# Case Study of an Innovative Forensic Investigation of a Dramatic Pavement Failure, 14 Street NW, Calgary, Alberta.

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**Abstract**

On the evening June 5th, 2007, the City of Calgary experienced an extreme weather event; over 70 mm of rainfall, much of which fell within one hour. This resulted in significant consequences in terms of surface runoff, storm sewer capacity and other related pressures on surface and subsurface infrastructure. Likely the most dramatic of the damage was the resulting distress to an approximate one kilometer section of 14 Street NW, a primary north/south commuter corridor accessing the City downtown core. Surface damage included severe upheavals in both the roadway and adjacent sidewalk, the extent and magnitude of which required closing of the facility to both vehicles and pedestrians.

The City of Calgary, Roads Division, commissioned EBA Engineering Consultants Ltd. to undertake an integrated pavement and subsurface assessment program. This included Road Radar™, geotechnical Ground Penetrating Radar (GPR) and Falling Weight Deflectometer (FWD) testing. This information was supplemented with detailed visual surveys and interviews with City personnel. In addition, the City undertook assessment activities such as video inspection of sewer installations.

This paper describes the innovative pavement assessment methodology and data presentation features, along with the methods used to identify the cause, nature and extent of pavement and subsurface distress. The design concepts employed for the necessary restoration are provided as well as several innovative project delivery concepts and construction details. These aspects were focused on addressing the impacted infrastructure, mitigating the reoccurrence of this phenomena, and fast-tracking the project to minimize traffic disruption on this primary route.

## INTRODUCTION

On an evening in June, 2007, the City of Calgary experienced an intense rainfall event. This resulted in significant consequences in terms of surface runoff, storm sewer capacity and other related pressures on surface and subsurface utility infrastructure. Likely the most dramatic of the damage was the distress effecting 14 Street SW, a primary north/south commuter corridor accessing the City downtown core. Surface infrastructure damage was to the extent that a portion of the facility, roadway and adjacent sidewalk, required closing to both vehicles and pedestrians.

The City of Calgary, Roads Division, commissioned EBA Engineering Consultants Ltd. (EBA) to undertake an integrated pavement and subsurface assessment program. This paper describes the innovative pavement assessment methodology and data presentation features, along with the methods used to identify the cause, nature and extent of pavement and subsurface distress. The design concepts employed for the necessary restoration are provided as well as several innovative project delivery concepts and construction details. These aspects were focused on addressing the impacted infrastructure, mitigating the reoccurrence of this phenomena, and fast-tracking the assessment and repair to minimize traffic disruption on this primary route.

## THE EVENT

Tuesday, June 5$^{th}$, 2007, began as another pleasant early summer day in the City of Calgary. Residents awoke to mid-teen temperatures under mostly cloudy skies. By mid-afternoon skies remained mostly cloudy with a high temperature of 22°C. According to Environment Canada records, sometime after 6:00 pm the temperature rapidly dropped over 10°C. By 7:00 pm Calgary was experiencing heavy thunderstorms / heavy rain showers. Moderate rain showers occurred for the remainder of the evening. The final accumulation recorded for June 5$^{th}$ at the Calgary International Airport was 72.4 mm, a record for this date and slightly less than the June record of 79.2 mm set in 1932.

Typically, the total amount of rainfall varies across the City. Subjective observations indicate that the majority of the rainfall occurred during a limited time; less than an hour. This resulted in significant consequences in terms of surface runoff, storm sewer capacity and other related pressures on surface and subsurface utility infrastructure.

Although no photographic documentation exists for the subject roadway on the evening of June 5$^{th}$, Figures 1 and 2 illustrate the severity of the storms impact on other major roadways in the city.

**Figure 1: Deerfoot Trail on the evening of June 5, 2007.**

**Figure 2: Glenmore Trail on the evening of June 5, 2007.**

Likely the most dramatic observed damage was the resulting distress to an approximate one kilometer section of 14 Street NW. This 4-lane roadway represents a primary north/south commuter corridor accessing the City downtown core. Figure 3 provides the location of the roadway section.


**Figure 3: Map Showing Location of the 14 Street NW Project**

The majority of the distress was exhibited by the northbound lanes. The pavement distresses included severe heave and blow-outs of the asphalt concrete surfacing. Other pavement distresses noted included a severe longitudinal crack along the roadway centre-line (i.e. between the northbound and southbound lanes) at the south end of the section.

In addition to the pavement distress, significant sidewalk distress was noted along the section. This included total concrete slab upheaval and a severe slab faulting. Separation of the monolithic curb and sidewalk and pavement, with in many cases differential vertical movement was also noted. In the south portion of the section there appeared to be significant spalling of the curb and gutter joints, resulting in a 30mm to 50mm gap.

