Sustainable Rehabilitation of Carling Avenue using Rubblization

Submitted as a Candidate for the 2006 TAC Sustainable Urban Transportation Award

PART 1 – PROJECT DESCRIPTION

Part 1 of this nomination package introduces the Carling Avenue project, as well as the innovative rubblization technique selected while Part 2 presents how the rubblization process directly meets the criteria for the TAC Sustainable Urban Transportation Award.

Introduction to Carling Avenue and Problem Description

As illustrated in Figure 1, Carling Avenue (Ottawa Road #38) is a 19 kilometre east-west corridor connecting the former City of Kanata (at March Road) with the downtown core (at Bronson Avenue). With the exception of a small section of its western length, Carling Avenue is 4 to 6 lanes wide with concrete curb and sidewalk.

Formerly provincial Highway 17B, Carling Avenue was the only link between Kanata and Ottawa until the construction of the grade separated "Queensway" (Highway 417) in the 1960's and 1970's. Carling Avenue remains a very busy route however – experiencing 28,500 vehicles and 450 transit buses per day.

The existing water and sewer infrastructure was primarily installed in 1959 and the road structure was upgraded through the installation of a 200 mm thick Portland Cement Concrete (PCC) layer. Although it is not known whether the PCC was left as the riding surface or immediately overlaid, Carling Avenue currently has between 75 and 150 mm of hot mix asphalt on top of the PCC layer and is therefore referred to as a "composite" pavement. While composite pavements tend to be very strong and resistant to traffic loading, they have some interesting properties that can lead to severe distress such as that observed on Carling Avenue.

Specifically, when the PCC layer was constructed on Carling Avenue, the joints between slabs were not reinforced or doweled as with modern concrete pavements. Joints at regular intervals (5 to 10m spacing) are necessary because as the concrete cures, it shrinks and introduces significant tensile stresses within the material. The joints release these initial curing stresses and also allow for seasonal expansion and contraction of the individual slabs due to temperature change. However, movement is only desirable horizontally along the 2 dimensions of the slab – if one slab moves upward or downward with respect to its neighbour (called "faulting"), a bump in the pavement surface is formed, which greatly reduces the smoothness of the ride.

Faulting of concrete slabs is a major failure mode with un-jointed concrete pavements such as that constructed on Carling Avenue. In the winter, water infiltrates down into the joints and freezes, causing the slabs to rise upward – often referred to as frost-jacking. Even if the water does not freeze, it can remove fine particles of soil under the slab and cause differential settlement and rough ride. Faulting mechanisms are shown in Figure 2.

The City was aware of the deteriorating condition of Carling Avenue for some time through its routine performance monitoring efforts. Indeed, the most recent condition survey (2005) indicated that the roughness of the road surface as measured by the International Roughness Index (IRI) was 4.59 m/km with a maximum of 8 m/km, which is on par with some gravel roads. However, rehabilitation had been repeatedly delayed as a result of other pending City transportation initiatives. Specifically, Carling Avenue had been identified as a priority Light Rail Transit (LRT) corridor and since no railway tracks exist anywhere along its length, it would be subjected to complete reconstruction in the event that the project was funded.

However, the 2005 condition data indicated that something had to be done about the condition of Carling Avenue. Future LRT priority corridor or not, the public would simply not tolerate the existing level of service. As such, City Council allocated $3.9 million to address the poor riding quality of Carling Avenue between Woodroffe Avenue and Kirkwood Avenue – a central section 3.2 km in length carrying the highest amount of traffic (Figure 3). Another $1 million was allocated to increase the depth of the sanitary sewer at two locations to address basement flooding in the area.

Project Scope and Pre-Engineering

While $3.9 million sounds like a lot of money to the average citizen, it is important to recall that at 6 lanes wide (21 m) and 3.2 km in length, the pavement surface to be rehabilitated was over 67,000 square metres – an area greater than 42 NHL hockey rinks or 11 Canadian football fields. As shown in Figure 3, the western limit of the project provides access to a major shopping centre, while the eastern limit of the project is an interchange from provincial Highway 417. As such, the high traffic density within the project limits required considerable traffic control measures, further reducing the funds available for the actual rehabilitation effort.

The original objective for the rehabilitation, however, was fairly straightforward – improve the smoothness of the road for the next 5-7 years to give the LRT project sufficient time to determine its needs for Carling Avenue, which will also involve a more comprehensive plan/budget to replace the water and sewer network that is currently 45 years old.

Significant pre-engineering is conducted in advance of any road rehabilitation project to ensure that the most appropriate and cost effective rehabilitation treatment is selected. In addition to site visits and review of the pavement management data, the City of Ottawa conducted non-destructive field-testing to evaluate the existing strength and composition of the road structure.

