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Evaluation of Pothole Patching Materials

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16. Abstract

The following report summarizes the results of the research that has been conducted on the evaluation of pothole patching materials and repair procedures.

The purpose of the project is the identification of improved bituminous pothole patching materials and repair procedures for bituminous concrete pavements and the establishment of laboratory techniques for quality assurance of those materials.

The New Jersey Department of Transportation sponsored the project and the research is conducted by the Department of Civil and Environmental Engineering, coordinated and monitored by NJDOT Bureau of Research. The project followed the SHRP-H-353 outline, since it is considered as the most extensive attempt to date for the evaluation of pothole patching materials.

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ABSTRACT

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More specifically, the evaluation plan consists of the following tasks:
1) Literature Search,
2) Field Performance and Demonstration Projects,
3) Laboratory Quality Assurance Tests,
4) Reporting - Final Conclusions.

LITERATURE SEARCH

Scope

The literature search was conducted in order to provide an overall view of existing information regarding patching materials, repair procedures, and laboratory tests for quality assurance. Information was obtained from several sources, such as The Pennsylvania Transportation Institute, Strategic Highway Research Program, and publications of Transportation Research Record, Ontario Ministry of Transportation and New York State Department of Transportation. The most extensive and recent work however, for the evaluation of pothole patching materials and procedures was found to be the SHRP-H-353 report.

Introduction

The following summarizes the literature search that has been conducted on the evaluation of pothole patching material and repair procedures, as practiced in the State of New Jersey and the United States.

Pothole repair strategies and procedures have not received a great deal of attention in the literature in past years. However, as highway maintenance agencies more concerned about the evaluation of the effectiveness of materials and techniques that can lead to more economical and long-lasting solutions, an increased emphasis has been given in pothole repair research.

In general, the pothole problem can be characterized as one of the most aggravating forms of asphalt pavement deterioration for the traveling public. Potholes can also pose danger to the traveling public and damage to the vehicles.

Potholes have always been a problem for highway maintenance organizations. Treatment however, is very costly and time consuming. The problem of pothole formation can be very serious, especially in areas where adverse weather conditions contribute to accelerated pavement breakup. There is an immediate need for repair of potholes to secure safety and rideability. The remedy used for potholes is termed "patching". Patching can be described as the filling of deteriorated areas in a road surface to keep traffic moving safely or to prevent rapid deterioration of an area that could become unsafe.

Therefore the evaluation of the pothole patching material in terms of longevity and serviceability of the repair could significantly help to the cost effectiveness of the repairs. For this reason and since potholes that must be filled repeatedly are expensive to repair, many different agencies conducted studies to evaluate specific types of materials and techniques which can lead to the most economical and long-lasting solution.

Mechanism of Deterioration

Failure in pavements can be the result of repeated loading, shearing, or deflection of materials due to the action of traffic, poor underlying support, adverse weather conditions (freeze-thaw action), or combinations of these factors. In most cases however, the pavement deterioration is caused due to intrusion of water. The presence of water in a pavement system will ultimately result in early pavement deterioration.

Flexible Pavements

The formation of a pothole in a flexible pavement begins in a weakened area of the pavement. The heavy loads due to traffic lead to an excessive bending of the pavement, which in turn causes cracks. Once the pavement section has cracked, water can easily enter the system and will gradually lead to the saturation of various layers of the material up to a point that the pavement cannot support heavy loads any more.

The effect of the water intrusion is even more pronounced during the winter because the pavement is subjected to freezing temperatures. As the water in the pavement layer freezes, it builds up forces due to expansion of the ice, which loosen the already weak pavement and in some cases, even cause lift off of the pieces of pavement. This lift-off worsens under the action of traffic and the cycles of alternating freezing and thawing, until the pothole is formed.

Rigid Pavements

Potholes in rigid pavements usually occur at the contraction joint or in areas where concrete has deteriorated. As the concrete cures after construction, the slab shrinks and the concrete cracks at the location of the joint. Adverse temperature makes the slab expand and contract at the joint location. The joint must therefore be sealed and maintained to keep the water out of the pavement.

Rigid Base Pavements
A rigid base pavement consists of an asphalt layer on top of a rigid pavement structure. If cracks exist in the rigid slab, the overlay begins to crack with any movement of the base. These are called reflective cracks, which gradually continue to enlarge. When reflective cracks are not sealed water can enter the system. During winter and as the temperature is low, the water freezes, expands, and lifts the surface layer off the pavement. As this process continues the formation of potholes takes place.

Bituminous Patching Mixtures

Bituminous patching mixtures are combinations of different binders and aggregates that have special characteristics needed for filling potholes in pavements. There are different types of patching mixtures and they can range widely in cost, stability, quality, and application. The patching mixtures can be generally placed in one of three groups, based on the type of mixing and the temperature of the mixture at the time of placement.

These groups are described as follows:

1. *Hot-Mixed, Hot-Placed Patching Mixtures*: These are asphalt concrete patching mixtures that usually contain asphalt cement binder and a well-graded aggregate. "They are used while hot, usually immediately after being produced. These mixtures are the highest quality of all bituminous patching mixtures and they have the same durability characteristics as asphalt concrete that is used for pavement surfacing" (1)

2. *Hot-Mixed, Cold-Placed Patching Mixtures*: "These are materials produced with liquid bituminous binders in a plant that uses a dryer to heat the aggregate or in a drum-dryer plant. These mixtures are carefully controlled and thoroughly mixed. They are used cold from a stockpile and are workable in all weather" (1).

3. *Cold-Mixed, Cold-Placed Patching Mixtures*: "These mixtures are composed of liquid bituminous binders and aggregates, that have not been heated. Mixing is done either in a plant, where the materials are proportioned, or on a paved surface with few controls. The mixtures are stockpiled until needed and used cold in any season. They have the lowest quality of all the patching mixtures" (1).

Hot-mix materials are usually expected to perform better than the cold-mixed variety and they are considered to be permanent. Therefore, many agencies use hot-mix during summer for permanent patching. Cold-mix materials can be used in winter for temporary repairs.

The most important properties that a bituminous patching mixture should have are:

- *Stability*, to allow the patch to resist displacement by traffic. Stability can be related to most material characteristics of the patching mix. For example, the better graded a mixture, the more stable it is. Stability also increases when the aggregate used has a rough surface texture and they are angular. Material properties that influence the compactability of the mixture also contribute to the stability of the mixture.

- *Stickiness*, so the patch will adhere to the sides of the pothole. Stickiness is important when the patching mixture must be feathered to thin edges. The property is influenced by the temperature of the mixture and the binder. Usually hot mixture materials have satisfactory adhesion when they are still hot, whereas cold- mixtures do not have adequate stickiness.

- *Resistance to water action*, to keep the binder from stripping off the aggregate. Patching mixtures lack water resistance when they are under-compacted. The property is also affected by the binder and the aggregate types.

- *Durability*, so that the patch has satisfactory resistance to disintegration. In terms of durability, hot-mix hot-placed materials are the ones that perform best. However, the durability of the cold-placed materials varies considerably. Cold-mixed cold-placed types, on the other hand, do not have high durability.

- *Skid resistance*, should be similar to the pavement in which the patch is placed.

- *Workability*, to enable the material to be easily shoveled and shaped. The most important factor that affects workability is temperature because it controls the hardness of the bituminous binders. Low viscosity binders can be used to improve the workability of the mixtures.

- *Storageability*, so the mixture can be stockpiled without hardening excessively or having the binder drain off the aggregate.

In Table 1(1), the common failures and handling problems are presented as related to the mix properties of the bituminous patching mixtures. In Tables 2 (2) and 3 (2), design considerations and performance requirements regarding the patching mixtures are also presented.

Distress Types

Identification of the different types of distresses and the related failure mechanisms is essential for an in-depth analysis of the pothole problem. By identifying the mechanisms of failure it is then possible to establish a set of performance criteria that can be used to develop improved patching materials.

The most commonly in-service failures in cold- mix patching materials are the following:
1. Shoving
2. Raveling
3. Dishing
4. Freeze-thaw
5. Poor skid resistance

6. Bleeding
7. Lack of adhesion to the side or the bottom of the repair

The mechanisms for each of the above type of failure are described as follows:
1. *Shoving* under traffic is caused by a number of factors that essentially reduce the stability of the mix. Improper compaction makes the mix more susceptible to shoving because proper compaction is required to develop the aggregate interlock that is primarily responsible for the stability of the mixture.

2. *Dishing* is the result of inadequate compaction. It usually occurs when the mix compacts under traffic, assuming that the design of the material is proper. Therefore, the dishing mechanism is properly addressed through mixture design and proper compaction.

3. *Raveling* can be described as a progressive loss of aggregate from the surface of the repair. It is basically the product of poor aggregate interlock and inadequate cohesion within the mix. Poor compaction may also contribute to raveling as it reduces cohesion. Most factors that cause shoving may also contribute to raveling.

4. *Freeze*-Thaw is the delamination of the patch from the original pavement. It is the result of the freezing water at the bottom of the repair. The freeze-thaw damage is caused by improper adhesion of the patch to the hole, as a result of improper compaction, tacking, or hole preparation.

5. *Poor skid resistance* can result from a flushed or bleeding surface, or polished aggregates. It can be controlled with an appropriate mix design.

6. *Bleeding* is related to excess of binder in the patching mixture.

7. *Lack of adhesion* is a result of poor preparation. It also happens when no tack is used or when the mix is not self-tacking.

In Table 4 (2), in-service problems and failure mechanisms in cold-mix patching materials are presented. Some examples of distress types are shown in Figures 1-5 (3).

Laboratory Testing

In order to evaluate, design, and approve bituminous patching mixtures, several tests should be conducted. The results of the testing allow for the characterization of the properties of the mixture and the properties of the aggregate and the binder. Since the field conditions (such as harshness, sequence duration of climatic conditions, and loading) cannot be duplicated in the laboratory, the results do not necessarily correlate with field performance. However, the tests provide a strong indication of the inadequacies the materials since failure in the laboratory under ideal conditions usually means failure in the field. Therefore, laboratory tests can be used for screening purposes, where materials with poor performance are rejected and those with satisfactory performance are given field trials.

The tests can be divided to the following groups:
1. Stability
2. Adhesion/Cohesion
3. Durability
4. Workability
5. Storageability

For the evaluation of the workability and cohesion of Cold-Patching Material, two relatively new tests have been developed based on simulation of field operation conditions, namely the Blade Resistance and Rolling Sieve tests. The Ontario Ministry of Transportation in Canada developed these particular tests. The tests were verified through field observations and sampling from different areas in the province of Ontario.

The advantage of these two tests relative to the existing laboratory tests (stripping resistance, workability and cohesion), is that they are claimed to "provide a more quantitative and non-subjective evaluation of CPM" (4).

In theory the applicability of the two tests show that they can be used as standard methods of testing. However the results from these evaluation tests prove otherwise to be deficient. The equipment used is what is normally available in a typical asphalt laboratory. The methods are summarized as follows:

Blade Resistance Test For Workability

"The test involves measuring the resistance in Newton of a compacted sample, at -10° C (14° F) to the penetration of a blade after 30 seconds of load application at 50 mm/min (2.0 in/min) using the Marshall apparatus. The higher the resistance, the poorer is the workability" (4). The workability requirement for this test is below 2000 N (450 lb).

Rolling Sieve Test for Cohesion

The test is very simple and it "involve[s] rolling a compacted briquette in a 19.0 mm (3/4 in) square opening sieve of 305 mm (12 in) in diameter. Except the freezer unit and/or a large metal tray, all of the equipment involved is common items in an asphalt laboratory. The sample is prepared by using a Marshall hand-held hammer and mold and compacted at -10° C (14° F). The percentage of materials retained on the sieve after rolling is called the cohesion index. The higher the index, the better is the cohesion". (4)

Repair Procedures

Different pothole repair techniques exist, namely "throw-and-roll" (also nonstandard) semi-permanent (also standard or "do-it-right"), and spray injection.

Throw-and-roll method
In the "throw and roll" method the material is first placed into the pothole (which may or may not be filled with water or debris). The material is then compacted using track tires to allow for a tighter patch for traffic. The remaining is crown between 3 and 6 mm (0.125 and 0.25 in). The maintenance crew moves to the next pothole and the repair is open to traffic as soon as maintenance workers and equipment are clear.

Semi-permanent method
In the semi-permanent method, the water and debris are first removed from the pothole. The sides of the patch area are then squared up until vertical sides exist in reasonably sound pavement and the mixed is placed. The patch is then compacted by using a device smaller than the patching area and the repair is opened to traffic as soon as the maintenance workers and equipment are clear.

Spray injection method
In the spray injection method the water and debris are first removed from the pothole and a tack coat of binder is sprayed into the pothole on the sides and bottom. The asphalt and aggregate are then blown into the pothole and the patched area is then covered by an aggregate layer. The repair is finally opened to traffic as soon as the maintenance workers and the equipment are clear.

Edge seal
In the edge seal procedure the material is placed into the pothole without any prior preparation or removal of water and debris. The material is then compacted using truck tires. The compacted patch is then checked for levelness. If depression is present then additional material is placed and rolled again to bring patch surface above the surrounding pavement level. The patch is then left to dry for one day after installation, and a band of bituminous tack material along the perimeter of the patch, between 100 and 150 mm (4 and 6 in) wide, is placed. A layer of cover aggregate is then placed over the tack material to prevent tracking.

Comparison between the "throw and roll" and semi-permanent method shows that in terms of longevity the semi-permanent method is superior as it increases the performance of patches by improving the surrounding support.

With the exemption of the spray injection method, the above procedures require cold-mix patching materials. The only major equipment used for the "throw and roll" method is the truck that carries the material.

For the semi-permanent method, the necessary equipment varies from agency to agency. The most common equipment however is the following:

- Material trucks (with hand tools)
- Compaction device (vibratory plate and single-drum vibratory roller are generally the most inexpensive and the most maneuverable)
- Air compressor
- Edge straitening device (jack hammer, pavement saw, cold mining machine)

For the spray injection technique, a device that can place virgin aggregate and heated emulsion into a pothole simultaneously is required.

In figures 6 to 11 (5) photographs regarding patching repair techniques and equipment are presented.

Effect Of Climatic Conditions

Pothole patching can be performed during various weather conditions, with temperatures anywhere from to –18^0 C and 38^0 C (0^0 F to 100^0 F). Pothole patching is generally performed either as an emergency repair under harsh conditions or as routine maintenance.

Adverse weather conditions can significantly aggravate the pothole problem, especially during the cold, wet periods of the year. Pothole repairs conducted during the cold, wet winter and spring months have in general a short life. The climatic conditions have an even stronger effect on cold-mix patching materials. These materials can withstand only a few cycles of freeze-thaw and usually they do not provide a permanent solution for winter patching.

Patching Cost Parameters

Hundreds of millions of dollars are spent annually in the United States on the maintenance of approximately 6.4 million kilometers (4 million miles) of roadways. The patching has to be done at a minimum cost and at the optimum time to secure the rideability.

The strategy followed for the repairs should give an optimal combination of equipment materials and manpower at a minimum cost and in such a way that it would provide a long-lasting repair. Longevity is the key word for the selection of the most cost effective patching procedure and material. Any comparison of different methods that does not take into consideration the longevity of the repair is incomplete.

Many transportation agencies adopt the traditional and the easier method "throw-and-go" because the correct procedures are believed to be more expensive and time consuming. The correct procedures are the ones that require proper cutting, compaction, and use of high quality materials.

In order to illustrate how different procedures and materials can influence the cost of the repair, a value engineering study conducted in 1975 is presented. In this study two different methods are compared, namely "throw-and-go" and semi-permanent.

The results show that a patch repaired with the "throw-and-go" method, has a serviceable life of one month and an annualized cost of $308 per ton ($340 per metric ton). However, a properly compacted repair made by cutting out the deteriorated pavement will last more than one year and has an annualized cost of only $65 cost per ton.

"A more recent finding shows that the uniform annual cost of repairing a pothole correctly, including manpower, material and equipment, is about \$100 per ton (\$110 per metric ton) whereas the "throw-and-go" procedure, has a cost of \$310 per ton (\$342 per metric ton). The cost can also be translated to a cost per repair. For example assuming an average pothole volume of 3 ft^3 (0.085 m^3) and a compacted unit weight of 133 lb/ft^3 (2130 kg/m^3) a ton of mix will repair 5 average potholes.

$$\#\text{ of Potholes Filled} = \frac{2000\text{ lbs or 1 ton}}{(\text{Volume per pothole or } 3\text{ ft}^3) \times (\text{Unit Weight or } 133\text{ lb / ft}^3)}$$

On this basis, the cost of repairing a pothole with the "throw-and-go" method would be approximately \$62 per pothole and the semi-permanent would cost \$20 per repair" (2).

In terms of material costs, it was found that a more expensive material could be used if it can contribute to an increase of the repair life. It has also been justified that material costs constitute less than 10% of the total cost of repair, combined of course with the most appropriate method.

Another comparison in terms of cost-effectiveness between "throw-and-go" and correct procedures is presented in the report TRB 1102, (1986), "Pothole Repair: You Can't Afford Not to Do It Right." The results of this research indicated that the nonstandard "throw-and-go" method is not cost effective compared with the standard procedures is about three times more expensive. The same report also indicated that training programs and proper selection of equipment could significantly reduce the overall cost. Apart from longevity, two other factors that influence the total cost are the daily production and the crew deployment practices. Finally, when the standard procedures are used, the material cost contributes less than 20% to the total cost. Therefore combining the correct procedures with the proper equipment and training can provide a minimization of the overall cost.

One way of evaluating the cost effectiveness of a patching job was presented through SHRP research (5). The method proposed includes some simple input parameters to produce a cost per pothole (or volume of pothole). The worksheet with descriptions of the input is presented in Appendix 1.

