Development of a system for ranking transverse cracks in pavements

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Detection, classification and rehabilitation of pavement distress is a serious problem involving the expenditure of considerable sums of money and manpower. Approximately 15 to 20 different types of distress are classified by pavement management personnel, and the repeated transverse crack is one of the more obvious to the motoring public that is especially annoying to the truck driver. The subject of this paper is the detection and classification of this type of crack. It describes a simple procedure that can produce a rated log of cracks in a form that the pavement manager can use to assess rehabilitation strategies.

1/ INTRODUCTION

Significant portions of Ontario's freeway and primary highway system were built in the 1950's using 6.1 m (20 ft) long reinforced concrete slabs. Much of this roadway has since been overlaid with asphalt pavement, and many construction joints between the concrete slabs have now reflected up to the surface as transverse cracks across the road. The combined actions of motion of the underlying concrete slab due to heavy axle loads, road salt, water and freeze-thaw cycles has led to deterioration of the structure at many of these cracks. Much of the deterioration is at the bottom of the original concrete structure, or at the interface between the concrete and asphalt, so is not always evident in a visual inspection. The results of existing subjective methods of classification [1] may vary according to the experience of the person conducting the survey. A method which automatically classifies distress according to its severity, and at the same time creates a log of locations while travelling at highway speed, would be a valuable tool for the pavement manager.

A preliminary investigation was carried out using a vehicle that was available from a previous project [2]. This vehicle, a semitrailer equipped with a three axis wheel force transducer mounted on an airlift axle, was driven on a section of rural freeway having a variety of transverse cracks, and measurements of axle vertical acceleration, axle displacement, air bag pressure and vertical tire load were recorded and analyzed. This test indicated a correlation between axle vertical acceleration and the severity rating assigned to some selected cracks by the pavement management staff.

Following this initial test, it was decided to perform a more detailed test on another section of the same highway. These tests included pavement core samples, Benkleman beam displacement, and laser level profile measurements at selected transverse cracks of various severities. Results from these tests were used to define more accurately the severity rating of the cracks. After analysis of all the data, it was decided that it was feasible to proceed with the development of a system using vehicle mounted instruments, to assess the severity and identify the location of pavement transverse cracks [3].

During 1989 and 1990, additional data was collected from various highways having a variety of cracks, using both the original semitrailer and a second short single axle semitrailer that was instrumented to measure wheel loads and axle vertical accelerations. Data was recorded on tape and replayed for analysis. From these data, decisions were made on how best to classify and document crack locations.

This paper describes the process which has been developed for identifying and classifying transverse cracks in pavements, and a method of presenting the results to pavement management staff. It is now implemented in self-contained hardware that incorporates the findings of the research conducted to date.

2/ OBJECTIVES

The objective of this program was to develop an instrument which could be installed on typical maintenance vehicles used by field personnel to allow them to monitor the severity and determine the location of pavement transverse cracks. The instrument should be able to distinguish between a light, moderate or severe crack, and log its location within one meter in 5 km of roadway. Data analysis should provide the density of cracks of selected severity in arbitrary distance increments.

3/ EQUIPMENT

Since pavement cracks appear to be more severe to the truck driver, and because the heavy truck axle loads may have some effect on pavement response, a tractor-semitrailer combination was selected as the test vehicle to carry the necessary instruments. The test trailer has one fixed axle at the rear, with a simple eight-leaf spring suspension on each side. The trailer also has an airlift axle ahead of the fixed axle. Concrete load blocks were placed on the trailer, and the airlift axle was raised during tests to place the full nominal load of 8180 kg (18000 lb) on the single test axle. This is representative of an average loaded

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truck axle, and is the standard equivalent single axle load used by pavement designers. Tires were dual Michelin 11R22.5 XZA radials, rated at 2660 kg dual (5850 lb) at 795 kPa (115 psig) pressure. All tests were run with tires inflated to this maximum recommended pressure.

Piezoresistive accelerometers were mounted on each end of the trailer's fixed axle, on the top of the axle between the leaf spring and the brake drum dust cover. These accelerometers had a frequency response from dc to 1000 Hz, and were used to monitor vertical accelerations for both left- and right-hand wheel paths.

Strain gage load sensing pads were welded to the front and rear of the axle stubs directly below the accelerometers, and were wired to produce vertical wheel load data from the axle shear strain.

The right wheel brake drum had its inward-facing edge machined and slotted with 60 teeth. A magnetic pickup was mounted to produce pulses from tooth passage. These pulses were conditioned to provide vehicle speed and distance travelled.

