FEASIBILITY OF USING ACCELERATED PAVEMENT TESTING TO EVALUATE THE LONG TERM PERFORMANCE OF RAISED PAVEMENT MARKERS

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Word Count:
Body text = 2292
Abstract = 193
Tables 3 x 250 = 750
Figures 5 x 250 = 1250
Total Words = 4485

ABSTRACT

Raised pavement markers (RPMs) are used to provide long range night-time guidance to drivers. The visibility of these markers reduces over time and must be replaced. Thus many state DOTs test various markers in order to provide the most durable marker available. One of the most critical is the field test where the markers are subjected to a roadway environment for a specified amount of time. Due to the durability of typical RPMs, several years of field testing may be required before the product is qualified for state roadways. In order to shorten the product evaluation period, the Heavy Vehicle Simulator (HVS) was employed to accelerate wear/deterioration of raised pavement markers. The HVS allows for the controlled application of realistic wheel loads to a pavement system, simulating long-term, in-service loading conditions.

This paper summarizes the results of HVS testing on 4 types of RPMs with regard to both the physical structure of the element and its level of retroreflectivity. While no correlation currently exists between the Average Daily Traffic (ADT) and the number of HVS passes (load applications), the evaluation did provide a relative measure of durability between the types of RPMs tested.

INTRODUCTION

Raised pavement markers (RPMs) along with pavement markings and signs are installed to provide the directional information necessary to safely navigate roads under a variety of conditions. Of these, RPMs are essential tools for traffic control as they are primarily used to provide long range delineation at night to the driver of changes in the roadway. Typically, drivers require a 2 second warning, or preview time of changes in roadway conditions to adequately react when driving under normal conditions. Additional preview time (3-5 seconds) is required under adverse conditions. RPMs are installed to provide this preview time by encompassing high visibility elements (*1*).

Pavement markings such as reflective paint lines are also made highly reflective to provide roadway delineation. Although they are not as effective as RPMs for long range guidance at night and do not perform as well in the rain, they are able to provide traffic control information such as passing rules and lane guidance to the driver that is difficult to convey using RPMs. Pavement markings play a more important role during the day as they are not typically as visible at night. Fortunately, there are more long range directional hints visible to the driver during the day, which reduces driver dependence on pavement markings.

RPMs were first implemented in California in 1954 (*2*). Initially RPMs were simply round convex buttons made of polyester resin which were fixed to the road surface for auxiliary delineation during periods of darkness, or wet weather. A rectangular style made of similar materials was then developed the following year to improve durability on asphalt and permit two-way delineation. Over time, highly reflective inserts which preferentially returned light in the direction of its source were added to both round and rectangular style RPMs to improve visibility. This method of reflecting light is called retroreflection. Both styles of RPMs are available without the inserts and are typically used as an alternative to traditional pavement markings. While traditional non-retroreflective pavement markings are noted for their durability (expected to last more than 10 years), conventional retroreflective raised pavement markers (RRPMs) typically have shorter operational lives typically due to the deterioration of the retroreflective element (*2*).

Thus the most critical part of the device for durability is the inclined surface on which a retroreflecting material is typically applied. This area is designed for increased illumination by headlights and visibility by the driver with minimal structural failure from tire impact. To accomplish this, current RPMs use high strength plastics to house and protect the retroreflective element (*2*). Water may reduce the visibility of a marking, thus the inclined face also permits channeling water away from the RPM. RPMs have an additional benefit in that they provide an audible response to lane wandering.

RETROREFLECTION AND RAISED PAVEMENT MARKERS

Retroreflectivity is an effect where light is reflected back into the direction of incidence. There are two approaches that are typically used in pavement markers to create a retroreflective effect. Glass beads may be attached to the surface of the marker, or a complex tetrahedral mirror arrangement, called a ‘cube corner’, housed in a protective sheath may be employed. In a cube corner-type reflector, light is reflected specularly back to its source. Glass beads, on the other hand, act through a process of light refraction and reflection to provide the same reflective effect. RPMs using a cube-corner retroreflective element tend to look brighter because light is reflected directly off of the mirrored panes instead of being diffused through the glass beads. Although this is the case, the fixed panes do not allow for optimal retroreflection over a wide range of angles as do glass beads. For long distance delineation, the angle of light does not change significantly, thus cube corner type RPMs are preferred. Glass beads are typically chosen to improve visibility for shorter distances and thus are employed in flat pavement markings.