DESCRIPTION OF SHRP-H-106 PROJECT

One of the most extensive attempts to improve the state of practice for pothole repair operations is a project conducted as a part of Strategic Highway Research Program, namely SHRP H-106. The report SHRP-H-353 based on this previous project is summarized in what follows. The SHRP-H-353 project was the first essential effort to test cold-mix asphalt patching materials, which are most commonly used for winter and spring pothole repairs.

The primary goal of this project was to identify an optimum cost effective combination of materials and patching techniques. The first objective was to identify a correlation between field performance and material characteristics determined in the laboratory. The second objective was to establish laboratory specifications that can lead to a desirable field performance.

Project Outline

The project began in March 1991. 1,250 pothole patches were placed at eight sites across the United States and Canada. The purpose of the project was to determine different cold-mix patching materials and installation techniques so that an optimum combination could be obtained to improve the cost effectiveness of patching operations.

Six Departments of Transportation, one Canadian Province, and one City Department of Public Works participated in the project. The first step of the project was the determination of existing repair materials and techniques. Materials used were different proprietary, state-specified, and local cold-mixes which are described analytically in what follows. In Table 5 (3) the combinations of test sites, materials, and procedures are presented.

The original plan called for 150-200 open potholes per site. Before any installation, several arrangements had to be made to ensure successful installation, such as material supply to the site and scheduling a crew. The manufactures' representatives were notified for the installation date so that they could be present to ensure that the placement procedures were consistent from material to material. The potholes were to be left open until experimental patches could be placed. It became apparent however, that no agency allowed that many potholes to remain open for such a long time, since they would pose a danger to the traveling public. The compromise to that problem was that the potholes could temporarily be repaired, as long as the patches could be removed and the original potholes could be used for the project.

The common equipment used for the installation, were dump trucks, pickup trucks, shovels, brooms, rakes, jackhammers, compressors, pavement saws, vibratory plate compactors, single-drum vibratory rollers, dual steel-wheeled rollers, and rubber-tired rollers. For spray injection method, the spray injection device was also used.

The major procedures used were throw-and-roll, edge seal, semi-permanent and spray injection. Two other procedures were also used by participating agencies in Illinois and Oregon. During the installation process, data was collected on the patches and operations performed, such as installation date, patch location, patch dimensions, and number of compaction passes. One of the major goals of the project was to measure the productivity of different patching techniques. Therefore, data was collected from the agencies on the productivity of the maintenance crews, for the four different repair procedures.

A number of laboratory tests were performed in order to evaluate material properties of the material that could be related to their field performance, so that specifications regarding the mixing and placement in the field could be developed. The characteristics sought were mostly related to the stability, workability, adhesion/cohesion, durability, and resistance to wear. The tests were intended to characterized not only properties of the mixture but also properties of the binder and the aggregate separately. Moreover, two field tests were performed during installation, to obtain additional information for the workability and the durability of the material.

In order to evaluate the field performance and consequently the cost effectiveness of the experimental patches, field observation, and distress monitoring was deemed necessary. The evaluations were scheduled for 1, 3, 6, 12, and 18 months after the installation. The same individual collected the data, so that variability could be minimized. The data collected can be divided into two categories. The first category included survival data - which essentially means number of patches still in service. The second category consisted of distress data. The distresses monitored included bleeding, cracking, dishing, edge disintegration, missing patch, raveling, and shoving.

Test Region and Site Characteristics

The sites of installation were the following:

1. Modoc Point, OR, in two different areas of US97
2. Alturas, CA, in three different areas of Route 395
3. Draper, UT, east of the Interstate 15
4. Las Vegas, NM, in the southbound lane of Route 518
5. Greenville, TX, on the intersection of Interstate 30 and US 69
6. Vandalia, IL, on Route 40
7. Bradford, VT, on the intersection of Interstate 89 and Route 25.
8. Prescott, ONT, west of the city limits and runs parallel to the highway 401.

The type of pavement in all test sites was asphalt concrete.

The above site locations are presented schematically in Appendix 2.

Since climate is considered as an important factor which influences the behavior of the patches, the entire testing area was divided into four climatic regions and each site corresponds to one of them. The climatic regions were originally defined for the SHRP Long-Term Pavement Performance projects and were adopted for this project.

Those were the following:

- Climatic Region I, Wet-Freeze
- Climatic Region II, Wet-Nonfreeze
- Climatic Region III, Dry-Nonfreeze
- Climatic region IV, Dry-Freeze

Based on the following distinction, Prescott (ONT), Bradford (VT) and Vandalia (IL) represent Region I, Greenville (TX) represents Region II, Las Vegas (NM) represents Region III, and Draper (UT), Alturas (CA) and Modoc Point (OR), represents Region IV.

Materials and Procedures

Materials

The materials used for the patches were selected according to SHRP H-105 project, based on their potential to perform very well. These materials were not used by many agencies and they had to be shipped to the test site from wherever they were produced by a single producer to minimize the variability between the different sites. Six were the major materials for the project and were the following:

UPM High-Performance Cold-Mix: It is a proprietary cold-mix material, produced using a specially formulated binder and aggregate. The cost of the material for this project was approximately $75 per ton ($83 per metric ton), not including the cost of shipping.

Perma-Patch: Perma-Patch is a proprietary material made with a specially formulated binder. It could be produced in any asphalt plant using local aggregate. For this project however only one plant was used. The cost of the material was $75 per ton ($83 per metric ton), not including shipping.

QPR 2000: This is a cold-mix proprietary material produced with a specially formulated binder. The material can be produced in any asphalt plant using local aggregate. Two different types of QPR 2000 were used, one for the warmer testing areas like Texas and New Mexico (southern mix) and the second for colder testing areas (northern mix). The cost of this material was $75 per ton ($83 per metric ton).

PENNDOT 485: The Penn DOT material was produced in Pennsylvania, according to Specification 485, in which acceptable bituminous additives, binders and aggregate are listed. The cost of the material was $35 per ton ($39 per metric ton), shipping not included.

PENNDOT 486: In the same manner as the previous material, PennDOT 486, was produced according to the Specification 486. The difference between the two materials was the addition of polyester fibers in PennDOT 486 material. The cost of the material is $40 per ton ($44 per metric ton), excluding shipping.

HFMS-2 (modified): The cold-mix material was produced using a high float, medium-setting emulsion that contains styrene butadiene. The cost of the material was approximately $60 per ton ($66 per metric ton), excluding shipping.

Spray Injection Materials: The spray injection materials consisted of a crushed aggregate and emulsified asphalt. A spray injection device was also used and the emulsion was heated to about 60^{0} C (140^{0} F). The cost of the daily rates operation for spray injection ranges from $700 to $1000.

Other Materials: Some local materials used by different agencies for patching operation on a daily basis were also used. These were mostly inexpensive cold-mixes dry looking materials, with rounded aggregate and very little binder. In some instances however, high quality proprietary mixes were used. The cost of the local materials varied from $16 per ton ($18 per metric ton) for local material to $100 per ton ($110 per metric ton) for proprietary materials.

Procedures

Four major repair procedures were used and they were the following:

1. Throw-and-Roll
2. Edge Seal
3. Semi-Permanent
4. Spray Injection

The above procedures have already been presented previously in this report. Participating agencies from Illinois and Oregon included two additional repair procedures and are described in what follows.

ILLINOIS: The material was first placed into the pothole, with no prior preparation or removal of water and debris. The patch is then compacted using truck tires, (between four and eight passes). The patch was then compacted for slight crown and if depression was present after rolling, additional material was placed and rolled again, till the patch surface was brought up above the surrounding pavement level. The crew was next moved to the next distress location. The day after the patch was placed, the entire surface of the patch was covered using bituminous material which was, in turn, covered with aggregate to prevent tracking.

OREGON: The pothole was first cleaned and water and debris were removed from the pothole. Asphalt emulsion was then placed into the pothole as tack coat that was then heated by using propane torch to get the emulsion brake faster. The cold-mix was then heated to make its placement easier and to improve the mixture compaction. The patch was then compacted by using a material truck. The compacted area was then checked for slight crown and if depression was present, additional material was placed and compacted again to bring the patch surface up above the surrounding pavement level.

Material Testing

In order to evaluate characteristics of the materials that could be related to their field performance, a series of laboratory tests were performed, which were accompanied by field tests. The laboratory tests were intended to characterize properties of the mixture, the aggregate and the binder. The majority of the laboratory tests were originally designed for hot-mix asphalt concrete materials and since the cold-mixes have different properties, the samples were aged into the oven to add them adequate stability for testing. This step was in particular necessary, for the Resilient Modulus and Marshall tests.

The laboratory tests that were performed were the following:

- *Resilient Modulus*: The test was performed according ASTM D 4123 at a temperature of 25^0 C (77^O F), at three different frequencies.

- *Marshall Stability and Flow*: It was performed according to ASTM D 1559. The samples were aged before compaction to add stability and obtain more representative results after several months of traffic.

- *Sieve Analysis*: It was performed according to ASTM D 136. A variety of sieves were used which made the direct comparison of the gradations of the different materials difficult.

- *Penetration (recovered binder only)*: It was performed according to ASTM D 5. The preparation of the samples required aging of the binder.

- *Ductility (recovered binder only)*: It was performed according to ASTM D113. The preparation of the samples required aging of the binder.

- *Softening Point (recovered binder only)*: It was performed according to ASTM D 36. The preparation of the samples required aging of the binder.

- *Workability*: The test was performed according to the Pennsylvania Transportation Institute (PTI) and utilized a probe developed by PTI.

- *Maximum and Bulk Specific Gravity*: They were performed according to ASTM D 2041 and ASTM D 2726 respectively. The values of these tests were used for the evaluation of the percent air voids to the mixture.

- *Anti-stripping*: It was performed according to ASTM D 1664. In this test no aging or special preparation was required.

- *Viscosity (recovered binder only)*: It was performed according to ASTM D 2171 on the binder recovered from the extraction process. Samples of binder were aged prior testing.

- *Binder Content*

The new laboratory tests that were performed were the following:

- *Blade Penetrometer*: It was conducted to allow for the evaluation of the workability of the mixture. Two different penetrometers were used; one developed by PTI and the other developed as a part of an FHWA study on cold- mixes. The difference between the two devices was that the PTI's bullet-shaped attachment was changed in FHWA study to a specially made blade. The test was done by simply inserting the penetrometer into a cold- mix and recording the maximum resistance encountered. Head-to-head testing was carried out at one point between the two penetrometers. Comparison of the results for the same material between the two different penetrometers indicates that the PTI device is better for stiffer mixes, whereas the FHWA device is more effective on looser materials. Since workability becomes a problem when the mixture gets stiff, the PTI device has been proved more reliable.

- *Rolling Sieve*: The test evaluates the durability of the patching materials under the action of traffic and was developed by the Ontario Ministry of Transportation. The procedure was carried out in both laboratory and field, so that correlation between the test results and field performance could be established. In this test, the Marshall mold, collar, and hammer are used for the preparation of the sample, which is then placed into a standard sieve with opening of 1 in (25 mm), covered with a lid. The sieve is rolled back and forth, for approximately 20 passes and then placed horizontally with the mesh down. The sieve remains in this position for ten seconds. Finally, the material loss is calculated by weighing the material retained into the sieve. One of the problems of the test is that the temperature in the field cannot be controlled as in the laboratory.

Field Performance

Field inspections were scheduled in order to evaluate the rates of deterioration and cost effectiveness of the patches. The field inspections took place after 1, 3, 6, 12 and 18 months the completion of the installations. To reduce the variability of the data, the same individual recorded the field performance data.

Two main types of data were taken namely survival data and distress data. The former, regards patches still in-service along the test site and the latter concerns types of distresses present in the patches. The patches were checked for bleeding, cracking, dishing, edge disintegration, missing patch, raveling and shoving.

For survival data recording, the repair types were grouped into sets at each site, according to how they were installed, so that comparison within each set could be obtained, since intraset comparison has the least variability in traffic, cross section, subgrade support and drainage.

The distress recording showed that the most significant distresses noted were dishing, raveling and edge disintegration. Bleeding was mostly present among the PennDOT 486 patches.

On average, the patching times for the throw-and-roll, semi-permanent, and spray injection methods were 2.6, 13.3, and 2.8 minutes, respectively. Also, average pothole volumes for the above methods were 1.1, 1.2, and 1.3 ft^3 (0.031, 0.034, 0.037 m^3), respectively.

Analysis

The analysis of the field data was done by the use of the statistical package SAS and comparison between two groups of repairs were included, considering all values for each repair type.

An attempt to correlate the field performance with the material properties was done by SAS package and by using a regression model. The analysis showed no significant correlation, the likelihood however could be improved by continuous monitoring.

One of the important aspects of the project was the documentation of the different patching operations. Therefore, data were collected from the eight different agencies during installations and for the different repair procedures. The data were taken with regard to patching times and pothole volumes.

The cost effectiveness of the patching operations were calculated based on the following:

- Labor rates (on per day basis)
- Material purchase and shipping costs (dollars per ton)
- Productivity of the patching crew (tons per day of material placed)
- Total quantity of potholes to be repaired (tons of material)
- Equipment costs (dollars per day)
- Performance of the repairs

Conclusions

The pothole repair project succeeded in monitoring the patches and keeping them from being overlaid. The most important observations that have been made are the following:

- The overall survival rates for dry-freeze sites are significantly higher than the ones for the wet-freeze sites. This indicates the weather conditions at the wet-freeze site cause quicker failures. However, a number of other factors have to be considered such as traffic, pavement age and subgrade support.

- Only four sets of experimental patches performed significantly poorer than the comparable control patches. These patches were made of inexpensive cold-mixes and they failed by raveling until the pothole reappeared.

- The "throw-and-roll" technique proved as effective as the semi-permanent procedure for the materials with which the two procedures were compared directly. In terms of productivity, labor and equipment costs, the "throw and roll" procedure has been proved to be more cost effective when quality materials are used.

- The success rate of the project indicates that the material can remain in service for more than one year.

- The spray-injection repair depends on the expertise of the operator. The low residual binder content led to raveling of the aggregate and other premature failures.

- Despite the fact that at most sites the spray-injection patches were still soft when opened to traffic, they performed well at all sites.

- Finally, three of the eight agencies participating in the project, switched from the inexpensive cold- mixes that were using previously, to one of the materials provided through the project.

Some of the recommendations derived from the SHRP H-106 project could be the following:

- *"Use high-productivity operations in adverse weather."* The primary objective in this case should be the quick repair of the potholes. The repair procedures that could be used is "throw and roll", (using high quality materials) or spray injection. The spray injection device should be operated and maintained by an experienced technician.

- *"Utilize the best materials available to reduce repatching."* Poor quality materials will result in a greater overall cost because of increased costs in labor, equipment, and traffic control.

- *"Consider safety and user delay costs in calculating operation costs."* Repatching can be avoided by using a more expensive cold- mix. The safety conditions are also improved by allowing less crew time in traffic.

- *"Testing should be performed to ensure compatibility of aggregate and binder."* The aggregate and binder should be tested on a small scale to determine if the two are compatible, especially when new combinations are to be used and no record of the material's performance exists.

DESCRIPTION OF EXPERIMENTAL MATERIALS - NJDOT PROJECT

Several different patching materials were selected for demonstration projects. These were proprietary High Performance Cold Patching materials and they are presented in Table 6, along with the manufacturers. A brief description of the materials is also presented in what follows.

The initial plan was to include some additional materials, which were later dropped due to lack of response or because a source could not be found. These materials were:

- IRR
- STYLINK
- PROMIX

Q.P.R. 2000

This is a proprietary cold- mix with a specially formulated binder. The aggregate of this cold- mix consists of a crushed limestone or approved equivalent. Its gradation follows ASTM C-136 specifications. The liquid blend also meets ASTM requirements heated no more than 149 ^{0}C (300^0 F). The mixing ratio is 5.5% LIQUID BLEND or 50 kg per metric ton (100 lbs per finished ton).

U.P.M.
This is also a proprietary cold- mix, made with a specially formulated binder. The mix consists of 5-6.5 % asphalt, heated to a temperature between 88 - 135 ^{0}C (190-275 ^{O}F), and cold aggregate 95 - 93.5 % combined in a pug mill and mixed for 30 - 45 seconds. The gradation of the aggregate meets the ASTM C-136 requirements. The asphalt blend and the aggregate also conform to the ASTM requirements.

I.A.R.
This is a high quality permanent repair patching material that consists of a proprietary bituminous liquid blend and aggregate mixed in a hot asphalt plant. The aggregate consists of 100% limestone or approved equal and its gradation is in accordance with ASTM C-136. The bituminous liquid is modified cut back asphalt, which meets or exceeds the ASTM requirements.

Wespro
This proprietary cold- mix is also composed of aggregate and Liquid Blend. The aggregate consists of Limestone or approved equivalent and complies with Gradation of Extracted Aggregate Results, according to ASTM C136.

SuitKote
It is a proprietary cold- mix that consists of crushed aggregate and bituminous material meeting the ASTM requirements. A batch mix plant, drum mix plant, or cold- mix pugmill are used for mixing. When mixing in a hot plant, the temperature is minimized so that stripping of the bituminous material can be avoided.

Perma Patch
It is a proprietary cold- mix prepared by using clean crushed limestone or approved equivalent as an aggregate and bituminous liquid that consists of special asphalt, pressure-sensitive plastics, and chemicals. The bituminous material is 5-6% by weight based on the total weight of the mix.

FIELD PERFORMANCE AND DEMONSTRATION PROJECTS

For the evaluation of patching materials described in the previous section, and following the SHRP-H-106 plan, experimental patches were installed in different testing areas and their behavior over time was observed and recorded. The experimental patching was performed by the NJDOT Bureau of Maintenance. The initial plan called for three testing areas, namely South Region, Central Region, and North Region. The Central Region however, was dropped in November 1996, due to lack of manpower.

