Ontario's Move to Hot Mix Asphalt Pavement Smoothness Acceptance Using High Speed Inertial Profilers

Seyed Tabib, Senior Bituminous Engineer

Materials Engineering and Research Office, Ministry of Transportation of Ontario

Chris Raymond, Head Construction Contracts

Contract Management and Operations Office, Ministry of Transportation of Ontario

Alexander (Sandy) Brown, Technical Director

Ontario Hot Mix Producers Association

Pamela Marks, Head Bituminous Section

Materials Engineering and Research Office, Ministry of Transportation of Ontario

Paper Prepared for Presentation
at the Measuring and Using Pavement Performance Data Session
of the 2013 Conference of the
Transportation Association of Canada
Winnipeg, Manitoba

September 22 to 25, 2013

ABSTRACT

The Ministry of Transportation Ontario (MTO) implemented a smoothness specification for newly constructed hot mix asphalt paving in 1997. Smoothness data collected since have shown that the ride quality of newly constructed asphalt pavements on Ontario highways has improved by about 25 percent. Up until 2010, the smoothness of new asphaltic pavements was accepted based on Profile Index (PI), measured by California profilographs. These 7.6 m long manual profilographs are operated at walking speed, measure one wheel path at a time and require lane closures. Therefore, MTO and the Ontario hot mix asphalt industry sought an alternative device that would be faster and safer to operate, alleviating the need for lane closures.

MTO conducted several studies to evaluate high speed inertial profilers which can measure both wheel paths simultaneously. Technical and financial comparisons were made between high speed profilers and California profilographs, leading to development of smoothness acceptance criteria based on inertial profiler measurements that were comparable to the existing smoothness criteria for California profilographs. The correlation between the data obtained by both devices was excellent and supported the phased-in use of high speed inertial profilers for acceptance on selected contracts in 2010 and 2011 with full implementation in 2012.

MTO adopted the ProVAL software program to calculate International Roughness Index (IRI) and identify localized roughness. This paper presents the transition from the TxDOT algorithm in ProVAL to the Smoothness Assurance Module (SAM) of ProVAL version 3 to identify localized roughness. In the 2010 and 2011 construction seasons, MTO conducted extensive analyses in collaboration with the Ontario hot mix asphalt industry to develop comparable acceptance thresholds between the two algorithms. From these analyses, a two-category payment reduction system was developed, to replace the former three-category system, for localized roughness.

This paper reports on studies supporting the transition from California profilographs to high speed inertial profilers, and the analysis that led to development of acceptance criteria for localized roughness based on the ProVAL Smoothness Assurance Module. The paper also provides an overview of the challenges that were faced during implementation of high speed profilers and how they were overcome.

INTRODUCTION

The purpose of a highway is to provide a smooth, safe, and durable surface for vehicles to run on at high speeds. Profilers are used to gather information about the smoothness of the new road, to estimate the satisfaction of the motoring public, which depends in large part on the ride experience in their automobile when using the road [1].

Smoothness can also be viewed as a lack of roughness. This requires a measurement of roughness and then interpreting it as a measure of smoothness. Some engineers prefer to consider smoothness as a more optimistic view of the road condition. Many techniques have been used for measuring roughness and virtually all of them focus on measuring the vertical deviations of the road surface along a longitudinal line of travel in a wheel path, known as the profile. Equipment for making these measurements has evolved, starting with straight edge devices in the early 1900s, to vehicles that can measure a profile while traveling at normal traffic speed. One of the early designs for obtaining pavement smoothness was the profilograph. A profilograph is a device used to quantify smoothness by measuring the deviations of a pavement surface using a mid-point measuring wheel from the reference established by a set of wheels at either end of the device. Profilographs are able to compute a smoothness index called the Profile Index (PI) [2]. This type of device is moved at walking speeds one wheel path at a time and the results are averaged. A very common profilograph in North America is the California profilograph which has six sets of wheels.