Both methods of employing retroreflection deteriorate over time. Deterioration is caused by the combined effects of abrasion by traffic, coating by road grime, physical instability and other thermal/environmental effects. As a marker is exposed to traffic, abrasion caused by the multiple impacts by tires scratches the lens of the RPM causing a scatter of the light going through it, which changes the direction of the reflected light. The RPM may be coated by the combined effects of tire rubber, leaking oil from vehicles and asphalt residue deposited on the marker which reduces lens clarity. Finally the lens or the retroreflective element may be cracked by the impact force of the tire, or by thermal cracking. A combination of these effects may reduce the retroreflectivity to between 1/20 and 1/50 of its original value within months.

In order to provide the most durable marker ASTM D4280 (*3*) identifies several laboratory procedures which test and thus characterize new markers. These include tests of the retroreflectivity and physical properties such as the flexural strength, compressive strength, color, impact strength and thermal cycling.

METHODS OF TESTING RETROREFLECTIVITY

Laboratory Method ASTM D4280

Testing the retroreflectivity of a marker can be one of the most critical tests as there are minimum standards for retroreflectivity. The measurement is made using a calibrated light source and a sensor that are situated 0.2 degrees apart (observation angle) as measured from a marker. The test marker is then placed on a goniometer where it can be angled at 0 and 20 degrees from the illumination axis (entrance angle), as shown in Figure 1. These angles simulate the angles experienced when a marker is far ahead of the vehicle and when the vehicle passes the marker. The measured value from the test is called the coefficient of luminous intensity and is given in units of either millicandellas per lux or candles per foot-candle. The unit essentially represents the fraction of the total emitted light captured by the receiver.

While the physical properties of the marker are important for estimating the life, in the field these properties are measured by the retroreflectivity of the marking. Thus only the retroreflectivity is typically measured during field trials. Observations of the physical markers may also be conducted to isolate the method of deterioration.

Florida Test Method 5-566 Field Test Procedure

While field trials are not a part of ASTM D4280 but are recommended, Florida test method 5-566 (*4*) delineates the field trial requirements for product acceptance. This procedure requires a testing period commensurate with the purpose of application. Thus, an asphalt field test site is chosen with an ADT between 8,000 and 12,000 per lane and markers are installed for a timeframe between one week and two years as shown in Table 1. During this time, 10 to 20 samples are periodically removed from the road and tested for their coefficient of luminous intensity. The results are then plotted for an extrapolation of their durability.

Although necessary for durability testing in the field, the time duration required for field testing creates a barrier to new marker introduction which can limit competition and increases the time necessary to implement new technology. Moreover, by installing RPMs in the field, it can be an extremely challenging task to determine the exact number of times an RPM has been passed over by a tire. In an attempt to test the feasibility of shortening the time necessary for field testing of RPMs, FDOT decided to explore the feasibility of using the HVS to rapidly apply multiple tire loads on a set of RPMs. The HVS is a device which subjects pavement surfaces to accelerated wear by multiple passes of a linearly actuated tire loaded at a given test weight. Since the lateral wheel wander can be accurately controlled using the HVS, the exact number of tire applications on a RPM can be calculated with ease. This can provide results on road failure criteria in a significantly reduced period of time.

OBJECTIVE

The primary objective of this research was to assess the feasibility of using the HVS to evaluate the long term performance of raised pavement markers. The performance was evaluated in terms of structural failure of the element and the change in its retroreflectivity.