Evaluation of Field Performance

For the evaluation of the behavior of the patching materials and the identification of distress types, field trips were conducted. The Rutgers Department of Civil and Environmental Engineering cooperated with NJDOT in the North Region, with the assistance of Pothole Materials Task Group. The final report regarding the South Region was completed on October 30, 1996, prior to any involvement of the Department of Civil Engineering.

The field performance evaluation included two sets of data: *Repair Survival* and *Distress Development Data*. The evaluation of the performance of these experimental patches followed the SHRP procedure.

- The *Repair Survival Data* essentially indicates the number of patches still in service, from which the optimum combination of material and repair procedure in terms of cost effectiveness can be determined.

- The *Distress Development Data* can determine the materials with superior field performance, by examining the critical distresses prior to failure and the critical material properties relatively to the critical distresses. The patches were inspected for different distresses by using a scoring system on a scale from 1 to 10; where 1 represents the worst behavior and 10 the best behavior. In Table 8 the different criteria regarding different distresses used for the field evaluation in this project, and introduced by SHRP are presented.

South Testing Area

The information regarding this region is taken from the Final Report (Oct. 1996), regarding this testing area which was prepared by Angelo Mendola, NJDOT Senior Engineer, New Products committee. All work in this testing area was completed prior to any involvement of the Department of Civil & Environmental Engineering.

The location of this testing area was Route 1 - southbound at Lawrenceville and at mileposts from 1.1 to 1.4. The material inspected in this testing area were UPM, WESPRO, QPR2000, and Stylink. The field data were collected at four and three month intervals, in February and in May. The monitoring included bleeding, cracking, edge disintegration, dishing, missing patch, raveling, and shoving. The results after 13 months of service indicate that the patches had an excellent performance, with minor signs of distresses. In Appendix 3, the actual data collected is presented.

North Testing Area

Similarly to the Southern Region, experimental patches were installed in the Northern region. The installation of the patches was completed in November 1996. The location of the patches was in Secaucus, NJ on Route 120 and 21. Six out of the seven materials were placed on Portland Cement Concrete type pavements and the seventh was placed on a Bituminous Concrete type pavement. The materials that were used for experimental patches were the following:

1. UPM,
2. PERFORMIX
3. QPR
4. WEST PRO
5. SUITKOTE
6. PERMA PATCH

For the evaluation of the behavior of the patching materials, the identification of distress types and following the SHRP procedure, it was decided that field trips should be conducted by NJDOT, with the coordination of the Department of Civil Engineering, and the assistance of Pothole Materials Task Group. The field trips were scheduled by the NJDOT person in charge of that project, (A. Mendola and later R. Espieg) and were responsible to notify the Department of Civil and Environmental Engineering. For any field inspection the representatives from both NJDOT and the Civil & Environmental Engineering Department were present. Photos were taken of the patches during the field inspections and are presented in Appendix 4.

The field data consist of:
1) Photo Inventory,
2) Material Type,
3) Location and Date and,
4) Climatic Conditions.

Two field inspections took place and the experimental patches were inspected for the following distresses:

1. Bleeding
2. Cracking
3. Dishing
4. Edge Disintegration
5. Missing Patch
6. Raveling, and
7. Shoving

The first field trip took place on December 22, 1996, two months after installation. The persons present were A. Mendola from NJDOT, F. Petsi from the Department of Civil Engineering - Rutgers University, and a representative from the NJDOT Maintenance crew. A safety crew was also present to control the traffic during inspection. The weather was sunny and cold at approximately 0 ^{0}C (32^{0} F). Several photographs were taken for each experimental patch to document their behavior and monitor their current condition for future reference.

The two-month-service inspection showed no signs of failure. All materials had an excellent performance and no significant distresses were recorded. The only exception can be the Perma Patch material, which failed completely very shortly after installation (one-day failure). However, conclusions regarding the performance of this material cannot be drawn from this single case. The reasons for the failure are not clear and can be possibly attributed to the location of the pothole. The pothole was located between joints and it can be seen in photographs in Appendix 4.

The second field trip took place on May 16, 1997, approximately six months after installation. The persons present were Ron Espieg from NJDOT, F. Petsi from the Department of Civil Engineering, and one representative from the NJDOT Maintenance crew, who also controlled the traffic during inspection. The weather was sunny and warm (approximately 70 ^{O}F). Photographs were taken for each experimental patch to document their behavior and allow for evaluation of their condition over time.

The six-month inspection showed that all the patches were still in service with minor signs of distresses. The behavior of the material ranged from very good to excellent and no major difference between their performance was noticed. For the evaluation of behavior of the experimental patches, the SHRP scoring system introduced was used. The results are presented in Appendix 6.

More specifically, UPM, Wespro, and Performix developed edge disintegration but their behavior is still well above the satisfactory level. Also, UPM, Performix, and SuitKote, developed dishing. The signs of this distress were minor in UPM and Performix (graded 9 and 8 out of 10 respectively), but more pronounced in SuitKote (6 out of 10). UPM and SuitKote also developed some bleeding but the performance can still be characterized as very good (8/10 and 9/10 respectively). Wespro developed some cracking but it was in the range of 9/10. None of the materials developed any raveling or shoving. Finally, as can be seen in Table 8 (1), the average rating of all the materials is above 9.1, except for the missing patch.

LABORATORY QUALITY ASSURANCE TESTS

The laboratory tests were conducted for the determination of the material properties of the experimental patches. The results are investigated along with the field performance data, to allow for the characterization of the material properties that are the most critical for the desired field performance.

The laboratory tests that were conducted along with the desired properties are presented in Table 9 (1). The Marshall Stability and Resilient Modulus tests were performed by the Civil and Environmental Engineering Department, Rutgers University. The remainder were either performed by the New Jersey Department of Transportation or were provided by the manufacturer.

Two additional tests found in the literature were conducted: namely Blade Resistance and Rolling Sieve tests (introduced by the Canadian Ministry of Transportation and included in SHRP-H-106 project.) The former measures the workability of the cold-mix and the latter is a measure of cohesion. The tests were done on an introductory basis, in order to estimate how their results compare with the ones performed by NJDOT.

Marshall Stability Test

The test was done according to ASTM D1559. Since the samples prepared by compacting the material cold were not testable (several samples prepared collapsed soon after extrusion and prior to testing), the procedure described in SHRP-H-353 report was followed. According to SHRP, in order to add some stability to the material and to make the result representative and simulate field conditions after several months of traffic, the materials should be aged before testing by putting them into the oven overnight at 135^0 C (275 ^{0}F). The material is then compacted hot, by using 75 blows on each side and left to cool into the molds. The sample is then extruded and tested.

The Marshall specimens were compacted with a mechanical compactor with a hammer weight of 4.5 kg (10 pounds) and a drop of 457 mm (18 in). The geometry of the samples consisted of 63.5 mm (2.5 inch) heights and 101.6 mm (4 in) diameters. No environmental conditioning was used for the compacted samples prior to testing due to the instability that higher temperatures cause. The samples were tested at 25 ^{0}C (77 ^{0}F) and within one day of compaction.

A correction factor for any sample that did not have a height of 63.5 mm (2.5 in) was applied as recommended by ASTM D 1559. The only correction factor applied in this study was to the Wespro material. All other compacted materials were within 1.6 mm (1/16") from the desired height of 63.5 mm (2.5 in). Wespro samples averaged at 57.1 mm (2.25 in), thus a correction factor of 1.19 was applied to the Marshall stability values, in accordance with ASTM D1559. Therefore an increased Marshall Stability is reported in this paper for Wespro.

The specimens were tested on a MTS Servo-hydraulic frame with data acquisition systems. Vertical deflections were measured with an LVDT at 2.5 mm (0.001 in) increments. The resistance was measured simultaneously at each deflection increment.

The output that is reported from this test is the maximum load the material can stand before failure and the deformation at that load. The first parameter is known as the Marshall Stability and the second is regarded as the flow index. Stability is an indicator on the cohesion of the material and the flow index is related to the internal friction. A higher value of stability can therefore be synonymous to better cohesion and a mix that would uphold to heavier loads in the field. A higher flow index indicates that the material will have less internal friction and thus a higher rate of permanent deformation in a pavement.

Stability is generally a function of the binder properties in an asphalt concrete mixture and this value can be increased with a stiffer binder. Flow index is directly related to the aggregate composition of the mix. The flow value can be altered by changing the aggregate gradation of a mix. Some researchers theorize that a lower flow value indicates that the void content is too high (or asphalt content to low) and thus the mixture is less durable (6).

Although this type of testing will probably be abandoned in the Superpave design scheme, it does provide a general strength parameter that pavement engineers can understand. However, the results from the Marshall Stability test do not provide useful data for a mechanistic pavement design.

Resilient Modulus Test

This is considered to be a more advanced test than Marshall Testing for two reasons. First, the equipment that is required in the resilient modulus tests needs to be of the utmost accuracy. A high capacity test frame, LVDT's, and an advanced data acquisition system are all required. Secondly, the resilient modulus test is more advanced simply because of the engineering properties produced from the data. Engineering parameters such as Poisson's ratio and resilient modulus are both useful in the mechanistic design of pavements.

The specification for this test is available through ASTM (D4123) or AASHTO (TP31). The very thorough AASHTO specification provides schematics of the test equipment and an excellent example on how to do calculations. The system used by Rutgers University for testing conformed to AASHTO, ASTM, and SHRP specifications. The calculations were automatically produced by the data acquisition software, but were checked to confirm that results were correct.

The test method requires four specimens for each material. The first specimen is tested to failure in indirect tension at 2 inches/minute. This test should be performed at 25^0 C (77^0 F). The reason for this first test is to establish testing loads for remainder of tests at various temperatures. In a typical test of hot mix asphalt, 30, 15, and 5 percent of the tensile strength measured at 25^0 C (77^0 F) are to be used in conducting the resilient modulus deformations at the test temperatures of 5, 25, and 40^0 C (41, 77, and 104^0 F) (7). However, SHRP recommended testing at 25^0 C (77^0 F) for cold-patch materials (3).

Thirty haversine pulses with a 0.1 second load duration and a 0.9 rest duration are applied to samples in the resilient modulus test. Data for results are taken from the last 5 cycles. The data taken consists of both total and instantaneous deformations of the sample deforming horizontally and vertically. The prescribed load and temperature of the test are also recorded. From this data, Poisson's ratio (μ) and resilient modulus (M_R) are calculated using the methods described in AASHTO TP-31. Both instantaneous and total values of μ and M_R are produced. After testing the samples at each temperature, they are again tested for indirect tensile strength to verify the original value or to establish the amount of damage to the specimen during resilient modulus testing.

Deformation measurements for resilient modulus testing are made with 4 LVDTs arranged at various locations on the loading fixture. Two of the LVDTs are located to the left and right of the specimen they measure the relative displacement of the two platens. The relative displacement of the platens equals the vertical deformation of the sample in the fixture. The Horizontal LVDT's measure the deformation directly on the sample. The averages of the vertical and horizontal deformations are used in the resilient modulus and Poisson's ratio calculation.

The first step in a resilient modulus test is to obtain 4 samples of the same asphalt mixture. One of the samples will be tested for indirect tensile strength. This consists of applying a strain-controlled load at 50 mm/min. The maximum value or resistance measured is considered the indirect tensile strength. The indirect tensile test must be done at 25 ^{0}C. Resilient modulus peak loads are based on a percentage of the indirect tensile strength. The calculation for indirect tensile strength is (from AASHTO TP31-94):

$$S_t = \frac{50.127 \times P_0}{t}\left[\sin\left(\frac{1455.313}{D}\right) - \frac{12.7}{D}\right]$$

S_t = Indirect tensile strength, kPa
P_0 = Maximum resistance, N
t = Thickness of specimen, mm
D = Diameter of specimen, mm

The software requires the input parameter to be in the form of a load (N) and not a pressure (kPa). Therefore the amplitude of the loading scheme must be back calculated according to the previous formula.

$$P_{MAX} = \frac{S_t \times C \times t}{5012.7\left[\sin\left(\frac{1455.313}{D}\right) - \frac{12.7}{D}\right]}$$

P_{MAX} = Peak, maximum, or amplitude of haversine loading, N
S_t, t, and D = Same as before
C = Percentage based on test temperature, %

The reason why percentages are taken of the stress rather than the load is because of differences in diameter and thickness of specimens. A stress is applicable across any size specimen. For example, the indirect tensile stress will be the same for both a 45 and 55 mm diameter specimen. However, the load measured from the indirect tensile strength will be higher for the 55 mm thick specimen.

The haversine loading used by the data acquisition formula is as follows. The peak of the haversine curve is the maximum load (P_{MAX}) which was calculated as a percentage based on the indirect tensile test. The time of the haversine pulse is 0.1 seconds. The constant contact load needed on the specimen is 10% of the maximum load. This is to maintain continuity and reduce impact loading on the specimen. We also know that the peak will occur at 0.05 seconds into the haversine pulse. The load at any time can then be calculated as:

$$P_t = 0.9 \times P_{MAX} \times \frac{1}{2} \times \left(1 - \cos\left(\frac{2\pi \times t}{0.1}\right)\right) + 0.1 \times P_{MAX}$$

P_t = Load at time t, Newtons
t = Time into the load pulse (0 to 0.1), seconds

Based on this formula, the data acquisition applies the corresponding load to the sample. The test lasts for 30 load cycles, using the data from the last 5 cycles to calculate resilient modulus and Poisson's ratio. The data recorded for these calculations include vertical deformations, horizontal deformations, and loads. Other variables used in calculations include the thickness and the Poisson's ratio (if it assumed rather than calculated).

When the test is initiated, there are specifications for the amount of difference between the two vertical LVDTs and between the two horizontal LVDTs. This is to insure that the specimen is properly placed in the load strips and concentric loading does not exist. The ratios of the two vertical LVDTs shall not exceed 2.0 and 1.5 for test temperatures at 5 ^{0}C and at test temperatures above 5 ^{0}C. The ratios for the horizontal deformation are the same as vertical deformation ratios. If the ratios become to high during the test, the data acquisition will cease the loading of the specimen. Also, the test cannot be started if the deformations are inadequate.

There are also limitations to the minimum and maximum deformations read during the test. If the vertical deformations are below 0.0025 mm, the test load should be increases until the deformations are above this value. However, the load should not be increased more than 20 percent of the original load. The upper limit for the vertical deformations is 0.625 mm. If the vertical deformations exceed this value, the loads and repetitions may be decreased.

There are two different resilient modulus (M_r) and Poisson's ratios (μ) calculated according to the most recent specifications. The first type of each, deemed instantaneous, refers to the resilient modulus and Poisson's ratio using only the recoverable deformations. Because the deformations are based on recoverable or elastic deformations, the M_r and μ are synonymous with the elastic aspects of the asphalt. The recoverable deformations are based on two regression lines on the deformation curves. The first line is a linear regression of the deformations from the peak to point where there is 75% rebound. The second is a linear regression of the last 0.75 second of the cycle. These lines are extended so that they cross. A vertical line from this crossing is followed up to the actual deformation curve. The four closest deformation values at this point are averaged to attain the instantaneous deformation recovery point. The deformation from the peak to this point is considered the instantaneous deformation. This process is done for the data from all 4 LVDTs on each of the last 5 cycles of the test.

The total resilient modulus consists of data throughout the cycle including the recovery phase. This value is more indicative of the visco-plastic aspect of asphalt. The total deflection is measured using the peak deformation and the average of the last 75% or 0.75 seconds of the test. The difference between these values is considered the total deformation. This process is done for all the LVDT data for horizontal and vertical deflections during each of the last 5 cycles of the test.

The resilient modulus and Poisson's ratio calculations for both total and instantaneous values are the same, except for the deformations, which have previously been discussed.

$$\mu_i = 3.59 \times \frac{\Delta H_i}{\Delta V_i} - 0.27$$

$$\mu_t = 3.59 \times \frac{\Delta H_t}{\Delta V_t} - 0.27$$

$$M_{ri} = \frac{P_{MAX} \times (\mu_{Ri} + 0.27)}{t \times \Delta H_i}$$

$$M_{rt} = \frac{P_{MAX} \times (\mu_{Rt} + 0.27)}{t \times \Delta H_t}$$

μ_i = Instantaneous Poisson's ratio
μ_t = Total Poisson's ratio
ΔH_i = Instantaneous horizontal deformation, mm
ΔH_t = Total horizontal deformation, mm
ΔV_i = Instantaneous vertical deformation, mm
ΔV_t = Total vertical deformation, mm
P_{MAX} = Maximum load, N
t = Thickness, mm
M_{Ri} = Instantaneous resilient modulus, MPa
M_{Rt} = Total resilient modulus, Mpa

Poisson's ratio has an upper and lower limit. If the calculated value of μ is more than 0.5, a value of 0.5 should be assumed. If the calculated value of μ is less than 0.1, a value of 0.1 should be used. Another method for calculation of Poisson's ratio is to make an assumption. Generally HMA has a μ of 0.35 +/- 0.05. This should be done sparingly, especially since the equipment is capable of calculating μ.

The instantaneous and total values for M_R and μ are calculated for each of the last five cycles. An average of each of these is then calculated at reported as the result of this test. However, if a value varies by more than 15 % from the average, it is omitted and the average of 4 of the cycles is used. If any of the remaining values is more than 15% from the new average, the test should be rerun.

A Marshall mechanical compactor was used to compact samples for the resilient modulus testing. Also, as a necessary measure to insure a stable material during compaction and to induce an aging mechanism, the cold-patch material should be heated for 12 hours at 135^0 C (275^0 F). Therefore, the compaction process is the same as what was mentioned previously in the Marshall Stability section.

Blade Resistance Test

This test was formulated to test the workability of a cold-patch material in cold temperatures. It is used to simulate the action of a scoop or shovel penetrating a cold-mix. (4)

The test procedure consists of using a flat blade type fixture to penetrate a rectangular sample at 50 mm/min (2 in/min) for 30 seconds and measuring the resistance. The sample should be conditioned to a -10^0 C (14 ^{0}F) temperature for 12 hours prior to testing to simulate field conditions.