Today, the popular systems for measuring pavement smoothness are inertial profilers [1]. An inertial profiler is a profile measurement device that measures the pavement profile using an accelerometer to form an inertial reference and a non-contact height sensor to measure the pavement surface height relative to that reference [2]. Inertial profilers are usually equipped with dual laser sensors to measure the distance to the pavement for each wheel path. Accelerometers are used to eliminate the bouncing effect that the vehicle experiences as it moves down the road. All inertial profilers take measurements of the actual surface profiles and then filter these measurements to calculate the International Roughness Index (IRI). Software can be used to simulate PI and produce PI-based profile traces similar to profilographs [3]. There are two general types of inertial profilers, a light weight profiler and a high speed profiler. Light weight inertial profilers are light vehicles (like golf carts) that travel at low speeds (less than 40 km/h) and need to be operated under lane closures. They are useful tools for contractors who want to measure surface profile behind the paver during paving. High speed inertial profilers can produce longitudinal profiles along both wheel paths at highway speed (faster than 60 km/h) and are the main focus of this paper.

The main advantage of high speed inertial profilers is that they can take measurements much faster than profilographs. Being able to run at highway speed allows them to operate with traffic thus eliminating the need for traffic protection and providing improved operator safety. High speed inertial profilers, unlike profilographs, can measure both wheel paths simultaneously [3]. IRI calculation requires a software program. This is sometimes accomplished with proprietary software but more typically, a common engineering software program known as ProVAL (Profile Viewing and AnaLysis) is used to maintain consistent output regardless of machine type. It is a product developed by the Transtec Group through a contract with the Federal Highway Administration (FHWA) and the Long Term Pavement Performance Program (LTPP) [2].

There are at least four broad categories of profiler applications [1]:

1. to monitor the condition of a road network for pavement management systems (PMS);
2. to evaluate the quality of newly constructed or rehabilitated pavement sections;
3. to determine the condition of specific sites and determine appropriate remedies; and
4. to study the condition of specific research sites.

Five reasons for measuring pavement smoothness are as follows [2]:

1. Pavement smoothness is important to the motoring public. Studies have found that road users judge a road primarily by its ride quality. This means that no matter how well a pavement is

designed and built, or how long that pavement lasts, the users of the roadway will call it "good" or "bad" primarily based on the smoothness of the ride.

2. Smoother roads last longer. Numerous studies have found that pavements built smoother tend to last longer. Certainly one reason could be the effect of dynamic loading. Rougher pavements tend to have more dynamic loading, resulting in earlier failure due to fatigue. While there are many other factors that affect pavement life, evidence has shown that smoother roads last longer. Table 1 illustrates the improvement in pavement life with better initial smoothness [4]. Table 1 suggests that a 25 percent improvement in as constructed asphalt pavement smoothness can result in a 9-20 percent increase in pavement life.
3. Smoother roads stay smoother longer. Studies on smoothness progression over time show that pavements built smoother will stay smoother longer. Obviously, there are design and construction factors that affect smoothness; but when designed and constructed properly, smoother roads tend to stay smoother longer.
4. Smoother roads are safer. Rough roads can result in a loss of vehicle control, a reduction in a person's ability to perform motor tasks, driver fatigue, and an increased frequency of lost load accidents. Additionally, when considering the effect of roughness on pavement friction, increased roughness results in higher average friction loss.
5. Smoother roads save money. Smoother roads save both the user and the agency money. Studies have found that pavements built smoother require less maintenance over the life of the pavement. Additionally, smoother pavements decrease both fuel consumption and vehicle maintenance, which is a savings for roadway users.

IMPLEMENTATION OF SMOOTHNESS SPECIFICATION IN ONTARIO

In 1997, MTO implemented a smoothness specification for hot mix asphalt paving based on measurements using California profilographs. Smoothness data collected during the first 10 years showed that the riding quality of newly constructed asphalt pavements in Ontario has improved by about 25 percent. Up until 2010, the smoothness of new asphaltic pavements was accepted based on Profile Index (PI), measured by the California profilograph. These 7.6 m long manual profilographs are operated at walking speed, measure one wheel path at a time and require lane closures. Therefore, MTO and the Ontario hot mix asphalt industry sought opportunities to use alternative devices that would be faster and safer to operate, alleviating the need for lane closures [3].

An inertial profiler task group, comprised of members from MTO and the Ontario Hot Mix Producers Association (OHMPA), was formed in 2007 to investigate high speed inertial profilers and develop a specification. Technical and financial comparisons were made between high speed profilers and California profilographs, leading to development of smoothness acceptance criteria based on high speed inertial profiler measurements that were comparable to the existing requirements for California profilographs. This was to reduce the impacts to industry of transitioning to the new technology. The correlation between the data obtained by both devices was excellent and supported the phased-in use of high speed inertial profilers for acceptance on selected contracts with full implementation in 2012 [3]. MTO requires that high speed profiler measurements be conducted at a minimum speed of 60 km/h.