The strength of Carling Avenue was tested with a Dynaflect and the resulting summary statistics are provided in Table 1. As the pavement deflects very little under the Dynaflect load, Carling Avenue is considerably stronger than the average City of Ottawa full load truck route – primarily due to the presence of the concrete base.

Table 1: Dynaflect Summary Statistics for Carling Avenue

	Dynaflect Maximum Deflection, mils	Standard Deviation, mils	Representative Rebound Deflection, mils
Carling Avenue – Eastbound Outer Lane (Woodroffe Avenue to Kirkwood Avenue)	0.463	0.184	0.832
Average Ottawa Full Load Truck Route	0.838	0.246	1.330

The composition of the road – most importantly the thickness of the existing asphalt and concrete layers – were determined using Ground Penetrating Radar (GPR). GPR sends electromagnetic waves into the pavement and a portion of these waves reflect back when they strike the interface between two different materials (such as asphalt and concrete). Unlike coring, which only provides layer thickness values at a discrete point, GPR provides layer thickness information for the entire length of the project. GPR is also very effective for identifying the presence or absence of reinforcing steel in concrete, as well as locating utilities under the pavement. An example GPR "radargram" is shown in Figure 4. GPR is conducted at normal travelling speed and is very cost effective for the amount of data collected (only $1500 for Carling Avenue).

The pre-engineering information was then used to develop rehabilitation alternatives, as briefly discussed in the following sections.

Analysis of Alternatives

As the "do nothing" alternative was no longer feasible and full reconstruction of the road was not financially feasible, the pre-engineering information was used to develop three rehabilitation alternatives for Carling Avenue.

Alternative #1 – Mill and Replace Asphalt

The first alternative involved simply milling the existing asphalt and replacing it with new asphalt. This alternative was the most simple to construct and had the least initial cost, however, would not address the concrete joint faulting. Although satisfactory performance could be expected for the first year or so, the asphalt would crack almost immediately, allow water into the joints and would result in continued joint faulting - particularly during the winter. This alternative was therefore considered unacceptable.

Alternative #2 – Mill Existing Asphalt, Dowel Bar Retrofit, and Replace Asphalt

Dowel Bar Retrofitting (DBR) is a process where steel bars are installed across the joints to prevent the slabs from moving independently of one another. To install the dowels, slots are cut into the concrete surface and the dowels are then grouted into place (Figure 5).

While DBR would directly prevent future faulting of the concrete pavement, the cost of installation is high as the process is conducted manually. Indeed, the estimated cost for this alternative was twice that of Alternative #1. Furthermore, DBR may only be conducted where the concrete at the joints is in good condition. Previous patching efforts on Carling Avenue suggested that the concrete at many of the joints had deteriorated due to the infiltration of water. Furthermore, local contractors are not familiar with DBR and may not have the appropriate equipment for the work, which may have resulted in higher cost or lower quality. Finally – and most importantly – given that the entire concrete base will be removed for the future utility replacement effort, financial investment toward the concrete base itself was not considered desirable. As such, the DBR process was not considered further.

Alternative #3 – Mill Existing Asphalt, Concrete Rubblization, and Replace Asphalt

As the name implies, rubblization involves the in-place crushing or shattering of the concrete layer into small pieces so that the resulting material acts more like a granular base than a solid slab. Although the underlying subgrade may continue to heave somewhat during the winter, no joints or cracks remain in the concrete layer and therefore the riding quality during the winter and spring will be greatly improved.

The rubblization alternative was slightly less expensive than Alternative #2 and had the added bonus of providing ready access to the underlying utilities in the future, as the shattered material may be easily removed (and recycled) with conventional equipment as opposed to removing the large concrete slabs. Therefore, the investment made in 2006 would not be wasted in the future.

Although rubblization in an urban environment had not been attempted in the City of Ottawa (or any other Ontario municipality), it was considered worth the risk given the potential for greatly improving the smoothness of the pavement at reasonable cost. A more detailed description of the rubblization process is provided in the following section.

The Rubblization Process

Whereas the DBR process prevents joint faulting by connecting the individual slabs together and preventing vertical movement, rubblization prevents faulting by completely removing the discreet joints and cracks. Rubblization may be accomplished with a resonant breaker (Figure 6) that vibrates the concrete at high frequency (approximately 44 Hz) and low amplitude until it shatters into small pieces (Figures 7 and 8). Other methods are available, but the use of resonant breakers prevents damage to the underlying utilities – a critical concern on Carling Avenue given the presence of watermain, sewer, cable, fibre optic communication lines, electrical and gas utilities. The existing asphalt layer must be removed prior to rubblization to prevent excessive damping of the vibration energy.