The specifications of the material and equipment are as follows. Two wooden boxes should be constructed with dimensions of 265 x 165 x 50 mm (10 x 6.5 x 2 in). These are to be used as the molds for the material prior and during the test. About 2 kg (4.4 lb) of material at 21 +/- 3 ^{0}C (70 +/- 5.4 ^{0}F) is placed loosely in each box. For compaction, a steel plate 150 x 150 x 6 mm (6 x 6 x 0.25 in) is attached to the end of a Marshall hammer. The material is compacted with 2 blows from the Marshall hammer with the steel plate in contact with the surface. The resulting height of samples is usually about 50 mm (2 in). This compaction is to simulate the consolidation that has been taken place in a stockpile. (4)

Two compacted samples are produced and placed in a freezer for 12 hours at -10^0 C (14 ^{0}F). Then at the time of testing the samples are brought out of the freezer and quickly tested. For load systems with an environmental chamber, a freezer is not necessary if the proper temperature can be reached.

The sample is then loaded at 50 mm/min (2 in/min) for 30 seconds, similar to the load rates in a Marshall test. This is stipulated so that this test can be performed on a Marshall test load frame. A blade, 130 x 50 x 3 mm (5.1 x 2 x 0.125 in), is used as the penetrating instrument in this test. It is situated so that the 3 mm end of the blade is flush with the sample. During the testing, the resistance the sample has to the blade is measured. This is regarded as the blade resistance.

The stipulation in the procedure provided by the Ontario Ministry of Transportation (4) is that the blade resistance should be below 2000 N (450 lb) for good workability.

Rolling Sieve Test

The rolling sieve test is used to measure cohesion of a material using a sieve and a Marshall specimen. According to the literature from the Ontario Ministry of Transportation (4), "this test is developed with the idea that, when the compacted briquette is subjected to the disturbance and attrition of a rolling sieve, the material retained on a 19 mm (3/4 in) sieve would give an indication as to the bonding or cohesion properties of the mixture."

A 19.0 mm (3/4 in) sieve with a 305 mm (12 in) diameter is used to perform this test. 3 specimens compacted in a Marshall compactor should be produced for this test. First, the loose material used in the method should be placed in a freezer at –10 +/- 2 ^{0}C (14 +/- 4 ^{0}F), along with the compaction hammer and molds for 12 hours. They are compacted using 5 blows on each side immediately after removal from the freezer. After compaction the samples are carefully extruded and moved to the testing area.

The briquette is placed in a 19.0 mm (3/4 in) sieve diametrically, so that it will roll along the edge of the wall of the sieve. A cover is then placed on the sieve. Then the sieve is rolled back and forth approximately 550 mm (22 in) for 20 cycles. Recommended test times for this test is approximately 20 seconds (4). Any material that falls out the sieve during the test is later weighed, as well as the material in the sieve. The calculated value for this test is the percent retained on the 19.0 mm (3/4 in) sieve.

$$RS = \left[\frac{r}{r+p}\right] \times 100\%$$

RS =Percent of cold- patch retained on the 19.0 mm (3/4 in) sieve
r = Mass of mix retained on the 19.0 mm (3/4 in) sieve
p = Mass of mix passing through the 19.0 mm (3/4 in) sieve

The percent retained is then a measure of cohesion of a cold-patch mixture. A higher percent would indicate a more cohesive material, whereas a lower percentage would indicate a less cohesive material. The Ontario Ministry of Transportation recommended a minimum percentage retained of 60% (4) for adequate cohesion in a cold-mix.

Results

The following are the results from the laboratory testing done at Rutgers University on the cold-patch materials in this study. The results consist of four laboratory performance tests previously mentioned in this report. Two laboratory tests, Rolling Sieve and Resilient Modulus, were not performed on IAR due to the lack of response from the manufacturer of this material. Five attempts were made to get material from this company with no avail. Thus, recommendations for this material must be made based on the tests that were performed on this material.

The results of the testing are shown in Table 10 and 11 as the blade penetration resistance, Marshall stability and flow, rolling sieve passing percent, instantaneous resilient modulus, total resilient modulus, and indirect tensile strength. It should be noted that the height of the Wespro samples used for Marshall stability testing were not of the same height as the other samples. A correction factor of 1.19 was applied to these samples according to ASTM recommendations (ASTM D1559). Therefore, the value in this chart is higher than the actual test value. The other samples were at the correct test heights.

Based on these results, Wespro had the highest value for Marshall stability and lowest value for Marshall flow. This indicates that Wespro has the greatest stiffness characteristics of all the materials. IAR had the lowest Marshall stability value and Performix had the highest flow value, indicating that these are the weakest materials in a Marshall test.

QPR 2000 had the lowest blade resistance indicating that it is the most workable of the materials; whereas Suitkote had the highest blade resistance indicating that it is the least workable. However, this test proved to have very erratic results an the shortcomings of the test specification may have caused inaccurate results. The values for blade resistance are reported as an average of 6 tests that had a high variance in results.

Performix seemed to have the best result in the rolling sieve test, which means it had the best cohesion out of all the materials. Wespro had the lowest amount of cohesion, even though it previously had the best Marshall stability and flow. UPM also had a low value for cohesion. The other samples performed about equal, with the absence of IAR. This test was performed on three samples per material and surprisingly produced a very low variance. The average is indicated in the table, but the variance from that value is very low for each sample, indicating a repeatable test.

The samples for resilient modulus were first tested for indirect tensile strength at a constant strain rate of 50 mm/minute. These values are shown in Table 10 and 11 . Performix and UPM had the highest indirect tensile strength whereas Wespro had the lowest strength. Ironically, even though Wespro had a far better Marshall stability than the other samples, it had a far lower indirect tensile strength. Suitkote also approached similar levels to that of Wespro. There is no real correlation between field performance and indirect tensile strength. There is also no correlation with any of the other lab tests and indirect tensile strength.

The resilient modulus test had a few modifications from ASTM and AASHTO specifications. The samples were tested only at 25 ^{0}C (77 ^{0}F). The peak load used for the test was 40% of the indirect tensile strength. This higher level was used because of the very low indirect tensile strength values of the samples. The recommended 15% (AASHTO TP31) of indirect tensile strength cannot be accurately maintained on the test frame.

The resilient modulus results proved to be inconclusive as to which mixture performed the best. All of the values for instantaneous and total resilient modulus were about the same for all the patching materials. Most of the values for resilient modulus were between 200 and 300 kPa, which indicates a fairly weak asphalt material. Performix was the best performing mixture in resilient modulus testing, but was not much better than the next best material.

CONCLUSIONS AND RECOMMENDATIONS

- The throw and roll method produces a patch that will last the shortest amount of time and economically will be more expensive on a per-year basis. Semi-permanent methods for patching will produce better per-year cost for a patch. (According to SHRP)
- The field tests performed on the materials in the North Region by Rutgers University seemed to produce the same results. All performed well, except for one missing patch, scoring above a score 9 out of 10 (10 being the best) in total patch rating. There was no data on Permapatch due to its disappearance after placement. IAR seemed to have a lower rating on the Missing Patch distress, whereas the rest of the distresses were rated 10 out of 10. Performix and Suitkote had a lower than average Dishing rating (6 out of 10, and 8.2 out of 10). UPM had a lower than average bleeding distress (8 out of 10). Wespro had a lower than average Edge Disintegration rating (8.4 out of 10).
- Considering the results from the field testing, all the materials performed about the same and no recommendations can be made on the best material from this data. Accordingly, cost should be the key issue for the patch material to be used.

- Blade resistance testing provided very little insight into material properties and should not be used in the future due to the erratic data.
- The rolling sieve test provided a low variance, highly repeatable result. However, the significance of that result is indeterminate due to the lack of correlation with field data. No distress correlated with the rolling sieve values. Wespro and UPM had the worst results in the rolling sieve test. Wespro also had a lower edge disintegration rating. Rolling sieve results may be an indicator of possible edge disintegration, because of the low ratings for Wespro. However, this theory is not correlated with the edge disintegration rating of UPM.
- Wespro had nearly double the stability of the next highest value. The flow measurement in the Marshall test also proved to give Wespro an edge. The worst performing material was IAR, having a Marshall stability of about 1/3 of that of Wespro. No correlation could be made with the field performance and this lab test.
- Although Wespro had the highest Marshall stability, it had the lowest indirect tensile strength.
- All the samples had about the same total and instantaneous resilient modulus values. The use of resilient modulus is therefore questionable for the evaluation of cold- patch material.

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Table 1. Common Failures, Handling Problems and Related Mix Properties to Bituminous Patching Mixtures (1)

FAILURE OR HANDLING PROBLEM	PRINCIPAL RELATED MIXTURE PROPERTY
Shoving (rutting)	Stability
Lack of adhesion to sides and bottom of the hole	Stickiness
Binder stripping from aggregate	Resistance to water action
Ravelling	Durability
Slick surfaces	Skid resistance
Excess of binder tracking and sticking to surfaces	Bleeding
Mix difficult to handle and shovel	Workability
Mix hardening in stockpile	Storageability

Table 2. Design Considerations For Cold- Mixes (2)

DESIGN CONSIDERATIONS	EFFECT ON MIXTURE
BINDER CONSISTENCY (before and during placement)	• Too stiff may give poor coating during mixing • Too stiff makes mix hard to shovel, compact • Too soft causes drainage in stockpile • Too soft may cause stripping in stockpile • Too soft may contribute to "tenderness" during compaction
BINDER CONSISTENCY (after placement)	• Too soft accelerates stripping, moisture damage in-service • Too soft accentuates rutting, shoving • Too soft may lead to bleeding, which causes poor skid resistance • Must cure rapidly to develop cohesion • High temperature susceptibility causes softening and rutting in summer
BINDER CONTENT	• Maximize to improve workability • Excess causes drainage in stockpile or hot box • Excess may lower skid resistance (bleeding) • Excess may cause shoving and rutting • Low binder content gives poor cohesion
ANTISTRIPPING ADDITIVE	• Correct type and quality may reduce moisture damage
AGGREGATE SHAPE AND TEXTURE	• Angular and rough aggregate gives good resistance to rutting and shoving but is hard to work • Rounded and smooth gives good workability but poor resistance to rutting and shoving
AGGREGATE GRADATION	• Reduced fines improves workability • Excess fines can reduce "stickiness" of mix • Coarse (>1/2 in) mixes are hard to shovel • Open-graded mixes can cure rapidly but allow water ingress • Well-graded mixes are more stable • Dirty aggregate may increase moisture damage • Too dense a gradation will lead to bleeding or thin binder coating, and a dry mixture with poor durability • Open or permeable mix may be poor in freeze-thaw resistance
OTHER ADDITIVES	• Short fibers increase cohesion, decrease workability

Table 3. Performance Requirements of Patching Materials (2)

1. Drainage Resistance
2. Workability
3. Stripping Resistance
4. Self-Tacking
5. Complete Curing
6. Stability
7. Bleeding Resistance
8. Non-raveling
9. Freeze-Thaw resistance
10. Safe for Workers
11. Environmentally Acceptable
12. Skid Resistance

Table 4. In-service Problems and Failure Mechanisms in Cold-Mix Patching Materials (2)

PROBLEM OR FAILURE SYMPTOM	PROBABLE CAUSES - FAILURE MECHANISMS
PUSHING, SHOVING	- Poor compaction - Binder too soft - Too much binder - Tack material contaminates mix - Binder highly temperature susceptible causing mix to soften in hot weather - Inservice curing rate too slow - Moisture damage - stripping - Poor aggregate interlock - Insufficient voids in mineral aggregate
DISHING	- Poor compaction - Mixture compacts under traffic
RAVELING	- Poor compaction - Binder too soft - Poor cohesion in mix - Poor aggregate interlock - Moisture damage - stripping - Absorption of binder by aggregate - Excessive fines, dirty aggregate - Aggregate gradation too fine or too coarse
FREEZE - THAW DETERIORATION	- Mix too permeable - Poor cohesion in mix - Moisture damage - stripping
POOR SKID RESISTANCE	- Excessive binder - Aggregate not skid resistant - Gradation too dense
SHRINKAGE OR LACK OF ADHESION TO SIDES OF HOLE	- Poor adhesion - No tack used, or mix not self-tacking - Poor hole preparation

Table 5. Combination of Test Sites, Materials and Procedures for SHRP-H-353 Project (3)

Patch Type	Material	Procedure	Sites Installed							
			CA	IL	NM	ON	OR	TX	UT	VT
A	UPM High Performance Cold Mix	Throw-and-Roll	▨	▨	▨	▨	▨	▨	▨	▨
B		Edge Seal	▨	▨	▨		▨	▨	▨	▨
C		Semipermanent	▨	▨	▨	▨	▨	▨	▨	▨
D	PennDOT 485	Throw-and-Roll	▨	▨	▨	▨	▨	▨	▨	▨
E	PennDOT 486	Throw-and-Roll	▨	▨	▨		▨	▨	▨	▨
F	Local Material	Throw-and-Roll	▨	▨	▨	▨	▨	▨	▨	▨
G	HFMS-2 w/Styrelf	Throw-and-Roll	▨	▨	▨	▨	▨	▨	▨	▨
H	Perma-Patch	Throw-and-Roll	▨	▨	▨	▨	▨	▨	▨	▨
I	QPR 2000	Throw-and-Roll	▨	▨	▨	▨	▨	▨	▨	▨
J	Spray Injection	Spray Injection	▨	▨	▨	▨		▨	▨	▨
K	QPR 2000	Edge Seal					▨			
L		Semipermanent				▨	▨			
M	PennDOT 485	Edge Seal					▨			
N		Semipermanent				▨	▨			
X	Local Material	Surface Seal		▨						
X	Local Material	Propane Torch					▨			

Table 6. Experimental Patching Materials

PRODUCT	MANUFACTURER
QPR 2000 (50LB BAG)	US PRO-TECH
UPM (50LB BAG)	UNIQUE PAVING MATERIALS
IAR/TON	INNOVATIVE BUILDING PRODUCTS Inc.
WESPO (60LB BAG)	WERPRO EAST
PERMA PATCH (60 LB BAG)	NATIONAL PAVING &CONTRACTING Co.
S-K MOD/TON	SUIT KOTE CORPORATION
PERFORMIX	HYDRO-LABS, Inc.

Table 7. Summary of Patch Ratings for Distress-Severity Combinations (3)

Distress	Estimated Quantity	Rating										
		10	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
Bleeding	Percent of Area	0	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Cracking	Quantity of Cracks	0	< 6-in	< 12-in	> 12-in	< 6-in	< 12-in	> 12-in	< 6-in	< 12-in	> 12-in	> 12-in
	Width of Cracks	0	crack width < 0.0625-in			crack width < 0.25-in			crack width > 0.25-in			alligator
Dishing	Depth of Dishing	0	< 0.25-in			0.25-in to 0.50-in			0.50-in to 1.0-in		< 1.0-in	
	Percent of Area	0	< 25%	< 50%	> 50 %	< 25%	< 50%	> 50 %	< 50%	> 50 %	< 50%	> 50 %
Edge Disintegration	Percent of perimeter	0	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Missing Patch	Percent of area	0	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Ravelling	Severity	none	Loss of small rocks			Loss of larger particles			Top 0.5-in gone		Top 1.0-in gone	
	Percent of area	0	< 25%	< 50%	> 50 %	< 25%	< 50%	> 50 %	< 50%	> 50 %	< 50%	> 50 %
Shoving	Height of shoving	0	< 0.25-in			0.25-in to 0.50-in			0.50-in to 1.0-in		< 1.0-in	
	Percent area	0	< 10%	< 25%	> 25%	< 10%	< 25%	> 25%	< 25%	> 25%	< 25%	> 25%

Table 8. Overall Ratings for Patches Placed in the North Region

Material	**Overall Rating**
IAR	9.6
Performix	9.6
Permapatch	0 (Missing Patch)
QPR-2000	9.9
Suitkote	9.1
UPM	9.4
Wespro	9.6

Table 9. Lab Testing Performed for Patching Materials

DESIRED PROPERTY	LABORATORY TEST	STANDARD
STABILITY	RESILIENT MODULUS MARSHALL STAB. DENSITY	ASTM D 4123, D1559, D 2950
RESISTANCE TO WEAR	ANTI-STRIPPING	ASTM D 1664
WORKABILITY (mix binder)	WORKABILITY, VISCOCITY PENETRATION	FHWA RD-88-001 ASTM D2171, D5
DURABILITY	SOFTENING POINT	ASTM D36
ADHESION/COHESION	DUCTILITY	ASTM D 113
STABILITY/DURABILITY	SIEVE ANALYSIS	ASTM C 136

Table 10. Laboratory Testing Results for Cold-Patch Testing at Rutgers University

Material	Marshall Stability (N)	Marshall Flow (mm)	Indirect Tensile Strength (kPa)	Instant. Resilient Modulus (MPa)	Total Resilient Modulus (MPa)	Blade Resistance (N)	Rolling Sieve (% retained)
IAR	3220.4	1.33	-	-	-	668.1	-
Performix	4938.2	1.87	629.8	291.4	311.3	793.5	98.3%
PermaPatch	6528.8	1.38	515.2	245.0	253.9	587.1	91.7%
QPR 2000	5472.8	1.40	510.6	216.5	282.8	378.1	93.6%
SuitKote	4752.2	1.42	418.9	286.6	241.5	858.5	95.6%
UPM	4952.4	1.20	613.4	248.8	282.8	608.5	21.8%
WesPro	9937.3	1.16	393.0	245.5	209.1	627.6	7.4%

Table 11. Laboratory Testing Results for Cold-Patch Testing at Rutgers University

