Crack Monitoring System for Cracked and Seated PCC Pavements

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A mechanical gauge was developed to monitor the movement of crack or joint openings in portland cement concrete structures (in general) and in overlaid and portland cement concrete pavements (in particular). Designed to be inexpensive and simple to operate, this gauge can record maximum, minimum, and instantaneous crack or joint openings. The design and manufacturing of such a gauge along with the field data collected from the prototype gauges installed at the Pavement Durability Research Facility of the Pennsylvania Transportation Institute are presented. The gauges were monitored from January 1990 to the end of February 1990 and from May 1990 to the middle of July 1990. These monitoring periods gave a wide range of expected temperatures and joint openings. Specific recommendations are made for recording minimum and maximum pavement temperature over the monitoring period.

Many miles of the aging portland cement concrete (PCC) pavements of the Interstates will require resurfacing to restore rideability, structural strength, and skid resistance. One way of restoring a good level of performance for these pavements is to apply asphalt overlay. However, this type of rehabilitation has suffered from extensive reflection cracking. Reflection cracks are believed to be caused mainly by horizontal and differential vertical movement at joints and cracks in the existing PCC (with the horizontal movements being considered more critical) (*1*). The horizontal movements are caused by contraction and expansion of the concrete slab because of seasonal and daily temperature cycles as well as traffic loading. The vertical movements are mainly caused by traffic loading. These movements induce excessive tensile and shearing stresses in the asphalt concrete overlay, leading to initiation and propagation of cracks.

Researchers have investigated several procedures intended to reduce or eliminate reflection cracking: fabrics, open-graded crack absorbent layers, sawing and sealing of overlay, bond breakers, and cracking or breaking and seating of the slab before overlay. Cracking and seating is one of the procedures widely used to reduce reflection cracking.

The FHWA *Pavement Rehabilitation Manual* defines the cracking and seating as follows (*2*):

> The intent of pavement cracking and seating is to create concrete pieces that are small enough to reduce horizontal slab movement to a point where thermal stresses which contribute to reflective cracking will be greatly reduced, yet still be large enough and still have some aggregate interlock between pieces so the majority of the original structural strength of PCC pavement is retained. Seating of the broken slabs after cracking is intended to reestablish support between the subbase and the slab where voids may have existed.

On the basis of the previous discussion and the *Pavement Rehabilitation Manual*'s (*2*) definition of the crack and seat activity, the movement of the slab under the asphalt concrete overlay represents the most critical factor. Whether that movement is caused by thermal expansion or contraction, by traffic loading, or by a combination of the two is not important. What is important is that the crack and seat operation should reduce or eliminate those critical movements. The FHWA has initiated a field project to evaluate the effect of the size of the broken slab on the horizontal movement at the joint or crack (*3*). This special project will evaluate the effectiveness of the break and seat technique on jointed reinforced concrete pavements. Break and seat is basically a crack and seat operation with a typical broken slab size of 6 to 18 in (15 to 45 cm), whereas the typical range for crack and seat is in the range of 18 to 48 in (45 to 120 cm) (*3,4*). It will also attempt to identify the minimum amount of breaking needed to destroy slab action while minimizing the loss of structural value in the old slabs. The instrumentation required for this project was identified as a simple, low-cost gauge to monitor the minimum and maximum movements of the slabs and a device to monitor minimum and maximum pavement temperature.

Instrumenting rigid pavement slabs to monitor their joint openings and their warping and curling has been accomplished mainly through the use of linear variable differential transformers (LVDTs). Poblete et al. (*5*) have used thermocouple and LVDTs to monitor the temperature gradients and movement of the slab corners and joints in 21 test sections on the Chilean highway system. Armaghani et al. (*6*) also used thermocouple and LVDTs to monitor the response of a specially designed test road at the Florida Department of Transportation. Both of these projects used LVDTs to monitor the joint opening and the movement of slabs under traffic and environmental actions.

To measure the total joint or crack movement using LVDT sensors, continuous monitoring of the system is required. In other words, each monitoring sensor must be connected to a specific conditioning and data acquisition unit. The cost of such a system is prohibitively high and would be overkill for the purpose of simply monitoring the total joint or crack movement. In the FHWA project, several test sections will be cracked and seated with different size break patterns before

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overlay, and the horizontal movement at the cracks and joints will be monitored. Because a large number of sites will be monitored, an inexpensive gauge was developed to monitor the maximum and minimum crack or joint opening. The design, construction, installation, and other characteristics of the gauge and the data from a field installation study conducted at the Pavement Durability Research Facility of the Pennsylvania Transportation Institute (PTI) are discussed.