MTO adopted the ProVAL software program to calculate IRI and identify localized roughness. Table 2 includes pay factor criteria calculated based on PI vs. IRI. Prior to the release of ProVAL version 3, localized roughness was determined based on an algorithm developed by Texas Department of Transportation (referred to as the TxDOT algorithm). This algorithm is similar in concept to the scallop determination used by California profilographs. According to the TxDOT algorithm, the difference between the average wheel path profile and the 7.6 meter moving average filtered profile is determined for every profile point, and deviations greater than 3.0 mm are considered a detected area of localized roughness. Table 3 includes payment reduction criteria based on scallops and localized roughness (using ProVAL version 2.7).

MTO used high speed inertial profilers for measuring pavement smoothness of newly constructed hot mix asphalt pavements in a quarter of 2010 contracts and in half of 2011 contracts. Table 4 provides a comparison between pay factor distributions of the contracts that used California profilograph specification versus those contracts that used the high speed profiler specification in 2011. The results indicate a similar pay factor distribution resulted from the two specifications. Table 5 provides a comparison between the payment reduction distributions of contracts that used the California profilograph specification versus those contracts that used the high speed profiler specification in 2011. The results indicate a similar distribution between various categories although contracts with the high speed inertial profiler specification resulted in a higher number of occurrences of localized roughness despite having fewer sublots when compared to the contracts with the California profilograph specification. This observation indicates that the high speed inertial profiler specification was similar to but slightly stricter than the California profilograph specification in terms of criteria for localized roughness. MTO specified high speed profilers for all new contracts in 2012.

TRANSITION TO SMOOTHNESS ASSURANCE MODULE

Version 3 of ProVAL software uses the Smoothness Assurance Module (SAM) for determining locations of localized roughness. SAM captures road irregularities based on a calculated IRI that has a better quantitative link to vehicle vibration. Soon after release of ProVAL version 3 in 2010, FHWA instructed the Transtec Group to stop providing technical support on ProVAL version 2 and to encourage all users to switch to ProVAL version 3 [5]. To support transition to ProVAL version 3, MTO, in collaboration with OHMPA, ran data analyses leading to the development of acceptance criteria for localized roughness based on the SAM algorithm.

MTO decided to use the following parameters of the SAM for identifying localized roughness on its contracts:

- short continuous analysis,
- Mean Roughness Index (MRI) as the selected ride quality index, and
- a 7.6 m baselength.

Note that TxDOT and SAM follow two separate concepts. Therefore, they do not necessarily provide the same localized roughness locations as illustrated in an example in Figure 1. The TxDOT method looks for large absolute variations in elevation. The SAM will identify areas where rapid variations in slope are concentrated. It is this difference that gives the method in SAM a much closer relationship to the way vehicles respond to the road. In practical terms, SAM will catch features in the road that cause axle hop and axle tramp vibration in vehicles that the TxDOT method will not. Both methods are likely to capture features that cause body pitch and bounce in vehicles, but SAM does this in a way that has a better quantitative link to vehicle vibration [5].

The main challenge was to determine appropriate threshold values in SAM that would result in a similar number of occurrences and categories of localized roughness to the TxDOT algorithm. After initial analysis and discussions at the MTO-industry inertial profiler task group meetings, MTO decided to simplify the localized roughness specification to a two-category model as follows:

- Payment reduction category,
- Rejectable category - requiring repairs.

Under a two-category localized roughness model and after review of the threshold values used by other jurisdictions in North America, it was decided to use an MRI of 3.5 m/km as the threshold for the rejectable category but perform further data analyses for determining a threshold for the payment reduction category, considering the following three threshold values:

- MRI = 2.3 m/km
- MRI = 2.4 m/km
- MRI = 2.5 m/km

Table 6 shows the results of analyses conducted for a total of 17 contracts built in 2011. The results have been presented separately for freeway and non-freeway highways. From these results, we can conclude that an MRI threshold of 2.3 m/km with the SAM algorithm would result in similar pay reductions to the TxDOT algorithm. Figure 2 provides a graphical depiction of how payment reduction varies with MRI threshold value. After considering that the TxDOT algorithm was slightly stricter than the former California profilograph specification and other jurisdictions, it was decided in consultation with industry, to select a threshold value of 2.4 m/km for the pay reduction category of localized roughness in MTO contracts starting in 2011. MRI's of less than 2.4 m/km are not subjected to payment reduction. Table 7 shows acceptance criteria for localized roughness based on the Smoothness Assurance Module of ProVAL version 3.