A retro-reflective photo sensor was mounted on the centre-line of the trailer fixed axle. It responded to reflective tape placed at known locations on the pavement before the test for event marks.

Data from the trailer-mounted sensors was electrically conditioned on the trailer and then FM multiplexed before being recorded on one track of a two track tape recorder mounted in the tractor. A precise time signal from an IRIG B time clock was recorded on the second track of the recorder. Voice comment was provided on the recorder edge track.

4/ CALIBRATION

4.1/ Accelerometers

The manufacturers calibration given in millivolts per g was accepted as true. The signal conditioning electronics was calibrated to provide +/-10 g full scale. A spot check of actual transducer output was accomplished by removing the accelerometers from the axle and tipping them upside down, which causes a 2 g change in output.

4.2/ Wheel Loads

The wheel load sensors were calibrated by placing the trailer's wheels on portable scales of the type used by vehicle inspectors, and concrete blocks were added to the trailer deck. Scale readings and the electrical output from the load sensing strain gages were recorded for each load level.

4.3/ Velocity and Distance

The right side wheel speed sensor produced 60 pulses per revolution, and its calibration required special attention. The rolling circumference was measured by driving the vehicle slowly ahead and measuring the distance travelled in ten revolutions of the wheel, which provided a calibration of 0.0535 m per pulse. Distance was measured by counting the pulses with a 16 bit counter when the data were played back. The minimum length of road to be tested was 25 km, so the raw pulse signal count was divided by 10 producing a resolution of approximately 0.5 m. This results in a maximum test section approximately 34 km in length.

The distance travelled per revolution of the wheel actually depends on tire pressure, temperature, tread depth, wheel load and vehicle speed. It was found that the calibration described above did not provide

the desired accuracy of 1 meter in 5 km. A straight and level section of roadway was marked accurately with reflective tape at 2.5 km increments using a precision trailing wheel to establish the marker locations. Upon completion of a measurement session, a separate run was made over the calibration section of road while the tire temperature, pressure and load were representative of the actual test conditions, and the total number of wheel pulses in the measured and known 5 km distance were counted. This secondary calibration allowed the distance measurement to be maintained within 1 meter. All tests were run at a speed of 80 km/h, which eliminated tire growth with speed as a factor.

After a number of distance calibrations had been completed it was found that for a given load, speed and ambient temperature, it was not necessary to run the calibration provided the test vehicle had been operated at highway speed for 20 to 30 minutes. This length of time appeared to be sufficient for tire temperature and pressure to stabilize.

4.4/ Pre-run Calibration

Tire pressure was checked with the tires cold, and was adjusted as necessary, before each test.

An electronic calibration sequence was recorded at the start of each test run, using electrical inputs corresponding to full scale instrument responses.

During the electrical calibration of the load sensors, the airlift axle was lowered. Using maximum air pressure, it was possible to lift the test axle clear of the road. This permitted a zero axle load condition to be recorded, and allowed the electronic output of the load sensors to be adjusted to zero.

5/ DATA PROCESSING

The load sensing strain gages, although useful for providing information on dynamic pavement loads, were found to be too insensitive to be of any use in classifying transverse cracks. The responses from heave of the trailer deck were of similar magnitude to those due to the impact load at a crack, so it was not always possible to determine the presence of a crack from these signals.

Figure 1 shows a very severe transverse crack, followed closely by a moderate one.

Figure 2 shows the acceleration response from this crack, replayed from tape through a set of FM discriminators with 200 Hz output filters to a PC based data acquisition system operating at its maximum sample rate of 200 Hz per channel, which is below the minimum sample rate for proper reproduction.

Cracks are relatively infrequent, and the continuous data recorded on the vehicle created voluminous files that contained much irrelevant data. Additional electronic circuitry was therefore designed and built to eliminate the need for high speed sampling. This rectifies the acceleration signal, scales the signal to 1 volt/g, and applies the result to a multi-level threshold. The threshold levels were set at 1.5, 2.5, and 3.5 volts, which correspond to the acceleration levels that were determined as the transitions from smooth road to light crack, light to moderate crack, and moderate to severe crack, for this vehicle [3].