EXPERIMENT DESIGN

The main objective of this research was to study the change in retroreflective properties of the RPMs after HVS trafficking. 32 RPMs representing fours different RPM types (Types 1 through 4) were tested as part of this study, therefore providing 8 replicates for each type. Each RPM type is respectively manufactured by a different vendor (Type 1 is manufactured by Vendor 1, Type 2 manufactured by Vendor 2, etc.). All the RPMs are all of the same ASTM class and are of similar design. They were installed in 2 arrays of 16 RPMs each, and were installed using a bituminous adhesive as specified in ASTM Database 4280. A schematic layout of the RPM array is shown in Figure 2. A photographic illustration of the RPM arrays after installation on the pavement and during testing is also shown in Figure 3.

The layout and configuration of the RPM array has the following features:

1. Each type of RPM has 8 replicates each, 4 in each array.
2. The RPMs have been divided into three groups (Groups 1 through 3), with each group receiving a different number of load (tire) applications. For each RPM type, one reflector each was placed in Groups 1 and 3, while 2 reflectors were placed in Group-2. This same configuration was repeated in the second array.
3. The spacing between the RPMs has been adjusted so that each set of RPMs receives either a ‘full-hit’ or a ‘half-hit’ with the HVS tire. A ‘full-hit’ is described when the loaded tire passes over the entire RPM, and a ‘half-hit’ is described when the tire passes only partly over the RPM. The ‘half-hit’ was designed to induce extra stress in the RPM caused by a tire running over it partly, thus inducing a structural failure.
4. Loading was applied in one direction only.

HVS Testing

Wheel load was applied to the RPMs through a Goodyear G165 (305 mm wide) super-single tire loaded to 40 kN (9000 lbs) at a speed of 12 km/h (8 mph). The load was applied in a uni-directional mode with a 1050 mm (42 in) wheel wander(outer edge to outer edge), in 50 mm (2 in) increments, with the tire pressure maintained at approximately 790 kPa (115 Psi). The super-single tire has a width of 300 mm (12 in) and traverses the 1050 mm wander in 16 passes. A total of 72,322 passes were made by the HVS. For computation purposes, one cycle is defined as the number of passes required by the test wheel to move from one end of the transverse wander to the other. One cycle therefore consists of 16 HVS passes. As the layout and spacing of the RPMs was very carefully monitored, it was possible to calculate the exact number of times the super-single tire passed over each set of RPMs. This calculation is shown in Table 2, and applies equally to each type of RPM. All loading was performed in a unidirectional mode with the tire hitting the reflective face of each RPM. The total duration of HVS testing was approximately one week.

Observations

The following observations were made at the conclusion of HVS testing:

1. None of the installed RPMs exhibited any kind of structural failure.
2. None of the RPMs showed any ‘settlement’ or indentation in the asphalt pavement.
3. Tire rubber build-up was noticed on most of the RPMs.
4. As the RPMs were mostly beneath the shade of the HVS, they were not exposed to direct sunlight (possible UV light)

Light Tunnel Testing

After HVS testing was complete, the RPMs were removed from the test section to be further analyzed in the laboratory. Retroreflectivity of the RPMs was measured according to the procedure outlined by ASTM D 4280-04, and was measured at angles of 0° and 20°. The results of the light tunnel testing are summarized in Table 3. The results of the light tunnel testing have also been plotted in Figures 4 and 5 for 0° and 20° respectively. In Figures 4 and 5, the initial (untested) results of the light tunnel testing are plotted as blank (unfilled) data points, whereas the final (after HVS testing) results for the same RPMs are plotted as solid (filled) data points. These figures show the change in retroreflectivity (in Candelas per Lux), after the RPMs were tested under the HVS.

As shown in these figures, it may be possible to compare the performance of different types of RPMs, when tested under similar conditions. One important point to note is that all the HVS testing was conducted under ambient environmental conditions. Since the total HVS testing time was approximately one week, the effect of environmental conditions on the performance of these RPMs could not be verified. However, these preliminary tests suggest that accelerated testing of RPMs can be a feasible and lucrative alternative to long-term field tests.