The extent and magnitude of the damage required closing of the facility to both vehicles and pedestrians. Figures 4 through 7 shows various aspects of the surface infrastructure damage.

**Figure 4: 14 Street NW Pavement Distress**

**Figure 5: 14 Avenue NW Pavement Distress**

**Figure 6: 14 Street NW Pavement Distress**

**Figure 7: 14 Street NW Sidewalk Distress**

## THE RESPONSE

The City of Calgary, Roads Division, contacted EBA on June 6, and subsequently commissioned them to undertake an integrated pavement and subsurface assessment program. The program included:

- Geotechnical Ground Penetrating Radar (GPR) to identify deep subsurface anomalies,
- Road Radar™ to characterize pavement structure thickness and shallow subsurface anomalies, in addition to providing a video log record, and,
- Falling Weight Deflectometer (FWD) testing to assess structural adequacy.

Due to the urgent nature of the situation, data collection platforms were mobilized from Saskatchewan and northern Canada. The field surveys were all completed on June 8th and 9th. Subsequently, post processing of the data was undertaken throughout the following weekend. A preliminary report, including the field data collection outputs, was presented to City personnel on June 12th. The following sections describe the data collection and presentation.

### Ground Penetrating Radar (GPR)

Geotechnical GPR was used to investigate and map deep sub-surface conditions along the northbound lanes to identify potential subsurface damage beneath the road. Subsurface GPR units operate on the same time-of-flight principle as conventional radar systems used for air traffic control or speed enforcement purposes. In basic terms, an electromagnetic (EM) pulse of extremely short duration is transmitted into the ground from a transmitter antenna, is partially reflected from multiple subsurface objects, and the reflections are detected at the receiver antenna, which accurately records their travel time. A series of these soundings, taken at regular intervals along a line, builds up a cross-sectional profile of the reflections beneath the line.

As the EM wave propagates downward through the ground, it encounters and passes through materials having specific physical properties. The two important material properties for radar surveys are the dielectric permittivity and electrical conductivity. The dielectric permittivity (or dielectric constant) affects the velocity of the EM pulse. At interfaces having different dielectric constants, a reflection occurs, the magnitude of which is proportional to the contrast in layer permittivity. Typically, dry sand has a dielectric constant of approximately 3, while water has a very large dielectric constant of approximately 80. The dielectric contrast would produce a large signal reflection at the water table interface depth in coarse sands and gravel. Strong reflections occur from metallic, polyethylene/polyvinyl or concrete objects whose physical properties differ significantly from those of the surrounding soil (such as buried pipes). Generally, an abrupt change in dielectric constant will be more detectable than a gradual change.

The other physical property of concern, electrical conductivity, affects the radar pulse attenuation. When a high-frequency EM pulse encounters a conductive material energy is removed from the pulse, limiting the penetration depth. In practical terms, this means that conductive soils are more difficult to penetrate with GPR.

Subsurface profiling using GPR is a non-destructive measurement procedure. Although the system is generally able to resolve all significant subsurface layers and anomalies, GPR is best used as an overview tool to identify areas where the reflection characteristics appear anomalous. These anomalous areas can then be accurately delineated for further investigated.

Four survey lines were acquired along the two north-bound lanes, nominally positioned in both wheel-paths. A fifth survey line was acquired immediately beside the curb. This survey layout was performed twice, first with a deeper penetrating 120 MHz GPR antenna, followed by a higher resolution 500 MHz antenna.

The GPR profiles were post-processed, analysed and reported using a comprehensive proprietary data analysis package. This analysis included the identification of any anomalous reflectors or other subsurface features of interest. Since each profile represents a cross-sectional view of the subsurface structure, these parallel surveys were correctly referenced and combined to produce a 3 dimensional view of the study area. This approach allowed the spatial correlation of any significant subsurface features, facilitating an assessment of feature depth, orientation and distribution across the road.

Analysis of the GPR data involved the identification of four distinct types of reflection signatures: above-ground infrastructure (i.e. bridges, overhead signs), below-ground infrastructure (pipes, man-holes, and gutters), major ‘disturbed’ regions, and individual anomalous ‘sub-asphalt’ reflectors. Disturbed regions and sub-asphalt reflections were identified by the nature of the profiles in those regions, relative to the nature of the profile in areas that didn’t appear to suffer damage (i.e. the extreme northern and southern ends of the survey area).

The processed, interpreted and annotated GPR profiles from the 120 MHz surveys, is presented in Figure 8. For this the figure, the 3 dimensional analysis has been sliced in a tomographic sense to present feature and anomaly results for a 2 – 3 metre depth below the surface.

