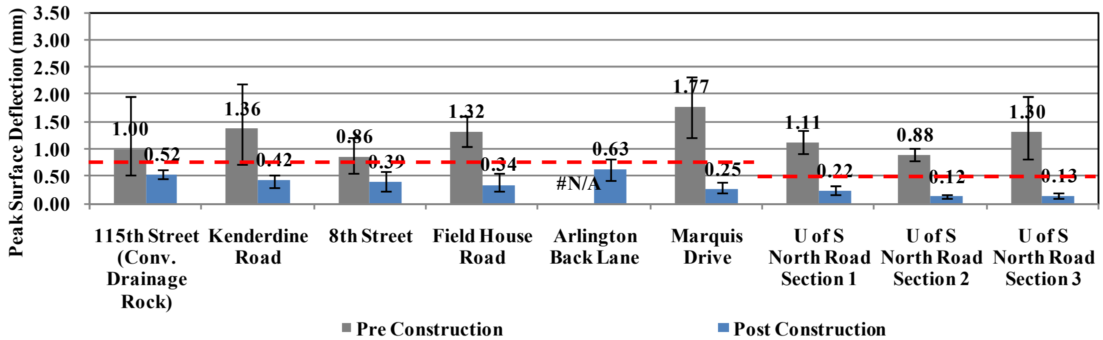
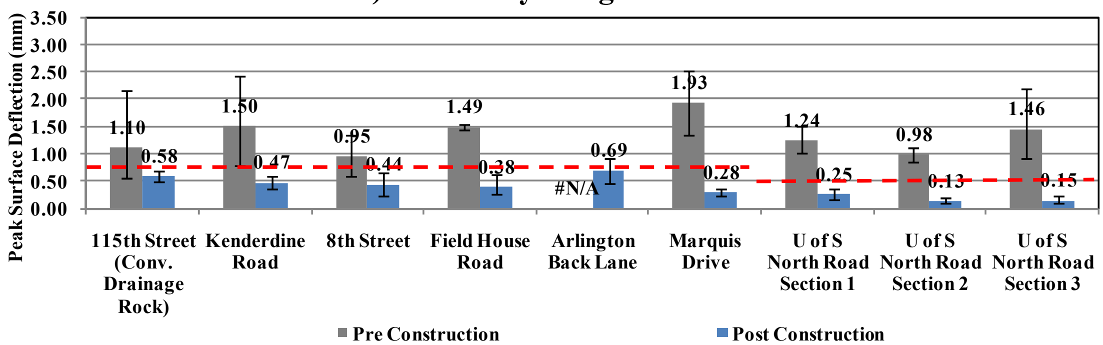


Figure 5 Dynamic modulus laboratory characterization of HMAC and stabilized remix

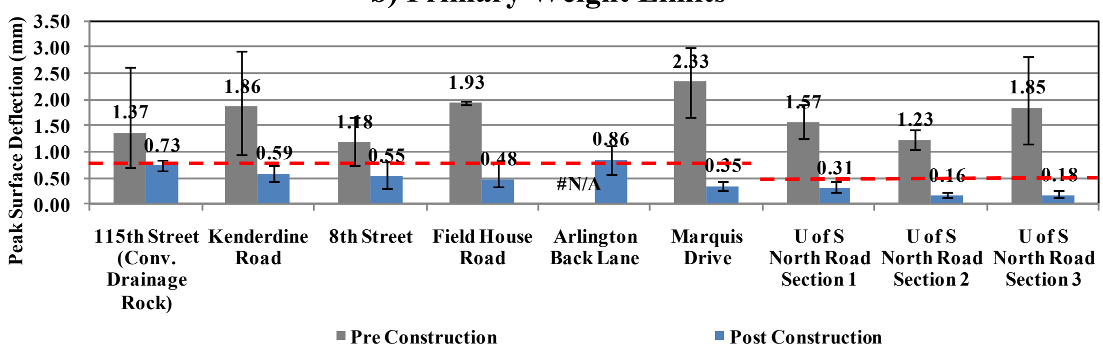
Figure 6 Heavy weight deflectometer on 8th Street



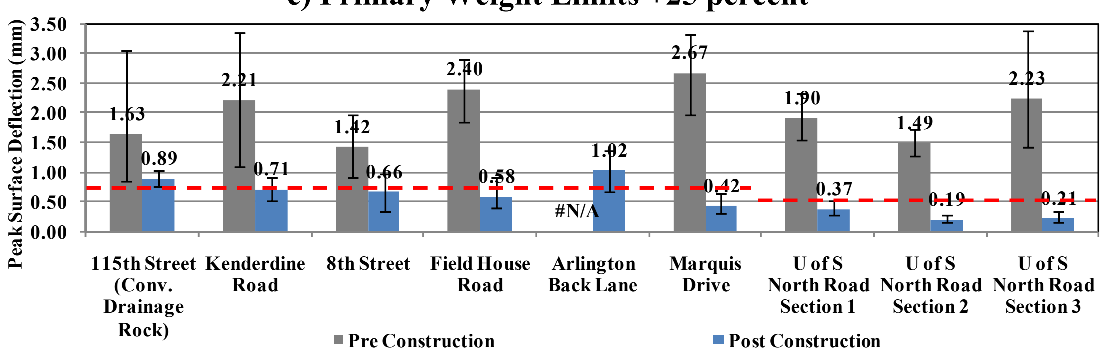
a) Secondary Weight Limits



b) Primary Weight Limits

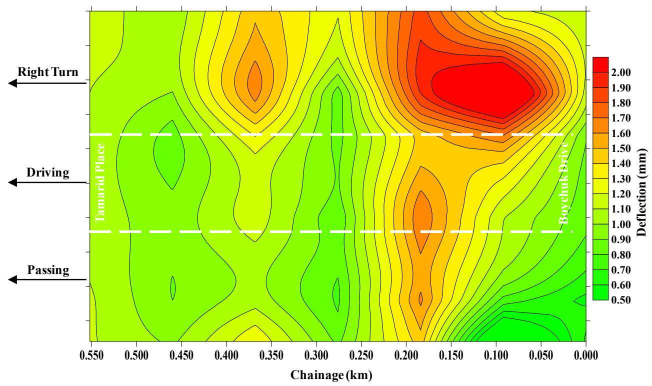


c) Primary Weight Limits +25 percent

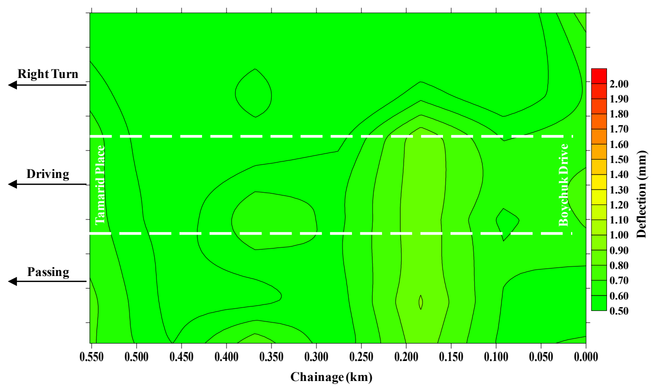


d) Primary Weight Limits +50 percent

Figure 7 Peak Surface Deflection across Applied Load Spectra



(a) Pre construction (May 2009)



(b) Post construction (October 2009)

Figure 8 Peak surface deflection contour plots at primary weight plus 50 % weight limits