Material	Marshall Stability (lb-f)	Marshall Flow (in)	Indirect Tensile Strength (psi)	Instant. Resilient Modulus (ksi)	Total Resilient Modulus (ksi)	Blade Resistance (lbs)	Rolling Sieve (% retained)
IAR	724.0	0.0525		-	-	150.2	-
Performix	1110.2	0.0735	91.35	42.27	45.15	178.4	98.3%
PermaPatch	1467.8	0.0544	74.73	35.54	36.83	132.0	91.7%
QPR 2000	1230.4	0.0550	74.05	31.40	41.02	85.0	93.6%
SuitKote	1068.4	0.0561	60.75	41.57	35.02	193.0	95.6%
UPM	1113.4	0.0471	88.97	36.09	41.02	136.8	21.8%
WesPro	2234.1	0.0458	57.00	35.61	30.33	141.1	7.4%

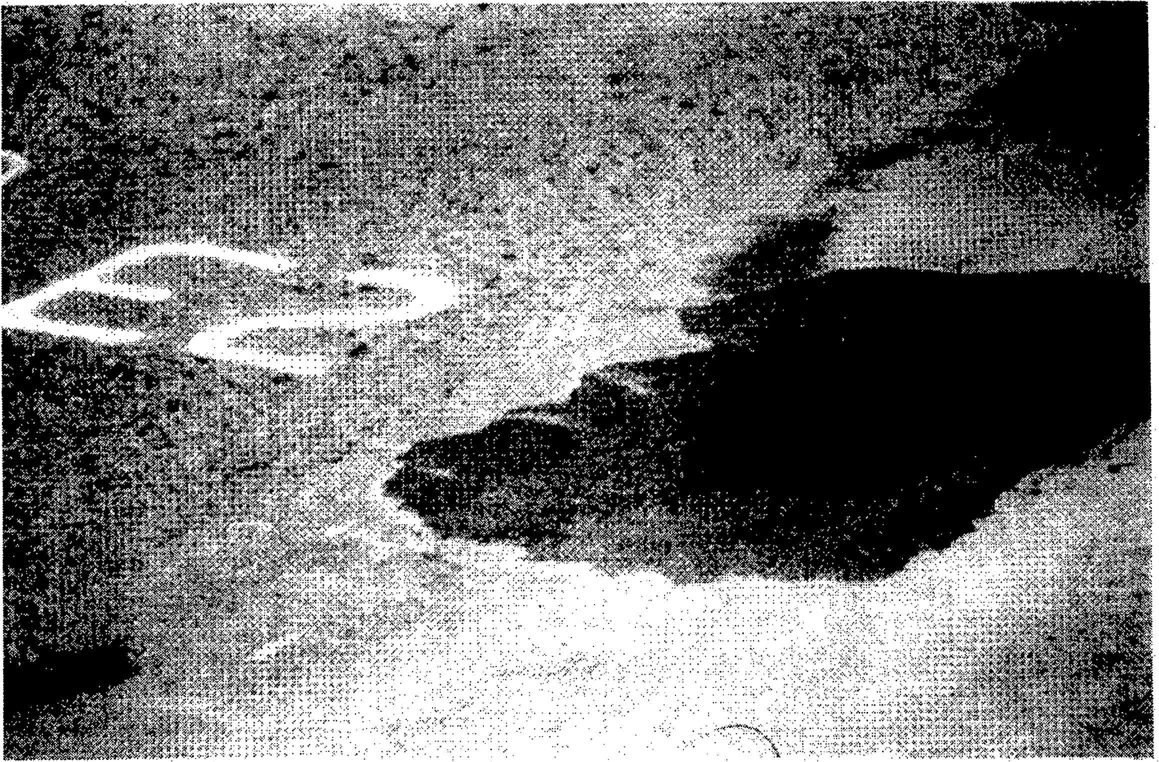

Figure 1. Bleeding Distress (3)

Figure 2. Cracking Distress (3)

Figure 3. Edge Disintegration Distress (3)

Figure 4. Raveling Distress (3)

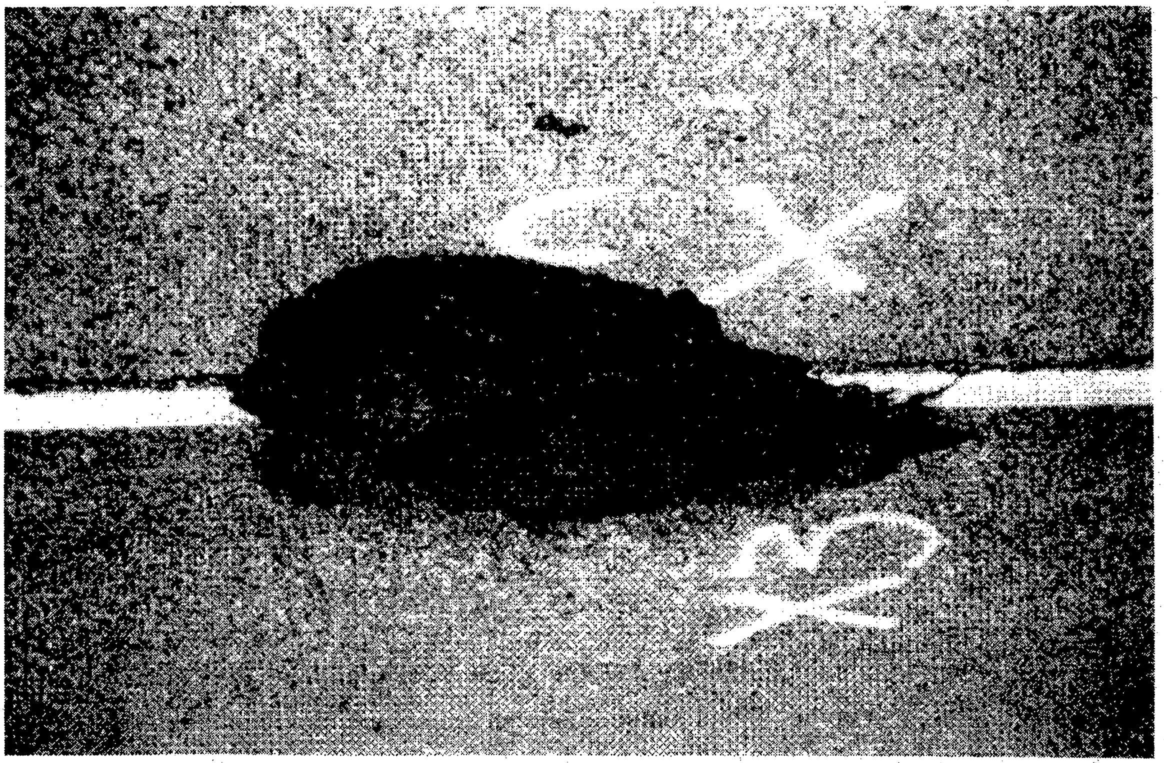

Figure 5. Shoving Distress (3)

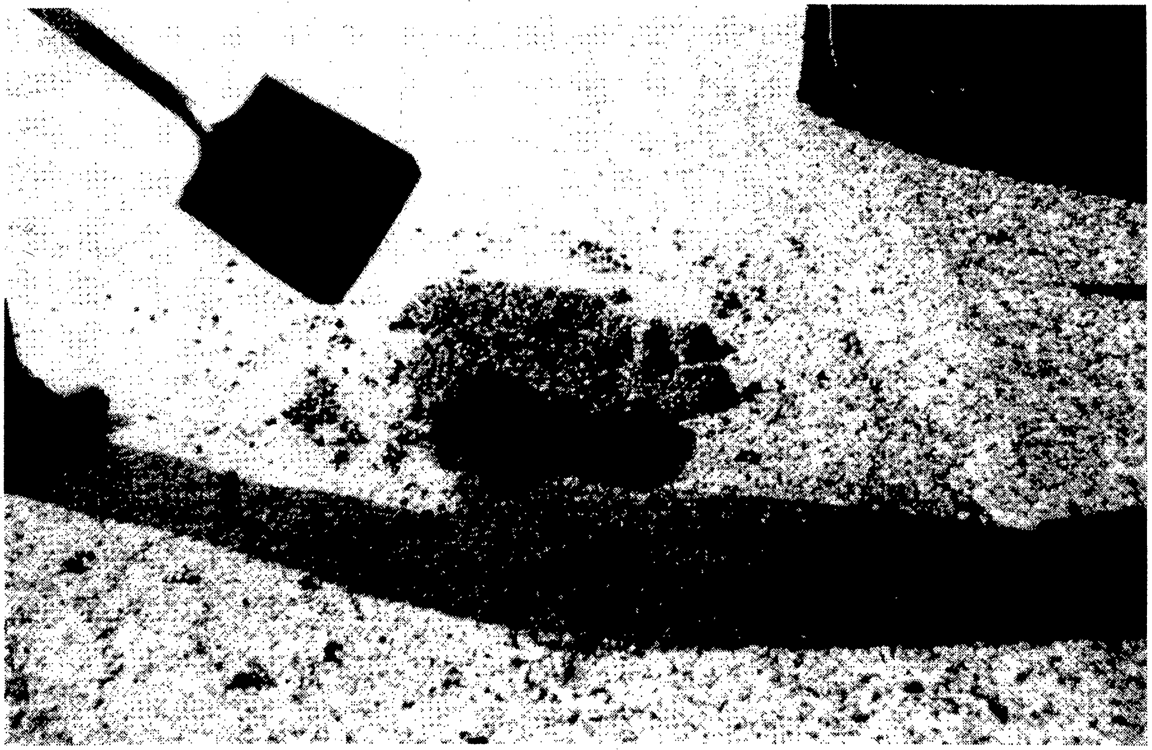

Figure 6. Throw-and-Roll Repair Method: Placement of Material (5)

Figure 7. Throw-and-Roll Repair Method: Compaction of Material Using the Wheels of a Truck on Site (5)

Figure 8. Semi-permanent Method of Pothole Repair: Saw-Cutting of Edges (5)

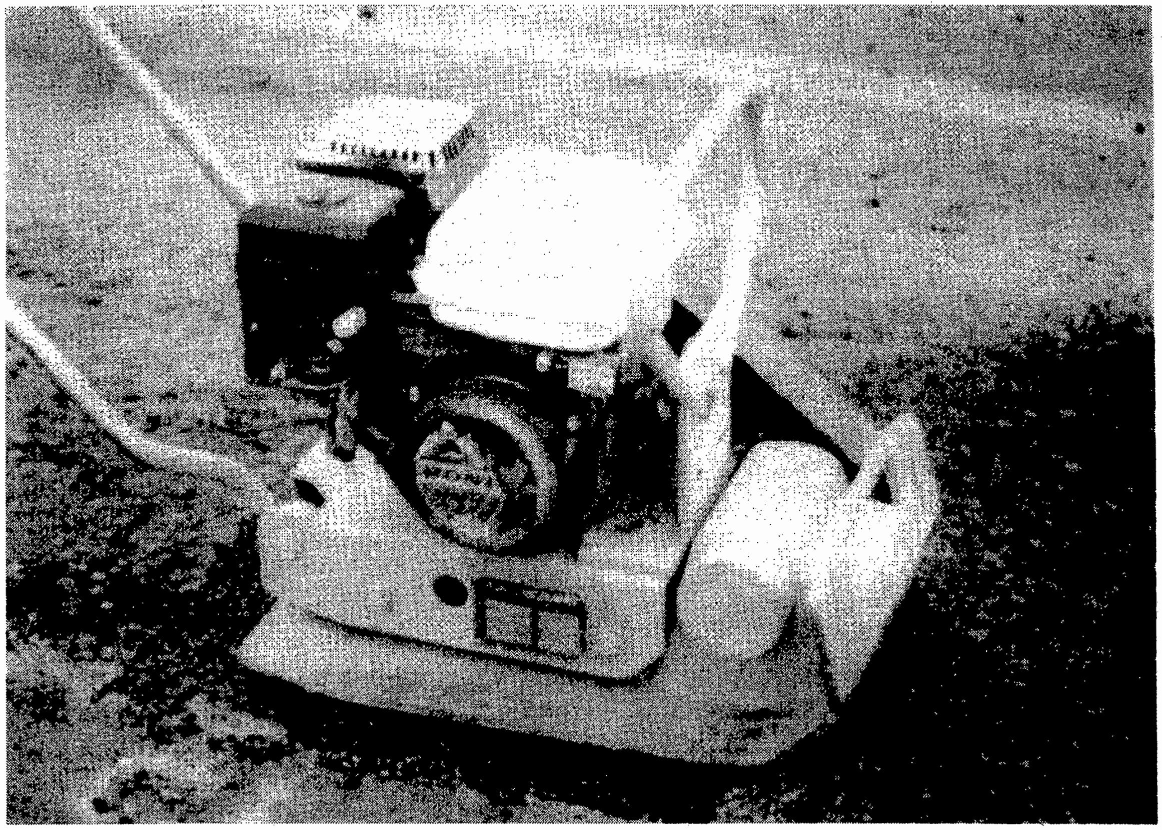

Figure 9. Semi-permanent Method of Pothole Repair: Compaction Using a Mobile Vibratory Plate Compactor (5)

Figure 10. Spray Injection Method of Pothole Repair (5)

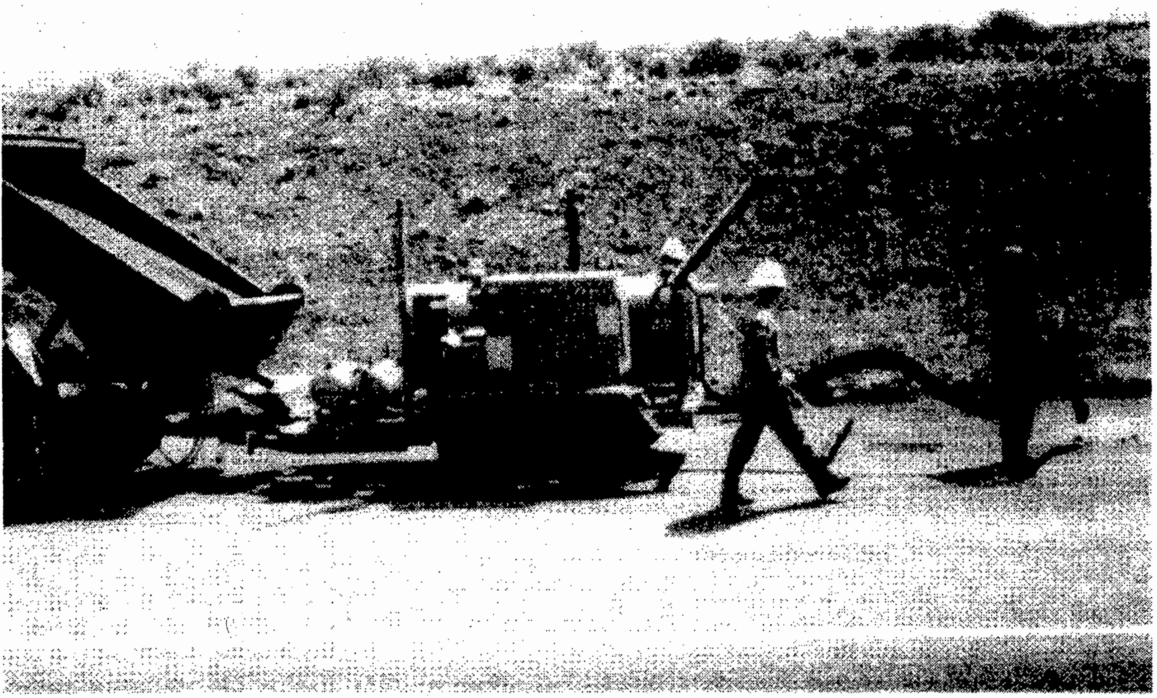

Figure 11. Spray Injection Method of Pothole Repair (5)

WORKSHEET FOR PATCHING COSTS (SHRP-H-348)

Material Costs

Material Purchase Cost ____________ $/ton (A)

Material Shipping Cost ____________ $/ton (B)

Anticipated Material Needs ____________ tons (C)

Labor Costs

Number in Patching Crew ____________ (D)

Average Daily Wage per Person ____________ $/day (E)

Number in Traffic Control Crew ____________ (F)

Average Daily Wage per Person ____________ $/day (G)

Supervisor Daily Wage ____________ $/day (H)

Equipment Costs

Material Truck ____________ $/day (I)

Traffic Control and Signs ____________ $/day (J)

Preparation Equipment ____________ $/day (K)
(Compressor, Jack Hammer, Pavement Saw, etc.)

Compaction Equipment ____________ $/day (L)
(Vibratory Plate, Single-Drum, etc.)

Extra Equipment Truck ____________ $/day (M)

Specialty Equipment ____________ $/day (N)
(Spray Injection Device, etc.)

User Costs

User Delay Costs ____________ $/day (O)

Figure 12. Worksheet for Patching Costs (SHRP-H-348)

WORKSHEET FOR PATCHING COSTS (SHRP-H-348)

Total Material Costs [(A + B) x C]		$	(P)
Total Daily Labor Costs [(D x E) + (F x G) + H]		$/day	(Q)
Total Equipment Cost [I + J + K + L + M + N]		$/day	(R)
Average Daily Productivity		tons/day	(S)
Estimated Days for Initial Patching [C / S]		days	(T)
Total User, Labor, and Equipment Cost [(O + Q + R) x T]		$	(U)
Total Labor and Equipment Cost [(Q + R) x T]		$	(V)
Total Patching Operation Costs with User Cost [P + U]		$	(W)
Total Patching Operation Costs without User Cost [P + V]		$	(X)
Patch Survival Rate		%	(Y)
Effective Patching Operation Costs with User Cost [W x {2 - (Y / 100)}]		$	(Z)
Effective Patching Operation Costs w/o User Cost [X x {2 - (Y / 100)}]		$	(AA)
Cost per Original Pothole Volume with User Cost [Z x (0.625 / C)]		$/ft^3	(BB)
Cost per Original Pothole Volume w/o User Cost [AA x (0.625 / C)]		$/ft^3	(CC)

Figure 13. Worksheet for Patching Costs (SHRP-H-348)

LEGEND FOR PATCHING COST WORKSHEET (SHRP-H-348)

(A) **Material Purchase Cost-** The cost of purchasing or producing the material, not including shipping costs. The amount entered should be in dollars per ton.

