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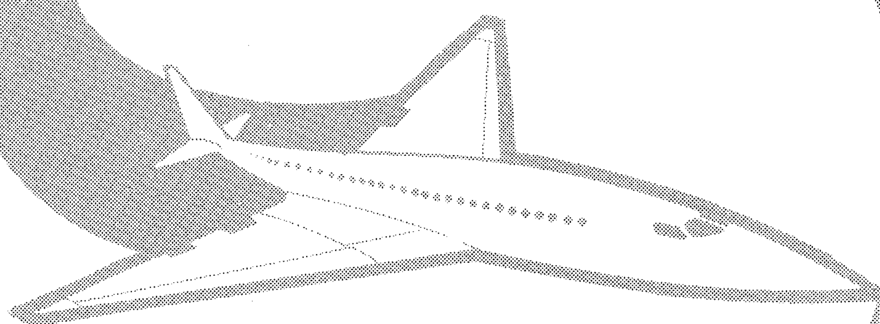
# Evaluation of Alternative Pavement Marking Materials

Keith W. Bagot



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16. Abstract

This study was undertaken to evaluate potential alternative marking materials for use on airport pavement marking systems. The materials were evaluated for conspicuity, durability, rubber buildup, color retention, friction, environmental acceptability, and cost benefits. In all, five materials (two water-borne, two epoxies, and one methacrylic resin) were evaluated at three test airports around the country for a period of one year. The three test airports, chosen for their different climatic conditions, were Atlantic City, Greater Pittsburgh, and Phoenix Sky Harbor International airports.

Epoxies and resins were more durable than water-borne paints in areas subject to heavy snowfall and snowplow activity, particularly when applied to Portland cement concrete surfaces. The epoxies tested, however, did show signs of yellowing after extensive ultraviolet exposure. It was also determined that the addition of silica and/or glass beads improved the conspicuity of the markings, improved friction, and minimized rubber adherence. The cost-benefit analysis showed that more durable materials and the addition of silica and/or beads does increase the initial cost of marking the airport surfaces but could reduce the number of painting cycles on many portions of the airport from several times per year to once every couple of years.

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# PREFACE

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Airport pavement markings are an important component of ground visual aids for pilots. These aids provide essential information to pilots to facilitate their tasks of taking off, landing, and maneuvering the aircraft on the airport surfaces. A common complaint by pilots is that airport pavement markings are not conspicuous enough. This problem is often simplistically seen as a failure to repaint, but the solution involves much more than frequent repainting. it is an involved and expensive task to repaint markings at most airports, particularly at the very busy ones.

This study was undertaken to evaluate potential alternative marking materials for use on airport pavement marking systems. The materials were evaluated for conspicuity, durability, rubber buildup, color retention, friction, environmental acceptability, and cost benefits. In all, five materials (two water-borne, two epoxies, and one methacrylic resin) were evaluated at three test airports around the country for a period of one year. The three test airports, chosen for their different climatic conditions, were Atlantic City, Greater Pittsburgh, and Phoenix Sky Harbor International airports.

Epoxies and resins were more durable than water-borne paints in areas subject to heavy snowfall and snowplow activity, particularly when applied to Portland cement concrete surfaces. The epoxies tested, however, did show signs of yellowing after extensive ultraviolet exposure. It was also determined that the addition of silica and/or glass beads improved the conspicuity of the markings, improved friction, and minimized rubber adherence. The cost-benefit analysis showed that more durable materials and the addition of silica and/or beads does increase the initial cost of marking the airport surfaces but could reduce the number of painting cycles on many portions of the airport from several times per year to once every couple of years.

# 1. INTRODUCTION.

Airport pavement markings are an important component of ground visual aids for pilots. A common complaint by pilots is that airport pavement markings are not conspicuous enough. This problem is often simplistically seen as a failure to repaint, but the solution involves much more than frequent repainting. it is an involved and expensive task to repaint markings at most airports, particularly at the very busy ones. Consequently, durability and conspicuity of markings may be viewed as a single concern in efforts to improve the safety of airport operations.

in 1992, at the request of the Office of Airport Safety and Standards (AAS-200), the FAA Technical Center initiated a project to improve the quality of airport pavement markings and to establish environmentally acceptable alternative marking materials. The project involved identifying the most promising products and techniques available for marking airport pavement surfaces. Every attempt was made to select materials that would adhere to concrete and asphalt surfaces and be able to withstand both winter and summer climates to ensure that the findings would be beneficial to airports around the country.

Selected materials included two epoxies, two water-borne paints, and one methacrylic resin. A number of airports were originally considered as test sites. The selected test sites were Atlantic City International, Greater Pittsburgh International, and Phoenix Sky Harbor International airports. The five selected test materials were applied at these airports during May and June 1993. The materials were left in place for a period of one year with field testing accomplished throughout the year.

An additional evaluation program, conducted in conjunction with this study, involved the application of supplemental beaded markings at the three test airports. This portion of the test was completed in response to a request by AAS-200 to examine the retro-reflectorization of runway and taxiway markings. Data were gathered on the long-term performance of the beads. All testing was completed over the same one-year time frame from June 1993 to June 1994. For further information on this evaluation refer to the Federal Aviation Administration Technical Center report, Evaluation of Retro-reflective Beads in Airport Pavement Markings, DOT/FAA/CT-94/120.

## 2. IMPROVED PAVEMENT MARKINGS.

### 2.1 PURPOSE OF THE STUDY.

The study was conducted to identify airport pavement marking materials that will improve visual guidance systems and aviation safety. This study focuses on the identification of more durable striping materials to achieve more conspicuous and longer lasting pavement markings.

### 2.2 OBJECTIVES.

This effort was directed specifically toward:

- Identifying new and improved marking materials for use on airports to assure maximum conspicuity while minimizing maintenance costs to the airport.

- Evaluating potential alternative marking materials considering conspicuity, durability, rubber buildup, color retention, friction, and cost benefits.

- Determining environmental acceptability of the marking materials evaluated.

### 2.3 BACKGROUND.

Airport pavement markings are a critical component of ground visual aids for pilots, and it is especially important that they be well maintained. In order to accomplish this, considerable resources are expended by airports to maintain the effectiveness of the marking systems. Current practices in marking airports have evolved over the years and are historically related to the application of roadway markings by highway departments. This caused the current-day practices for paint, equipment, retro-reflective beads, application techniques and procedures, and specifications to evolve, in large part, from highway transportation sources.

A number of documents outline standard practices in highway pavement markings. These include such references as the Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects from the Federal Highway Administration[1], the Manual on Uniform Traffic Control Devices for Streets and Highways from the Federal Highway Administration[2], the AASHTO Guide Specifications for Highway Construction[3], and the NCHRP Synthesis of Highway Practice, No. 138, Pavement Markings, Materials, and Application for Extended Service Life[4] .Over the years, the Federal Highway Administration has sponsored research on more durable[5] and faster drying[6] pavement marking materials. While this has offered benefits in the transfer of technology and application techniques, airport pavements present some unique requirements for marking materials. Among these are adhesion, climate, abrasion, resistance to jet fuel and jet blast, as well as braking/friction characteristics. These additional criteria require special testing to ensure suitability.

## 2.4 STANDARDS AND SPECIFICATIONS.

The Federal Aviation Administration (FAA) outlines specific airport markings, materials, and procedures in a number of government documents. Pavement markings required on the airport's runways, taxiways, and aprons are detailed in the FAA Advisor Circular (AC) 150/5340-IG, Marking of Paved Areas on Airports.[7] Striping material requirements for construction on airports are detailed in AC 150/5370-IOA, Standards for Specifying Construction of Airports[8]. In addition, approximately six government specifications govern individual types of marking materials. These are maintained by the Government Services Administration (GSA) and are depicted in table 1.

TABLE 1. MARKING SPECIFICATIONS

1. TT-B-1325B, "Beads (Glass Spheres) Retro-Reflective."
2. TT-P-85, "Paint, Traffic and Airfield Marking," Solvent Based.
3. TT-P-87, "Paint, Traffic and Airfield Marking," Solvent Based, Pre-Mixed, Reflectorized.
4. TT-P-110, "Paint, Traffic Black," (Nonreflectorized).
5. TT-P-115, "Paint, Traffic," Oil Based White and Yellow.
6. TT-P-1952B, "Paint, Traffic and Airfield Marking, Water Emulsion Base."

Because of the close relationship between airport and highway striping technology, the latest developments in the field of highway markings were reviewed with the intent of using those materials, devices, and applications in airport runway, taxiway, and apron markings. This included painted markings, tapes, plasticized materials, and new applications for retro-reflective devices.

Various types of marking systems are currently in use in the individual States. These include water-borne paints, solvent-borne paints, thermoplastics, epoxy thermoplastics, thermosets, polyesters, tapes, beads, and raised markers. Solvent-borne paint is by far the most commonly used material because of its durability and ease of application. Water-borne paints are being carefully examined by several States and the Federal Highway Administration because of the increasingly stricter Environmental Protection Agency requirements.

## 2.5 APPROACH.

The approach taken during the course of the study was to evaluate potential materials for operational and environmental suitability, select candidate materials, and install the materials at three airport test sites around the country. The materials were then evaluated over a one-year period. In addition to the marking materials, an evaluation of the use of various types of retro-reflective beads was included in the testing effort. This report discusses only the results and conclusions of the marking material study.

## 2.6 ENVIRONMENTAL CONSIDERATIONS.

In recent years, environmental restrictions have increased significantly. The use of the five original GSA specified paints has been limited by some states. Only the water-borne paint meeting specification TT-P-1952B has been relatively unaffected. The primary concern is air pollution and the contaminants with the greatest impact on airport markings are those with volatile organic compounds (VOCS). The South Coast Air Quality Management District (Los Angeles) has placed limits on the amount of volatile emissions that can be released per day. This impacted the ability to apply traffic striping using solvent-borne paints, and as a result, they have gone to water-borne paints. The use of water-borne traffic paint is now standard practice in most of Southern California. Concern has arisen in other States due to the problem of disposing of the solvent-borne paint shipping containers (55 gallon drums) which are classified as hazardous materials.

The Clean Air Act of 1970 provided the legislation which established pollution limitations. Among the pollutants that are to be controlled is ozone, which is a function of the amount of VOCs in the ambient atmosphere. In areas with ozone problems, action plans have been established to help control contamination. This has led to limitations on the use of solvent-type paints which emit and exceed VOC requirements. Thus paints that contain photochemically reactive solvents are increasingly unavailable for use. Consequently, more and more airports are being forced to use water-borne paints that have a short usable life span in an airport environment. This creates a greater need for alternative materials.

Another environmental concern involves the source of pigment color used in marking materials. Lead chromate is the traditional source of yellow in paints. Restrictions on the use of heavy metals such as lead and chromium have been implemented because of health and environmental concerns. Standards need to be devised to provide durable marking materials that are both cost-effective and environmentally friendly.

The project included an environmental impact review of the selected materials and their compliance with current and projected environmental regulations. General areas of concern included:

- Toxicity of material during installation and the concern of industrial hygiene.
- Leaching of material into ground water after surface application.
- Cracking and pealing of the material, allowing it to be carried by the wind and potentially enter the animal food chain.

The environmental review was conducted by Espey-Huston and Associates, Austin, Texas. The review was submitted to the FAA in April 1993. No significant environmental concerns regarding the selected materials were noted in the review.

## 3. GENERAL FRAMEWORK FOR TESTING.

### 3.1 SELECTION OF PRODUCTS FOR TESTING.

In order to evaluate the marking materials available for use at airports, a number of products were evaluated for suitability and effectiveness.

### 3.2 SCREENING THE MATERIALS.

Twenty-six manufacturing firms were contacted regarding their production of the following products:

- Water-borne paints
- Thermoplastics
- Methacrylic resins
- Polyester paints
- Two-part epoxies
- Polymorphic resins
- Penetrating paints
- Polyurethane
- Adhesive Tapes

An informational questionnaire was sent to all potential suppliers requesting material information, current and past product applications, performance history, product life, installation procedures, installation cost, and swatch samples. Each company was contacted separately and an attempt made to obtain as much information as possible to help in the evaluation of their products. The goal was to select only certain representative products for testing. Selected materials should specifically:

- Have application for both asphalt and concrete surfaces.
- Be usable in both winter and summer climates.
- Be durable enough to withstand the traffic loads on both taxiways and runways.
- Meet all environmental considerations outlined in paragraph 2.6.
- Require minimal runway or taxiway down time for application.
- Pose no potential foreign object damage (FOD) due to delamination in large pieces.