CERTIFICATION OF HIGH SPEED PROFILERS

Since 2008, MTO has been carrying out annual high speed profiler correlation and certification programs and issued certificates to successful profilers and operators. For a service provider to be allowed to perform quality assurance or referee testing on MTO contracts, their equipment and respective operators must carry a current correlation certificate. MTO follows AASHTO R56 for certification of high speed inertial profilers. Figure 3 shows a view of the correlation site used in the 2012 certification program. It was observed that some profilers had difficulties meeting the minimum 90 percent requirement for accuracy when compared to the reference profile. They were required to re-apply for certification until they were able to achieve the minimum requirement for accuracy. As the profiler operators gain experience with inertial profilers, their ability to meet AASHTO requirements has improved.

SUMMARY AND CONCLUSIONS

This paper reports on studies supporting the transition from California profilographs to high speed inertial profilers, and the analysis that led to development of acceptance criteria for localized roughness based on the SAM of ProVAL version 3. The third generation of ProVAL uses SAM to identify localized roughness rather than the TxDOT algorithm that was used in previous generations of ProVAL. In the 2010 and 2011 construction seasons, MTO conducted extensive analyses in collaboration with the Ontario hot mix asphalt industry to develop comparable acceptance thresholds between the two algorithms. From these analyses, a two-category payment reduction system was developed to replace the former three-category system for localized roughness determination. Analysis of 2011 contract data demonstrated that the proposed acceptance criteria based on SAM compared well with the TxDOT algorithm criteria.

The following conclusions can be drawn:

- MTO in collaboration with the Ontario hot mix asphalt industry successfully implemented the use of high speed inertial profilers to replace California profilographs. High speed inertial profilers are faster, safer and do not require lane closures.
- A review of several contracts built in 2011, with some using high speed inertial profilers and some using California profilographs, indicated that the smoothness specification developed for high speed profilers compared well with the California profilograph specification in terms of payment factors as well as payment reductions related to scallops/localized roughness.
- With the introduction of the SAM in ProVAL version 3, an MTO-OHMPA inertial profiler task group worked to develop acceptance criteria for localized roughness with an MRI of 2.4 m/km being the threshold for payment reduction and 3.5 m/km being the threshold for repair. Analysis of actual contract data was used to arrive at these threshold values.
- Meeting certification requirements as per AASHTO R56 has been a challenge for some of the high speed profilers in Ontario. As the profiler operators gain more experience, their ability to meet AASHTO requirements improves.

GOING FORWARD

- Contractors are encouraged to use the Grinding Module of ProVAL version 3 to estimate the repair length and limits for localized roughness
- Currently, high speed inertial profilers are using stationary reflectors to trigger on/off data collection. The triggering technology needs to be upgraded to improve efficiency and safety. MTO has had on-going discussions with service providers to replace the reflectors with GPS technology.
- MTO will continue working with high speed inertial profiler service providers and manufacturers to improve the level of accuracy for MTO's correlation program.

REFERENCES

1. Michael Sayers and Steven Karamihas. "The Little Book of Profiling". University of Michigan, September 1998.

2. The Transtec Group Inc. “Glossary” & “Understanding Specs”, 2012. Available online: www.smoothpavements.com

3. John Blair and Kai K. Tam. “Moving to International Roughness Index Measured by Inertial Profilers in an End Result Specification for New Asphalt Construction in Ontario”. Proceedings of the Transportation Association of Canada, 2008.

4. K. L. Smith, et al. “Smoothness Specifications for Pavements: Final Report”. National Cooperative Highway Research Program (NCHRP) Web Document 1, Project 1-31, March 1997, Page 98.