(B) **Material Shipping Cost-** The cost of shipping the material from the site of production to the location of the stockpile. The amount should be entered should be in dollars per ton.

(C) **Anticipated Material Needs-** The amount of patching material needed for one year of pothole patching. The amount entered should be in tons.

(D) **Number in Patching Crew-** The number of workers who will be performing the patching operation. This number does not include traffic control personnel.

(E) **Average Daily Wage per Person-** The average wages paid to the members of the patching crew. Multiplying this figure by (D) results in the total labor costs for the patching crew. The amount entered should be in dollars per day.

(F) **Number in Traffic Control Crew-** The number of workers required to set up and maintain the traffic control operation when the patching crew sets up traffic control operation. When the patching crew sets up traffic control before patching, the number of traffic control workers is zero, so that the workers are not counted twice.

(G) **Average Daily Wage per Person-** The average wages paid to the members of the traffic control crew. Multiplying this figure by (F) results in the total labor costs by the traffic control crew. The amount entered should be in dollars per day.

(H) **Supervisor Daily Wage-** The wage paid to a supervisor or foreman who oversees the patching operation. If the supervisor is not exclusively involved in the patching iperations for the entire time, a fraction of the daily wage should be entered to estimate the time spent with the patching operation. The amount entered should be dollars per day.

(I) **Material Truck-** The operating charges associated with the truck carrying the material. Only the trucks transporting material should be included. The amount entered should be in dollars per day.

(J) **Traffic Control Signs-** The cost associated with all traffic control trucks and devices, including arrow boards, attenuators, etc. If vehicles are used to both set up traffic control and for other activities during the day, a fraction of the daily cost should be used to estimate traffic control. The amount entered should be in dollars per day.

(K) **Preparation Equipment-** The cost associated with any equipment used to prepare the pothole before placing the patching material. If the throw-and-roll or spray injection methods are used, this value is zero. The amount entered should be in dollars per day.

(L) **Compaction Equipment-** The cost associated with any extra equipment used to compact the patches. If the material truck is used for compaction, this value is zero. The amount entered should be in dollars per day.

(M) **Extra Equipment Truck-** The cost associated with any extra truck used to transport preparation or compaction equipment to the site. The amount entered should be in dollars per day.

(N) **Specialty Equipment-** The cost associated with any special equipment used for the patching operation. The amount entered should be in dollars per day.

(O) **User Delay Cost-** The cost to users of the roadway of the delay caused by the patching operation. The amount entered should be in dollars per day.

(S) Average Daily Productivity- The rate at which the patching crew can place the patching material. This amount should be for the crew size specified above. The amount entered should be in dollars per day.

(W) Patch Survival Rate- An estimate of the percent of patches that will survive for one year. The value should be entered as a percentage.

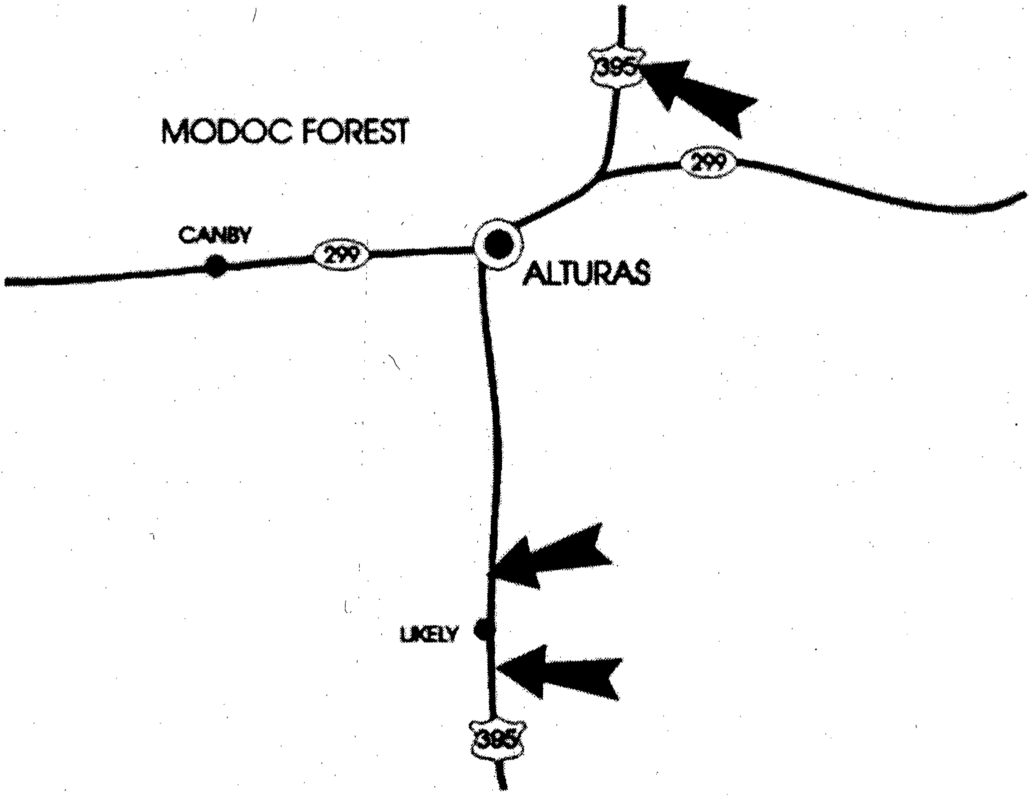

Figure 14. Repair Site in Alturas, CA: US 395 (3)

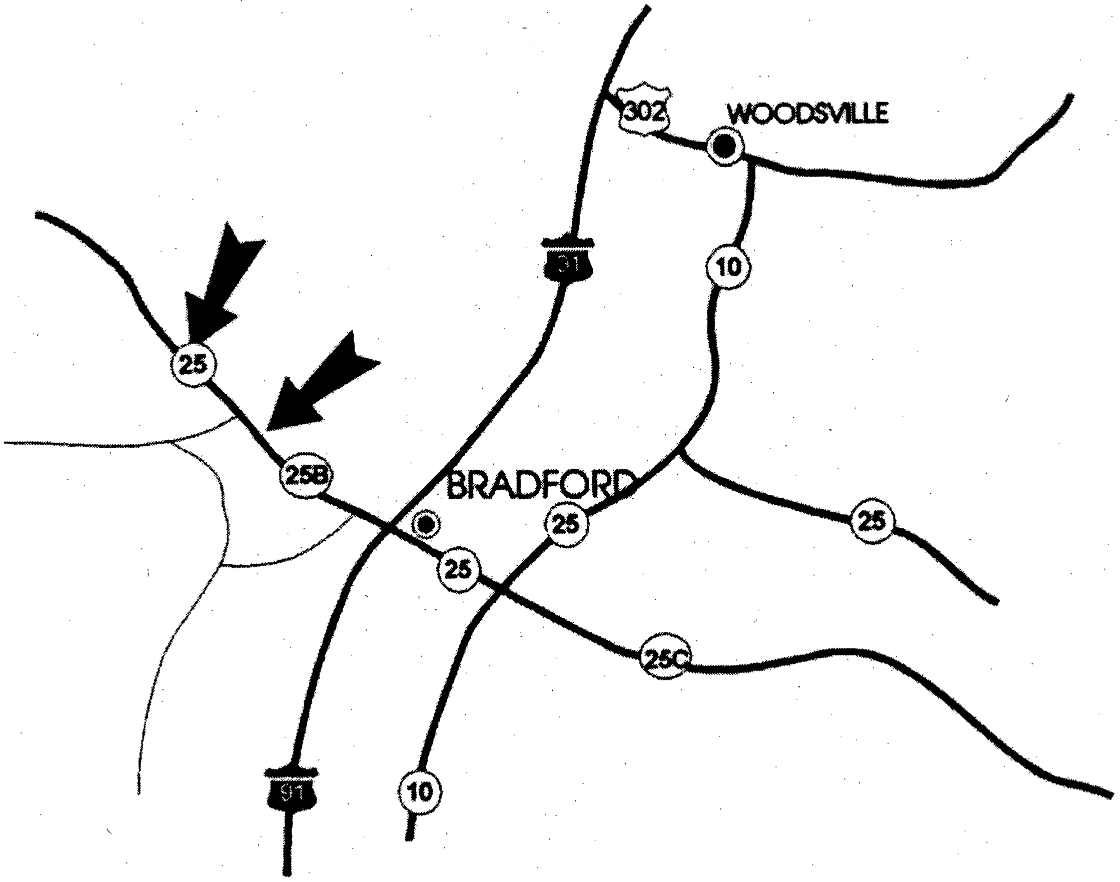

Figure 15. Repair Site in Bradford, VT: Route 25 (3)

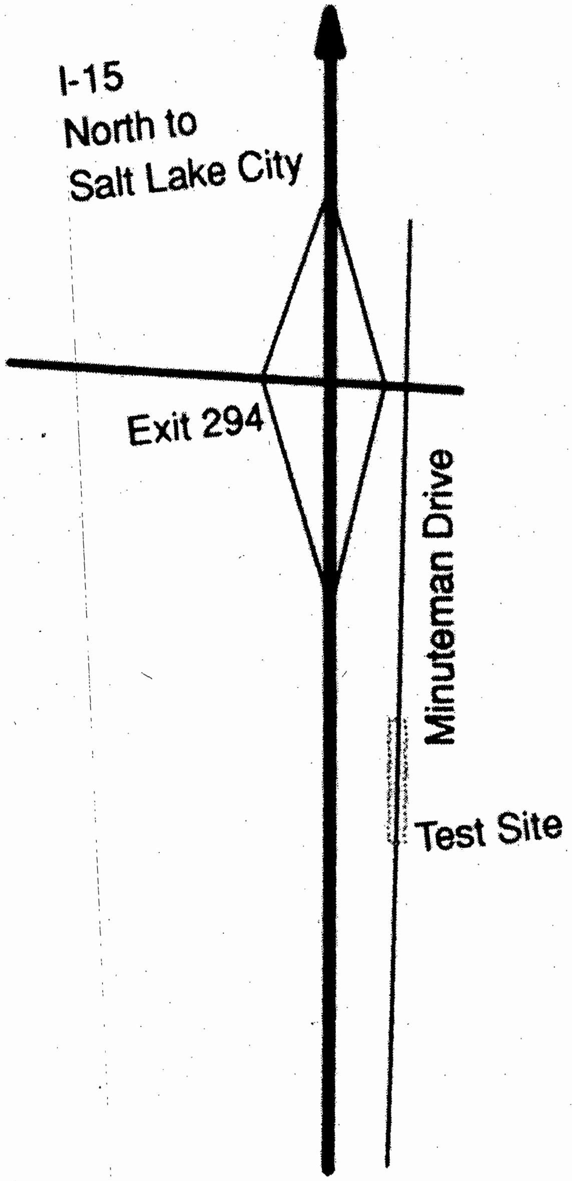

Figure 16. Repair Site in Draper, UT: I-15 [(3)]

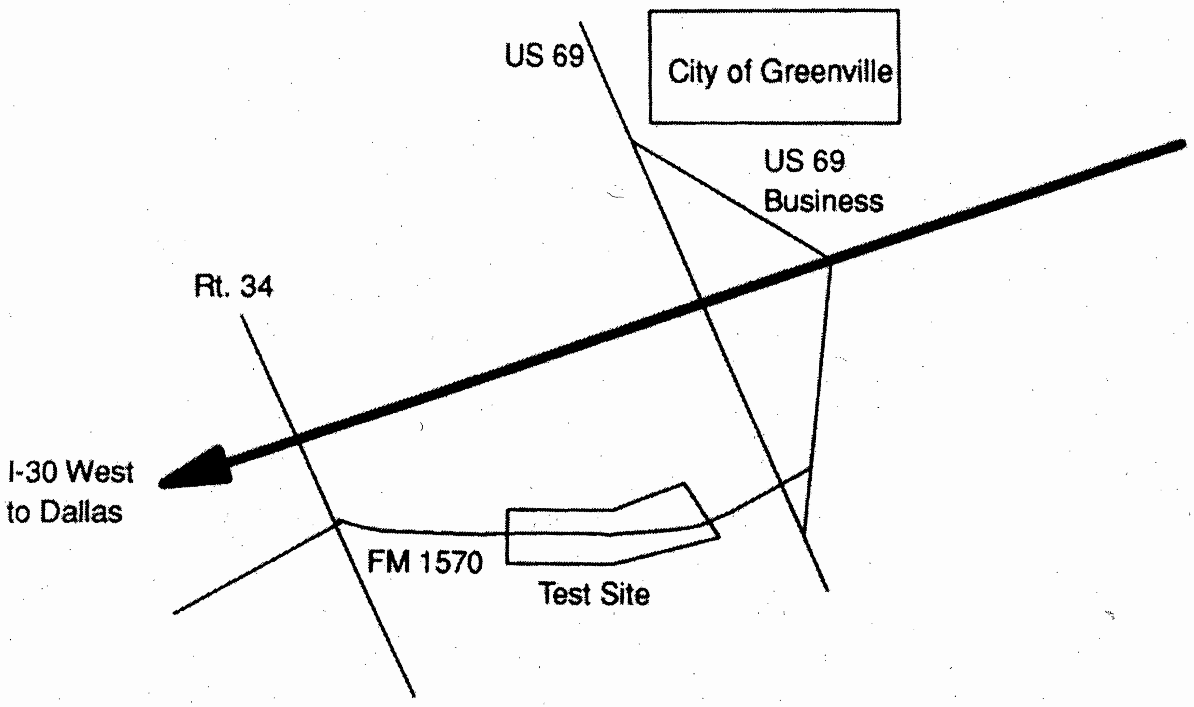

Figure 17. Repair Site in Greenville, TX: FM 1570 (3)

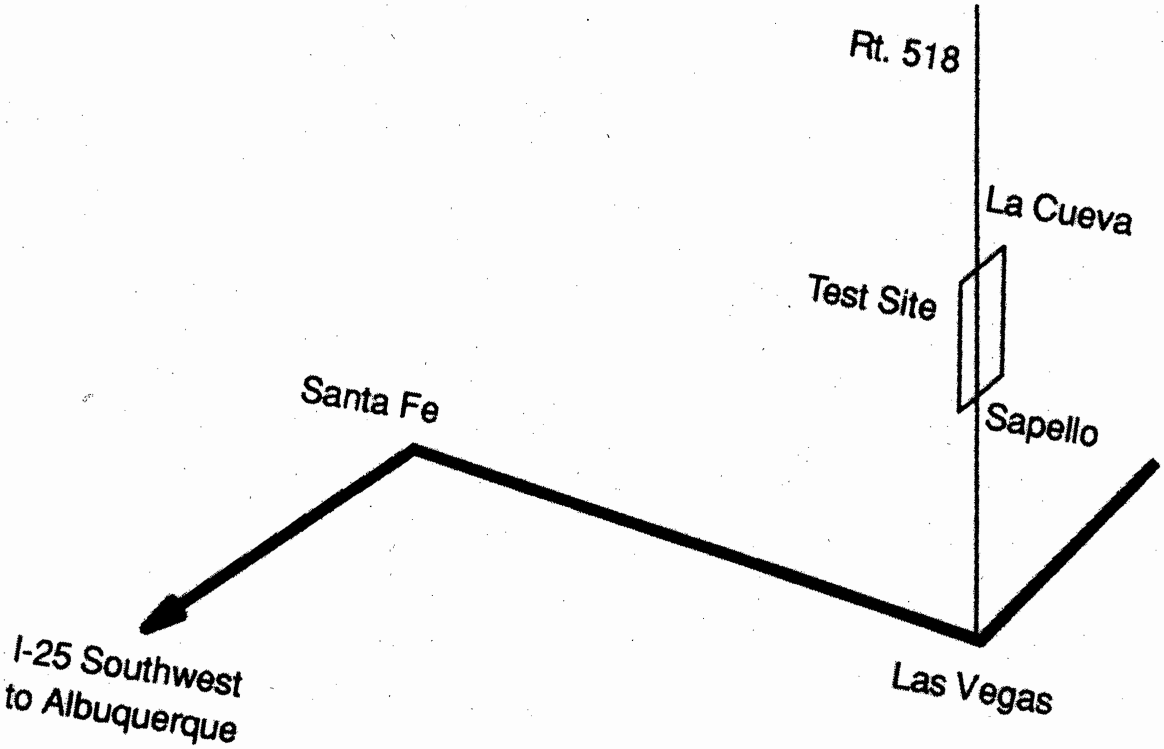

Figure 18. Repair Site in Las Vegas, NM: Route 518 (3)