Manufacturers also had to exhibit an interest in active participation in the evaluation. Following receipt of manufacturer responses, product information was analyzed. Specific paint materials and manufacturers were then identified for inclusion in the test program.

## 3.3 SELECTED TEST MATERIALS.

Table 2 contains the manufacturers and marking materials that were selected for participation and application of their materials at the airport test sites. Any material not meeting all of the criteria outlined in paragraph 3.2 was not considered for the evaluation.

TABLE 2. TEST MATERIALS

| TYPE MATERIAL | MANUFACTURER/MATERIAL |
|---|---|
| Water-borne Paint | Rohm and Haas (water-borne no. 1)<br>Morton International/Duroline 2000 (water-borne no. 2) |
| Two-part Epoxy | ADI/Safeway, Inc. /Safegrip (epoxy no. 1)<br>Poly-Carb, Inc./ Mark-55 (epoxy no. 2) |
| Methacrylic Resin | Morton International/Dura-Stripe |

### 3.3.1 Water-borne Paint.

Water-borne traffic paint is applied as a single component, similar to solvent-borne paint, with the solvent being mostly water. The organic co-solvent, which is necessary to achieve proper application properties, is restricted to a low level.

### 3.3.2 Methacrylic Resin.

This material is a two-component system, cold-curing compound designed to work well with both asphalt and concrete. The material is composed of acrylic monomers and polymers, plasticizers, and pigments.

### 3.3.3 Two-part Epoxy.

Two-component epoxy traffic paint is a high-solids system. It consists of a liquid epoxy resin and a liquid hardener together with proper pigments. The two are proportioned in a specific ratio and then mixed and sprayed to form a traffic stripe of about 15 mils. The subsequent cured material is thermosetting.

## 3.4 CRITERIA FOR EVALUATION.

Several criteria were used in evaluating test materials, including conspicuity, durability, rubber resistance, color retention, friction, and cost benefits.

3.4.1 Conspicuity.

Conspicuity was evaluated by obtaining a series of photographs to monitor visual changes in the material over time. Periodically the condition of the materials was visually inspected and compared with the condition of the originally installed materials. Any major deficiencies in durability, rubber resistance, or color retention would result in the pavement marking losing its conspicuity.

3.4.2 Durability.

Durability was evaluated visually using a series of photographs and original "drawdown" samples to monitor visual changes in texture of the material. Any breaking or cracking of the material which would contribute to a shorter life was identified. A key component to the durability of a material was how it bonded to either concrete or asphalt. The test stripes were also examined for traces of contaminants such as hydraulic fluids and oils.

3.4.3 Rubber Resistance.

Rubber buildup was evaluated on those materials installed on the runway surfaces. Taxiway stripes would not generally be affected by rubber buildup except near a turn when the nose gear and/or main gear tires would "scrub" across a stripe. Subsequent analysis identified those materials which better resist rubber buildup. In addition an analysis of the effects of rubber removal was performed on runway marking test materials installed at the Phoenix airport.

3.4.4 Color Retention.

Changes in color characteristics were examined in order to determine the effects of ultraviolet light on the color of the material over time. This is important because of the need to maintain standardization of visual aid colors between airports. Drawdown samples were used to show a comparison of the original application color and the existing color of the stripe after exposure to the environmental elements.

3.4.5 Friction.

Friction testing was conducted at two of the three selected airports. The Atlantic City and Pittsburgh airports had the friction testing equipment necessary to collect the skid resistance data required for this test. The device used at both airports was the K.J. Law Runway Friction Tester (RFT). Data from the friction measurements were collected after application of the test materials and subsequently on a quarterly basis. A low friction reading of a particular material or surface would indicate a low skid resistance.

### 3.4.6 Cost-Benefit Analysis.

A cost-benefit analysis was accomplished to determine whether additional cost of a particular material is offset by the life extension provided. Due to the short period of testing (one year), life-cycle characteristics beyond the one-year point had to be interpolated.

## 3.5 AIRPORT TEST SITES.

A number of airports were considered as test sites. Desirable features included diverse climate and sun conditions as well as wide geographical distribution. Air carrier operations and availability of friction testing equipment, as well as the airport management's expressed desire to participate and their ability to support the application of materials, were also factors in the final selection. Following the tentative recommendations in the early test plan, initial site visits were conducted and the airports were then identified for application of test materials. The selected test sites were the Atlantic City International, Greater Pittsburgh International, and Phoenix Sky Harbor International airports.

### 3.5.1 Test Configuration.

Basic test-marking configurations were developed to permit evaluation of each color and bead. Six test stripes were applied at selected taxiway locations on each airport. Test stripes were painted in yellow (3) and white (3). One of each was unbeaded, one beaded with 1.5 IOR beads, and one beaded with 1.9 IOR beads. The configurations were arranged in the same manner at each location to provide consistent displays at each airport. Reference appendix A figures A-1 through A-7 for the runway and taxiway test stripe configuration at the three test airports.

In addition to the taxiway test stripes, selected runway stripes (3 feet x 120 feet) were also re-marked at each of the test airports. The runway stripe installations involved replacing the existing runway centerline stripes with test materials. Seven runway stripes were repainted at the Atlantic City and Pittsburgh airports and four stripes were repainted at the Phoenix airport. The test stripes were located toward the center of the runway to expose each stripe to an equal amount of landing gear impact.

### 3.5.2 Atlantic City International Airport.

Atlantic City International Airport was chosen for its warm, wet climate. The airport is also home to the FAA Technical Center allowing project personnel to inspect the markings more often over the one-year evaluation.

The first test area was located on the runway 13-31 centerline toward the center of the runway. The runway installation replaced the selected seven existing runway centerline stripes.

The second and third test sites were taxiway test locations. Two locations selected were on asphalt taxiway Bravo (B) and on concrete taxiway Hotel (H). Six stripes were applied by each subcontractor at each taxiway location, with the stripes 6 inches in width and 6 feet in length.

3.5.3 Pittsburgh International Airport.

Pittsburgh International Airport was selected for its winter weather conditions. The cold weather, along with snow and ice, exposed the materials to elements which might tend to make them very brittle. Additionally, Pittsburgh International experiences a considerable amount of snow accumulation and therefore the markings are subjected to possibility of damage from snow removal equipment.

The first test area was located on the runway (IOR-28L) centerline. The runway installation replaced seven existing runway centerline stripes.

The second test area was located on taxiway Victor (V). Six stripes were applied by each subcontractor at the taxiway location, each being 6 inches in width and 8 feet in length.

3.5.4 Phoenix Sky Harbor International Airport.

Phoenix Sky Harbor International Airport was selected for its hot, dry climate. The Phoenix Airport is an ideal location for determining whether a material might become elastic or discolor due to heat and ultraviolet exposure.

The first test area was located on the runway (8L) centerline. The runway installation replaced four existing runway centerline stripes. One subcontractor was unable to install their materials (epoxy no. 1) on the runway due to logistics problems. They were able to complete the taxiway installations however. All runway pavement markings at Phoenix contained glass beads with a refractive index of 1.9.

The second and third test areas were located on taxiway Echo (E) at E-4 and E-8. The E-4 site is constructed of Portland cement concrete pavement material and the E-8 site is composed of asphalt pavement material. Again, six stripes were applied by each subcontractor at these taxiway locations, each stripe being 6 inches in width and 8 feet in length.

## 3.6 APPLICATION SCHEDULE.

The application of materials was accomplished at each of the three airports in accordance with the pre-planned schedule. Installation was completed during May and June 1993. Each installation was accomplished as planned with the exception of the Phoenix location, where only four runway stripes were applied. This exception was due to unavailability of materials for the (epoxy no. 1) product due to a misplaced shipment.

## 3.7 SURFACE PREPARATION.

Surfaces were prepared prior to application of marking materials at all test locations. This was necessary to insure a clean surface for maximum adhesion. At Atlantic City and Phoenix a combination of sandblasting and surface grinding was used to prepare the surface. At Pittsburgh, hydroblasting was used for preparation of runway and taxiway surfaces. It was noted that hydroblasting and sandblasting were effective means of removing oil and fuel residue as well as concrete curing compounds on new pavement surfaces. It was also noted that the only successful means of totally removing multi-layered paint was by grinding the paint off the surface. However, this technique does result in some slight pavement damage.

## 3.8 DRAWDOWNS.

Each Subcontractor provided a drawdown (sample) of the materials applied on the day of installation at each airport location. The material was applied to a thin piece of aluminum during the taxiway test stripe installation. Each drawdown was then marked to identify the manufacturer and material name. The drawdowns were used as a baseline for comparison with field test specimens over the one-year time frame.

## 4. RESULTS.

The installation of test materials was accomplished in accordance with the pre-planned schedule. Initial evaluation of the test materials commenced shortly after installation with a detailed examination at each of the test sites. Visual observations were made, and friction readings were obtained.

Periodic visits were made at each airport to evaluate test materials for conspicuity, durability, and rubber buildup. The evaluation schedule was maintained with visits to Atlantic City each month from June 1993 to June 1994. Phoenix and Pittsburgh airports were each visited in September and December 1993, and March and June 1994. Friction testing of the various materials was conducted at the Atlantic City and Pittsburgh airports on a quarterly basis. Participating paint manufacturers were encouraged to attend these reviews and accompanied project engineers on several occasions at each location.

It became apparent early in the test program that variations existed in performance between similar kinds of materials as well as between similar materials at different locations. The two epoxies exhibited different color, friction, retro-reflectivity, and rubber resistance characteristics. Similarly, the two water-borne materials exhibited different characteristics at the different test locations. Figures A-8 to A-33 of appendix A depict materials' status from installation until completion of testing.

Results of the tests provided the evaluators with diverse material performance data. Some materials exhibited significant improvements in performance over traditional materials. Certain materials performed in an exceptional manner. These included the methaerylic resin and a water-borne material. Overall, the results of the runway and taxiway marking materials tests were very positive. These results should lead to implementing changes to the existing pavement marking specifications. Figure A-34 provides a brief summary of the performance results of all five materials at the three test airports.

### 4.1 ATLANTIC CITY INTERNATIONAL AIRPORT.

The taxiways Bravo and Hotel test stripes were each inspected on a monthly basis. One stripe of epoxy material (Epoxy no. 2, white, non-beaded) was noted to have not completely cured and assumed a blackened appearance. The blackened appearance was a result of the partially cured epoxy collecting the dirt from the main gear of the aircraft and vehicle tires as they passed over the test stripe. One benefit to be mentioned is that the material remained in place even though only partially cured. The test stripe did not delaminate from the concrete surface therefore eliminating the potential for foreign object damage (FOD).

Runway centerline marking results at this location were mixed. Significant yellowing occurred with the epoxy no. 1 centerline marking. Rubber adhesion was a problem on many of the centerline markings, particularly on the water base no. 1 stripe which became almost totally obscured. Friction readings were performed in May, September, and December 1993, and March and June 1994 by an FAA Technical Center engineer. The RFT was utilized to obtain friction readings on the various runway striping materials for baseline data. Friction readings were very good with the exception of the unbeaded no. 2 epoxy. In general the friction readings for the two beaded stripes (nos. 6 & 7) were as good as, or better than those for the unbeaded materials.

## 4.2 GREATER PITTSBURGH INTERNATIONAL AIRPORT.

Following the initial installation of materials at the Pittsburgh airport, (June 9, 1993) the materials were inspected and baseline comparative photos were taken of the test stripes and drawdowns.

Friction testing of the various runway striping materials at this location was also accomplished on a quarterly basis. Results were similar to those obtained at the Atlantic City airport test sites, although ambient pavement friction was lower. In general the friction readings for the two beaded stripes (nos. 6 & 7) were as good, or better than those for the unbeaded materials. Refer to table 3 for specific readings.

The overall condition of the test materials at the various locations at Pittsburgh airport varied considerably. At the completion of testing in June 1994, runway markings were in generally good condition. Very little rubber adhesion had occurred on the runway centerline test stripes. significant yellowing was noted on the epoxy no. 1 material. The taxiway test stripes were significantly damaged, particularly the water-borne materials which suffered delamination from snow plow activity. Refer to figures A-26 through A-32 for photographs of the of the damaged test stripes. One of the epoxies also suffered delamination prior to completion of the test period at the Pittsburgh airport site. The methacrylic resin provided excellent performance in all criteria throughout the test period. The epoxy no. 2 performed very well also, with the exception of friction readings.