SUMMARY

The main objective of this research was to assess the feasibility of using the HVS as a tool for evaluating the long term performance of RPMs. Correlation to field measurements was beyond the scope of the current research. In summary, accelerated testing of RRPMs using the HVS can potentially be a practical and efficient test method for testing the durability and retroreflective properties of raised pavement markings. Although, only a limited number of RPMs (32) were tested in this study, the results have demonstrated that long term effects on RRPM retroreflectivity can be simulated using the HVS.

ACKNOWLEDGEMENTS

The work represented herein was the result of a team effort. The authors would like to acknowledge Steve Ross, Ron Aparicio, Shaine McConnell, Shawn English and Kyle Younger for their diligent efforts and contributing knowledge.

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2. Migletz, J., J. Fish and J. Graham, *Roadway Delineation Practices Handbook,* FHWA-SA-93-001 August 1994.
3. ASTM D 4280, Standard Specification for Extended Life Type, Non-plowable, Raised Retroreflective Pavement Markers. July 1, 2004.
4. Florida Method of Test for Raised Pavement Markers Laboratory and Field Test, FM 5-566, September 1, 2000.

LIST OF TABLES

LIST OF FIGURES

TABLE 1 Time Frame for Field Testing of RPMs

Marker Type	Duration of Field Exposure
Temporary Work Zone (Class E)	1 week
Work Zone (Class D)	1 month
Temporary (Class A)	3 months
Permanent (Class B)	2 years

TABLE 2 Calculation of Tire Passes over Each RRPM

Group	No. of RPMs in Group	Half-Hits per cycle	Full-Hits per cycle	Total Number of Half-Hits	Total Number of Full-Hits	Total Number of Tire Hits
1	2	1	1	4,520	4,520	6,780
2	4	2	5	9,040	22,600	27,120
3	2	1	3	4,520	13,560	15,820

TABLE 3 Results of Light Tunnel Testing

Array	Group	RPM Type	Color	Coeff. Of Luminous Intensity (Cd.lux)			
				Initial		After HVS Testing	
				0°	20°	0°	20°
1	1	1	White	0.44	0.23	0.38	0.19
2	1	1	White	0.48	0.24	0.38	0.17
1	2	1	White	0.52	0.27	0.36	0.17
1	2	1	White	0.44	0.25	0.35	0.19
2	2	1	White	0.58	0.37	0.46	0.26
2	2	1	White	0.67	0.44	0.42	0.25
1	3	1	White	0.49	0.29	0.45	0.28
2	3	1	White	0.48	0.24	0.36	0.20
1	1	2	White	0.83	0.37	0.28	0.15
2	1	2	White	0.65	0.24	0.22	0.08
1	2	2	White	0.97	0.4	0.24	0.21
1	2	2	White	1.10	0.34	0.24	0.13
2	2	2	White	0.67	0.32	0.16	0.07
2	2	2	White	0.87	0.33	0.21	0.08
1	3	2	White	0.78	0.32	0.31	0.17
2	3	2	White	0.74	0.32	0.3	0.12
1	1	3	White	0.74	0.29	0.39	0.2
2	1	3	White	0.74	0.29	0.43	0.21
1	2	3	White	0.81	0.27	0.23	0.11
1	2	3	White	0.66	0.36	0.37	0.22
2	2	3	White	0.81	0.27	0.35	0.11
2	2	3	White	0.66	0.36	0.33	0.19
1	3	3	White	0.79	0.3	0.55	0.30
2	3	3	White	0.79	0.3	0.45	0.21
1	1	4	Yellow	0.72	0.34	0.71	0.34
2	1	4	White	0.76	0.42	0.29	0.17
1	2	4	Yellow	0.51	0.35	0.47	0.26
1	2	4	Yellow	0.52	0.36	0.36	0.21
2	2	4	White	0.51	0.27	0.15	0.09
2	2	4	White	0.63	0.32	0.15	0.09
1	3	4	Yellow	0.7	0.37	0.61	0.39
2	3	4	White	1.02	0.41	0.44	0.26