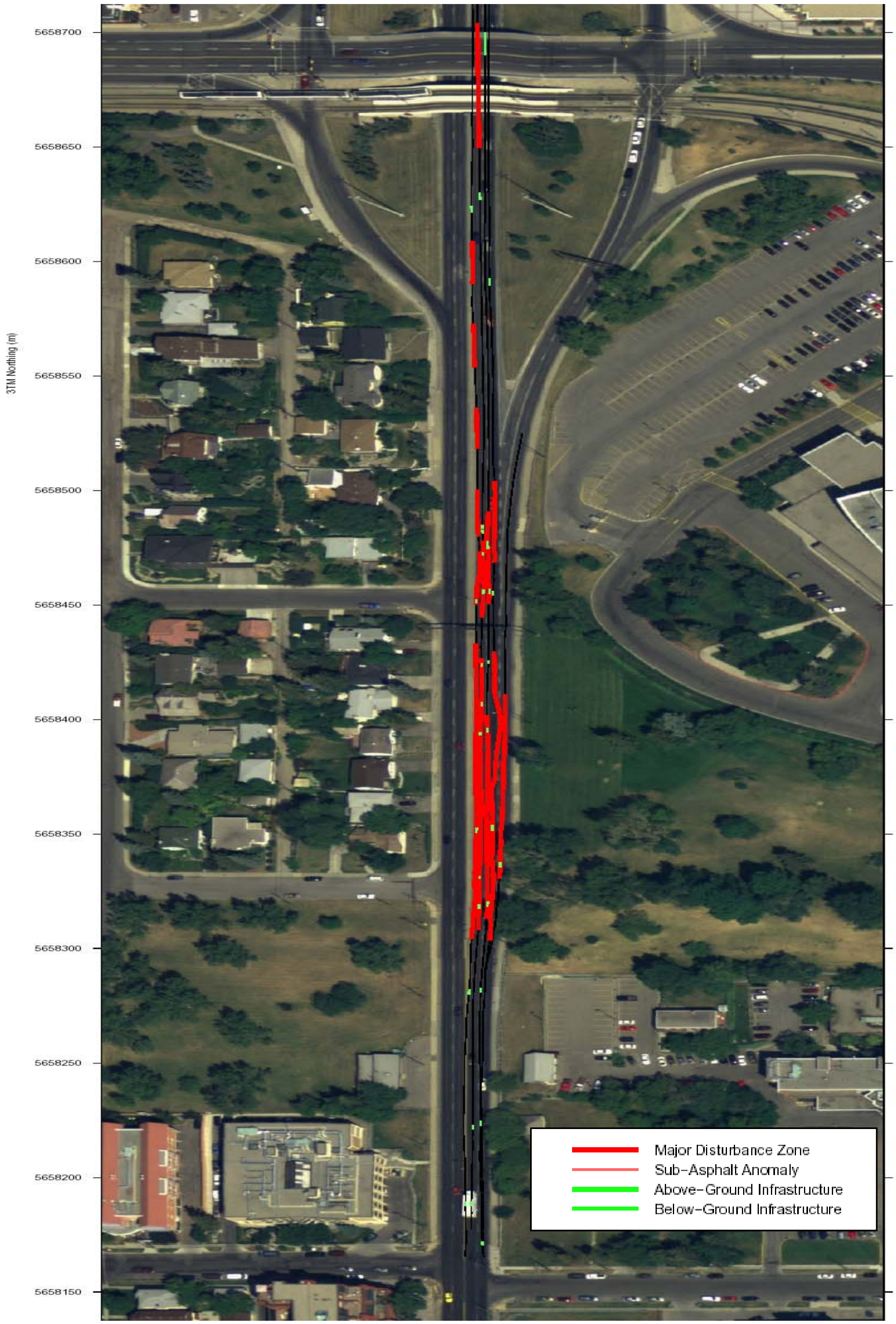


**Figure 8: 120 MHz GPR Anomaly Analysis (2 to 3 Metre Depth**

## ROAD RADAR™ Survey

EBA's ROAD RADAR™ SYSTEM is a GPR based technology developed specifically to optimize the non-destructive assessment of pavement and bridge structures. The system has the ability to resolve pavement layers as thin as 25mm to a typical maximum penetration depth of 1.8 metres at speeds up to 100kph. For the 14 Street surveys, the system was configured to collect subsurface measurements at 10cm intervals producing structural layer interface depth measurements with an absolute accuracy of ±5%. All collected data was both linearly and spatially referenced and included digital video logs for all surveys.