## 4.3 PHOENIX SKY HARBOR INTERNATIONAL AIRPORT.

At this location, only four of the test materials were applied at the runway stripe locations due to the loss of the epoxy no. 1 materials enroute to the site. Historically, rubber buildup occurred quickly on the runway stripes at this location, and the bulk of the data derived came from the taxiway test locations. In addition, all runway stripes on this airport were beaded for enhanced retro-reflectivity.

The two taxiway test sites at the airport were located on taxiway E, on both asphalt and Portland cement concrete concrete pavement surfaces. Each of the taxiway E test stripes (60 total) were inspected quarterly. All five materials performed well at this location. Due to the extreme ultraviolet (UV) exposure, the two epoxies' white test stripes did show signs of the catalyst yellowing.

In September 1993, a chemical removal product was demonstrated at the location. Significant contamination existed on four of the runway test stripes at Phoenix airport, and the rubber removal effort was initially conducted on the centerline area of the four affected stripes. The chemical was applied by a sprayer-brush combination in multiple passes. The removal operation was accomplished in approximately ninety minutes. At the end of the period the area was flushed with water and vacuumed dry. The result was a completely clean surface area with all the markings restored to near original condition.

### 4.4 CONSPICUITY.

The conspicuity of each material remained relatively stable at all sites throughout the first six months of the test. Thereafter, varying degrees of degradation occurred at the diverse sites. The primary change in conspicuity was due to rubber contamination. At Atlantic City airport, the runway centerline stripe painted with water-borne no. 1 rapidly became 90 percent obscured. of the taxiway test stripes at Atlantic City, the epoxy no. 2 test stripes on taxiway H blackened, and this appeared to be caused by improper mix during application. Nighttime conspicuity and effectiveness are greatly dependent on the proper application of the beads. Also considered significant was the enhancement of long-term effectiveness of the use of silica and/or beads as an additive to sustain conspicuity of materials. Reduced rubber adhesion was an additional benefit derived.

### 4.5 DURABILITY.

Durability was evaluated visually and through the use a series of comparative photographs of test materials taken during periodic inspections and original drawdowns to monitor visual changes in texture of the material. Breaking/cracking of the materials was noted at the various locations and some significant reductions in durability were noted during the course of testing.

A harsh winter environment caused significant damage to all but the most durable materials. A number of snowfalls were experienced at the Pittsburgh and Atlantic City airports exposing the materials to snow removal operations. In Pittsburgh a significant amount of damage from snow plowing was experienced on the materials applied to the concrete taxiway surfaces. The use of a more durable, environmentally acceptable marking material along taxiways, aprons, and areas of the runway surface not conducive to heavy rubber buildup would be most beneficial.

At Phoenix, the deterioration, as may be expected, occurred at the slowest rate. At the completion of the one-year period the water-borne materials had begun to evidence some cracking and delamination, although not to the point of failure. In general the water-borne materials also showed some evidence of deterioration through wear. The epoxies and methacrylic resin materials held up well, with only the unbeaded materials cracking and discoloring (with rubber).

### 4.6 RUBBER RESISTANCE.

The effectiveness of materials used for visual markings is dependent, to a significant degree, on the quality of the installation and on the operational and climatic environment. Rubber resistance in particular showed wide variations between materials in different environments.

Resistance to rubber buildup is an important factor on those materials which have been installed in an area subjected to the impact of aircraft landing gear. At the Atlantic City location, the water-borne material no. 1 was almost totally covered with rubber within a short time after application. Each of the other materials had significantly less rubber coverage at this site. Certain materials offered greater rubber resistance than others. Resistance to rubber buildup was better when silica and/or bead additives were applied to the material, as opposed to the heavier buildup noted with similar materials not having silica or beads applied.

The silica appeared to cause the rubber to "flake" away and not smear onto the paint as was the case with the test stripes that did not have silica. There was a significant difference in rubber adherence between the epoxy runway test stripe with silica and the epoxy without silica along with the water-borne runway stripes with and without silica. In both cases the materials with silica retained their white color and did not get obscured by rubber. The addition of the silica to the test stripes was at the discretion of each of the manufacturers involved in the study.

While using silica and/or beads showed higher resistance to rubber buildup, none of the materials totally avoided the problem. In hot climates such as Phoenix, it appears that rubber buildup will occur rapidly regardless of the material type. At such locations the runway pavement markings in the vicinity of the touchdown area need to be painted more often, regardless of the marking material used. Therefore, no benefit is gained by use of more durable materials. It must be noted, however, that the addition of beads results in improved nighttime visibility, even when rubber adhesion resulted in the loss of daytime conspicuity.

## 4.7 COLOR RETENTION.

Changes to color characteristics were recorded to determine the effects of ultraviolet light on the color of the material over time. Since epoxies are sensitive to the effects of ultraviolet light, some yellowing of the white materials was anticipated. At all three airports the white epoxy no. 1 materials yellowed significantly during the initial 24 hours after application. The manufacturer became aware of the problem and provided assurance that a new formulation was under preparation. The other epoxy, no. 2, provided stable coloration at the Atlantic City and Pittsburgh test sites. Some slight yellowing of this material was noted at Phoenix.

At Atlantic City airport the water-borne material no. 2 was found to have developed a rust-colored cast on the runway threshold stripes and on the asphalt taxiway stripes. Since this occurred only on the asphalt pavement surfaces, it was believed that a component in the asphalt mix was interacting with the materials. Use of drawdowns and comparative photographs illustrated the color transformations that occurred. Refer to the appendix for individual comparisons. Overall, the test materials displayed a constancy in color characteristics with the exceptions already noted.

## 4.8 FRICTION.

Friction testing was conducted at two of the three selected airports. The Atlantic City and Pittsburgh airports possessed the friction testing equipment to collect the skid resistance data necessary for this test. Data were collected initially upon application and quarterly using the RFT vehicle. Refer to figure A-18 for a depiction of the vehicle in operation. Friction data obtained from the various materials indicate that certain marking materials exhibited positive friction benefits compared with others. For example, it was determined that the epoxy materials exhibited poor friction values if a silica friction enhancement was not included in the application. A low friction reading of a particular material or surface would indicate a low skid resistance.

For this test the materials had a silica additive with a gradation requirement in the 50/60 range and was composed of 99.5 percent white silica. Any silica of less than 99.5 percent purity will begin to discolor the striping. The silica was applied at a rate of two to four lbs. per gallon of paint.

For comparative purposes the existing paint markings at Pittsburgh were an oil-based paint with a friction value of 0.2 mu and the ambient pavement friction was determined to be 0.75 mu

(60 mph test with the self-watering system on) at the time of the initial installation of the test stripes. The minimum maintenance level for unpainted surfaces of the runway is 0.41 mu at 60 mph as specified in the FAA Advisory Circular 150/5320-12B, Measurement, Construction, and Maintenance of Skid-Resistant Airport Pavement Surfaces[9]. Refer to table 3 for specific friction data for the Atlantic City and Pittsburgh locations.

## 4.9 COST-BENEFIT ANALYSIS.

A comparison was made relative to the cost of purchasing and installing the various materials on a typical (10,000 ft.) airport runway. A number of sources were contacted regarding the actual costs for performing this type of work. Inputs from the manufacturers regarding the estimated cost for application of their products were also obtained. Since a variety of products, application rates, and cost variables were encountered, hypothetical parameters had to be established to provide "typical" costs for marking a runway. The selected criteria are outlined below:

| | |
|---|---|
| Runway Length: | 10,000 Feet |
| Runway Width: | 200 Feet |
| Type Markings: | Precision Markings - Both Ends |
| Type Paint: | Variable |
| Paint Coverage: | 107 sq. feet/gallon |
| Paint Cost: | $ Variable - $6.50 to $35 per gallon |
| Paint Application Rate: | 15 Mils/Wet |

Using the above criteria it was determined that 142,500 sq. ft. of painted area would be required on the hypothetical runway. This would require 1332 gallons of paint. Labor costs were based on current government wage grade salaries involving a crew of 4 applying materials at the rate of 10,000 sq. feet per hour.

Labor costs are broken down as follows:

| | |
|---|---|
| Application (crew of 4): | 10,000 sq. ft. per hour Labor |
| hrs. for a 10,000 Runway: | 14.25 crew hours |
| Labor Rate: | $20.00 per hour/individual |

Refer to table 4 for the various types of materials and costs associated with painting this "typical" runway. Life estimates of the durable materials was interpolated using manufacturers' recommendations and the results of the one-year evaluation. Further testing could prove that the durable materials may have a useful life greater than the four years used in table 4. The annual cost comparison is based on the installation cost of the material divided by the maximum estimated lifespan of the material.

TABLE 3. FRICTION TEST RESULTS

**PITTSBURGH**

| 40 MPH TEST | STRIPE | MATERIAL | ADDITIVES | 6/11/93 | 12/14/93 | 3/22/94 | 6/22/94 |
|---|---|---|---|---|---|---|---|
| | 1 | Epoxy | Silica | 0.60 | 0.65 | 0.65 | 0.62 |
| | 2 | Epoxy | None | 0.32 | 0.13 | 0.27 | 0.26 |
| | 3 | Water-borne Paint | None | 0.44 | 0.42 | 0.50 | 0.46 |
| | 4 | Water-borne Paint | Silica | 0.77 | 0.53 | 0.68 | 0.56 |
| | 5 | Methacrylic Resin | Silica | 0.68 | 0.58 | 0.65 | 0.58 |
| | 6 | Methacrylic Resin | Silica/1.5 Bead | 0.52 | 0.52 | 0.68 | 0.52 |
| | 7 | Methacrylic Resin | Silica/1.9 Bead | 0.51 | 0.52 | 0.62 | 0.54 |

| 60 MPH TEST | STRIPE | MATERIAL | ADDITIVES | 6/11/93 | 12/14/93 | 3/22/94 | 6/22/94 |
|---|---|---|---|---|---|---|---|
| | 1 | Epoxy | Silica | 0.53 | 0.61 | 0.63 | 0.58 |
| | 2 | Epoxy | None | 0.24 | 0.12 | 0.22 | 0.22 |
| | 3 | Water-borne Paint | None | 0.37 | 0.33 | 0.37 | 0.39 |
| | 4 | Water-borne Paint | Silica | 0.60 | 0.46 | 0.60 | 0.50 |
| | 5 | Methacrylic Resin | Silica | 0.56 | 0.50 | 0.56 | 0.51 |
| | 6 | Methacrylic Resin | Silica/1.5 Bead | 0.39 | 0.43 | 0.64 | 0.45 |
| | 7 | Methacrylic Resin | Silica/1.9 Bead | 0.49 | 0.44 | 0.58 | 0.45 |

**ATLANTIC CITY**

| 40 MPH TEST | STRIPE | MATERIAL | ADDITIVES | 5/27/93 | 9/15/93 | 12/2/93 | 5/11/94 |
|---|---|---|---|---|---|---|---|
| | 1 | Epoxy | Silica | 0.90 | 0.90 | 0.95 | 0.89 |
| | 2 | Epoxy | None | 0.40 | 0.37 | 0.32 | 0.30 |
| | 3 | Water-borne Paint | None | 0.47 | 0.43 | 0.48 | 0.54 |
| | 4 | Water-borne Paint | Silica | 0.99 | 0.86 | 0.88 | 0.89 |
| | 5 | Methacrylic Resin | Silica | n/a | 0.37 | 0.47 | 0.52 |
| | 6 | Methacrylic Resin | Silica/1.5 Bead | 0.51 | 0.36 | 0.44 | 0.52 |
| | 7 | Methacrylic Resin | Silica/1.9 Bead | 0.42 | 0.43 | 0.42 | 0.59 |

| 60 MPH TEST | STRIPE | MATERIAL | ADDITIVES | 5/27/93 | 9/15/93 | 12/2/93 | 5/11/94 |
|---|---|---|---|---|---|---|---|
| | 1 | Epoxy | Silica | 0.75 | 0.80 | 0.86 | 0.77 |
| | 2 | Epoxy | None | 0.32 | 0.27 | 0.26 | 0.25 |
| | 3 | Water-borne Paint | None | 0.39 | 0.38 | 0.37 | 0.47 |
| | 4 | Water-borne Paint | Silica | 0.86 | 0.72 | 0.75 | 0.78 |
| | 5 | Methacrylic Resin | Silica | 0.37 | 0.27 | 0.32 | 0.42 |
| | 6 | Methacrylic Resin | Silica/1.5 Bead | 0.31 | 0.27 | 0.26 | 0.40 |
| | 7 | Methacrylic Resin | Silica/1.9 Bead | 0.35 | 0.31 | 0.33 | 0.44 |

* Average mu of each run using the K.J. Law Runway Friction Tester, self-watering system "on".