Figure 3 shows the result of rectification, and the pulses generated by the threshold device. These pulses along with the divided distance pulses were fed to inputs on a digital counter card in a laptop computer. A program was developed in the BASIC

language to capture the pulse generated by a crack and store the contents of the distance counter which corresponded to the crack's location. To prevent counting severe cracks as light, moderate and severe, since the analog signal crosses the threshold from light to moderate before becoming severe, it was necessary to incorporate logic loops to determine whether a higher severity was detected before the signal dropped to a lower level. In addition, it was necessary to determine the best pulse width to give maximum distance resolution while preventing multiple counts from a single crack. If the pulse width was too narrow, then tire dynamics made a single event look like two or more separated by a short distance. A medium severity pulse was adjusted to a width of approximately 60 milliseconds, which avoided multiple pulses from the same crack. After the program detects a pulse, it waits for 20 milliseconds before the distance counter is read so that the computer can decide whether the crack severity has escalated to a higher level.

Referring again to Figures 1, 2 and 3, it is evident that this crack created a very severe response. Visual inspection of this particular distress showed a double crack coming in from the right shoulder. The pulses generated go from moderate to severe then back to moderate. It is unfortunate that the sample rate for Figures 2 and 3 was not higher. The analog data showed that the pulse from the severe crack returned to zero slightly before the second moderate pulse occurred.

The latest software accepts photopulses and manual marks to give vehicle location information, wheel distance pulses, and signals from both left and right accelerometers. It logs the event marks, the crack severity as light, moderate or severe, and the elapsed distance from the start of the run. In addition, it determines whether significant left- and right-hand wheel responses occur within 1 meter of each other. If they do, the distress is classified as a transverse crack with the severity of the most severe side. If a response is detected only on the right side and the vehicle is in the right driving lane, or the left side and the vehicle is in the passing lane, then it is logged as an edge crack. If it is detected only on the side away from the edge of the pavement, it could be any one of a number of forms of distress, and it is simply logged as an event to be investigated.

The BASIC program produces an ASCII file that can be imported into popular PC spreadsheet software for further analysis.

6/ TEST RESULTS

The data file from the BASIC program is imported into a spreadsheet program. This produces a summary listing of all cracks found during the run, and bargraph charts that show the number and severity of cracks, the crack density, in arbitrarily selected increments of distance.

Figure 4 is a fragment of the summary, from the start of a 30 km portion of Highway 401, a four-lane rural freeway. The summary indicates the test site, test date, the total number of cracks detected at each severity, and the accurate distance calibration in meters per ten wheel speed sensor pulses. It also gives a detailed list of all cracks and their locations. The list starts with a photomark, shows a severe crack at 20 meters, followed by a moderate crack at 22 meters. These are in fact the cracks shown in Figure 1, and it illustrates that adjacent cracks can be resolved to the desired accuracy. The summary
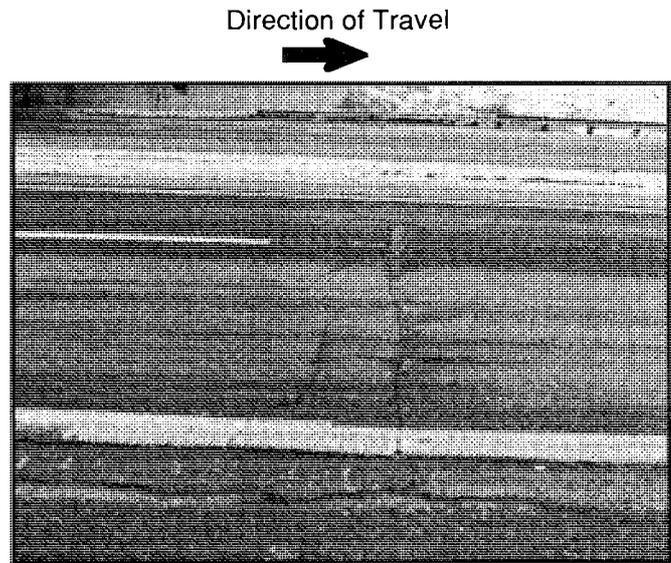
Direction of Travel
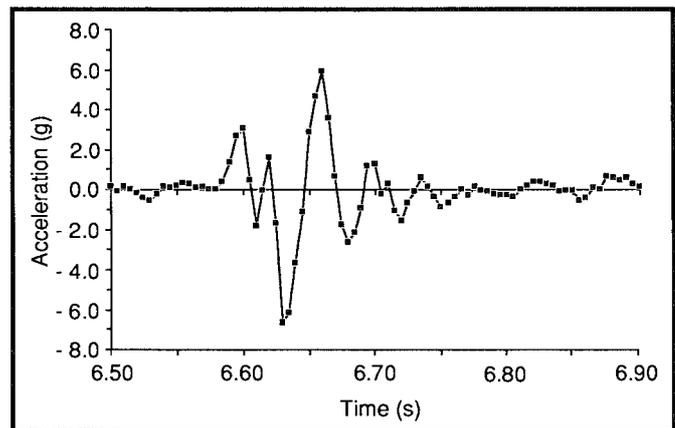