The ROAD RADAR™ SYSTEM post-processing and analysis was focused on highlighting structural anomalies and atypical subsurface features. An overview of the analysis and radar signature recognition configuration used for the 14 Street forensic study is summarized below;

- Layer interface events, the interface between dissimilar materials, produce horizontal multicoloured bands. For the ROAD RADAR™ SYSTEM, these interface signatures consist of three bands of opposite colour (black-copper-black or copper-black-copper). The intensity of the band colours is indicative of the signal strength, which reflects a relative measure of the adjacent layer material dielectric contrast (very dissimilar materials produce strong contrasts). For these surveys, the base interfaces have been designated with a weak, medium or strong classification according to the intensity of the signal reflected from that interface.
- Transverse crack events are identified as vertical stripes in the graphical radar data, more severe cracks appear as wider vertical stripes, and the crack depth may be determined by the propagation depth of the vertical stripe signature into the road structure. The shorter survey sampling interval (0.10m) used for these surveys was selected to ensure the reliable detection of transverse crack events.
- Void events are identified as localized (spatially narrow) high intensity reflectors. For cracked roadways, these events are typically coincident with a horizontal layer interface and a vertical crack. The high intensity reflector arises from a strong dissimilarity between the host layer material and either the air filled or water filled void. The shorter survey sampling interval (0.10m) used for these surveys was selected to ensure the reliable detect identify void events less than 0.5m in length.
- Point reflector events (buried objects with spatially small sizes with respect to the direction of travel) would appear as hyperbolas (approximated by inverted V's). The apex of the inverted hyperbolic radar signature identifies the actual location of the substructure object. A transverse pipe is one source of these types of radar signatures.

The automatic classification of the different layers types (asphalt concrete, Portland cement concrete or granular base/subbase etc.) is based on the measured signal velocity and corresponding calculated dielectric values of each detected layer. Although the classification of the individual layer material type may be in error using this characteristic material dielectric approach, the measured layer thicknesses will be correct.

An example of the detailed continuous profile radar survey results for the surveys is provided as Figure 9.

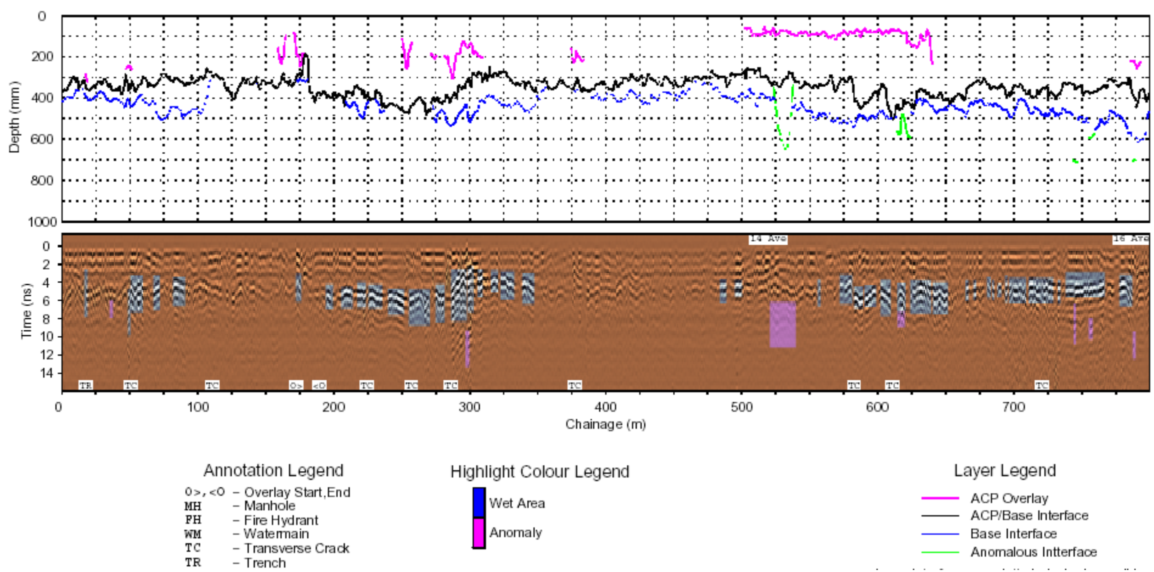


**Figure 9: Typical ROAD RADAR™ Profile Presentation**

The ROAD RADAR™ SYSTEM survey methodology used for the northbound lanes of 14 Street NW allows the rendering of all measured parameters using a contoured plan map format. Dimensions on the plan maps are given in meters for both the longitudinal position (chainage from 8th Avenue) as well as transverse position. An appropriate legend is provided for each map. The descriptions of the reported parameters and any corresponding rendering details are discussed below.