TABLE 4. COST COMPARISON

| Type of Material | Epoxy | | Water - borne | | M.E. Resin |
|---|---|---|---|---|---|
| Name | ADI / Safeway (no. 1) | Poly - Carb (no. 2) | Rohm - Haas (no. 1) | Morton Duroline (no. 2) | Morton Dura-Stripe |
| Paint Area in Sq Ft | 142,500 | 142,500 | 142,500 | 142,500 | 142,500 |
| Surface Coverage in Sq Ft / Gal | n/a | 107 | 107 | 107 | 40 |
| Gallons of Paint Used | n/a | 1332 | 1332 | 1332 | 3563 |
| Paint Cost Per Gallon | n/a | $35 | $6.50 | $8.50 | $30 |
| **Total Paint Cost** | n/a | $46,620 | $8,658 | $11,322 | $106,890 |
| **Total Labor Cost** | n/a | $1,138 | $1,138 | $1,138 | $1,138 |
| **TOTAL COST** | n/a * | $47,758 | $9,796 | $12,460 | $108,028 |

SQUARE FOOTAGE COST COMPARISON

| | | | | | |
|---|---|---|---|---|---|
| Cost per Sq Ft | $1.58 | $0.34 | $0.07 | $0.09 | $0.76 |
| Paint Area in Sq Ft | 142,500 | 142,500 | 142,500 | 142,500 | 142,500 |
| **TOTAL RUNWAY COST** | $225,150 | $47,758 | $9,796 | $12,460 | $108,028 |

ANNUAL COST COMPARISON

| | | | | | |
|---|---|---|---|---|---|
| Lifespan | 4 Years | 4 Years | 6 mo. - 1 yr. | 6 mo. - 1 yr. | 4 Years |
| **ANNUAL COST** | $56,288 | $11,940 | $9,796 | $12,460 | $27,007 |

*ADI/Safeway provided only a cost estimate for a painted area of 142,500 sq. ft., no cost breakdowns were provided.

## 5. CONCLUSIONS.

Based on the results of this evaluation effort, it is concluded that:

- New and improved marking materials for use on airports to assure maximum conspicuity while minimizing maintenance costs to the airport were identified.

- Potential alternative marking materials were evaluated for conspicuity, durability, rubber buildup, color retention, friction, and cost benefits. The methacrylic resin proved to be the most promising material tested for applications in any climatic region on both concrete and asphalt.

- The two epoxies tested showed positive results for durability; however, they need to overcome the yellowing characteristic inherent to their white materials. The two epoxies did not exhibit the same degree of discoloration thus it is possible that another epoxy using a different catalysts may have overcome this problem. The discoloration becomes more prevalent under high ultraviolet exposure such as that experienced in Phoenix. No significant discoloration was evident in the yellow epoxy taxiway test stripes.

- The addition of silica and/or glass beads proved effective for maintaining conspicuity of the markings and minimizing rubber adherence.

- It was determined that all marking materials evaluated were environmentally acceptable under the strictest State and Federal standards.

- It was determined that the epoxies and the resin were more durable in areas subjected to heavy snowfall and snowplow activity. The water-borne materials did not survive well, particularly on Portland cement concrete concrete surfaces.

- Airports installing painted signs on taxiway surfaces will benefit from the use of durable marking materials. The labor-intensive activity necessary for sign preparation and application are not conducive to frequent repainting.

- Another finding not specifically related to the quality of the materials tested was the positive performance of chemical rubber removal agents at the Phoenix Sky Harbor Airport. This removal process restored the markings to almost original quality without any damage to the markings or to the micro texture of the runway surface.

## 6. REFERENCES.

1. Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects, FP-85; dated 1985, Federal Highway Administration.

2. Manual on Uniform Traffic Control Devices for Streets and Highways; 1984, Federal Highway Administration.

3. AASHTO Guide Specifications for Highway Construction, American Association of State Highway and Transportation Officials, Washington, D.C.

4. NCHRP Synthesis of Highway Practice, No.138, Pavement Markings, Materials, and Application for Extended Service Life; Transportation Research Board, June 1988, Washington D.C.

5. Hofener, S.D. and Woods, D.L., Research Report FHWA-RD-79-14 Thermoplastic Striping With Improved Durability, Texas A&M University, August 1977, College Station, TX.

6. Pandalai, K. and Pandalai, N., Research Report FHWA-RD-80-068, Fast Drying Traffic Paints, Pandalai Coatings Company, June 1980, Breckenridge, PA.

7. Advisory Circular 150/5340-IG, Marking of Paved Areas on Airports, Washington, DC 20591.

8. AC 150/5370-10A, Standards for Specifying Construction on Airports, Washington, DC 20591.

9. AC 150/5320-12B, Measurement, Construction, and Maintenance of Skid-Resistant Airport Pavement Surfaces, Washington DC 20591.