Figure 1/ Double Transverse Crack

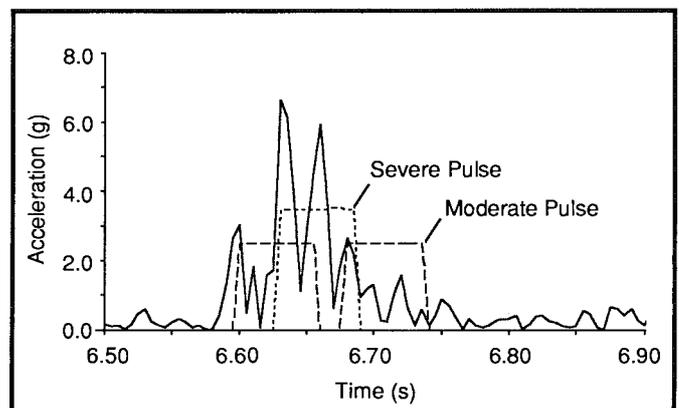Figure 2/ Right Wheel Vertical Acceleration

Figure 3/ Rectified Acceleration

continues, listing the location and severity of all subsequent cracks in the 30 km test section.

Figure 5 is a sample bargraph plot produced from the spreadsheet program that shows the density of moderate and severe cracks for the full 30 km section of road. This graph gives a visual indication of where the most severe cracks are located, and shows that the right wheel path, closest to the shoulder, had much greater distress than the left wheel path. The crack density graph also shows the location of the major overpasses that were marked with the reflective tape. Such bargraphs provide an overview of long sections of roadway, and quickly identify those areas that demand consideration for maintenance activity. They can also provide a historical record of roadway condition.

With the results in spreadsheet form, it is a simple matter for the pavement manager to add repair and rehabilitation unit costs, and the spreadsheet program can be used to assess repair strategies and priorities, perhaps in relation to the funds available.

HWY # 401 E/B, DORCHESTER ROAD TO SWEABURG ROAD						
PAVEMENT TRANSVERSE CRACK SURVEY				REF MARKS		8
LOCATION AND SEVERITY				HI SEVERITY		265
CONDUCTED 24-OCT-90				MEDIUM SEVERITY		91
WHEEL CALIBRATION = 0.560915				TOTAL EVENTS		364
FILE ..PAVE/90297 401EBL2R.PRN				(Driving Lane, Right Wheel Path)		
EVENT	DISTANCE	REFERENCE	CRACK	SEVERITY	RATING	LOCATION
count	meters	marker	medium	=>hi	#	name
1		1			4	Dorchester Road
2	20			1	3	
3	22		1		2	
4	106		1		2	
5	223			1	3	
6	252			1	3	
7	302		1		2	
8	341			1	3	
9	362		1		2	
10	453			1	3	

Figure 4/ Crack Location Summary

7/ PRESENT STATUS

Self contained hardware has been built which incorporates the findings of the research conducted to date. This hardware is mounted in a waterproof enclosure on the trailer used for the measurements, and is powered by the vehicle's 12 volt electrical system. A laptop computer has been fitted with a multiple-input counter card that permits capture of the crack data on board the vehicle during a test run.