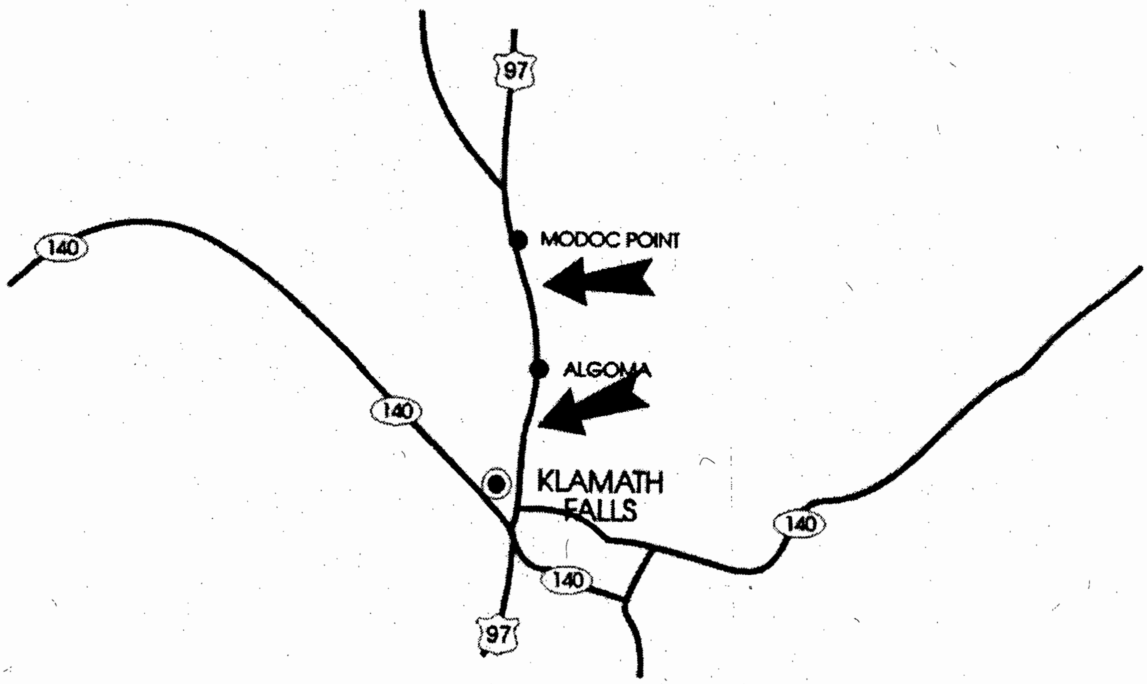

Figure 19. Repair Site in Modoc Point, OR: US 97 (3)

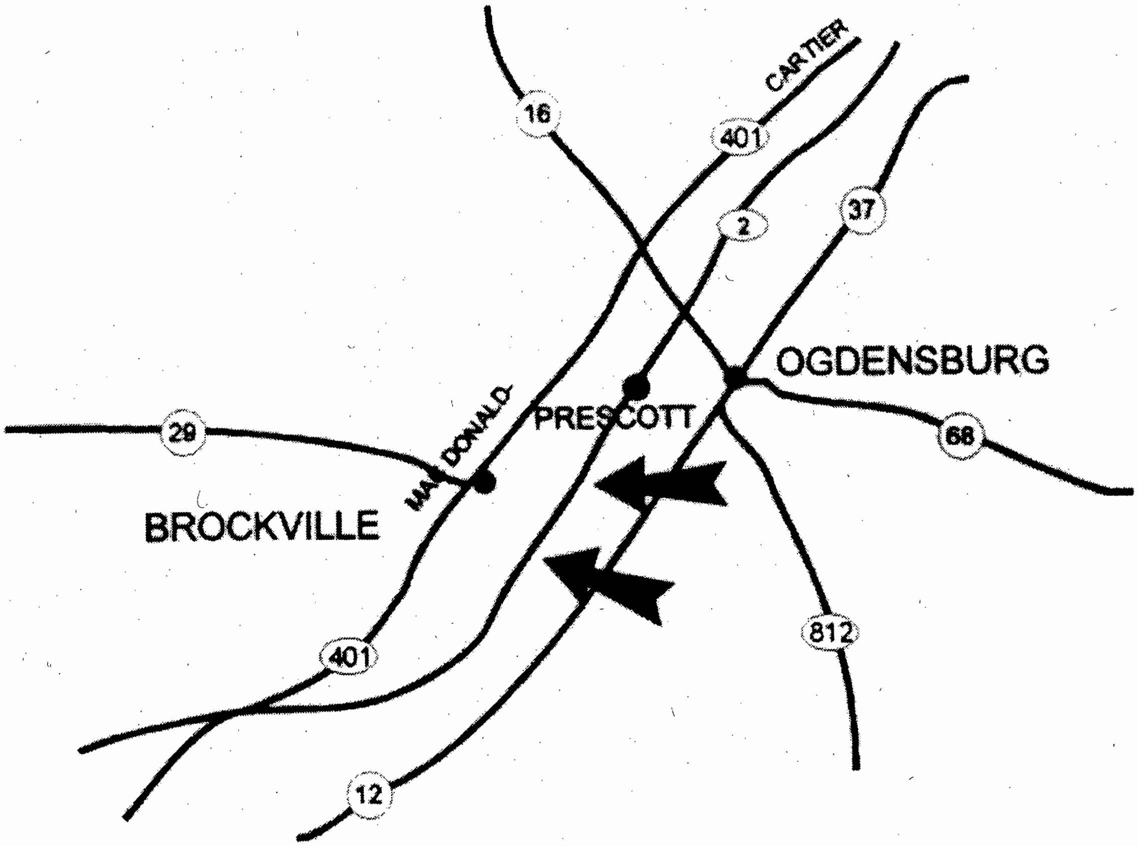

Figure 20. Repair Site in Prescott, ON: Route 2 (3)

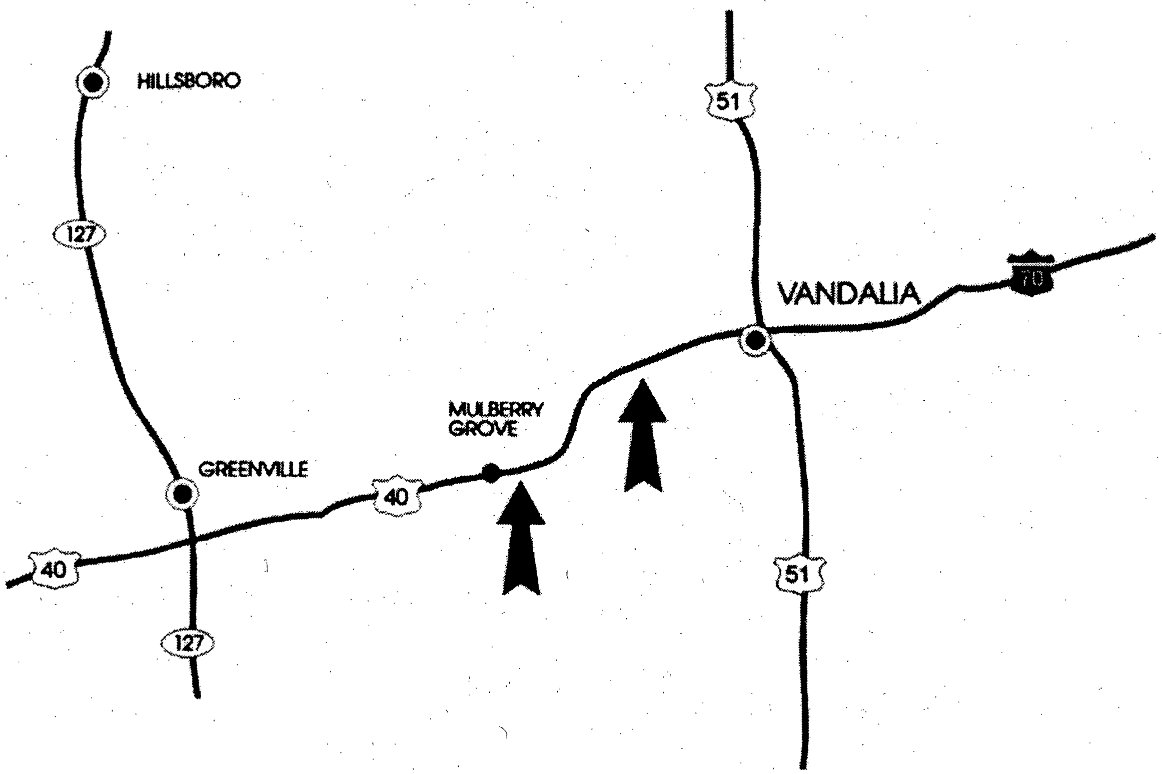

Figure 21. Repair Site in Vandalia, IL: I-70 (3)

Table 12. New Jersey South Region Field Testing – Twelve Month Subjective Performance Summary

Crew No.	UPM	QPR-2000	Wespro	Repave	Performix	S-K Mod	PermaPatch	IRR	IAR
410		10		0		10			
411	9	10	9	9	9	9	9	9	9
413	7	10	6	5					
414	4	8	8	5		5		5	
415		10	4	4					
416				0	9				
417		10		4					
419		10							
420		10					6		
421	10	10		1					
422									
423	8	10		5					
425		8		1					
426	10	7		2					
428	4	8		5					
430		10					10		
432		7		5					
434		10		9					
Avg.	**7**	**9**	**7**	**4**	**9**	**8**	**8**	**7**	**9**

Note: Blank box indicates material not evaluated by that crew

Table 13. Marshall Testing of Cold Patch Materials

Material	Sample ID	Weight (grams)	Max Load (pounds)	Flow (inches)	Prepared	Tested
QPR 2000	A1	1071	1359.0	0.0541	9/25/97	9/29/97
	A2	1078	1130.1	0.0480		
	A3	1081	1202.1	0.0630		
		Average	1230.4	0.0550		
UPM	B1	1068	1038.6	0.0411	8/6/97	8/7/97
	B2	1062	1162.9	0.0470		
	B3	1062	1138.6	0.0532		
		Average	1113.4	0.0471		
IAR	C1	1051	700.2	0.0630	8/7/97	8/11/97
	C2	1060	762.7	0.0522		
	C3	1058	709.0	0.0422		
		Average	724.0	0.0525		
SKMOD	D1	1062	1075.4	0.0572	8/8/97	8/11/97
	D2	1050	1077.6	0.0461		
	D3	1055	1052.2	0.0651		
		Average	1068.4	0.0561		
Performix	E1	1058	1129.0	0.0753	8/12/97	8/14/97
	E2	1065	1065.1	0.0751		
	E3	1079	1136.6	0.0701		
		Average	1110.2	0.0735		
WesPro	F1	1090	1886.8	0.0362	8/13/97	8/14/97
	F2	1092	1859.6	0.0532		
	F3	1078	1885.8	0.0480		
		Average	1877.4	0.0458		
		Corrected	2234.1	0.0458		
PermaPatch	G1	1098	1481.0	0.0480	8/14/97	8/22/97
	G2	1077	1455.3	0.0522		
	G3	1084	1467.2	0.0630		
		Average	1467.8	0.0544		

* A factor of 1.19 applied to the Marshall Stability of Wespro for height variance according to ASTM D1559

** All other materials were within the tolerances for no height correction.

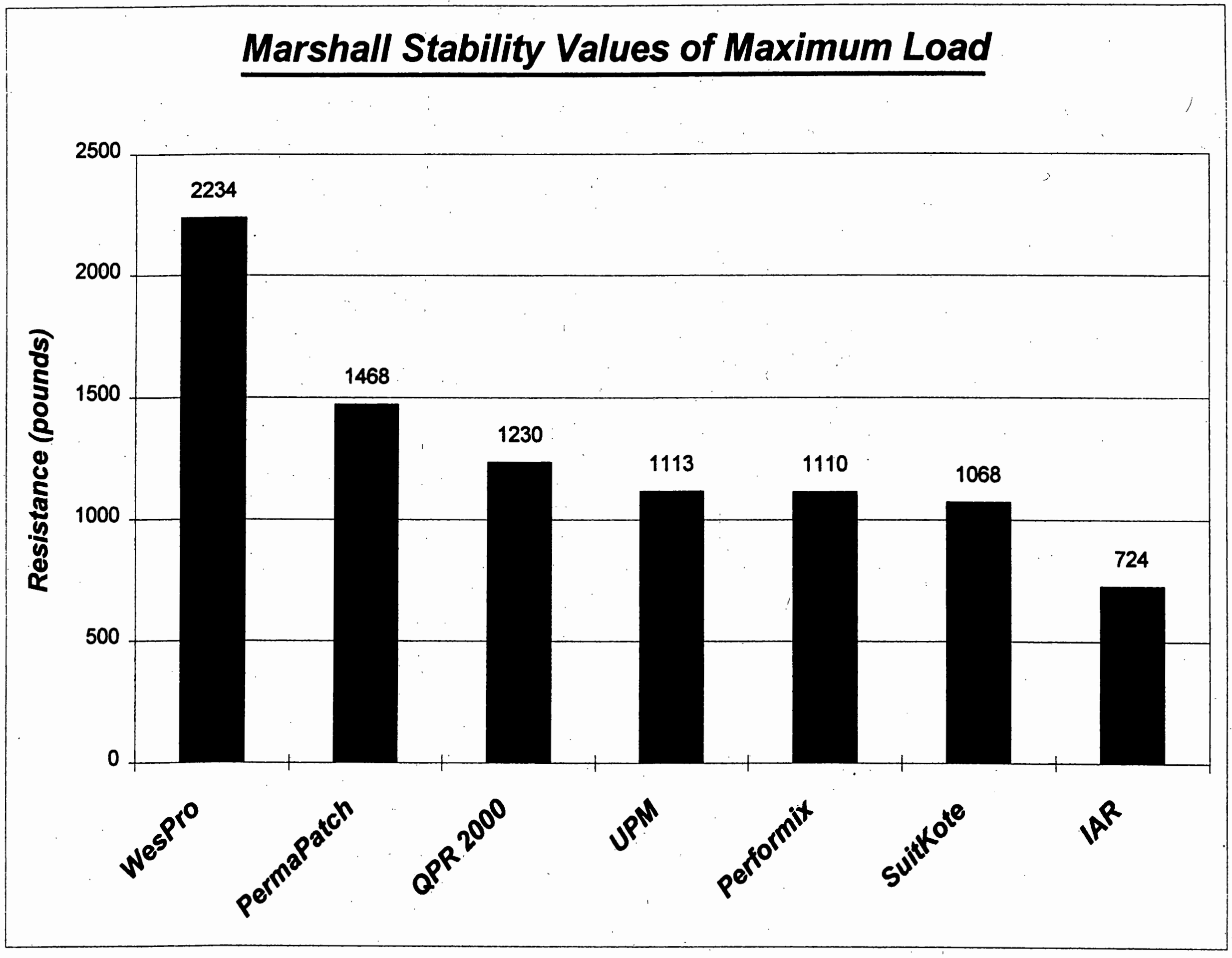

Figure 22. Marshall Stability Values of Maximum Load

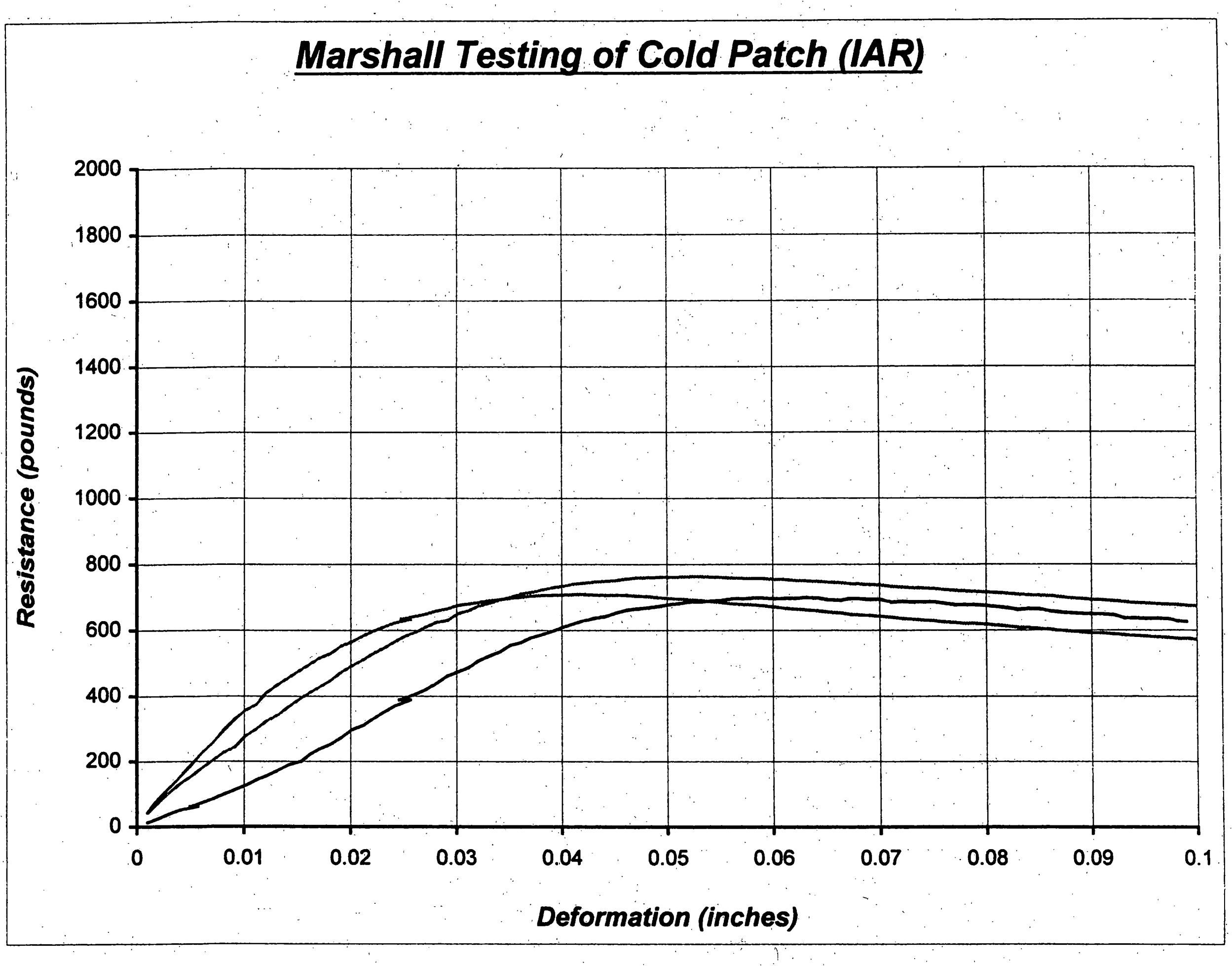

Figure 23. Marshall Testing of Cold patch (IAR)