# APPENDIX A – RUNWAY/TAXIWAY TEST CONFIGURATIONS AND INSPECTION PHOTOGRAPHS

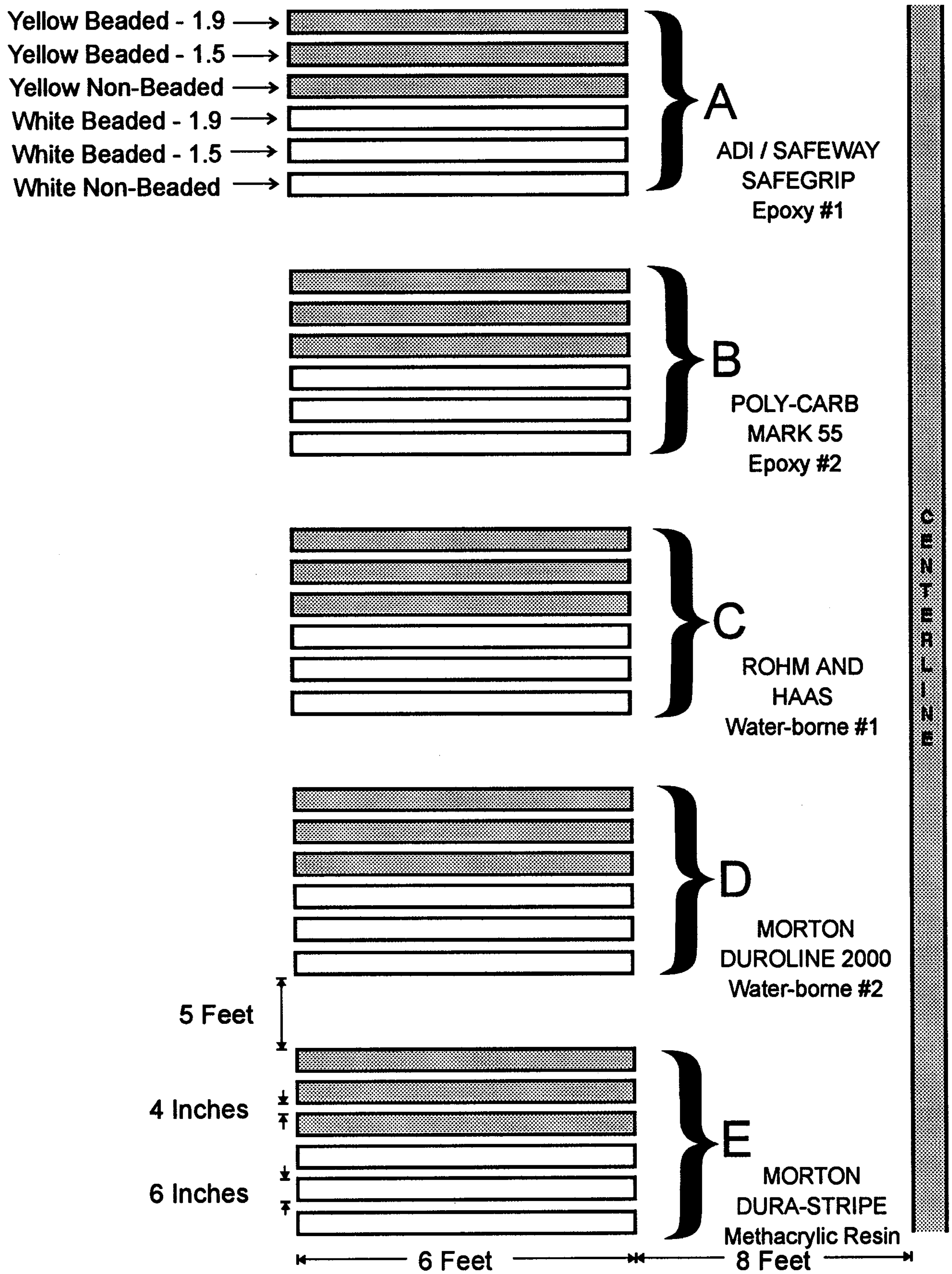


FIGURE A-1. TAXIWAY MARKING TEST LAYOUT

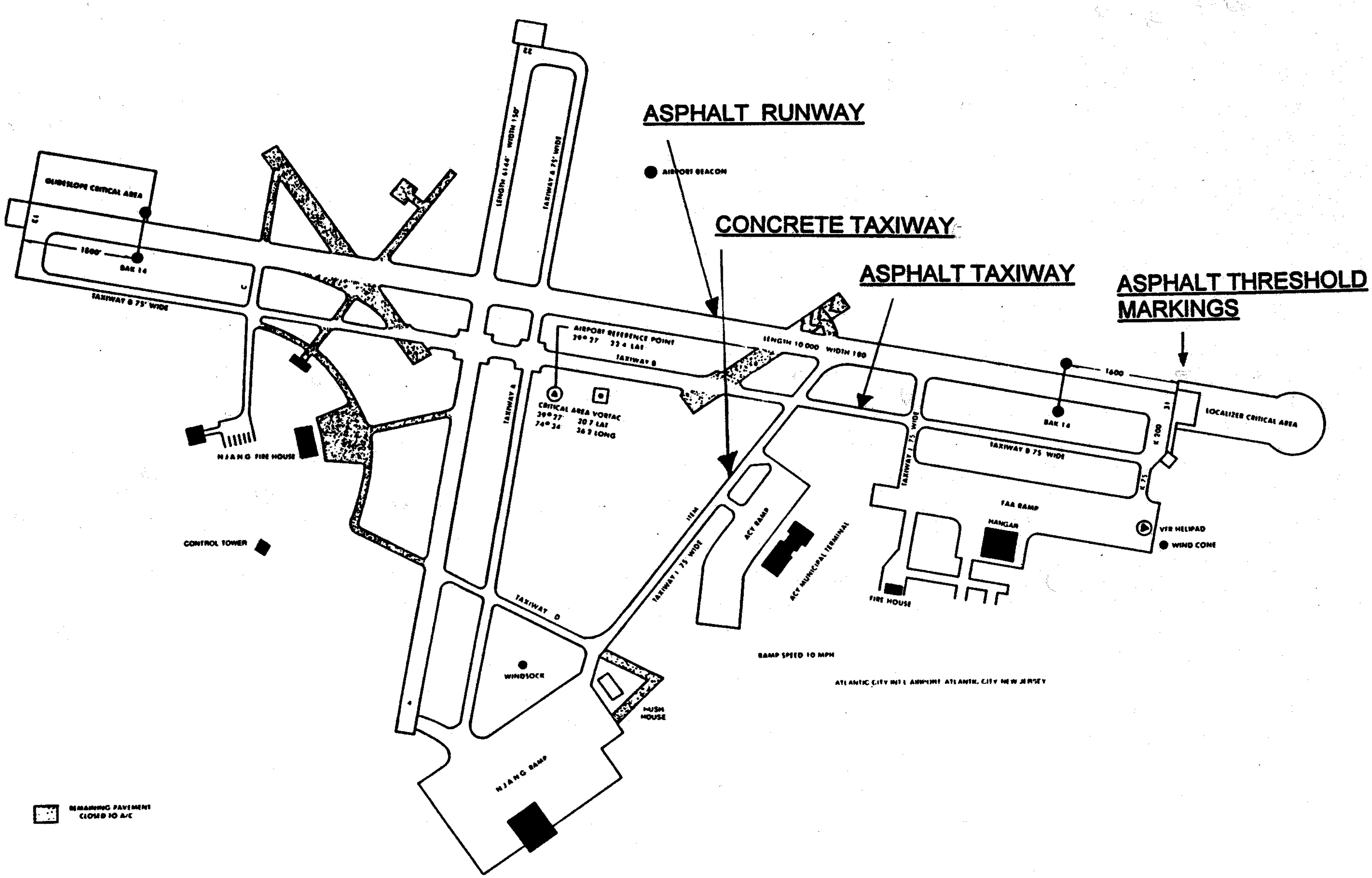


FIGURE A-2. ATLANTIC CITY INTERNATIONAL AIRPORT DIAGRAM

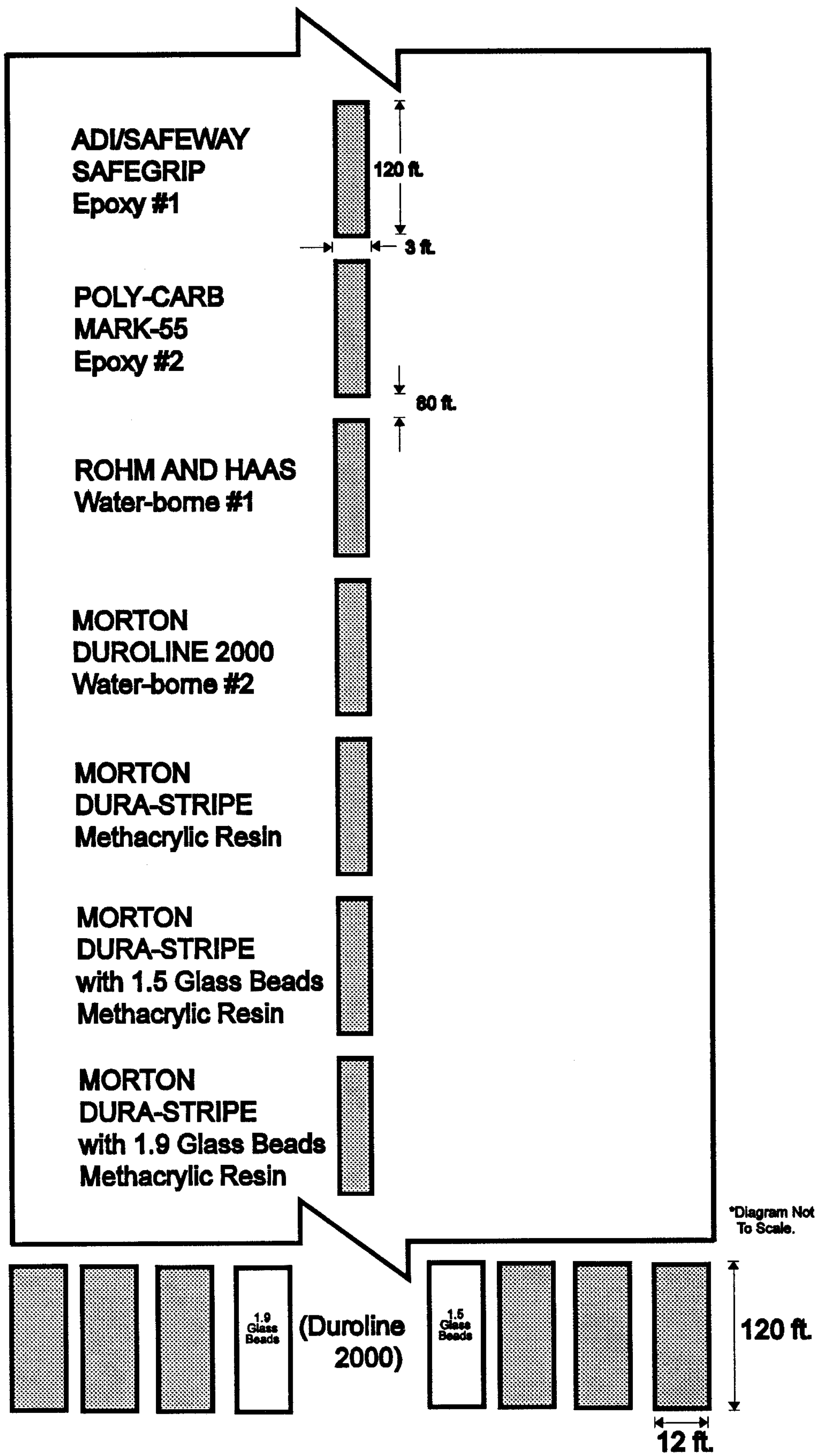


FIGURE A-3. ATLANTIC CITY RUNWAY TEST MARKINGS

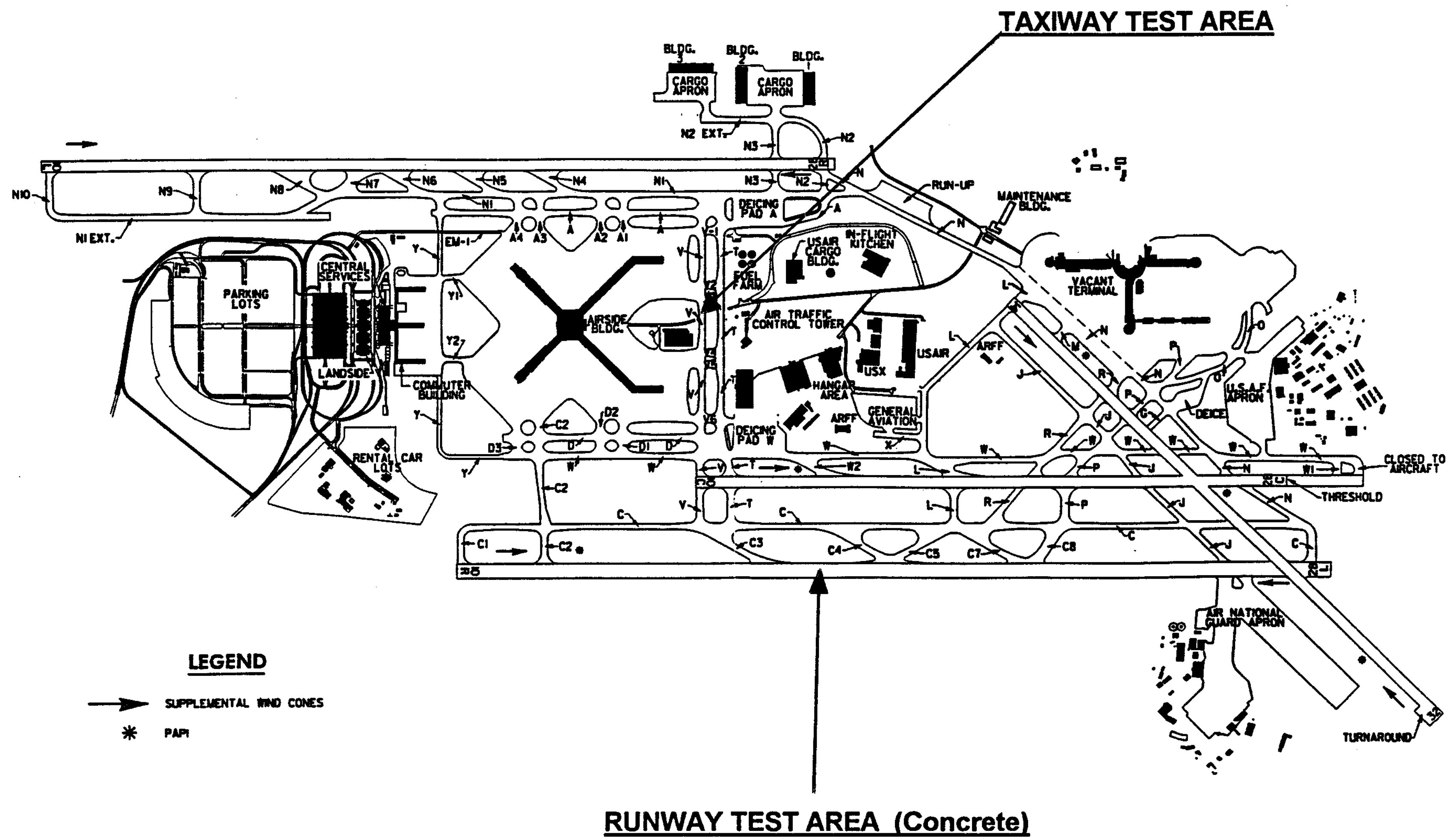