Asphalt Concrete Thickness Plan Map (Figure 10)

This plan map shows the measured asphalt concrete thickness. This measurement is reported from the roadway surface to the top of the first detected base layer. The worst case measurement accuracy for this parameter is 6 mm or 5%, whichever is greater. A legend is provided which relates each color to a thickness range and identifies the percentage of the total area corresponding to that thickness range.

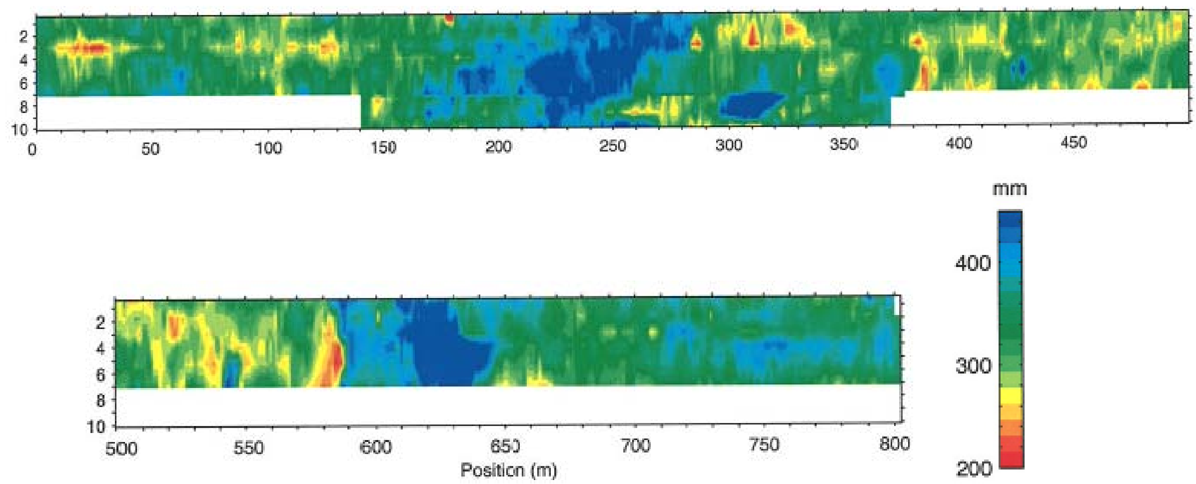


**Figure 10: Asphalt Concrete Thickness Plan Map**

Granular Base Thickness Plan Map (Figure 11)

This plan map displays the thickness of the total base below the ACP, with a worst case measurement accuracy of 12 mm or 10%, whichever is greater. A legend is provided as for the Granular Base Thickness Plan Map.

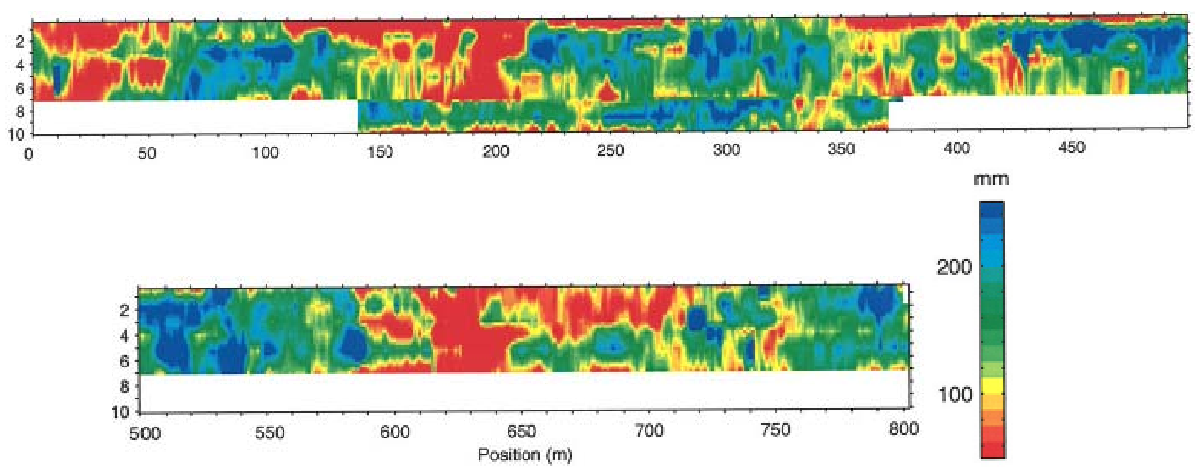


**Figure 11: Granular Base Thickness Plan Map**

ROAD RADAR™ Subsurface Anomaly Plan Map (Figure 12)

This plan map shows the location and areal extent of the anomalies detected between the interpreted Asphalt/Granular Base boundary. These features have been classified as wet areas and anomalies. Wet areas are anomalies delineated by localized dielectric increases. The remaining anomaly features (red areas) are areas in the radar data with abnormal radar signature characteristics at the asphalt concrete/granular base boundary. These signatures were identified as areas where the base material fines may have washed away due to the heavy flooding, and therefore, represented localised air or water filled voids at the time of survey.