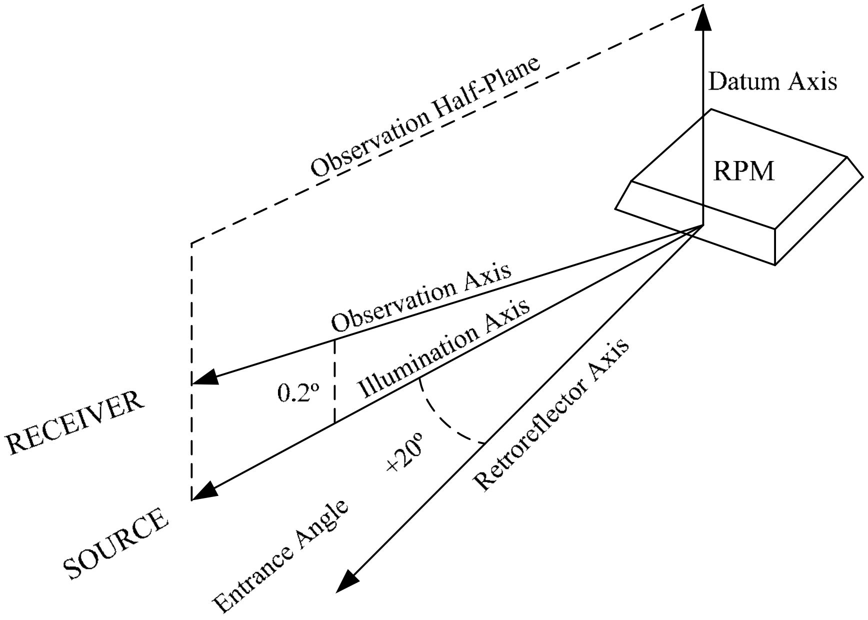
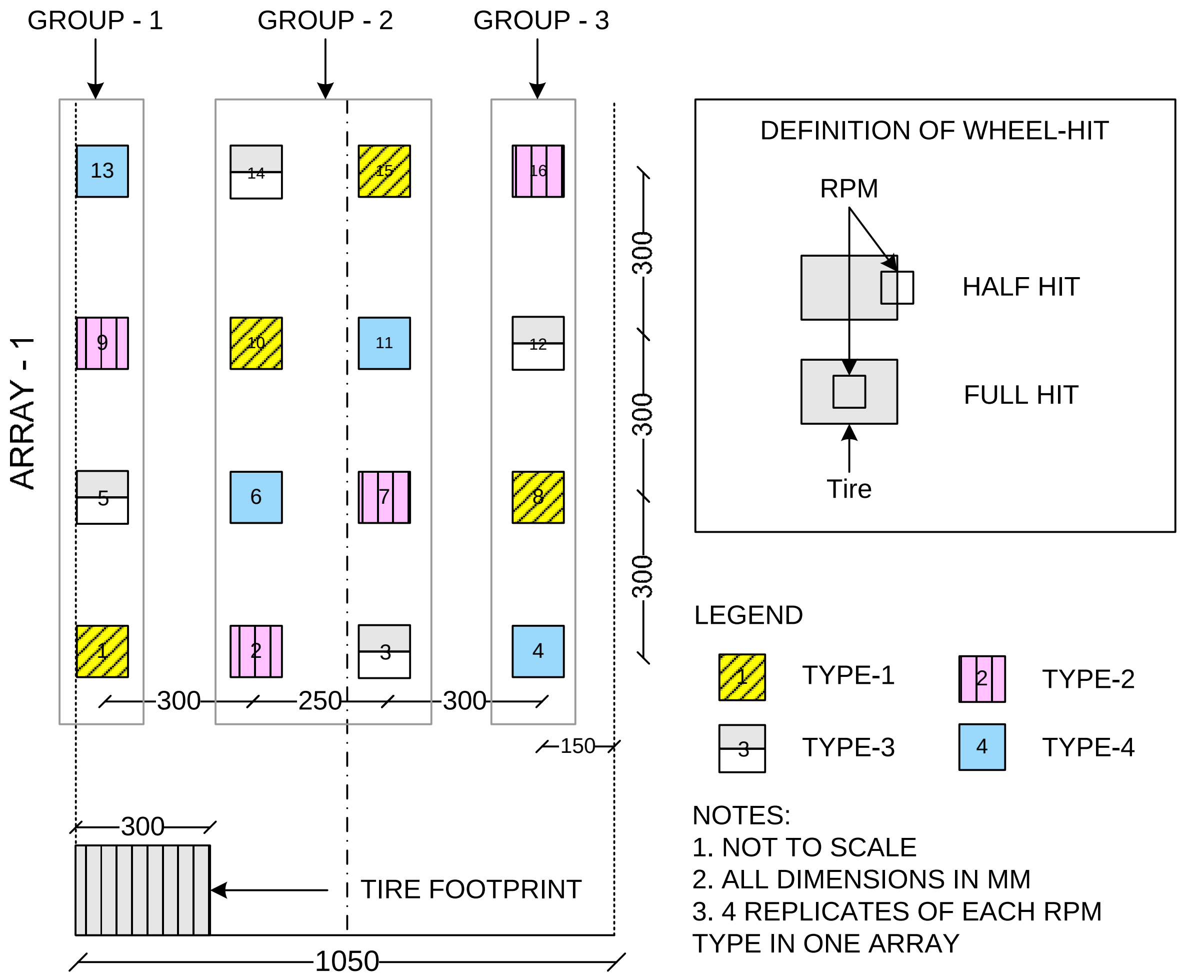