FIGURE A-4. GREATER PITTSBURGH INTERNATIONAL AIRPORT DIAGRAM

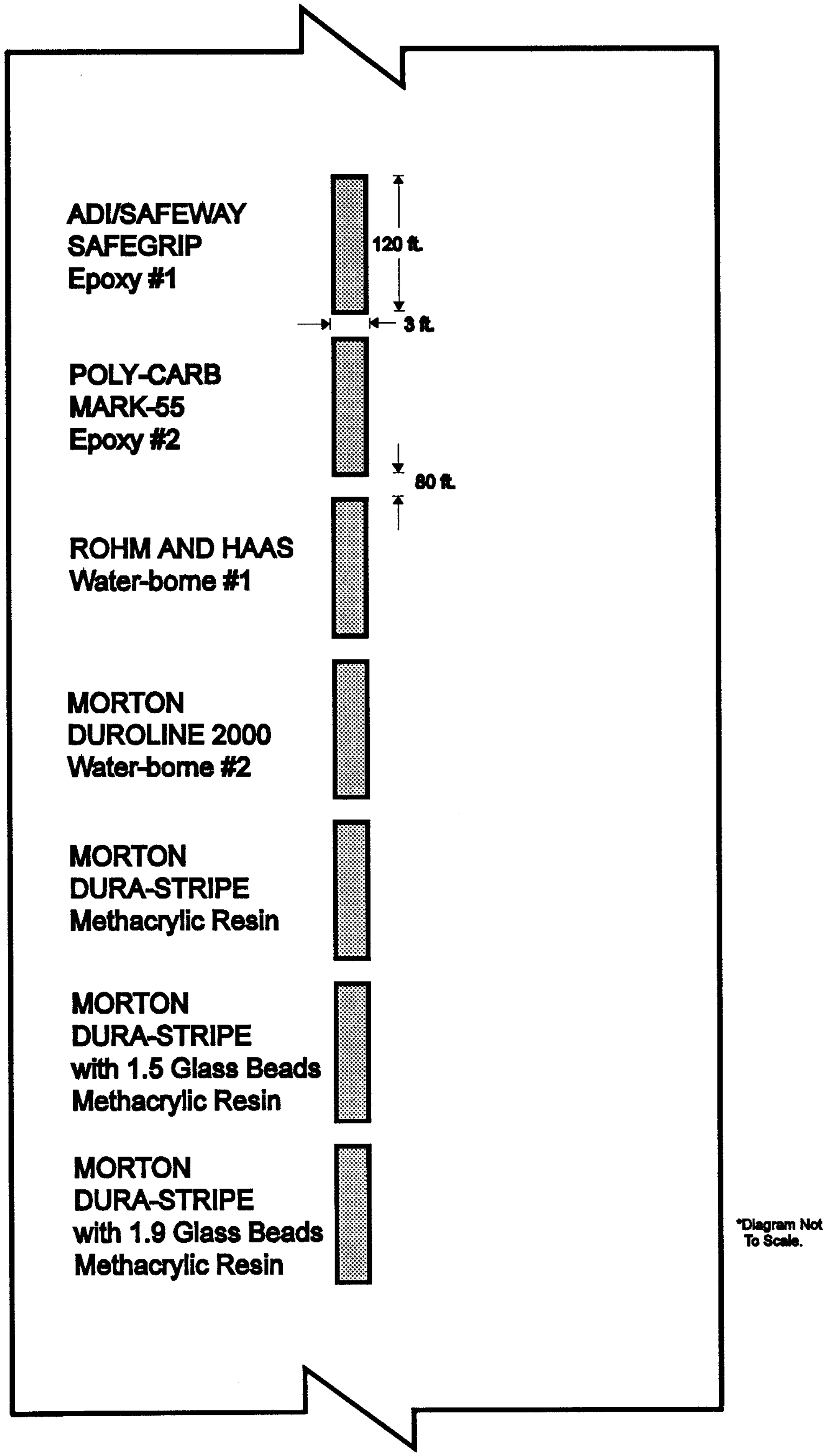


FIGURE A-5. PITTSBURGH RUNWAY TEST MARKINGS

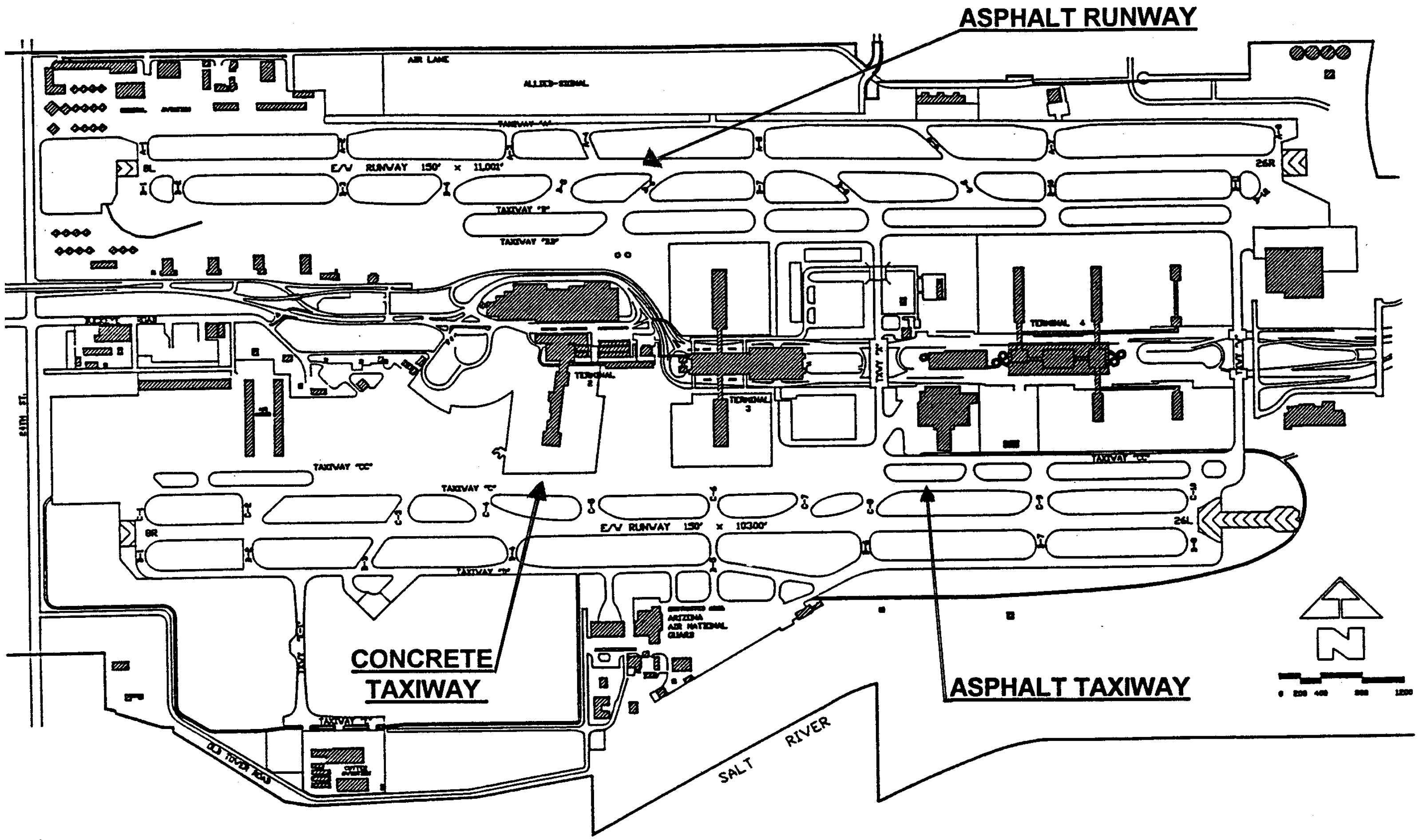


FIGURE A-6. PHOENIX SKY HARBOR INTERNATIONAL AIRPORT DIAGRAM

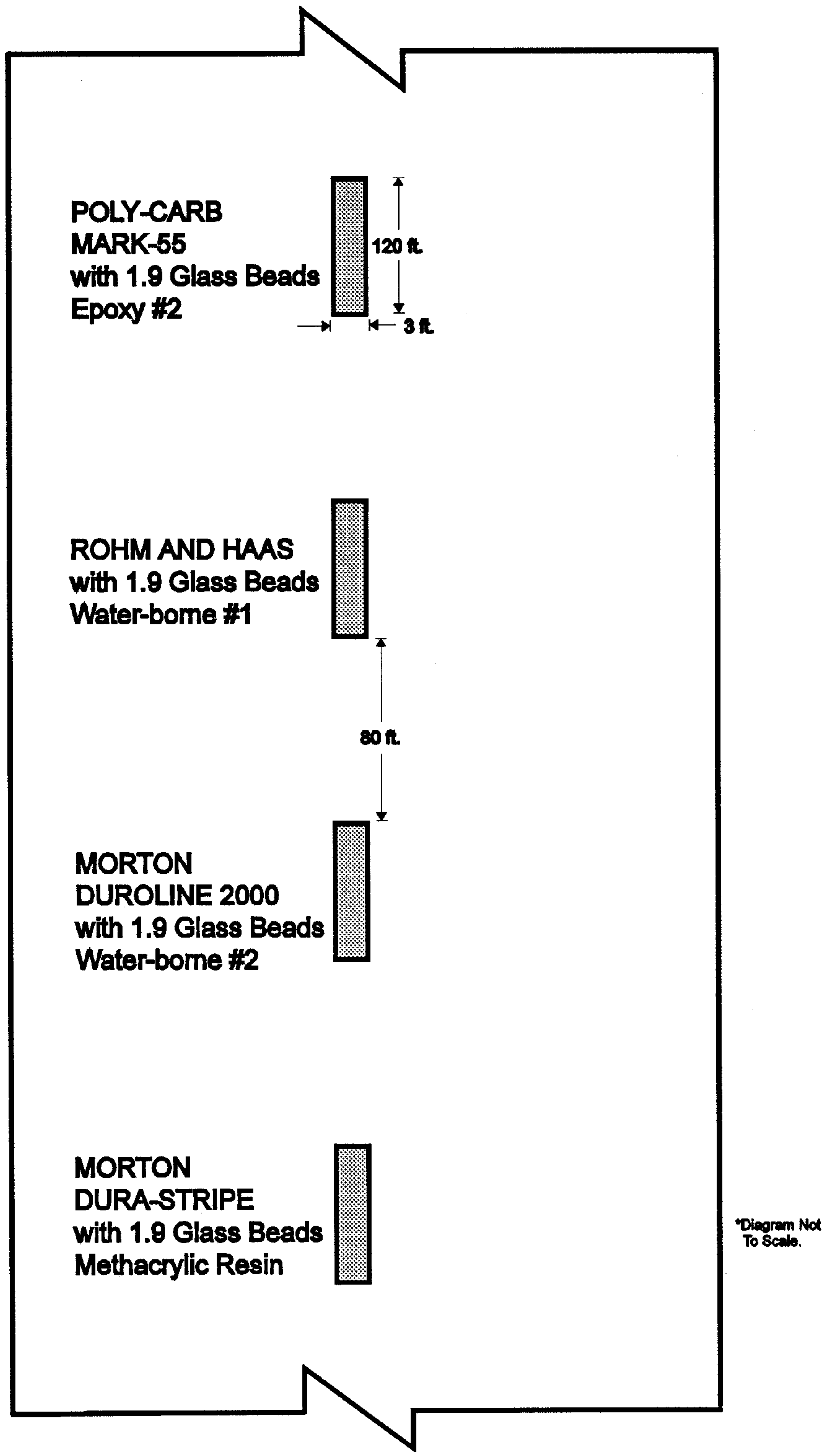


FIGURE A-7. PHOENIX RUNWAY TEST MARKINGS


FIGURE A-8. SURFACE PREPARATION - GRINDING