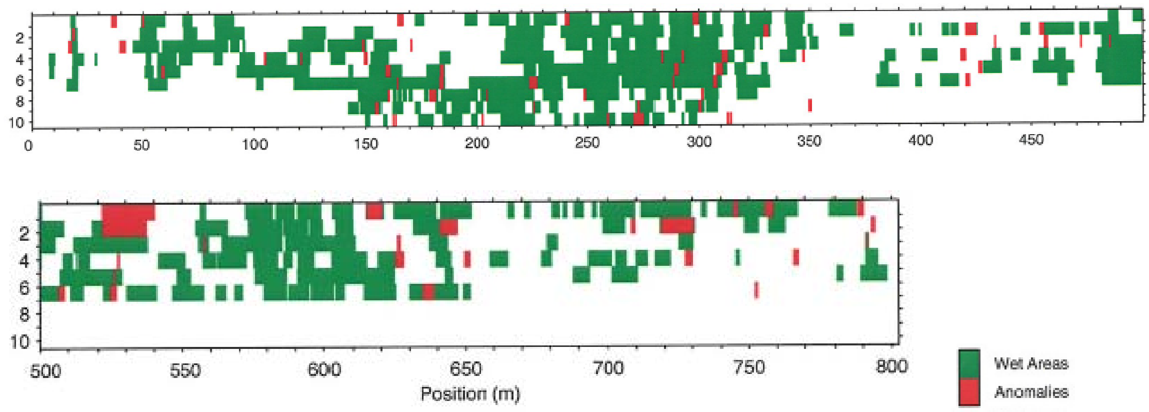


**Figure 12: ROAD RADAR™ Subsurface Anomalies Plan Map**

## Falling Weight Deflectometer Survey

Pavement load/deflection testing was completed using one of EBA's Falling Weight Deflectometer (FWD) testing platforms. A FWD is an impulse type testing device which imparts a transient load upon the pavement surface. The magnitude and duration of the imparted load closely approximates the load applied by a single 18 KIP Equivalent Single Axle Load (ESAL) moving at moderate speeds. The FWD was configured with nine radial geophone sensors providing surface deflection data at known distances from the load application point. At each test location, three applied load levels were used (26, 40 and 53KN) to determine the deflection response of the pavement.

FWD test data was post-processed using Dynatest's Evaluation of Layer Moduli and Overlay Design (ELMOD) analysis program. In addition, to assessing the typical pavement attributes, back-calculated subgrade support modulus and pavement stiffness, the ELMOD analysis supplemented by the ROAD RADAR™ measured subsurface thickness information enabled evaluation of the suspect granular base layer.

ELMOD Derived Base Layer Resilient Modulus Plan Map (Figure 13)

This plan map shows the location and areal extent of the derived ELMOD base layer resilient modulus values. The in-situ post-flood base strength as determined using ELMOD has been divided into three categories: Normal (white areas), Weak (values less than 1500 MPa) and Very Weak (values less than 200 MPa).