CRACK MONITOR GAUGE

A number of criteria were considered critical for the design of the crack monitor gauge. Specifically, the gauge must be accurate, inexpensive, easy to install, simple to operate, and durable. In addition, because the gauge will be used in remote areas over long periods of time, it must operate without electrical power. These requirements rule out the use of any electronic instruments and make mechanical gauges virtually the only option.

One type of mechanical crack monitor gauge is available through Avongard and Soiltest. However, that gauge only measures the instantaneous crack or joint opening, with a resolution of 0.020 in. (0.5 mm). Currently, a mechanical gauge that can register maximum, minimum, and instantaneous crack or joint openings is not commercially available. The total cost of the gauge designed and built in this research is approximately $15.

Design

Figure 1 shows the schematics of the mechanical gauge designed for this project. The gauge consists of two separate parts: a base plate and an overlapping plate. The base plate is firmly attached to the left side of the crack or joint (approach side). It contains a 2.5-in. (64-mm) slot along which two pins can slide with some degree of friction. Each end of the slot has a keyhole to facilitate replacement of the pins, if necessary. There is also a fixed reference pin that is used to measure the relative position of the sliding pins.

The overlapping plate consists of a remote arm that is placed between the pins on the base plate and a flat portion that is firmly attached to the right side of the crack or joint (leave side). As the crack or joint widens, the remote arm pulls the right pin toward the right until the crack or joint reaches its maximum opening. When the crack or joint opening starts to close, the remote arm moves toward the left pin. As the crack or joint resumes its initial opening and continues to narrow, the remote arm pushes the left pin toward the pin position corresponding to the minimum crack or joint opening. It is assumed that the crack monitor gauge is installed such that the base plate will be located at the left side of the joint or crack and the overlapping plate is at the right side. However, in some cases the gauge assembly may be rotated 180 degrees to facilitate its installation.

Fabrication

Figures 2 and 3 are engineering drawings of the designed gauge. The overall dimensions given in Figures 2 and 3 are not critical. However, they have been selected to facilitate precise manufacturing and appropriate installation and operation of the gauge. The gauge is fabricated from $\frac{1}{16}$- or $\frac{1}{32}$-in.-thick (1.6- or 0.8-mm-thick) stainless steel plate.

Aluminum or hard plastic plates $\frac{1}{16}$ in. (1.6 mm) thick can also be used in certain applications. For most applications, stainless steel or aluminum is preferred over plastic because the overlapping plate remote arm can be easily adapted to accommodate any possible lateral misalignment of the sides of the crack or joint. Stainless steel is stronger and more resistant to environmental effects than aluminum. However, it is heavier and more expensive.

The sliding pins are made of $\frac{5}{16}$-in.-diameter (7.9-mm-diameter) Teflon rods. The sliding motion of the pins in the slot is frictional to prevent any accidental movement of the pins caused by vibration. However, the friction between the pins and slot should not be so high as to prevent the sliding of the pins.

Accuracy

Satisfactory performance of the crack monitor gauge depends on several factors, including proper manufacturing, installation, and measurement. The key point to be considered when installing the gauge is that each plate must be firmly connected to its appropriate side of the crack or joint such that the connections do not yield under the force caused by contraction or expansion of the slab. This can be minimized by using a stiff epoxy compound for the attachment of the gauge. Further, the gauge components must be properly aligned to each other and parallel to the top of the slab.

Accurate measurement of the positions of the sliding pins relative to the reference pin can be ensured by using a digital

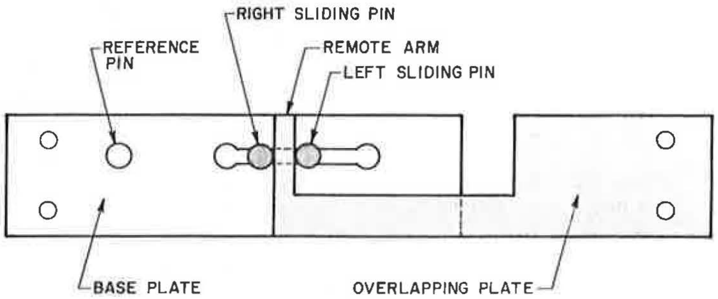

FIGURE 1 Schematics of the crack monitor gauge.