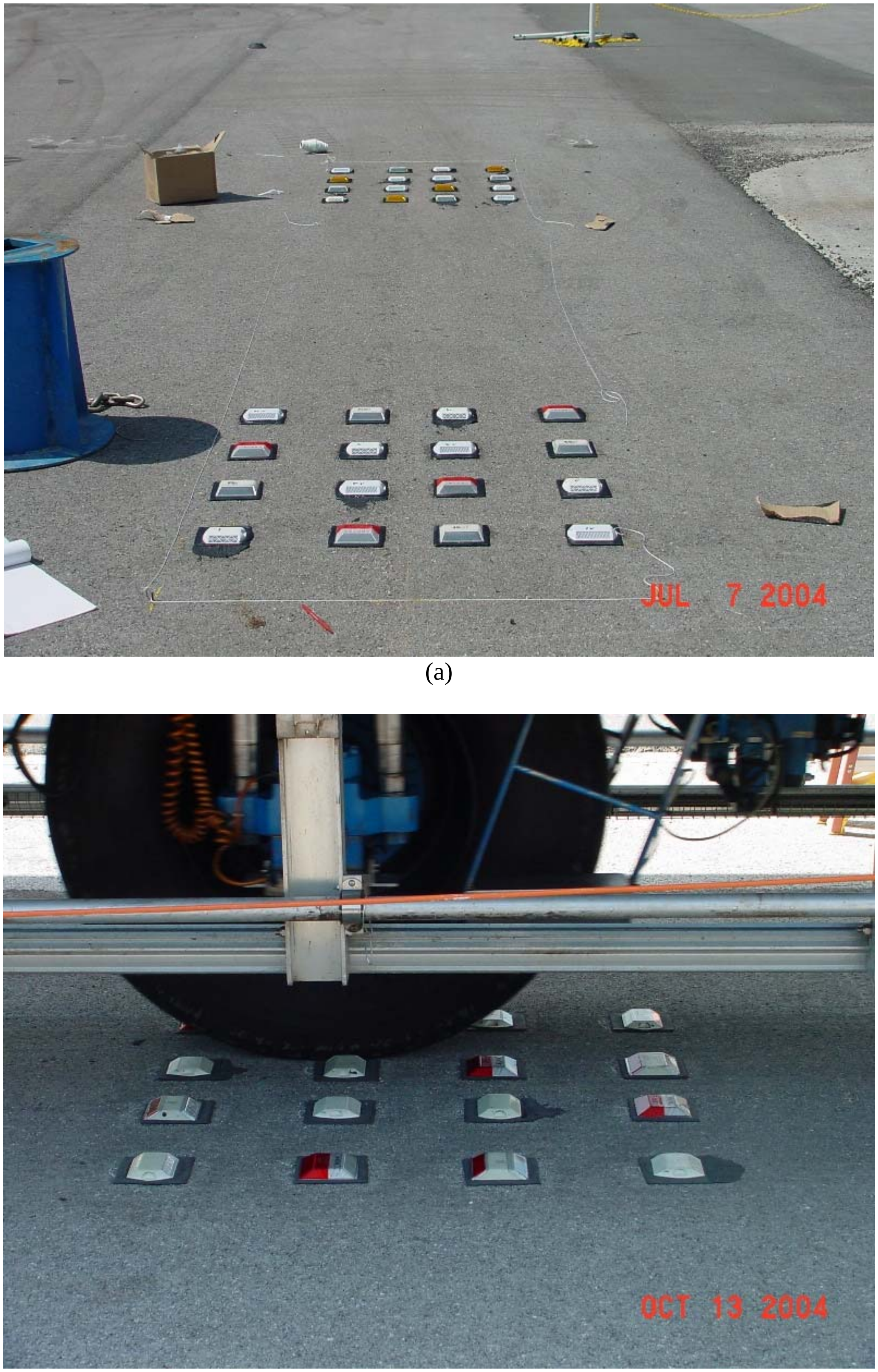