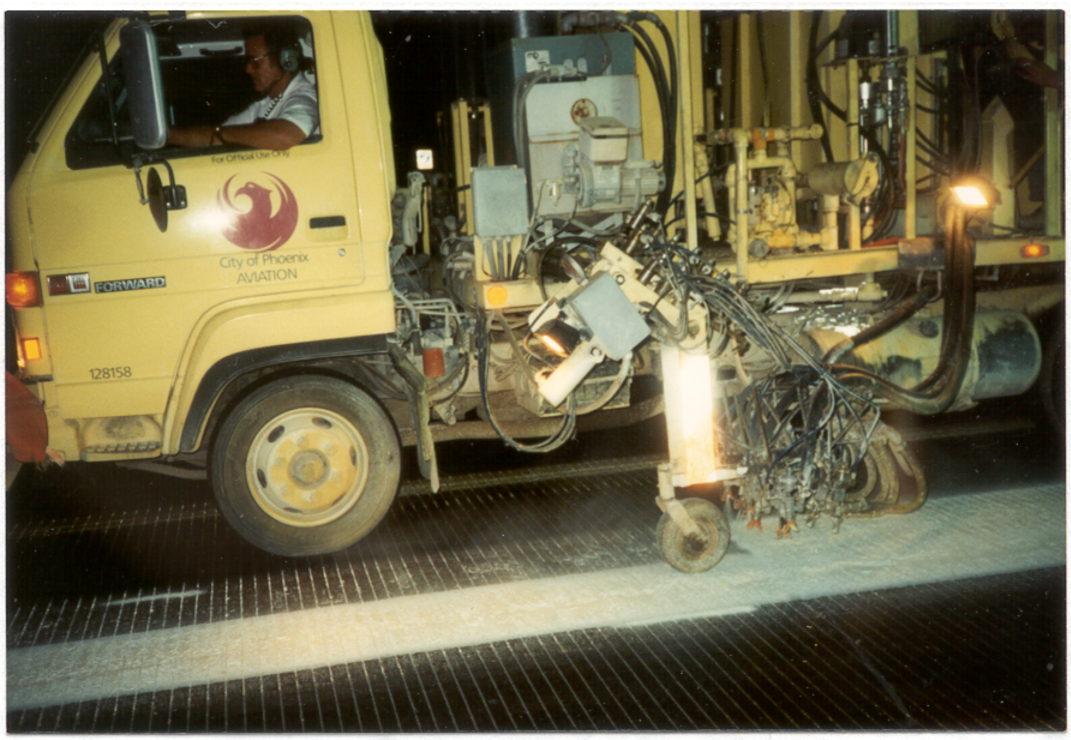


FIGURE A-9. WATER-BORNE PAINT APPLICATION - PHOENIX

FIGURE A-10. EPOXY TAXIWAY TEST STRIPE APPLICATION

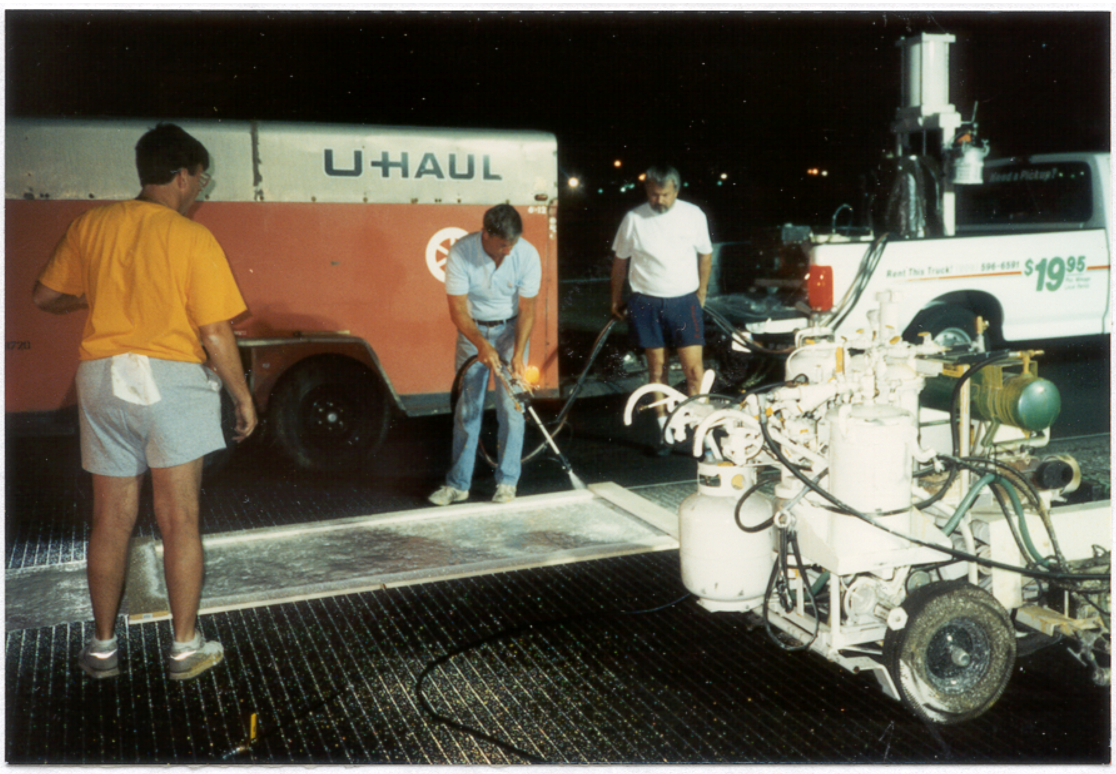


FIGURE A-11. METHACRYLIC RESIN RUNWAY TEST STRIPE APPLICATION

FIGURE A-12. EPOXY TEST STRIPE APPLICATION AT PHOENIX

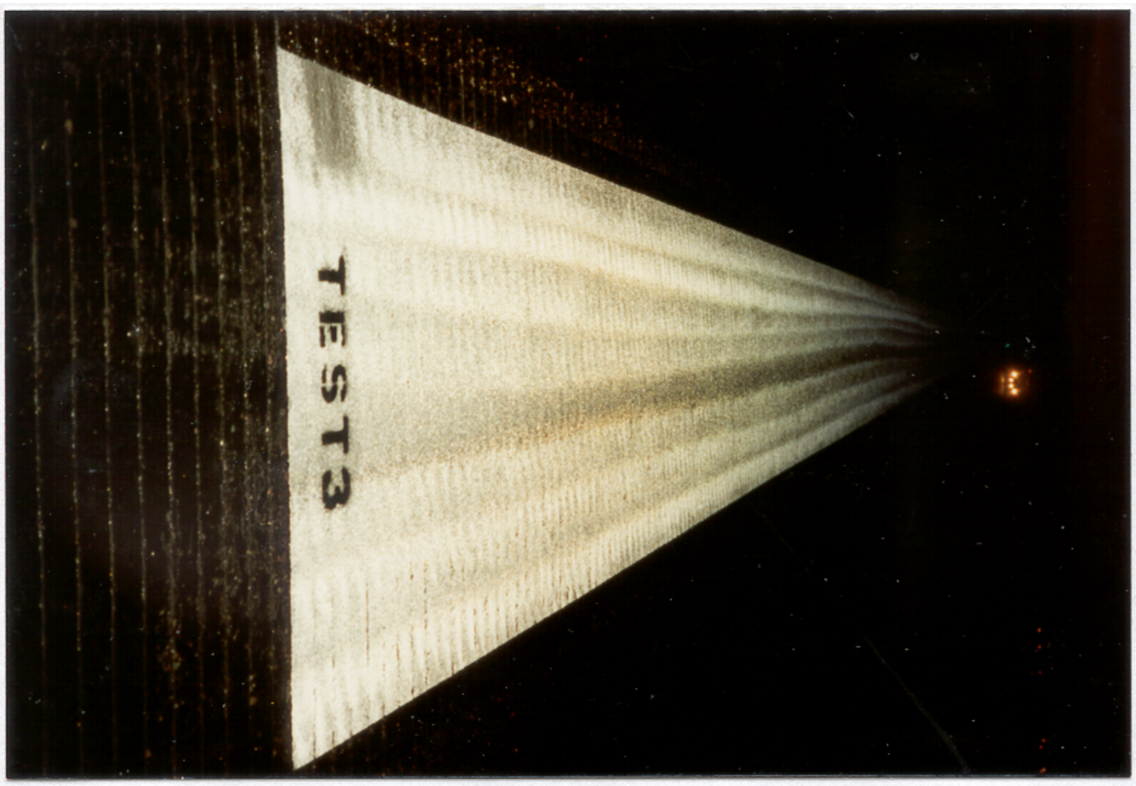


FIGURE A-13. PAINTED RUNWAY TEST STRIPE (BEADED)