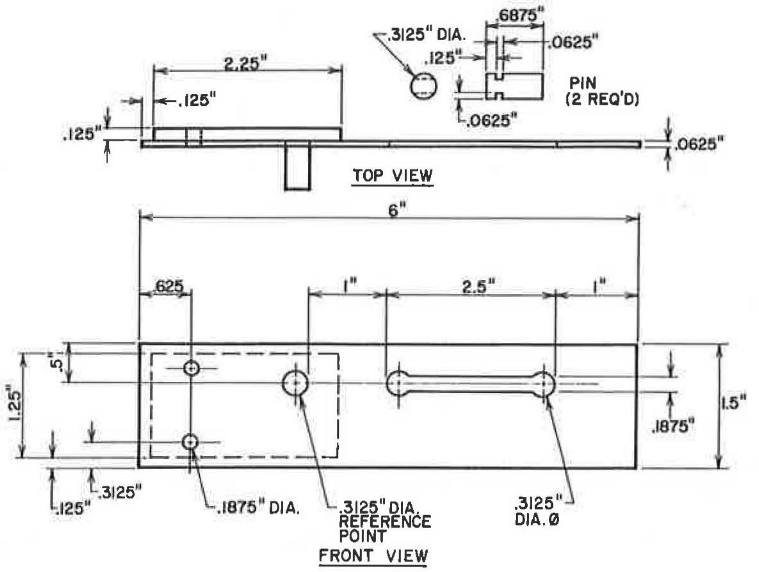

FIGURE 2 Engineering drawing of the base plate of the crack monitor gauge.

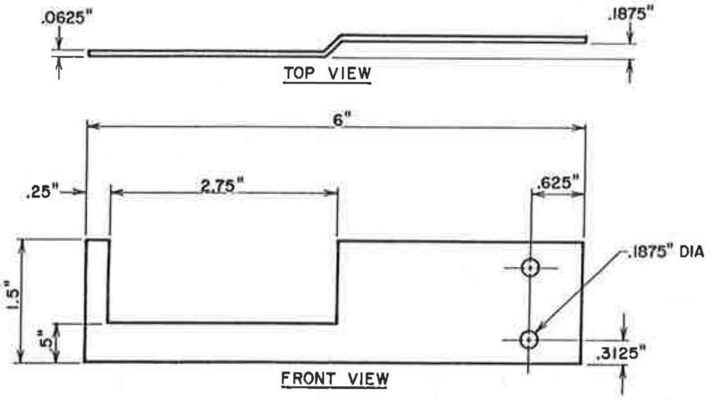

FIGURE 3 Engineering drawing of the overlapping plate of the crack monitor gauge.

caliper with adjustable friction at its thumbwheel. The friction of the thumbwheel should be set to its minimum value such that the measuring jaws of the caliper do not move the pins during the measurement.

Digital calipers can usually resolve measurements to 0.0005 in. (0.01 mm) and have an accuracy of ±0.001 in. (0.025 mm). Considering the possible error of the operator, the expected accuracy of the readings from the crack monitor gauge is about ±0.01 in. (0.25 mm).

Field Installation

The crack monitor gauge has been specifically designed to monitor crack or joint movement of PCC pavement slabs. However, the gauge can be used to monitor cracks in many other types of structures as well. The installation procedure described in this section pertains to its use on cracked and seated jointed concrete pavement slabs that are overlaid with asphalt concrete and have a paved shoulder. The gauge is designed to be installed on the edge of the slab at the outside lane-shoulder longitudinal joint.

After cracking and seating of the old concrete pavement slab, the station numbers of the cracks or joints selected for monitoring should be recorded and referenced. The candidate crack or joint should not exhibit a large lateral misalignment between both sides of the crack or joint nor have badly broken edges. Given the overall dimension of the crack monitor gauge, the minimum dimension of broken slab pieces required for installation is 1 ft (30 cm). When the break pattern specified is less than this dimension, breaking operations must be prohibited within 2 ft (60 cm) of the joint or crack to be instrumented. The crack monitor gauges will be retrofitted after the rehabilitation process is concluded including bringing the shoulder to grade. The gauge can be installed by applying epoxy to the mounting surfaces of the gauge as well to the lower and the side edges of the base plate, as shown in Figure 4. Detailed installation of the gauge was described by Tabatabaee and Sebaaly (*7*).