High speed paint spraying equipment and its associated control electronics has been assembled which interfaces with the electronics box. It is triggered by pulses of a selected severity. This feature has been included so that cracks detected can easily be identified by field staff for visual inspection. Selection of the fluid to be used must still be made, as it is considered desirable to create a mark which will wash away rather than be permanent.
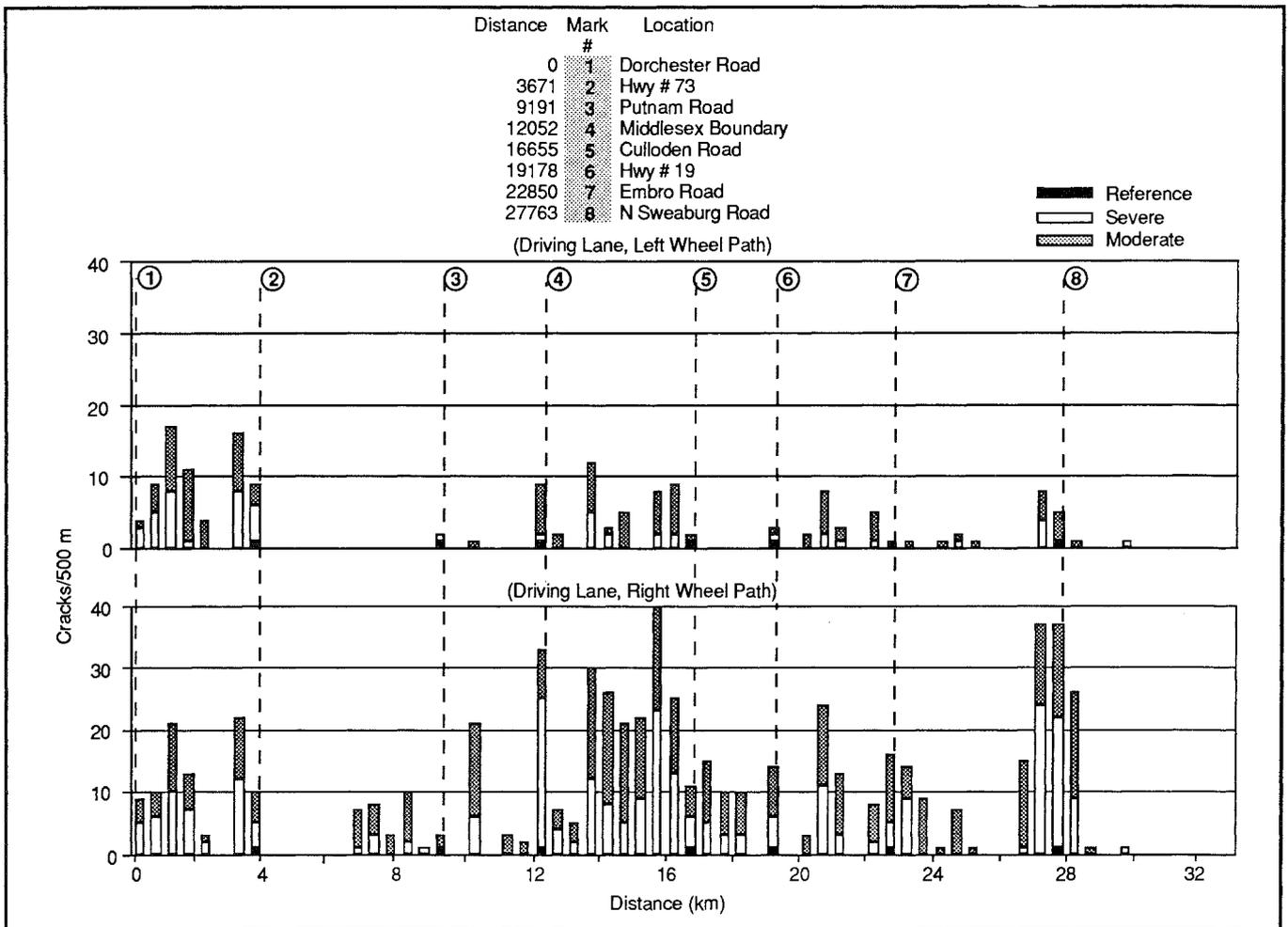

Figure 5/ Crack Density

8/ CONCLUSIONS

Hardware has been procured, designed and built that can detect both transverse cracks and edge cracks in pavements, and can classify the cracks according to severity. The equipment is relatively inexpensive, and can be installed on any single axle trailer.

Detailed lists of crack location and severity are created in the form of a computer spreadsheet, with sufficient accuracy of location to permit physical inspection of selected areas. The spreadsheet format allows pavement management staff to assess their repair strategies and priorities. The data can be maintained for historical purposes, to track the state of a section of road, and to determine whether crack rehabilitation has been successful.

REFERENCES

1. Chong G.J., Phang W.A. and Wrong G.A., "Manual for Condition Rating of Flexible Pavements, SP-024", Ontario Ministry of Transportation, August 1989.

2. Mercer W. and Stephenson W., "Development of a Mobile Tire Test Dynamometer and Tests of Three Truck Tires", Proceedings of International Symposium on Heavy Vehicle Weights and Dimensions, Kelowna, B.C., June 1986.

3. Chong G.J., Stephenson W. and Wolkowicz M.E., "Transverse Cracking Distress and Vertical Dynamic Impact Load From Heavy Truck Axles - A Feasibility Study", Proceedings of Second International Symposium on Heavy Vehicle Weights and Dimensions, Kelowna, B.C., June 1989.