Interestingly, because the energy from the resonant breaker dissipates rapidly with depth, the resulting particles are smallest at the top of the concrete layer and increase in size with depth. As such, the material retains more bearing capacity than a granular base layer due to an arching effect (Figure 9). This type of structure is similar to the original Macadam technique.

Once rubblized, a small amount of granular material may be added to correct the profile and grade and then the particles are locked into place using heavy rollers (Figure 10). New asphalt is then placed and compacted on the rubblized surface.

Rubblization requires some specialized geotechnical testing to identify areas of saturated soils that may liquefy under vibratory energy. In the case of Carling Avenue, no such issues were identified. Furthermore, infrastructure such as curbs must be detached from the concrete pavement by sawing to prevent damage during the rubblization process (Figure 11).

The rehabilitation of Carling Avenue was completed between June and October of 2006 – quite an achievement in itself given the complexity of the traffic control operations. Despite requiring

10-12 passes per lane, the rubblizer operated at about 6.5 km/hr and the process was completed very quickly.

No significant issues arose during the rubblization effort. The City was concerned about vibration complaints from neighbouring homes and businesses, but no complaints lodged. A number of catchbasin and manhole collars were damaged (despite saw cutting), however, this was attributed to their considerable age and did not impose significant delay or cost.

Superpave was selected for the base and surface hot mix asphalt. The City has used Superpave since 2002 and assisted the Municipal Engineers Association (MEA) and MTO develop the latest specifications for Ontario. A picture of the completed project is provided as Figure 12. A video camera survey of the sewers after project completion confirmed that no damage was imposed by the rubblization effort.

PART 2 – SUSTAINABLE URBAN TRANSPORTATION CRITERIA

Development and Enhancement of Sustainable Urban Transportation

According to the Centre for Sustainable Transportation at the University of Winnipeg[1], a sustainable transportation system is one that:

i) Allows the basic access needs of individuals and societies to be met safely and in a manner consistent with human and ecosystem health, and with equity within and between generations (Social component),

ii) Is affordable, operates efficiently, offers choice of transport mode, and supports a vibrant economy (Economic component), and

iii) Limits emissions and waste within the planet's ability to absorb them, minimizes consumption of non-renewable resources, limits consumption of renewable resources to the sustainable yield level, reuses and recycles its components, and minimizes the use of land and the production of noise (Environmental component).

As a major east-west transportation corridor with access and mobility for private automobiles and transit buses, Carling Avenue provides for the needs of all transportation users, as well as the free movement of goods to the business sector. The rubblization project addressed a major distress mechanism (joint faulting) to increase the smoothness of the road, thereby increasing safety and comfort.
The rubblization process proved very cost effective ($7/m^2) as the concrete material was left in-place as opposed to broken up and trucked off site (approximately $17 to $25/m^2). In addition to the direct cost savings, the use of rubblization <u>prevented the landfilling of over 25,000 tonnes of concrete</u>, as well as the associated trucking requirements. To put this achievement into perspective, a standard 3-axle dump truck is able to carry 20 tonnes of material. As such, a total of 1250 truckloads would have been required to remove the concrete base on Carling Avenue.

[1] Definition available at http://cst.uwinnipeg.ca. Accessed February 12, 2007.

Even if the concrete was recycled (as encouraged by the City of Ottawa), the distance from the project to the contractor's quarry was approximately 30 kilometres. With an average fuel consumption of 41 L/100 km[2], each truck would require approximately 24.6 litres of fuel (60 km round trip) for a total of 30,750 litres of fuel for the hauling portion of the project. This does not include fuel wasted during idling of the trucks, which has been calculated at approximately 3 L/hr[3]. Therefore, assuming an average of 0.5 hours of idling per truck to account for waiting at the job site to load, etc., an additional 1875 litres of fuel would be required. As such, a minimum of 36,625 litres of fuel was saved during the Carling Avenue project.

Processing of the concrete in-place also eliminated the need for virgin aggregates and the energy associated with their production. Furthermore, the Superpave asphalt base layers incorporated 30% reclaimed asphalt pavement (RAP) by mass, representing a savings of approximately 4275 tonnes of aggregate and 225 tonnes of virgin asphalt cement.

With respect to the environment, the substantial savings in fuel directly resulted in substantial reduction in greenhouse gas emissions. The US Environmental Protection Agency (EPA) reports that each litre of diesel fuel results in approximately 2.66 kg of carbon dioxide when combusted[4]. As such, the fuel savings observed for the Carling Avenue project resulted in a savings of over 97,400 kg (97.4 tonnes) of carbon dioxide. Additional emissions savings were observed through the use of RAP, although not specifically quantified. Recognizing that this was only a single 3 km section of road, the environmental component was therefore very significant.