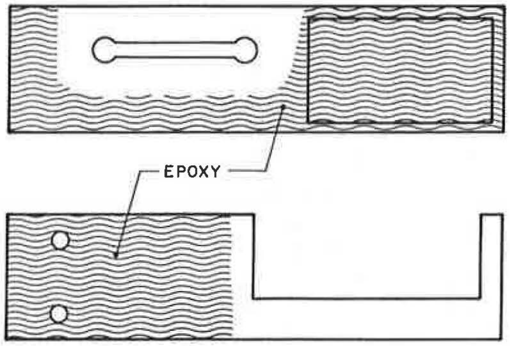

FIGURE 4 Application of epoxy to the mounting surfaces of the crack monitor gauge.

OPERATION AND MEASUREMENT

At the beginning of the gauge monitoring period, the crack or joint opening (W_i) should be accurately measured and recorded on the data sheet (Figure 5). Then the sliding pins should be pushed against both sides of the remote arm, and the distance between the fixed reference pin and the left sliding pin (R_i) should be measured and recorded with an inside caliper (see Figure 6). This reading will also be used as the reference distance for calculation of the maximum and minimum crack or joint openings of the first period. At the end of each monitoring period, the distances between the reference pin and the new positions of the sliding pins are measured using an inside caliper and recorded on the data sheet (SD and LD). The sliding pins are then manually pushed against both sides of the remote arm, and the distance between the reference pin and the left sliding pin (R_n) is measured and recorded on the next line of the data sheet (to be used as the reference distance for the next monitoring period). Once these parameters have been measured for a given period, the maximum, minimum, and instantaneous crack or joint openings over that period may be calculated.

Location: Top Gauge
Date of installation: 01/24

Initial Joint Opening, mm (Wi): 6.13
Initial Reference Distance, mm (Ri): 41.96

		Measured Parameter, mm			Calculated Parameter, mm		
		Referenc	Close	Far	Joint Opening		
Date	Time	Distance Rn	Marker SD	Marker LD	Instant Wn	Minimum Wmin	Maximum Wmax
01/25	14:05	41.96	41.96	55.50	6.13	6.13	6.63
01/26	14:25	42.02	41.85	55.57	6.19	6.02	6.70
01/30	16:45	42.35	42.29	55.94	6.52	6.46	7.07
01/31	14:00	42.72	42.35	55.96	6.89	6.52	7.09
02/01	15:00	42.67	42.59	56.12	6.84	6.76	7.25
02/16	14:00	42.62	41.48	56.02	6.79	5.65	7.15
02/23	11:30	41.50	41.33	56.17	5.67	5.50	7.30
05/02	18:15	41.38	39.34	57.23	5.55	3.51	8.36
05/11	15:30	39.90	39.47	54.66	4.07	3.64	5.79
05/17	15:30	40.06	39.39	54.49	4.23	3.56	5.62
05/22	12:45	39.63	39.63	54.22	3.80	3.80	5.35
05/30	15:45	39.93	39.33	54.20	4.10	3.50	5.33
06/06	12:15	39.40	39.12	54.06	3.57	3.29	5.19
06/15	15:49	39.31	39.05	53.62	3.48	3.22	4.75
06/20	12:30	39.08	38.94	53.15	3.25	3.11	4.28
07/09	09:30	39.15	39.04	53.43	3.32	3.21	4.56
		39.32	NA	NA	3.49	NA	NA

Footnote:

Wn = Rn + Wi - Ri
Wmin = Wn - (Rn - SD)
Wmax = Wn + LD - (Rn + b + d)
b = Width of the remote arm = 6.62 mm
d = diameter of the left sliding pin = 6.42 mm

FIGURE 5 Data sheet for a rigid pavement joint at the PTI Pavement Durability Research Facility.

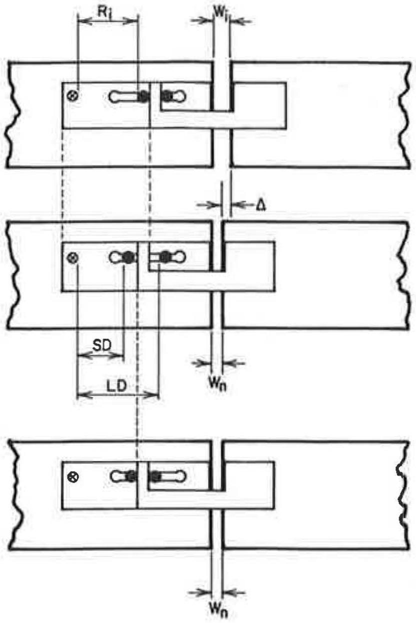

FIGURE 6 Schematics of operation of crack monitor gauge.