5. The Transtec Group Inc. “ProVAL”, 2013. Available Online: http://www.roadprofile.com/

Table 1 - Average Percent Increase in Asphalt Pavement Life [4]

Reduction in Roughness / Reporting Agency	10%	25%	50%
Illinois	4	9	18
Alabama	8	20	39
Arizona	3	9	18
Minnesota	5	11	23

Table 2 - Pay Factor Based on PI vs. Pay Factor Based on IRI

Average Profile Index (PI) for a California Profilograph (mm/km)	Mean Roughness Index (MRI) for a High Speed Inertial Profiler (m/km)	Payment Factors
≤ 150	≤ 0.500	1.200
151 to 230	> 0.500 to 0.650	1.575 - (0.0025 x PI) 1.867 - (1.333 x IRI)
231 to 430	> 0.650 to 1.000	1.000
431 to 550	> 1.000 to 1.250	1.358 - (0.00083 x PI) 1.40 - (0.4 x IRI)
551 or greater	> 1.250	REJECTED (Requires repairs)

Table 3 - Payment Reduction for Scallops vs. Localized Roughness (using ProVAL 2.7)

Amplitude of Scallops using California Profilograph (mm)	Localized Roughness using High Speed Inertial Profiler and ProVAL 2.7 (mm)	Payment Reduction
10.0 to 11.5	**3.00 to 3.50**	$1,500 for each scallop or localized roughness located in freeway $1,250 for each scallop or localized roughness located in non-freeway
12 to 14.5	**3.55 to 4.70**	$3,000 for each scallop or localized roughness located in freeway $2,500 for each scallop or localized roughness located in non-freeway
> 14.5	**> 4.70**	Rejected. Every scallop or localized roughness shall be repaired in this range.

Table 4 - Payment Factor Distribution Obtained for 2011 Contracts using California Profilograph vs. Contracts using High Speed Inertial Profilers

Type of Smoothness Measurement	# of Sublots* Measured	Sublots* in the Following Ranges (%)			
		bonus	full pay	pay reduced	rejectable
California profilograph (24 contracts)	7786	45.2	49.8	4.4	0.6
high speed inertial profiler (20 contracts)	5862	44.2	47.9	6.4	1.5

* Sublot is a continuous traffic lane having a 100 m length

Table 5 - Payment Reduction Distribution Obtained for 2011 Contracts using California Profilograph vs. Contracts using High Speed Inertial Profilers

Type of Smoothness Measurement	# of Sublots* Measured	Count	Scallops or Localized Roughness in the Following Categories (%)		
			small pay reduction	large pay reduction	rejectable
California profilograph (27 contracts)	8314	507 scallops	53.8	33.2	13.0
high speed profiler (22 contracts)	6172	520 localized roughness	55.4	33.6	11.0

* Sublot is a continuous traffic lane having a 100 m length

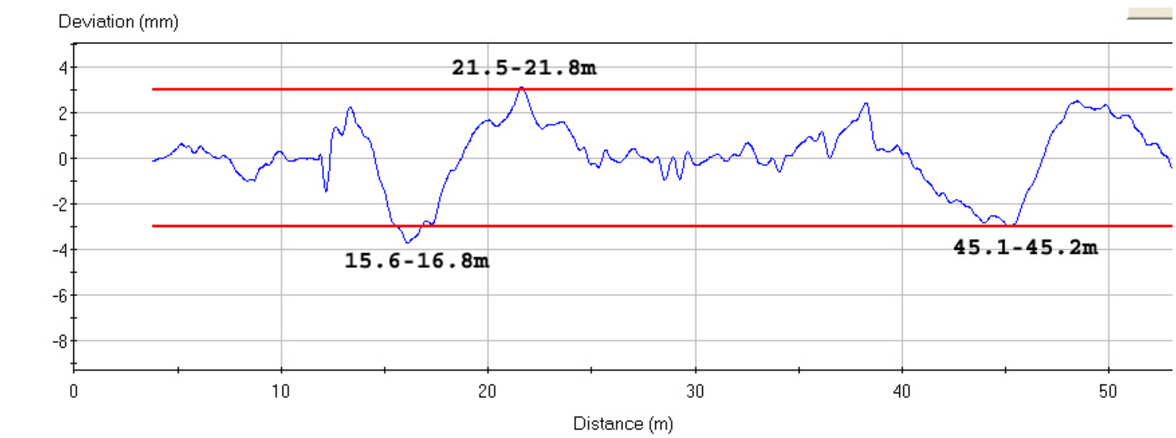
Table 6 - Comparison of Pay Reductions for Localized Roughness between TxDOT Algorithm (ProVAL 2.7) and Smoothness Assurance Module (ProVAL 3.3), with three SAM Thresholds for Pay Reduction Category