Degree of Innovation

Although Oxford County and the Ontario Ministry of Transportation have conducted rural rubblization projects, Carling Avenue represented the first use of this technology in an urban environment in Ontario. Due to the presence of underground and surface utilities, as well as grade restrictions from curbs and sidewalks, the urban environment presents a much more difficult rehabilitation scenario than rural highways.

For example, determination of the strength of the rubblized layer is required for pavement design purposes. In a rural environment where the pavement elevation may be increased (ie. additional asphalt or granular layers added), the concrete is rubblized first and then tested using a Falling Weight Deflectometer (FWD) to determine if additional strength is required to resist the anticipated traffic loading. For Carling Avenue, there was no opportunity to increase the asphalt thickness from the existing condition due to the presence of curbs. The consultant therefore used a sensitivity analysis with a range of AASHTO layer coefficients for the rubblized layer and determined that the risk of premature failure of the road in fatigue was acceptable.

In addition, the use of Ground Penetrating Radar (GPR) prevented any unexpected surprises with respect to changes in layer thickness that may affect the strength of the resulting pavement.

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[2] Gains, L., Vyas, A. and Anderson, J. "Estimation of Fuel Use by Idling Commercial Trucks." Presented at the 85th Annual Meeting of the Transportation Research Board, National Academies, Washington, DC. 2006.
[3] ibid.
[4] United States Environmental Protection Agency. "Emission Facts: Average Carbon Dioxide Emissions Resulting from Gasoline and Diesel Fuel." Report EPA420-F-05-001 February 2005. Available at http://www.epa.gov/otaq/climate/420f05001.htm. Accessed February 19, 2007.

Overall, the project was considered so successful that the project team was recognized by the City Transportation and Transit Committee for innovation and a second portion of Carling Avenue has been approved for rubblization in 2007.

Interestingly, follow-up performance testing with the FWD after the project was completed has indicated that the rubblized layer is slightly stronger than expected. As such, the Carling Avenue rehabilitation project will provide a longer service life than anticipated, thereby providing even lower life cycle cost. Finally, even when the pavement reaches the end of its design life, there will no longer be any annoying transverse bumps at regular intervals because the concrete joints no longer exist.

Transferability to Other Canadian Communities and Organizations

With proper pre-engineering, rubblization technology is directly applicable across Canada to rehabilitate any distressed PCC pavement. The equipment required is portable and flexible enough to work in any operating environment ranging from long straight sections to tight urban geometries. Specifications for agencies to tender rubblization contracts are also readily available.

As a result of this project and others in the City of Montreal, the US-based rubblization contractor is investigating the potential for a Canadian office. Furthermore, presentations concerning the project have already been made to the MEA and Association of Ontario Road Supervisors (AORS), resulting in considerable interest from other Ontario municipalities.

Added Value

Although originally envisioned as a short to medium term solution, the use of rubblization on Carling Avenue will provide the City of Ottawa with considerable value added with respect to the future (and considerably more costly) utility replacement project that will involve complete reconstruction of the road. By shattering the existing concrete slab, access to the underground utilities in the future becomes a simple operation using a standard equipment instead of a more time consuming and expensive operation involving sawing and breaking of intact concrete slabs. Therefore, in addition to providing a smooth riding surface for the immediate and coming years, <u>the current project represents an investment</u> toward reducing the future cost of reconstruction.

SUMMARY

The City of Ottawa remains committed to pavement recycling and the associated environmental and performance benefits toward a sustainable urban transportation system. The Carling Avenue Rehabilitation Project presented an opportunity to take a calculated risk and try an innovative technique that not only cost effectively addressed a severe performance issue, but did so with a greatly reduced impact on the environment.

Figures

Figure 1: Aerial View of Carling Avenue from Kanata to Downtown Ottawa (Project Limits shown as dashed line)

