Reference Surface

A reference surface is required to verify the accuracy of the scanner. The ideal reference surface would be perfectly flat and have uniform surface properties (scattering, reflectance and absorption) that are representative of the pavement to be tested.

At least one user of Selcom laser based bar sensors uses a series of cups plumbed together and filled with milk. This does produce uniform levels but at only discrete points. One could use a trough at the expense of more milk, however with the higher power employed by the PPS system, it is likely that the bottom of the trough would be profiled. Two approaches that have been developed by PSI are described below.

Figure 1. Water trough calibration setup (circa 1997).

Rain Gutter with Mylar

The initial approach employed by PSI was a trough formed of snap together PVC rain gutter filled with water to a minimum depth of 0.5 inches with a continuous strip of mylar painted with sandable gray primer spray paint floating on the surface. This setup is shown in Figure 1.

The boards were there to reduce the possibility of kicking the trough and spilling water. The plastic was abandoned relatively soon as spills were relatively infrequent and did not involve large amounts of water.

The mylar was cut from a roll normally used in wide bed printers. As seen in the photograph in Figure 2, the mylar tended to cup upward normal to the scan plane due to the meniscus formed by the surface tension of the water in the trough. However this seemed to be quite flat in the scan orientation. Unfortunately it was not practical to verify the flatness by an independent means such as dipstick. Although this was attempted with limited success with calipers referenced off of a flat board.

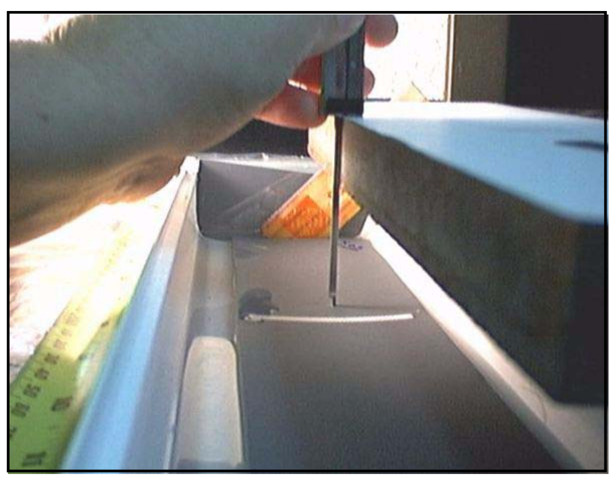

Figure 2. Profiling mylar surface with caliper and elevated reference plane established by a board.

This approach has been replaced by the rigid beam described below in the PSI factory/lab setting, however this is still a reasonable approach where are portable field setup is desired to verify system operation.

In the field, it was found that the stability of the setup was readily affected by forces of wind and inadvertent bumping or tripping. Also great care had to be exercised to avoid getting dirt or water onto the surface of the mylar. Also the PVC is flexible and the trough had to be shimmed at several points to deal with the uneven surface of the underlying pavement.

Figure 3. Water trough calibration surface under RWD trailer.

Prepared Beam

Consideration was given to a range of ideas for structures that could be manufactured to be flat over the full scan length 14 feet (>4 meters), stable and robust over time, and reasonable cost. The approach that won out is based on an Aluminum I-beam covered with self-leveling epoxy as shown in Figure 4.

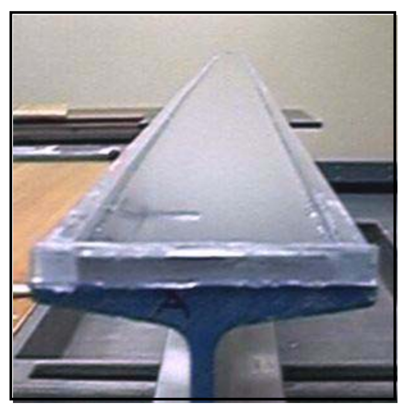

Figure 4. Calibration beam right after epoxy application.

An I-beam of alloy 6061-T6), 15 feet long, 8 inches high, 4 inches wide with a web thickness of 0.27 inches was selected. Bending due to the beam's own weight is minimized by supporting the beam at two places along the beam at a distance of 0.233 times its length from each end. Structural analysis of this configuration showed that the deflection of the beam would be less than 0.001 inches over a 20°C temperature range.

The flatness of the beam surface is not manufactured with sufficiently tight tolerance. While it may be possible to find a facility capable of machining or lap grinding the surface to a flatness of 0.001 inches over its length, this appeared to be extremely challenging and expensive. Further the transport of the beam back from the fabrication facility in such a manner than did not disturb the flatness seemed to be extremely challenging as well. Hence an approach to apply a self-leveling epoxy that would harden to be flat was developed. The following steps comprise the procedure:

1. Establish the support points 0.233 of the total length from each end and support the beam there during this procedure and at all times hence to minimize any distortion due to changes in loading under its own weight. A pair of self-adhesive rubber pads were placed at each position to assure that the loading occurred at the prescribed points along the beam.
2. Verify the flatness of the beam. This was done by stretching a line along the beam as a straight edge to gauge the maximum deviation from flat. It should be well under 0.1 inches.
3. Level the beam both along and perpendicular to the beam's length.
4. Build a dam on the surface of the beam. This was accomplished by applying 3/8 inch square acrylic extrusion with a bead of clear Silicon RTV to the outer perimeter of the upper surface.
5. Test the dam's integrity and the quantity of liquid required to fill the dam such that the entire surface is covered with a minimum of 0.1 inch of liquid. Remove the water and allow ample time to assure that the beam surface is 100% dry as any moisture can degrade the quality of the epoxy to be applied.
6. The dam is then filled with a component low-exothermal low-viscosity epoxy system number EP29LP from Master Bond: http://www.masterbond.com/, 201.343.8983, 154 Hobort Street, Hackensack, NJ 07061-3922. If other material is used it is critical that it be low-exotermic. CAUTION: most epoxy used as required below, specifically a large quantity with significant thickness, will get very hot and could even catch fire.
7. The specified epoxy is slow curing and has a viscosity similar to Castor Oil. Hence it will self-level. The epoxy cures over a three day period and should be done in a low-humidity environment to produce a smooth surface finish quality. The result is a hard stiff stable surface that is shiny as shown in Figure 5. There is a slight curvature adjacent to the acrylic wall due to surface tension, but this is well outside the center zone where the testing will be done. Caution is advised to mix the epoxy gently to avoid the introduction of entrained bubbles. A paint mixing propeller driven with a variable speed drill was employed. It was found that it was impossible to break the few small (<0.05 inches) bubbles that were present. A pin point was used to tease the bubbles to the edge of the epoxy where they would no affect the finished surface.

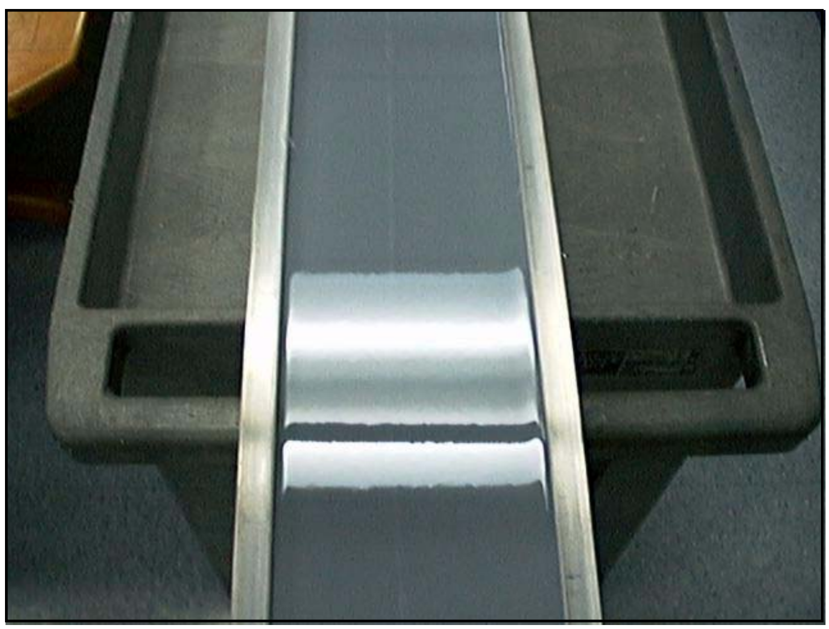

Figure 5. Finished shinny epoxy surface on calibration beam reflecting the overhead florescent lighting fixture.

Figure 6. Tape covering epoxy on calibration beam.

8. The epoxy was specified with a gray pigment to try to match the reflectivity of pavement, however the surface was too reflective. A specialty gray duct tape (3M Highland #6910) used typically by movie gaffers to prevent unwanted reflections on movie sets was selected to cover over the epoxy. The tape shown in Figure 6, is applied as a continuous strip along the surface of the beam. The surface has reflectivity and scattering properties that are similar to inservice AC pavement. Tape products in general have a very uniform thickness due to the manufacturing process and hence do not alter the quality of the flatness of the epoxy surface.

We have never tried to remove the acrylic damn as no requirement to do so has presented itself. However this may be simple to do, it was felt that the acrylic affords a degree of protection to the epoxy, though this may not be necessary as the epoxy is strong and has high adhesive strength.

Two views of the completed calibration beam are shown in Figure 7. The photo on the left is with normal lighting. The photo on the right was made when strips of paper with a gray scale pattern were placed periodically to test response to changes in reflectance and while the scanner was operating. The 810nm laser beam is clearly imaged by the typical digital camera CCD sensor. In operation some type of beam viewing system should be employed to assure that the scanner is operating along the centerline of the beam.

Figure 7. Calibration beam.

Operational Considerations

The calibration setup for use in PSI's laboratory is shown in Figure 8. The beam is set on stacks of 3/4 inch thick melamine covered particle board. By changing the number of boards under each support point the distance from the scanner to the beam and the slope of the beam can be adjusted quickly in a step-wise manner for sensitivity studies.

It is important to consider that the beam elevates the calibration surface above the support surface when trying to use the beam with the scanner installed on a vehicle. Provision to raise the scanner on the vehicle of raise the vehicle itself is required to place the calibration surface at the correct distance relative to the scanner. The purpose is not to measure precise distance changes but rather to change the relative distance or slope.

It is important to realize that this document presents concepts and procedures that have proven useful, however they are not necessarily perfect. PSI welcomes any feedback regarding problems or improvements.

Figure 8. Calibration in use in PSI's laboratory.