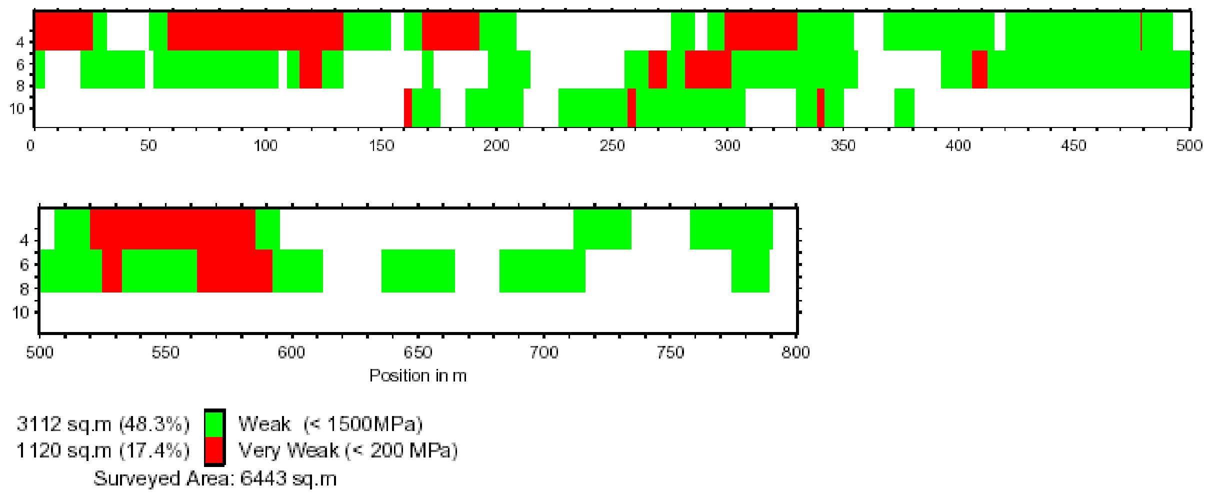


**Figure 13: ELMOD Derived Base Resilient Modulus Plan Map**

As shown by Figure 13, extensive areas of the subject pavement were identified as weak or very weak granular base support.

Of note is the adjacent southbound lanes of 14 Street SW were also assessed with FWD testing and analysis. The results of this evaluation confirmed that no structural deficiency existed, which coincided with the fact that there was no visible distress as a result of the storm event.

### Supplementary Assessment Activities

City personnel conducted camera inspections of both the storm sewer and sanitary sewer which run beneath the 14 Street northbound lanes. Discussions with City personnel visiting the site identified the following relevant background information relative to the incident:

- The storm sewer line is generally located down the northbound outside lane (the centre lane within the three lane section), and then under the east sidewalk for ≈100m north of 8 Avenue.
- The sanitary sewer runs down the median and inside northbound lane.
- Based on the preliminary review of the camera inspection information, no problems with the piping were observed of the storm or sanitary sewer within the affected area.
- Within the area exhibiting pavement, curb and gutter, and sidewalk distress (generally from the crest of the hill (≈400m north of 8 Avenue) to 8 Avenue, the storm sewer system includes eight manholes, six within the outside through lane and two within the east sidewalk.

- The upper 300mm to 400mm for most manholes in the affect area (typically constructed with concrete rings and/or bricks to enable grade corrections) was compromised.
- The nature of the system in terms of catchments area and storm sewer capacity, would indicate that the greatest system pressure during an extreme storm event would initially be located at the manhole south of the crest of the hill, with pressure generally decreasing going south (or downgrade) in the system.
- Due to storm sewer manhole lids dislodging previously during storm events, some manhole lids, if not all, had been secured to the manhole collar by tack-welding.

## THE FINDINGS

The results of the field investigation activities (ROAD RADAR™, geotechnical GPR and FWD) and discussions with City utility personnel provided extensive evidence with regards to the extent and potential cause of the pavement distress. This post-flood non-destructive forensic analysis, along with field observations with respect to nature, severity, location and "pattern" of the distresses evident in the pavement and associated surface works, provided a basis for the development of a detailed hypothesis regarding the damage cause and effect. This hypothesis was as follows, and is illustrated by the schematic illustration provided in Figure 14.

*"As a result of the relatively short duration / high precipitation storm event, the storm sewer was beyond its capacity and pressurized to a point where the storm water escaped, in very high quantities, from the "weakest link"; the upper portion of the storm manholes. The escaping water permeated and saturated the surrounding pavement structure, within the granular base layer, trapped by the relatively impermeable subgrade below and the overlying asphalt concrete layer. The water built in pressure within the pavement structure, in some cases causing failure of the overlying asphalt concrete layer, finally finding relief in the adjacent sidewalk where it escapes at an approximate 45° angle "downstream" of the manhole where it originated. The first occurrence of this "venting" was at the manhole located just below the crest of the hill. Subsequently, after some time interval, this occurred at each of the six storm manholes located within the roadway, sequentially moving downhill. The pressure and volume of water escaping each successive manhole lessened, resulting in less pavement damage and subsequently less damage to the concrete surface works when the water escaped."*