Figure 2: Concrete Pavement Faulting Mechanisms

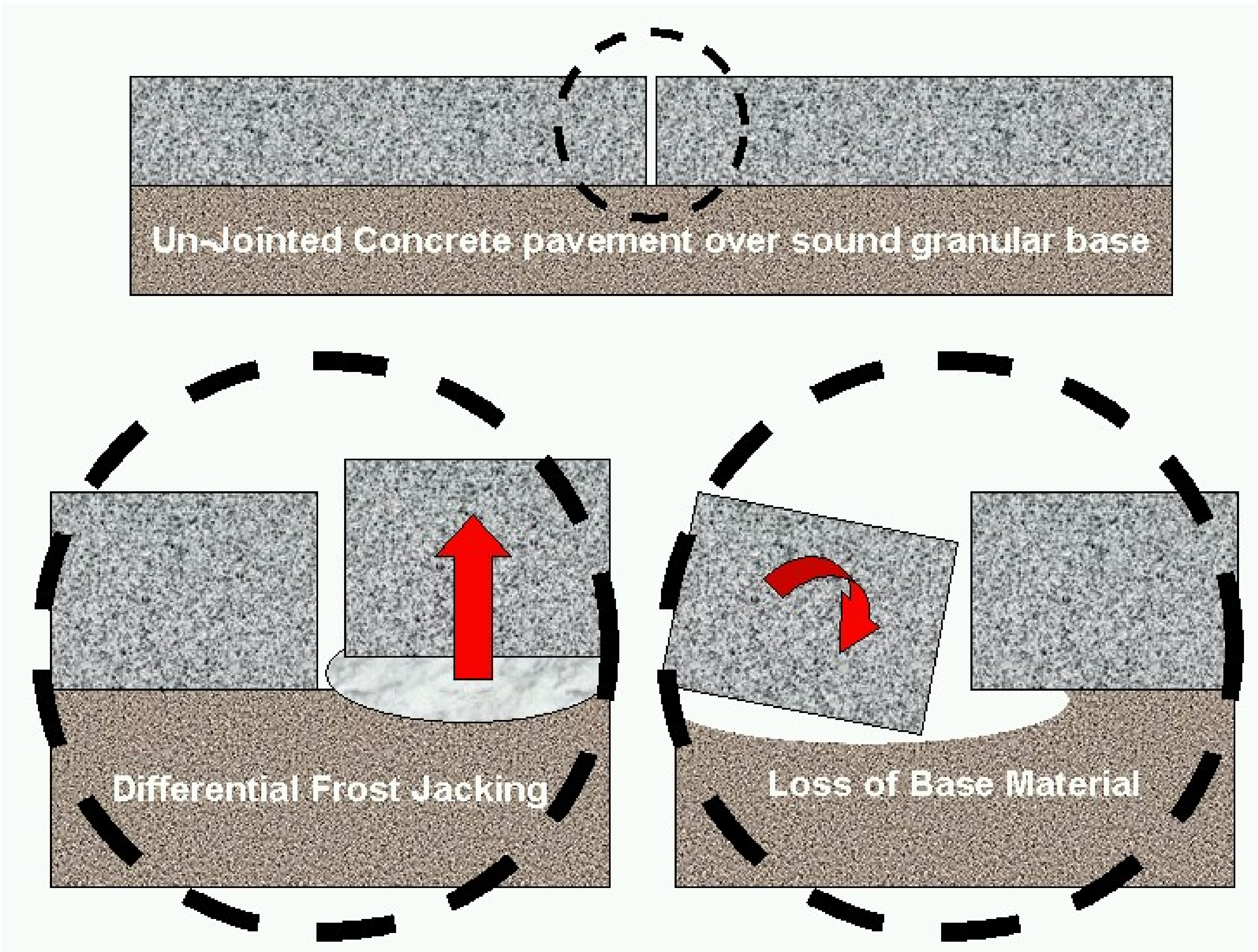

Figure 3: Aerial View of Carling Avenue Project Limits (Woodroffe Avenue to Kirkwood Avenue)