Highway Type	**# of Contracts**	**ProVAL 2.7 Results** three category model using TxDOT algorithm			**ProVAL 3.3 Results** two category model using Smoothness Assurance Module (SAM)						
		Payment Reduction Categories		**Repair**	**Payment Reduction Category**						**Repair** assuming SAM threshold of **3.5 m/km**
					assuming SAM threshold of **2.3 m/km**		assuming SAM threshold of **2.4 m/km**		assuming SAM threshold of **2.5 m/km**		
		# of LR[1]	total pay reduction[2] ($)	# of LR	# of LR	total pay reduction[2] ($)	# of LR	total pay reduction[2] ($)	# of LR	total pay reduction[2] ($)	
non-freeways	10	465	813,750	126	325	812,500	270	675,000	229	572,500	82
freeways	7	101	217,500	19	58	174,000	47	141,000	34	102,000	18

1. LR means localized roughness
2. See Table 3 for payment reduction amounts applied to each incident of localized roughness

Table 7 - Payment Reduction for Localized Roughness (using ProVAL 3.3)

Incidents of Localized Roughness using High Speed Inertial Profiler (MRI Calculated using ProVAL 3.3, m/km)	**Payment Reduction**
2.400 to 3.499	$3,000 for each localized roughness incident located in freeway $2,500 for each localized roughness incident located in non-freeway
≥ 3.500	Rejected. Every localized roughness shall be repaired in this range.



(a)

(b)

Figure 1 -
(a) ProVAL 2.7 identified three localized roughness locations using TxDOT method
(b) ProVAL 3.3 identified two localized roughness locations at different stations using SAM

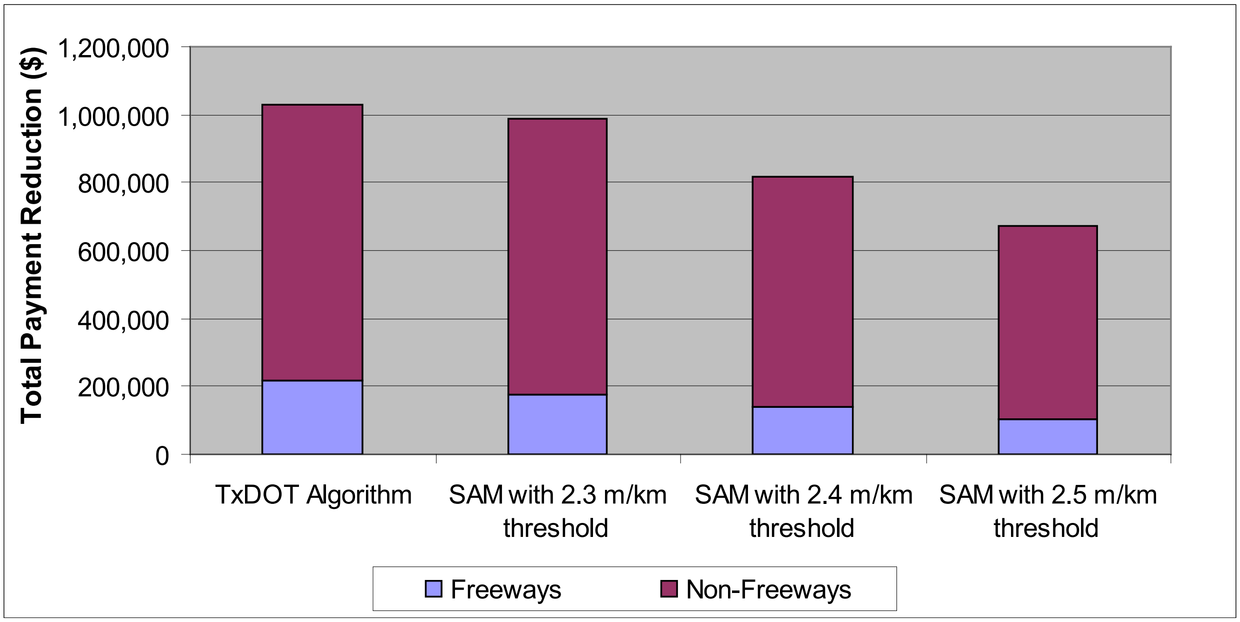


Figure 2 – Total payment reduction for localized roughness in 17 contracts from Table 6 based on TxDOT algorithm and three SAM thresholds

Figure 3 – A view of the correlation site used for certification of high speed inertial profilers in 2012