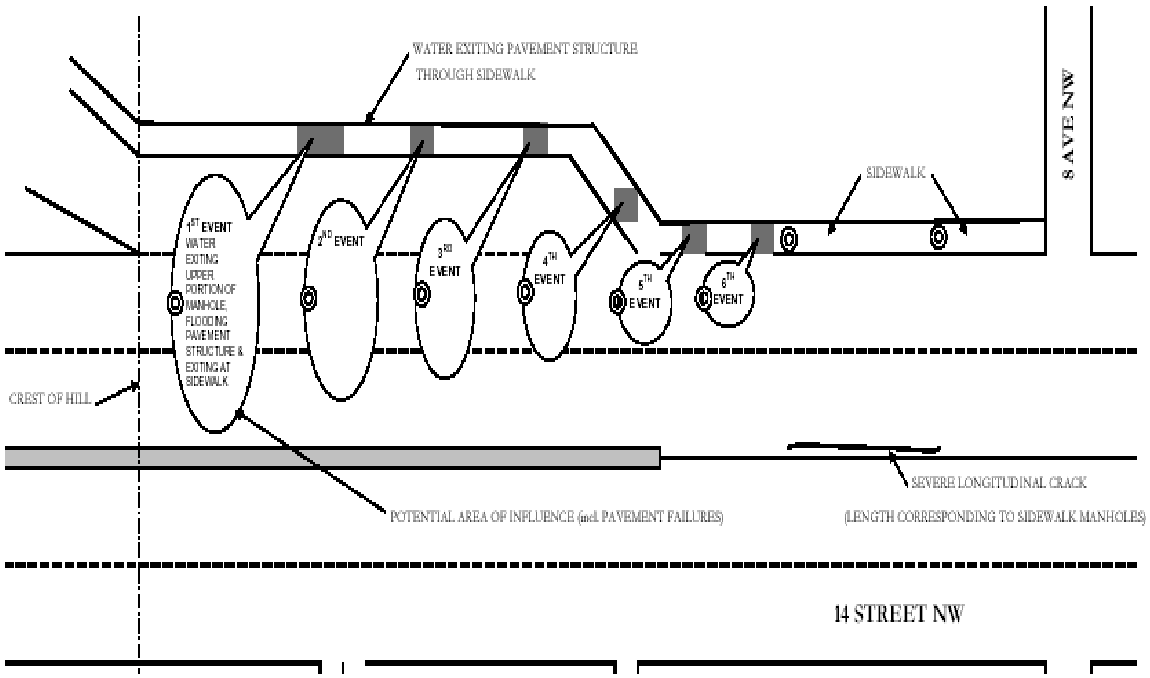


**Figure 14: Schematic Showing 14 Street NW Distress Manifestations**

Figure 15 provides an illustration of one of the primary failure points, as described in the hypothesis.

**Figure 15: Primary Point of Failure at Storm Manhole**

It was evident from both the subsurface and FWD assessments, along with visual observations, that not only had the strength of the underlying pavement structure (primarily the granular base layer) been seriously compromised, but that in fact a significant amount of granular material had been piped out of the structure through pavement and sidewalk failures. This essentially eliminated the potential for surface or partial depth rehabilitation and reconstruction of the effected pavement structure was deemed warranted.

## REINSTATMENT

Design of a replacement pavement structure was initiated immediately. Several options were assessed based on the information made available by the evaluation previously undertaken. The design adopted could be termed a "thin" pavement structure comprised of a relatively thick asphalt concrete layer (240 mm) and a relatively thin granular base layer (250 mm). Factors supporting this alternative included:

- Salvage and incorporation of the remaining granular material at a 490 mm depth into the upper subgrade layer to provide additional subgrade strength and support.
- Reducing the potential for conflict with shallow utility installations, which would negatively impact the construction schedule.
- Offering a shorter construction duration compared to alternatives requiring deeper excavation and removal.

Due to the uphill grade and the presence of transit bus traffic the appropriate Superpave mix type and PG 70-31 polymer modified binder were identified for the upper asphalt concrete layers.

The City immediately solicited local contractors for their availability to undertake the necessary works. Although the industry empathized, unfortunately, due to the busy construction season already underway in Calgary, no contractor had the capacity to complete the project expeditiously. Therefore, City forces acted as the prime contractor with equipment and operators provided by the private contracting sector.

One issue remained to be addressed. How would the reconstruction deal with the cause of the dramatic failure such that its reoccurrence would be mitigated? A total redesigning and reinstallation of the storm system would be a lengthy process and, in fact, plans were already underway for an off-site storm sewer upgrade in the area. The preferred solution was monolithic cast-in-place manholes with specially design vented covers with a release mechanism which would enable the cover to lift to a modest level to relieve storm water pressure if necessary. Installation of these manholes is shown in Figure 16.

**Figure 16: Installation of Cast-In-Place Manholes**

## THE RESULT

On the morning of July 19th, 2007, the City of Calgary, Roads Division announced that northbound 14 Street NW, between 8 Avenue and 16 Avenue would be open for traffic at noon, in time for the afternoon commute. It had been 43 days since the June 5th storm event. Within that time frame, an integrated, comprehensive pavement evaluation had been executed, engineering and design of an appropriate solution had been successfully delivered, and the reconstruction of an approximate one kilometer section of two-lane arterial roadway, complete with sidewalk, curb and gutter, had been completed. In an environment where surface infrastructure projects sometimes take years to come to fruition, the 14 Street NW project is truly a success story, combining innovation in pavement evaluation, design and project delivery.

Excellent performance of the roadway section has been shown to date and no indications of problems associated with storm events have been observed.