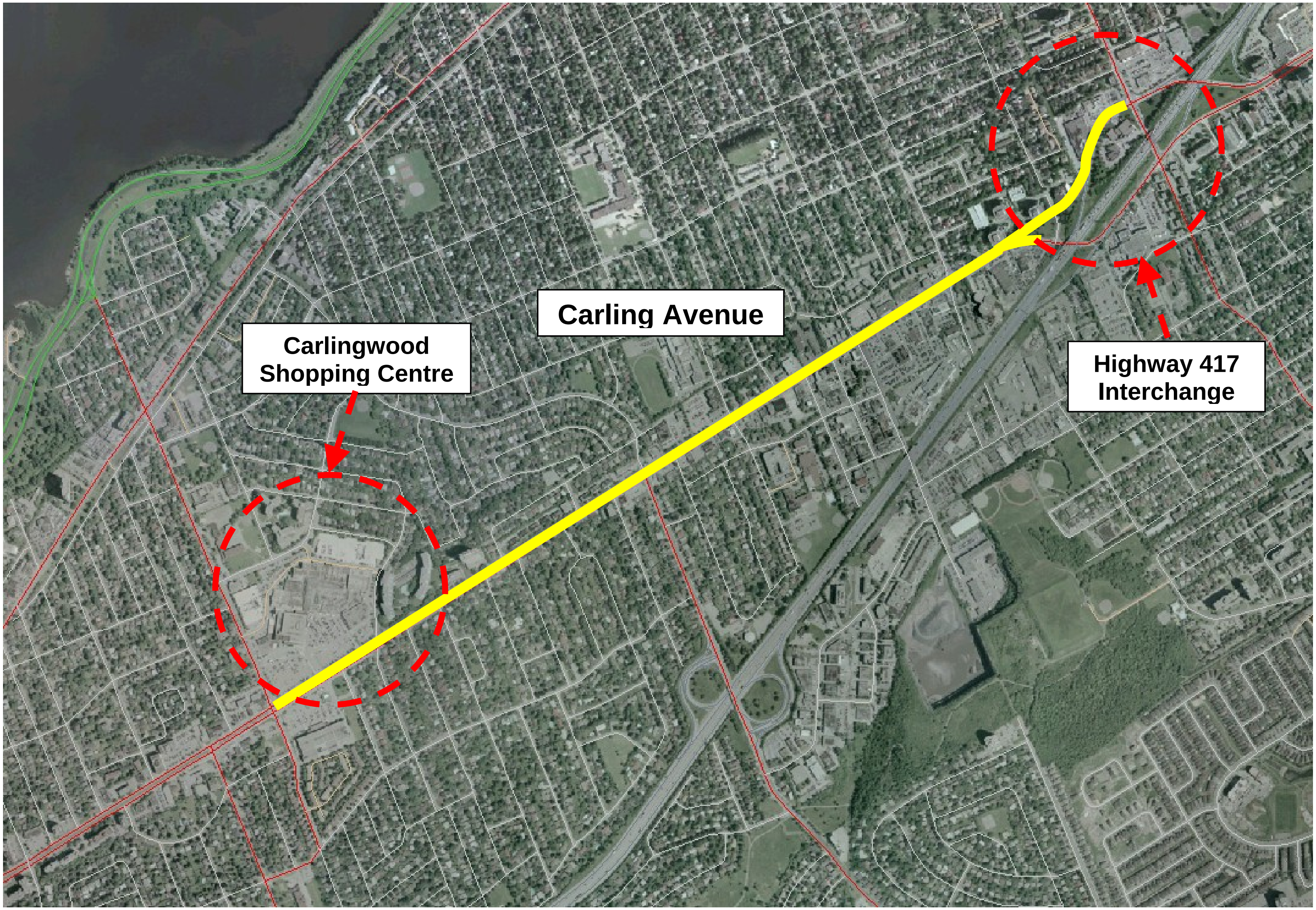

Figure 4: Example Ground Penetrating Radar (GPR) “Radargram” displaying Layer Thickness Data

Blue Line represents Bottom of Asphalt Layer/Top of Concrete Layer
Red Line represents Bottom of Concrete Layer
Purple Line shows areas where Reinforcing Steel were Located