FIGURE 1 Position of an RPM for photometry, +20° entrance angle (*4*).



NOTES:
1. NOT TO SCALE
2. ALL DIMENSIONS IN MM
3. 4 REPLICATES OF EACH RPM TYPE IN ONE ARRAY

FIGURE 2 RPM layout for one array.



(a)

(b)

FIGURE 3 RPMs installed on a test section.

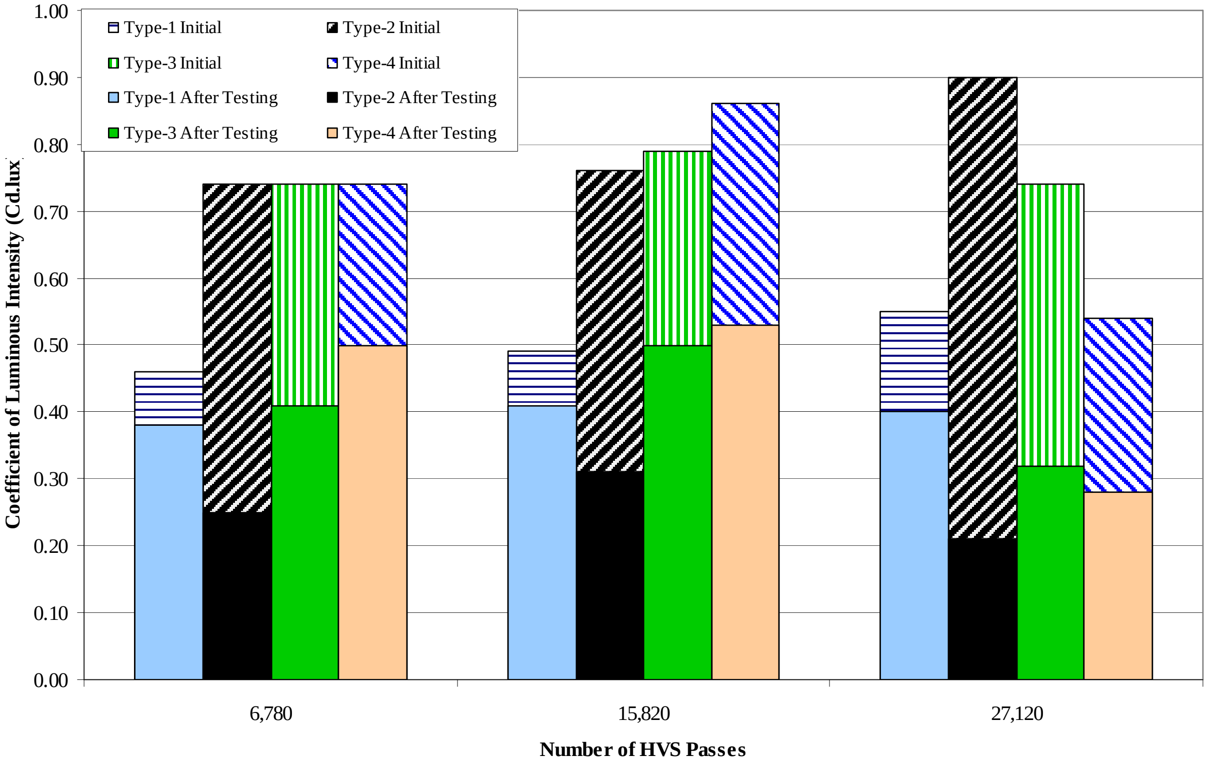


FIGURE 4 Coefficient of luminous intensity before and after HVS testing, at an angle of 0 degrees.

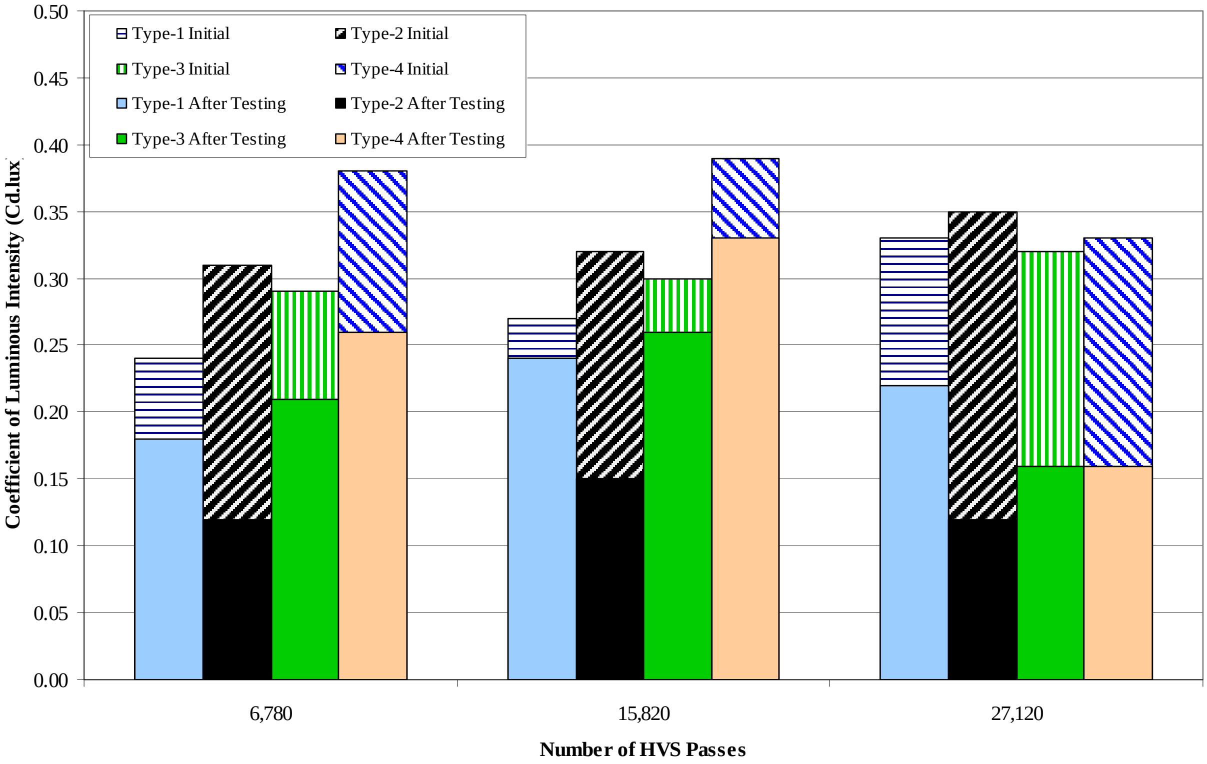


FIGURE 5 Coefficient of luminous intensity before and after HVS testing, at an angle of 20 degrees.