If the crack or joint opening changes by an amount equal to Δ in one direction, the remote arm moves by the same amount in the same direction (see Figure 6). Therefore,

$$W_n = W_i + \Delta \qquad (1)$$

and

$$R_n = R_i + \Delta \qquad (2)$$

where

W_i = initial joint opening,
W_n = instantaneous joint opening,
R_i = initial reference distance, and
R_n = instantaneous reference distance.

The elimination of Δ between Equations 1 and 2 by subtracting both sides and rearranging yields.

$$W_n = W_i + R_n - R_i \qquad (3)$$

When the concrete slabs expand, the crack or joint opening becomes smaller. From the discussion with reference to Figure 6, this reduction in the joint opening is equivalent to the distance that the left pin is pushed to the left by the remote arm.

Crack or joint opening reduction during the period

$$= (\text{Initial short distance}) - (\text{Current short distance})$$

$$= R_n - \text{SD} \quad (4)$$

where SD is the short distance (the distance between the reference pin and the left sliding pin).

Subtracting the joint opening reduction (Equation 4) from the instantaneous joint opening results in the minimum joint opening during the period:

$$W_{\min} = W_n - (R_n - \text{SD}) \quad (5)$$

As the concrete slabs contract, the joint opening increases and the remote arm pulls the right pin to the right. This increase in crack or joint opening is equivalent to the distance that the right pin has moved:

$$\text{Original position of right pin} = R_n + b + d \quad (6)$$

Crack or joint opening increase during the period

$$= \text{LD} - (R_n + b + d) \quad (7)$$

where

b = width of the remote arm,
d = diameter of the left pin, and
LD = long distance (the distance between the reference pin and right sliding pin).

Adding the joint opening increase (Equation 7) to the instantaneous joint opening yields the maximum crack or joint opening:

$$W_{\max} = W_n + \text{LD} - (R_n + b + d) \quad (8)$$

The equations are valid for any consistent units of measurement.

TEMPERATURE SENSOR

In order to monitor maximum and minimum crack or joint movement in PCC pavements, a continuous record of pavement temperature is essential. The most practical device that can provide a continuous temperature history for the pavement and that does not need electricity for monitoring and recording is a chart-recording stem thermometer. By installing two of these units, one at the top and one at the bottom of the pavement slab, a complete temperature history as well as gradient temperatures can be obtained for the pavement. These units come with a 24-hr or 7-day recording chart and cost approximately $280 per unit.

Another alternative is to use a temperature-measuring device that can record maximum and minimum temperatures in the pavement over a period of time. Two devices of this type are commercially available: gas-actuated and bimetallic thermometers. The former type is more accurate and costs approximately $180 per unit. The latter type is more rugged and costs only approximately $65 per unit.

The sensing element in this device is the bimetallic element, a single, low-mass helix that fits inside the thermometer stem. The bimetallic element is responsive to temperature changes. In order to improve its accuracy, the element is usually heat treated, aged (to relieve inherent stresses), and coated with a viscous silicon to reduce pointer oscillation and enhance temperature transmission.

These thermometers are constructed from stainless steel. They are available in 3- and 5-in.-diameter (76- and 127-mm-diameter) display faces (dials) and come in various stem lengths and temperature ranges and models. The location of the stem relative to the display dial varies among available models.

For measuring extreme temperatures experienced by pavement, the model with a 4-in. (100-mm) stem, 3-in. (76-mm) display dial, and working range of −40°F to 160°F (−40°C to 71°C) is recommended. A special order is required to customize these thermometers with minimum and maximum pointers.

The bimetallic thermometers should be installed close to the crack monitor gauges. The detailed installation procedure for this device was described by Tabatabaee and Sebaaly (*7*).

FIELD STUDY

In order to study the performance of the crack monitor gauges, two gauges were installed at a transverse joint of two PCC slabs at the PTI's Pavement Durability Research Facility. To investigate the appropriate depth for installation of the gauges, two gauges were installed at different depths. These gauges were installed 1 and 5 in. (2.5 and 12.5 cm) below the top of a 10-in.-thick (25-cm-thick) slab. The gauges were monitored from January 1990 to the end of February 1990 and from May 1990 to the middle of July 1990.