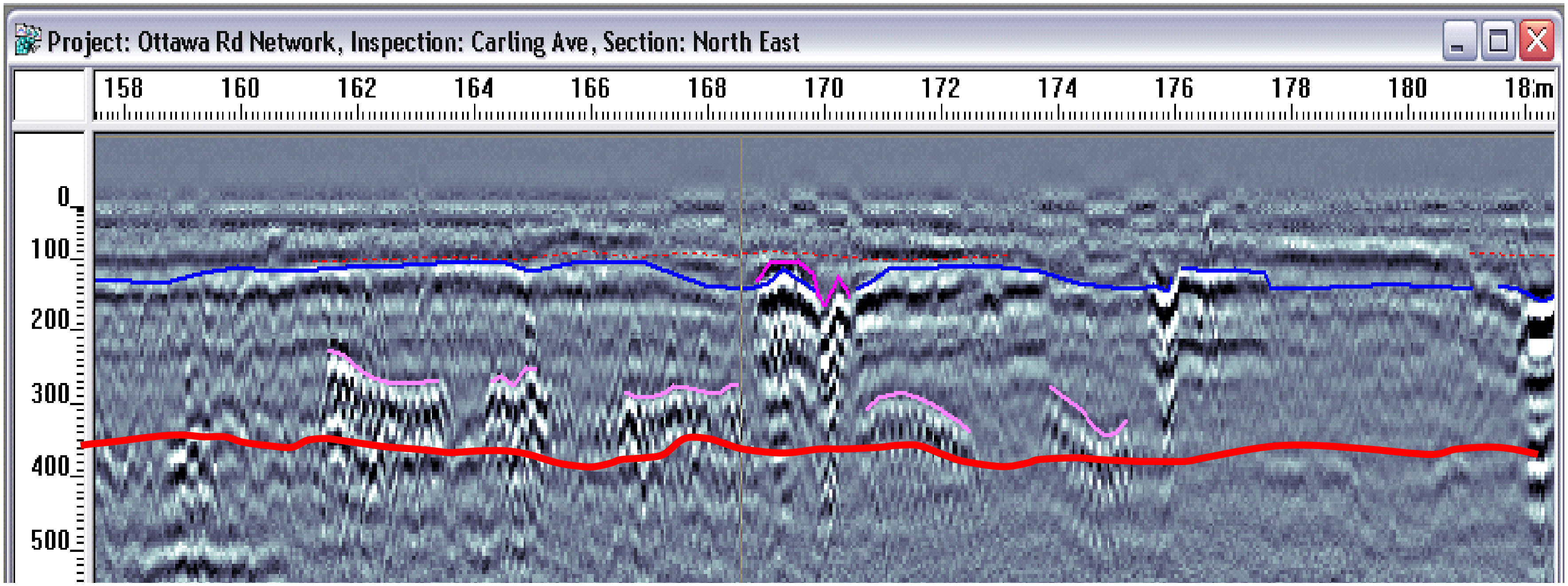

Figure 5: Dowel Bar Retrofitting

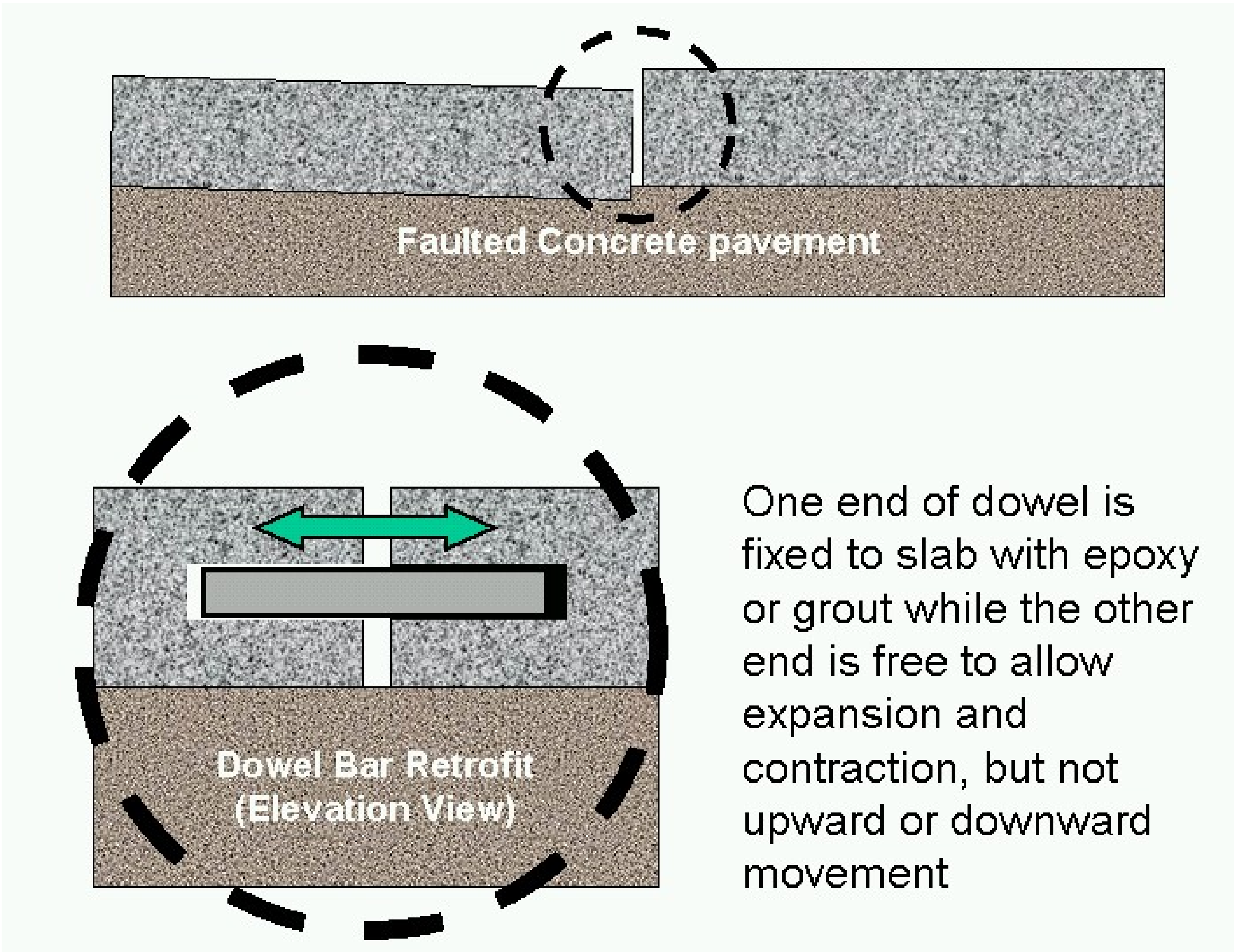

Figure 6: Rubblizer (Dashed Circle highlights single Resonant Breaker Head)