FIGURE A-14. TAXIWAY TEST STRIPES ON CONCRETE SURFACE

FIGURE A-15. TAXIWAY TEST STRIPES ON ASPHALT SURFACE

FIGURE A-16. EXAMINING DRAWDOWNS FOR COLOR RETENTION

FIGURE A-17. DRAWDOWNS ON ASPHALT SURFACE


FIGURE A-18. FRICTION TESTING AT PITTSBURGH

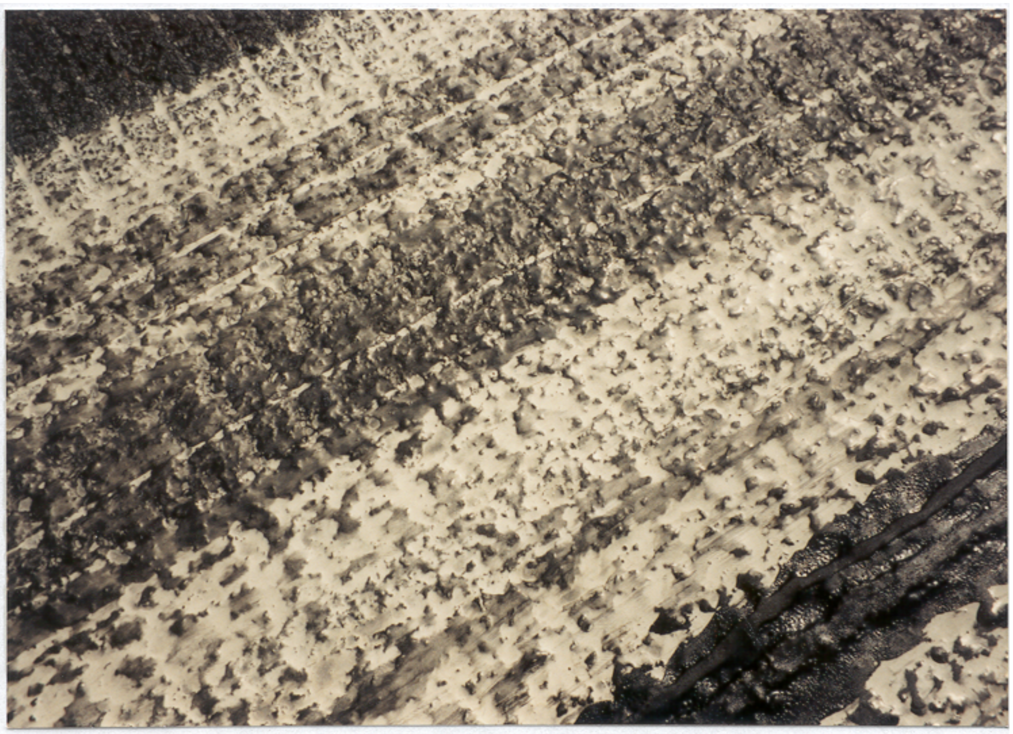

FIGURE A-19. RUBBER BUILDUP ON RUNWAY TEST STRIPE

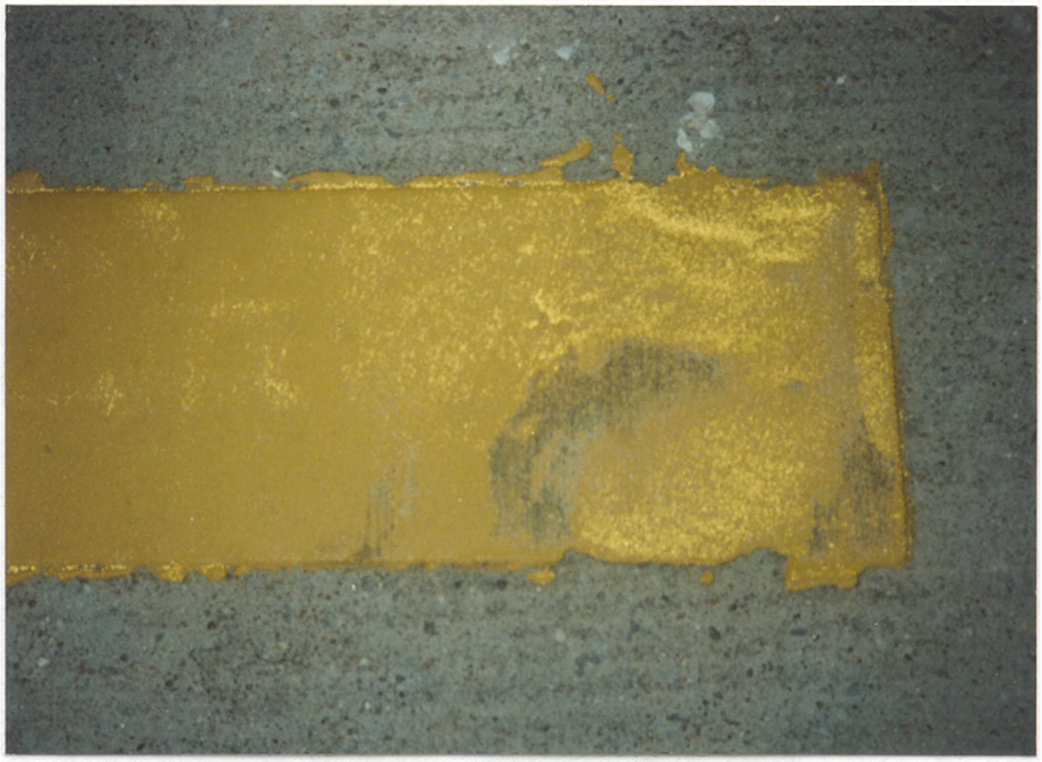

FIGURE A-20. SNOWPLOW STRIKE ON METHACRYLIC RESIN

FIGURE A-21. EPOXY NO. 2 - INCOMPLETE HARDENING

FIGURE A-22. RUBBER ACCUMULATION ON RUNWAY TEST STRIPE

FIGURE A-23. COLOR VARIANCE - ATLANTIC CITY

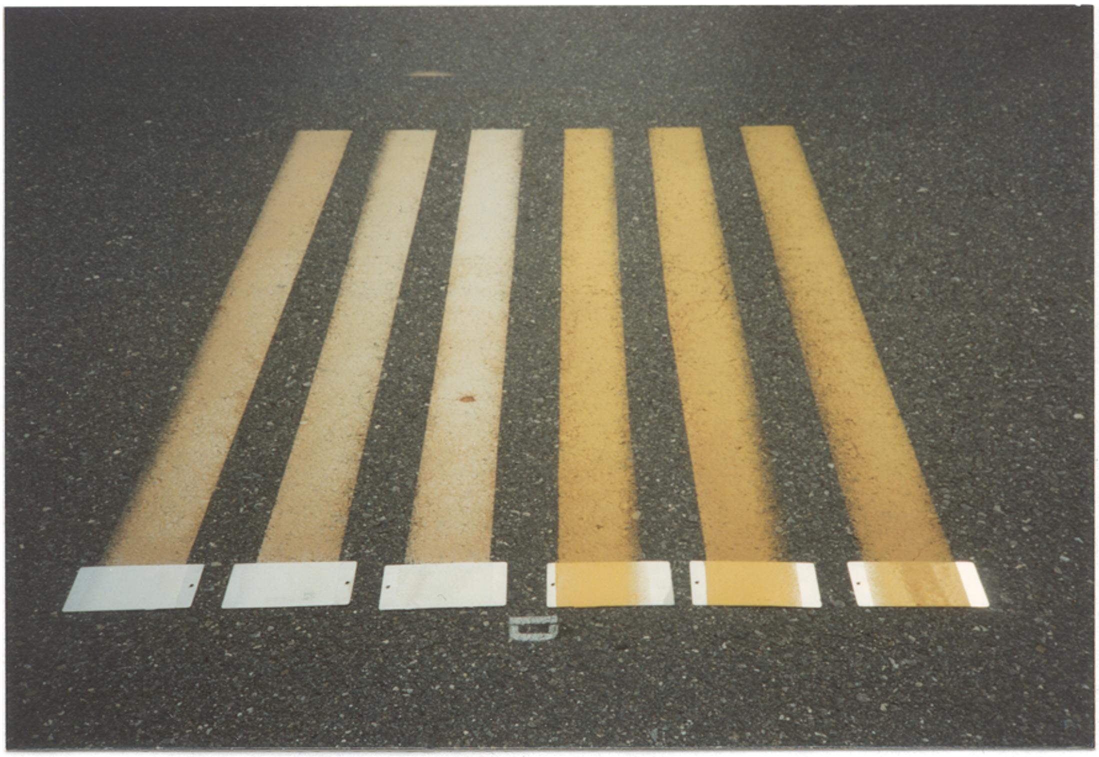

FIGURE A-24. WATER-BORNE DISCOLORATION - ASPHALT SURFACE

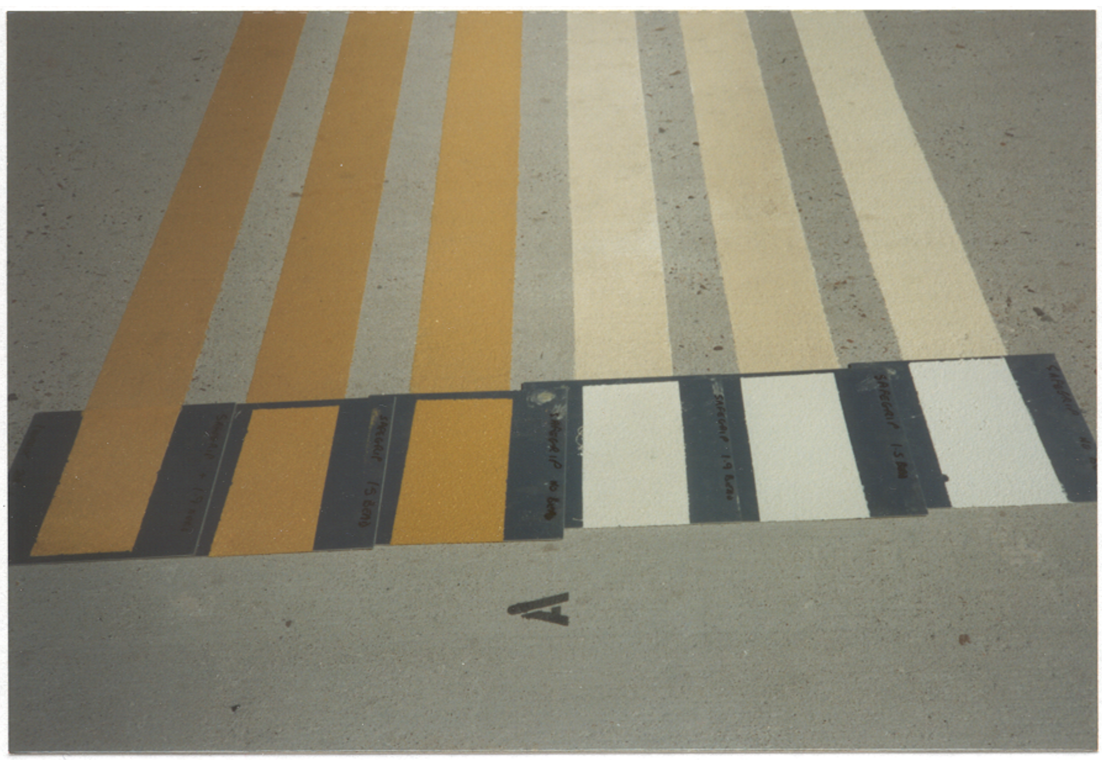

FIGURE A-25. EPOXY NO. 1 DISCOLORATION - CONCRETE SURFACE


FIGURE A-26. TAXIWAY TEST STRIPES - PITTSBURGH (NORTH VIEW)


FIGURE A-27. TAXIWAY TEST STRIPES - PITTSBURGH (SOUTH VIEW)

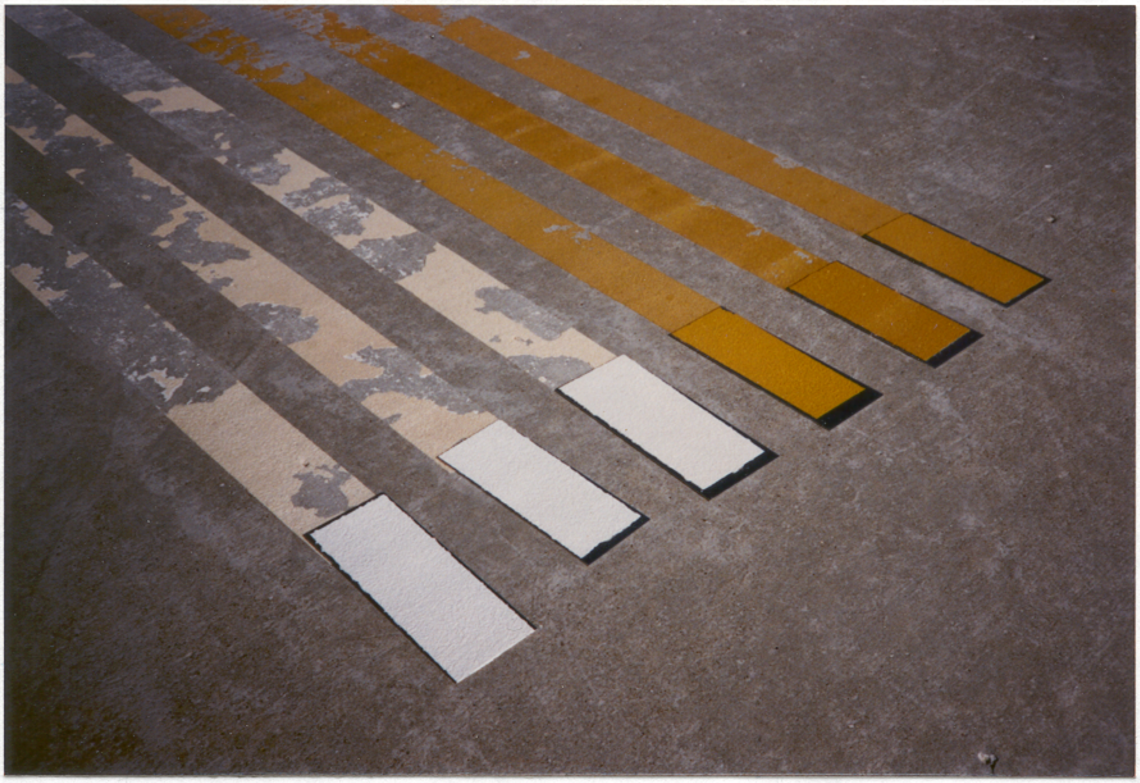

FIGURE A-28. EPOXY NO. 1 TAXIWAY TEST STRIPE AFTER 1 YEAR - PITTSBURGH

FIGURE A-29. EPOXY NO. 2 TAXIWAY TEST STRIPE AFTER 1 YEAR - PITTSBURGH

FIGURE A-30. WATER-BORNE NO. 1 TAXIWAY TEST STRIPE AFTER 1 YEAR - PITTSBURGH

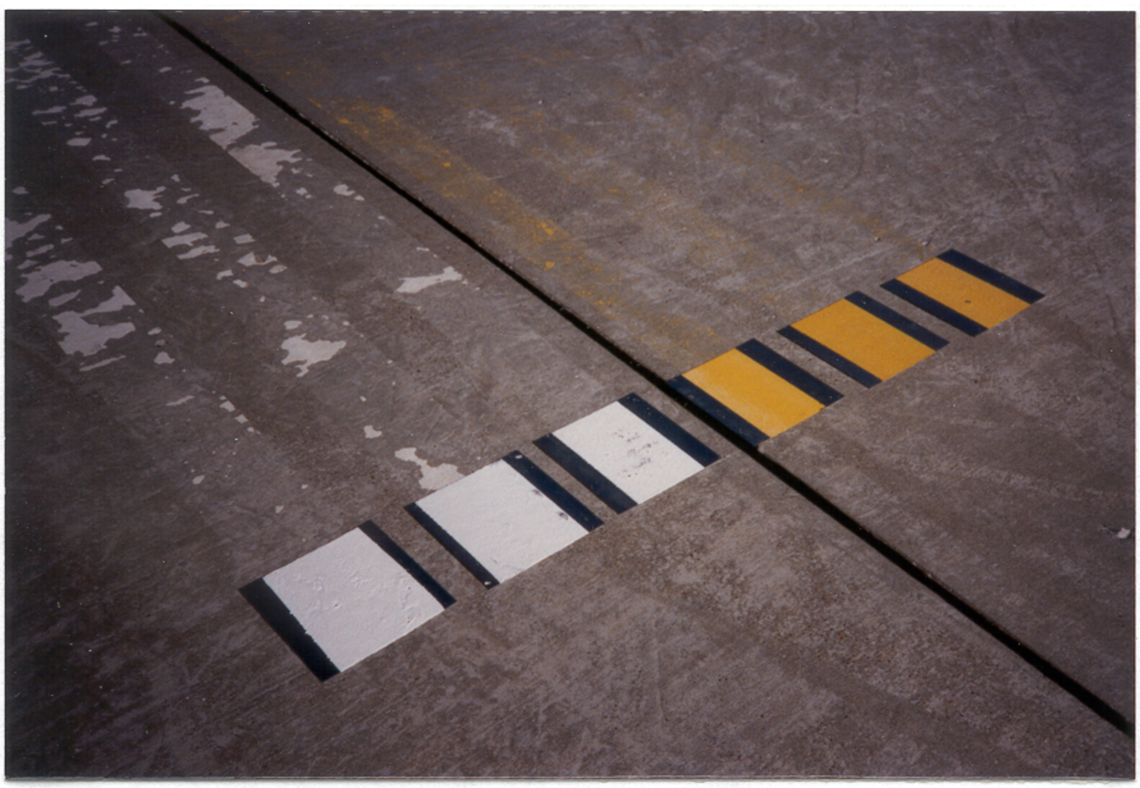

FIGURE A-31. WATER-BORNE NO. 2 TAXIWAY TEST STRIPE AFTER 1 YEAR - PITTSBURGH

FIGURE A-32. METHACRYLIC RESIN TAXIWAY TEST STRIPE AFTER 1 YEAR - PITTSBURGH

FIGURE A-33. RUNWAY TEST STRIPE AFTER 1 YEAR - PITTSBURGH

| CRITERIA FOR EVALUATION | SURFACE MATERIAL | EPOXY NO. 1 | | | EPOXY NO. 2 | | | WATER-BORNE NO. 1 | | | WATER-BORNE NO. 2 | | | METHACRYLIC RESIN | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ACY | PIT | PHX | ACY | PIT | PHX | ACY | PIT | PHX | ACY | PIT | PHX | ACY | PIT | PHX |
| CONSPICUITY | | | | | | | | | | | | | | | | |
| | ASPHALT TAXIWAY | G | | G | G | | G | A | | G | A | | G | G | | G |
| | CONCRETE TAXIWAY | G | P | G | P | G | G | G | P | G | G | P | G | G | G | G |
| | ASPHALT RUNWAY | A | | A | P | | A | P | | A | G | | A | G | | A |
| | CONCRETE RUNWAY | | A | | | A | | | G | | | G | | | G | |
| DURABILITY | | | | | | | | | | | | | | | | |
| | ASPHALT TAXIWAY | G | | G | G | | G | G | | A | G | | A | E | | E |
| | CONCRETE TAXIWAY | G | P | G | G | G | G | A | P | A | A | P | A | E | E | E |
| | ASPHALT RUNWAY | G | | G | G | | G | A | | G | G | | G | E | | E |
| | CONCRETE RUNWAY | | G | | | G | | | A | | | A | | | E | |
| RUBBER RESISTANCE | | | | | | | | | | | | | | | | |
| | ASPHALT TAXIWAY | G | | G | G | | G | G | | G | G | | G | G | | G |
| | CONCRETE TAXIWAY | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G |
| | ASPHALT RUNWAY | E | | P | P | | P | P | | P | G | | P | G | | P |
| | CONCRETE RUNWAY | | E | | | A | | | A | | | G | | | G | |
| COLOR RETENTION | | | | | | | | | | | | | | | | |
| | ASPHALT TAXIWAY | P | | P | A | | P | P | | A | P | | A | G | | G |
| | CONCRETE TAXIWAY | P | P | P | A | A | P | G | G | G | A | G | G | G | E | G |
| | ASPHALT RUNWAY | P | | N/A | A | | N/A | P | | N/A | A | | N/A | G | | N/A |
| | CONCRETE RUNWAY | | P | | | A | | | G | | | G | | | E | |
| FRICTION | | | | | | | | | | | | | | | | |
| | ASPHALT RUNWAY | E | | | P | | | A | | | G | | | G | | |
| | CONCRETE RUNWAY | | E | | | P | | | A | | | G | | | G | |

N/A = RUBBER CONTAMINATION ON THE RUNWAY PREVENTED COLOR RETENTION CHARACTERISTICS TO BE EVALUATED
E = EXCELLENT G = GOOD A = AVERAGE P = POOR

FIGURE A-34. SUMMARY OF THE PERFORMANCE OF THE TEST MATERIALS AT THE THREE AIRPORT TEST SITES