Figures 7 and 8 show minimum and maximum air temperatures during the monitoring periods. Figures 9–12 show the minimum and maximum joint openings as measured by the crack monitor gauges at the top and middepth of the instrumented joint.

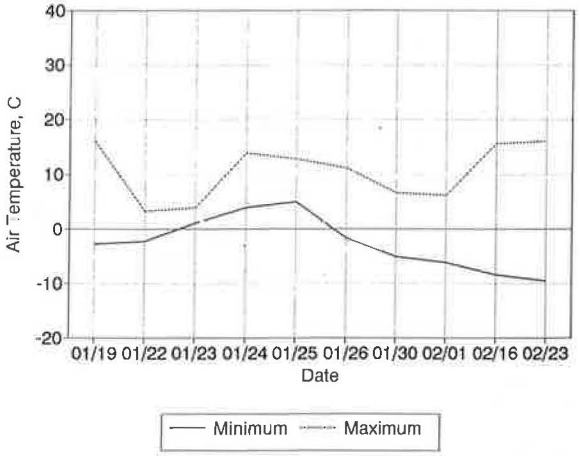

FIGURE 7 Minimum and maximum air temperature for January and February 1990.

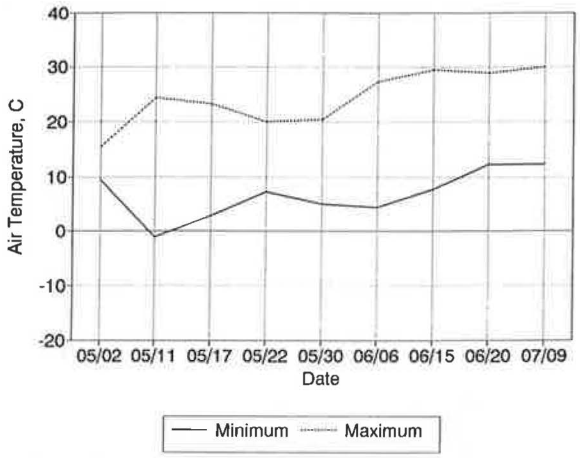

FIGURE 8 Minimum and maximum air temperature for May, June, and July 1990.

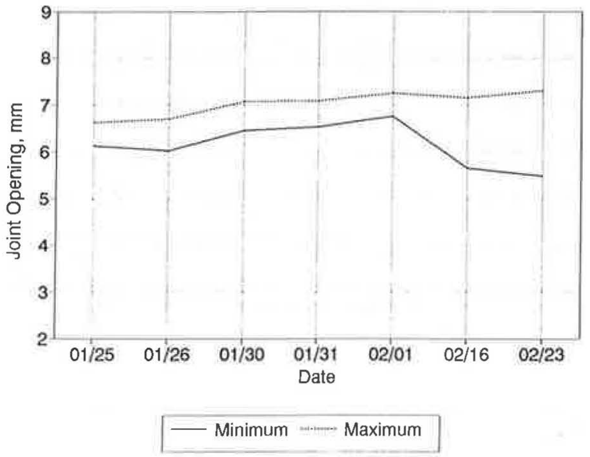

FIGURE 9 Joint opening measured by the top gauge during January and February 1990.

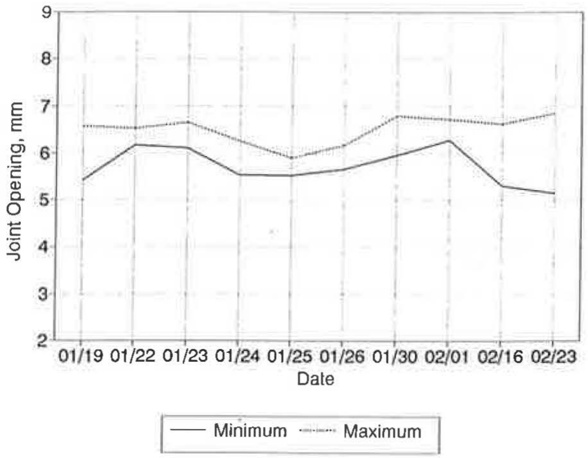

FIGURE 10 Joint opening measured by the middepth gauge during January and February 1990.