Figure 7: Rubblizer in Action on Carling Avenue

Figure 8: Comparison of Intact and Rubblized Concrete Surface (Plan View)

Figure 9: Arching Effect of Rubblized Layer versus Traditional Granular Material

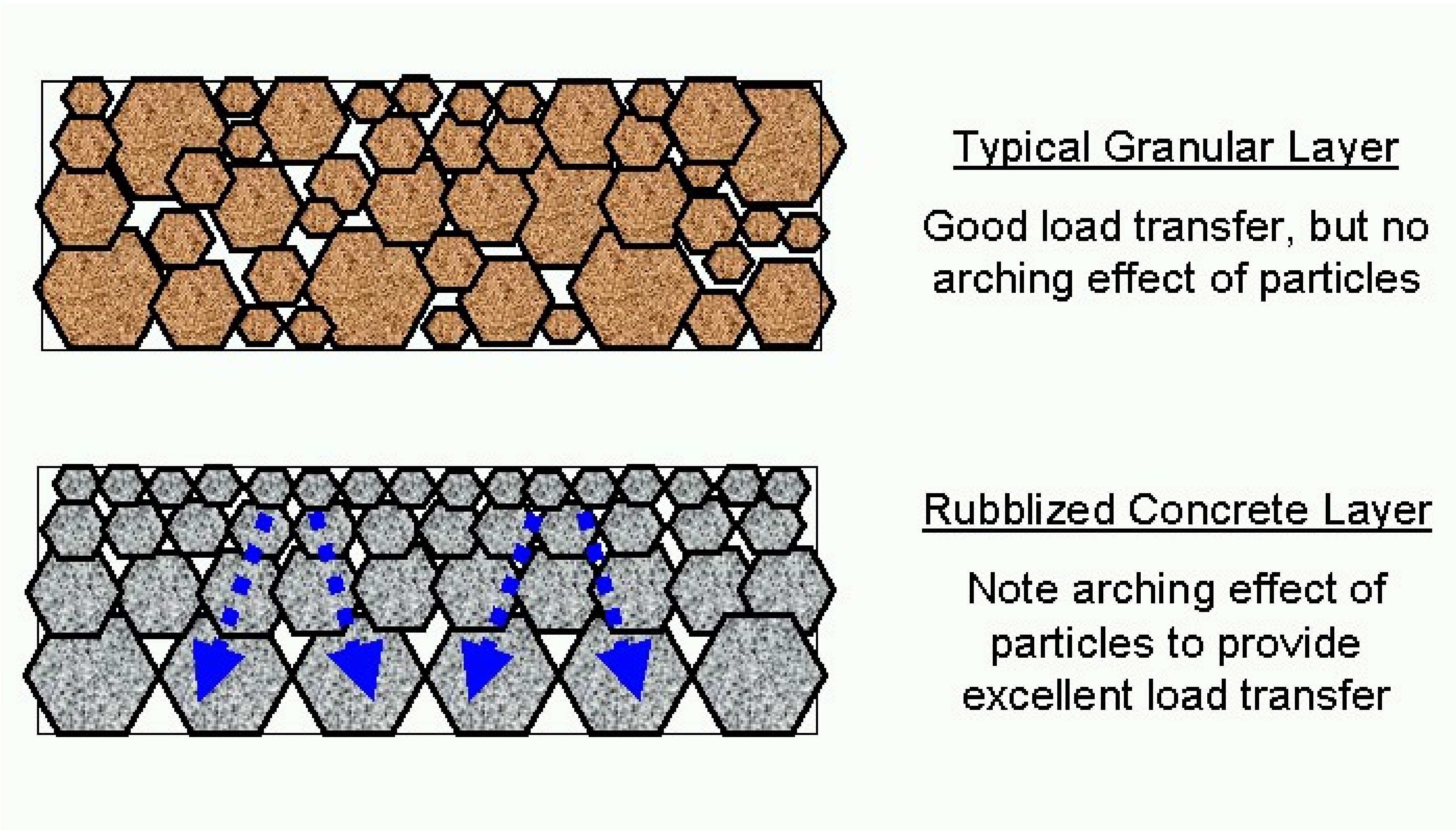

Figure 10: Levelling the Grade and Profile with Granular A and Compacting the Rubblized Surface

Figure 11: Saw Cutting to Separate Curbs, Intersections, Catchbasins and Manholes

Figure 12: Completed Project - Carling Avenue with Superpave Asphalt on Rubblized Concrete Layer