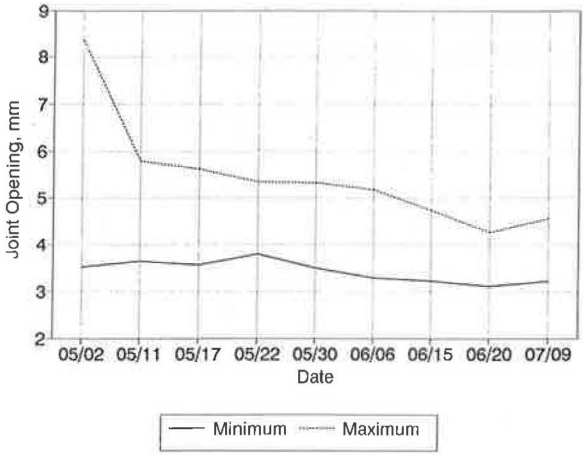

FIGURE 11 Joint opening measured by the top gauge during May, June, and July 1990.

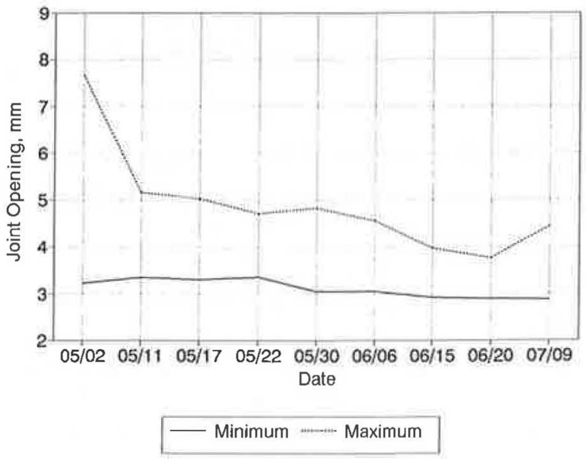

FIGURE 12 Joint opening measured by the middepth gauge during May, June, and July 1990.

Figure 7 indicates that the average air temperature (i.e., the average of minimum and maximum values) is about 37°F (2.8°C) throughout January and February. Figure 8 indicates that the average air temperature is about 60°F (15.5°C) throughout May, June, and July. Comparison of Figures 9 and 10 with Figures 11 and 12 indicates that the joint openings are larger for the period of January and February than for May, June, and July. This effect can be explained by the lower temperatures during January and February than during May, June, and July. Another interesting aspect of these measurements is that the range of maximum and minimum joint openings of the top gauge on January 26 is about 0.027 in. (0.68 mm) (Figure 9); the corresponding difference between the maximum and minimum temperatures is around 55°F (13°C). On the other hand, the difference between the maximum and minimum joint openings of the top gauge on May 17 is about 0.081 in. (2.06 mm) (Figure 11); the corresponding difference between the maximum and minimum temperatures is about 69°F (21°C).

According to these values, there is a direct relationship between the maximum and minimum air temperatures and joint openings. However, this relationship is not linear. For crack and seat applications, the range of joint openings is critical because it represents the amount of crack movement and the potential of cracking at the bottom of the asphalt concrete overlay. In other words, the range of movement of the PCC slab over a wide range of crack openings is more critical than the higher absolute maximum or lower minimum of crack openings. Therefore, any gauge used to monitor the movements of PCC broken slabs must have at least the capability of measuring both the maximum and minimum crack openings.

SUMMARY

A mechanical gauge was developed to monitor the movement of crack or joint openings in PCC pavements. Although it was designed specifically for monitoring crack or joint movement in rigid pavements, the gauge can be used for other types of concrete structures as well. Measurements of maximum, minimum, and instantaneous crack or joint openings can be obtained from this gauge. Low cost, high accuracy, and ease of installation and operation are some of the characteristics of this mechanical gauge.

The field data obtained from the installation of two prototype gauges at the PTI Pavement Durability Research Facility indicated that there is a direct relationship between the range of maximum and minimum air temperature and the range of joint openings. However, this relationship is not linear. It is expected that the wider ranges of temperature will occur during the summer months. However, under high temperatures, the asphalt concrete overlay can withstand larger amounts of movements. Therefore, the combination of a wider range of PCC slab movements and the degree of brittleness of the asphalt concrete overlay (as a function air and pavement temperatures) will dictate the critical situation under which the cracks from the broken PCC slab will propagate through the asphalt concrete overlay.

ACKNOWLEDGMENT

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