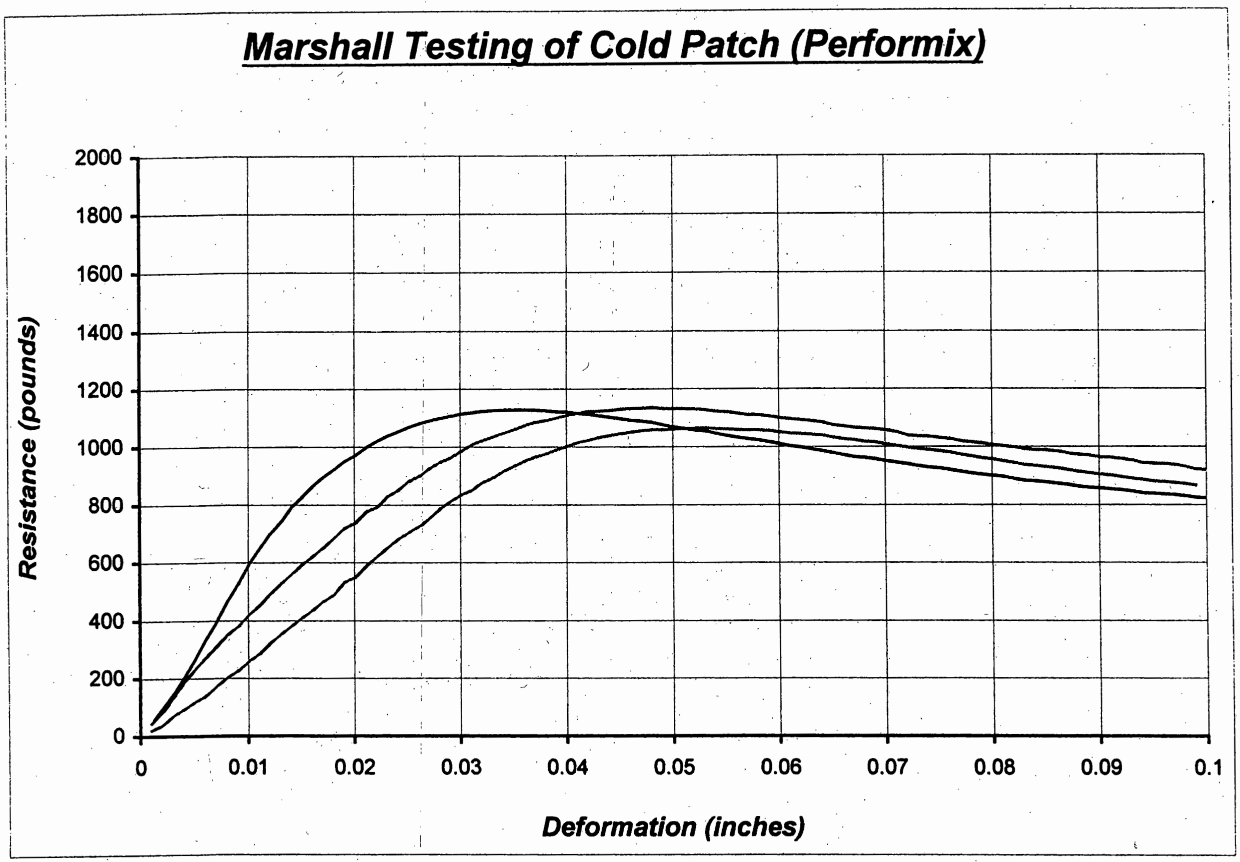

Figure 24. Marshall Testing of Cold patch (Performix)

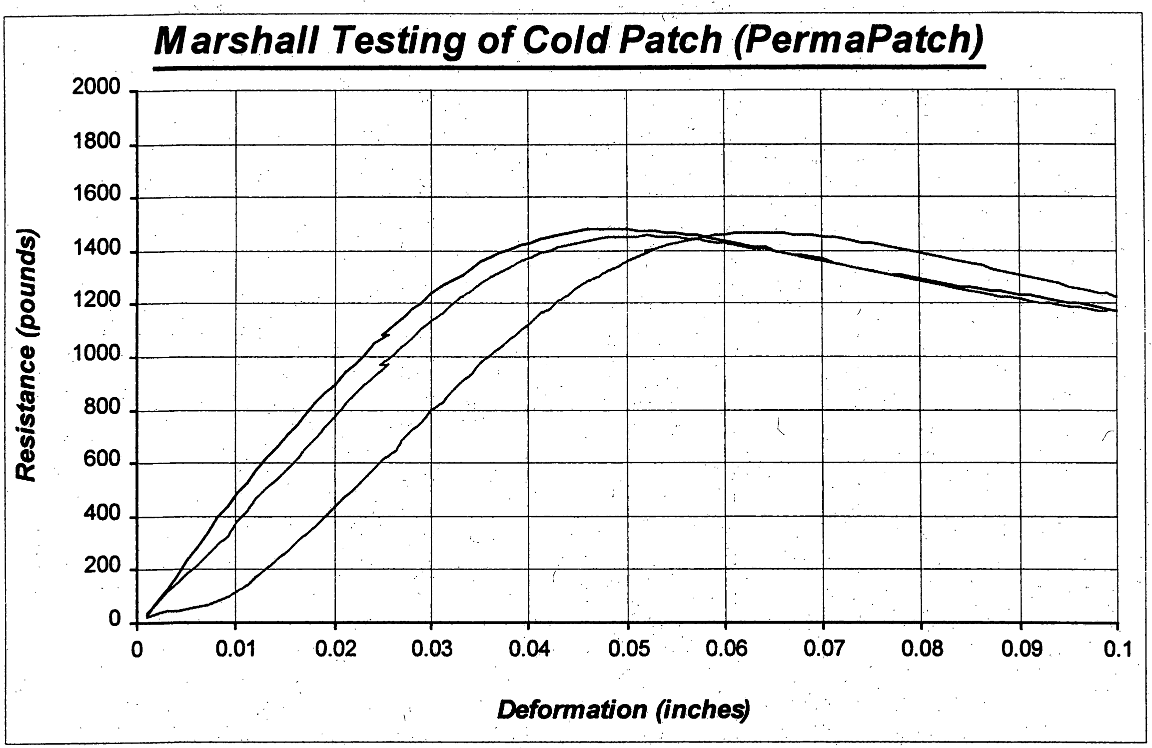

Figure 25. Marshall Testing of Cold patch (PermaPatch)

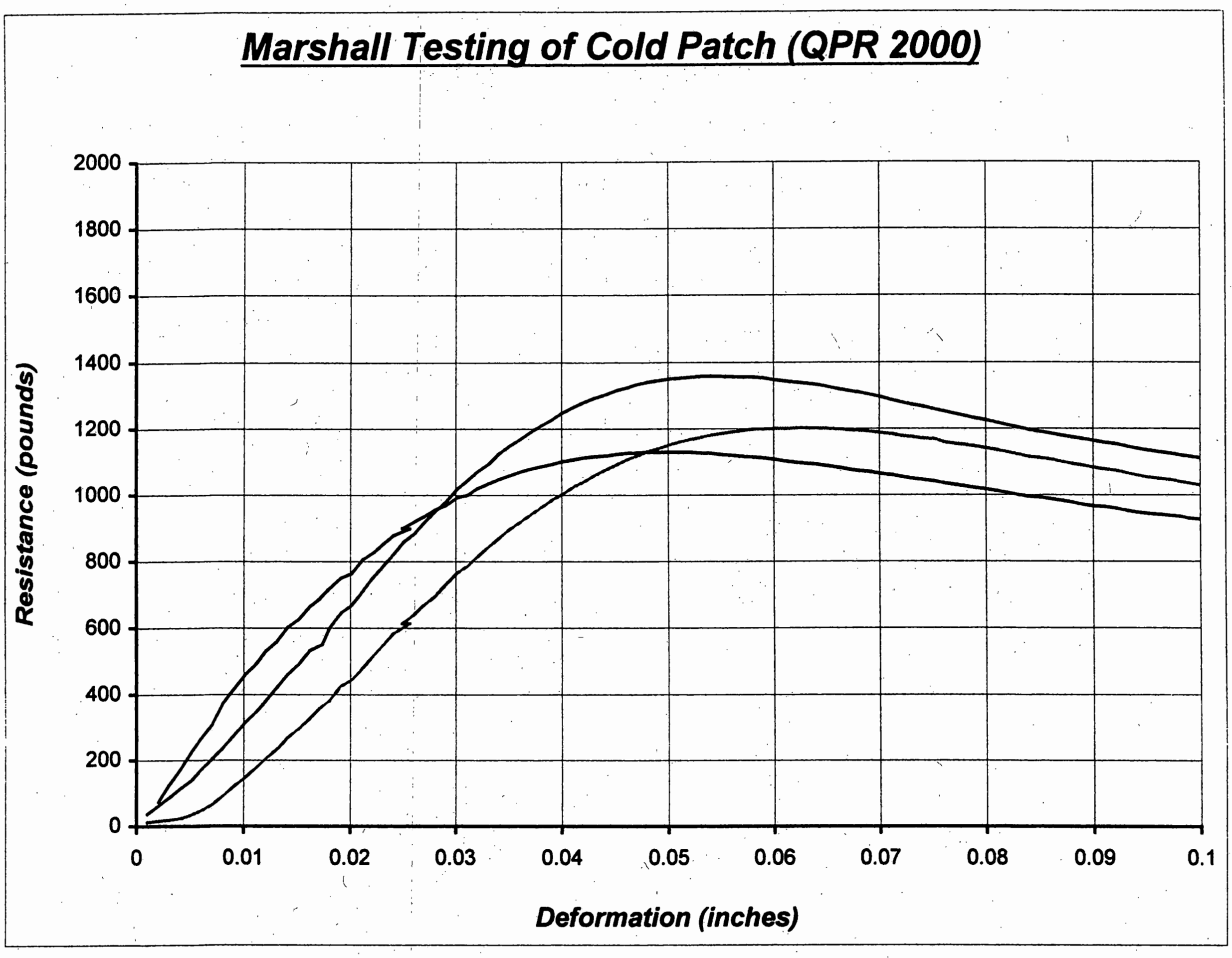

Figure 26. Marshall Testing of Cold Patch (QPR 2000)

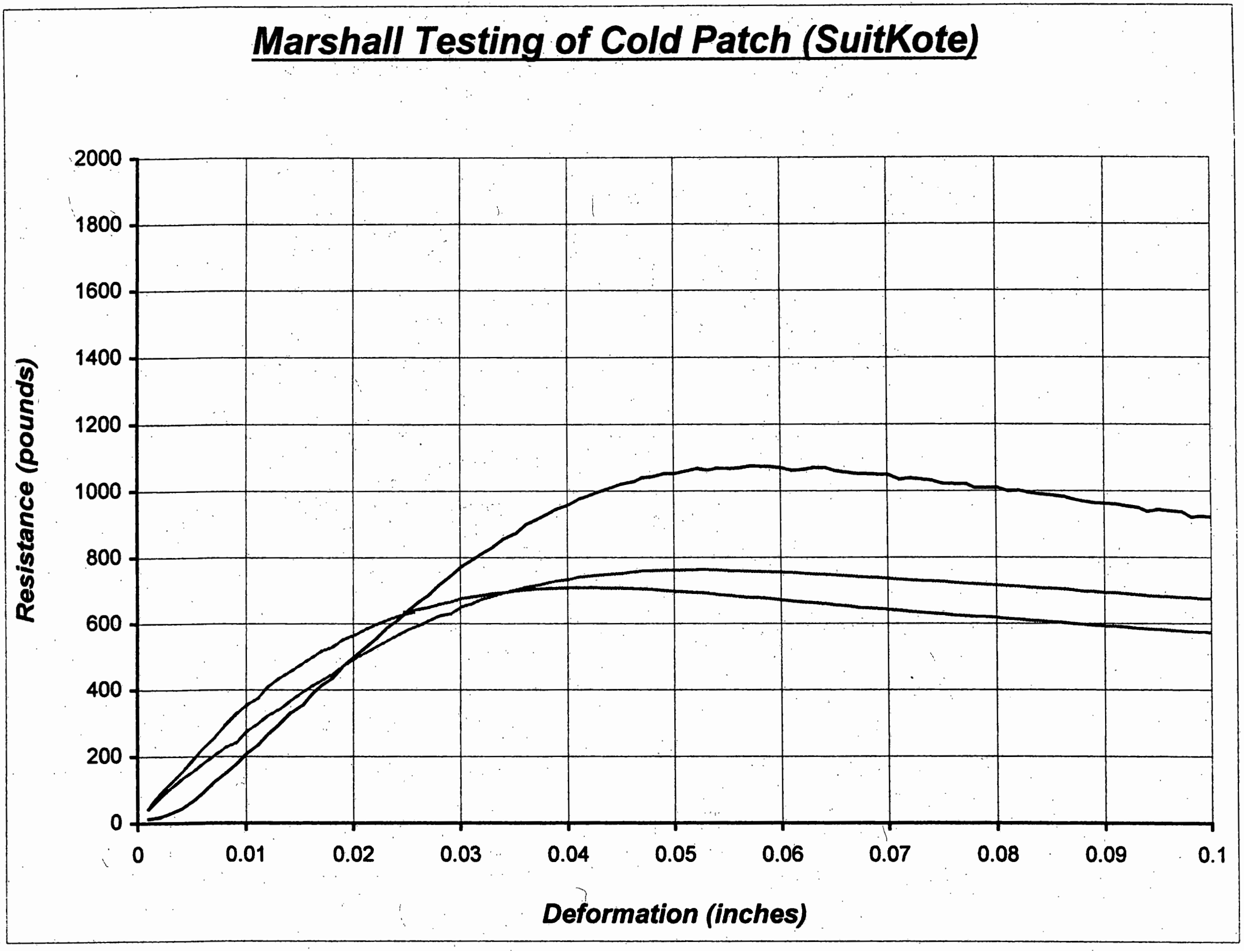

Figure 27. Marshall Testing of Cold Patch (SuitKote)

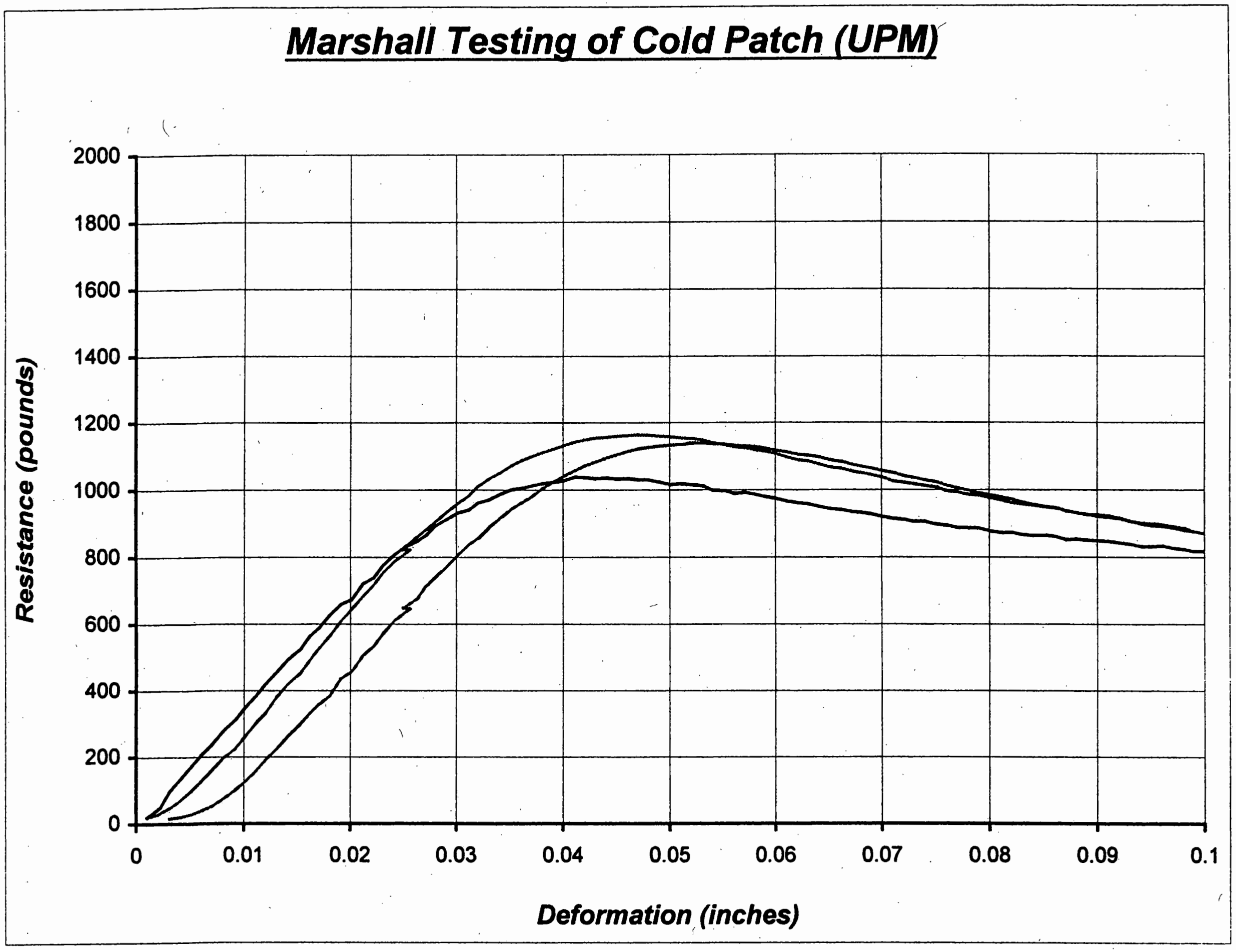

Figure 28. Marshall Testing of Cold Patch (UPM)

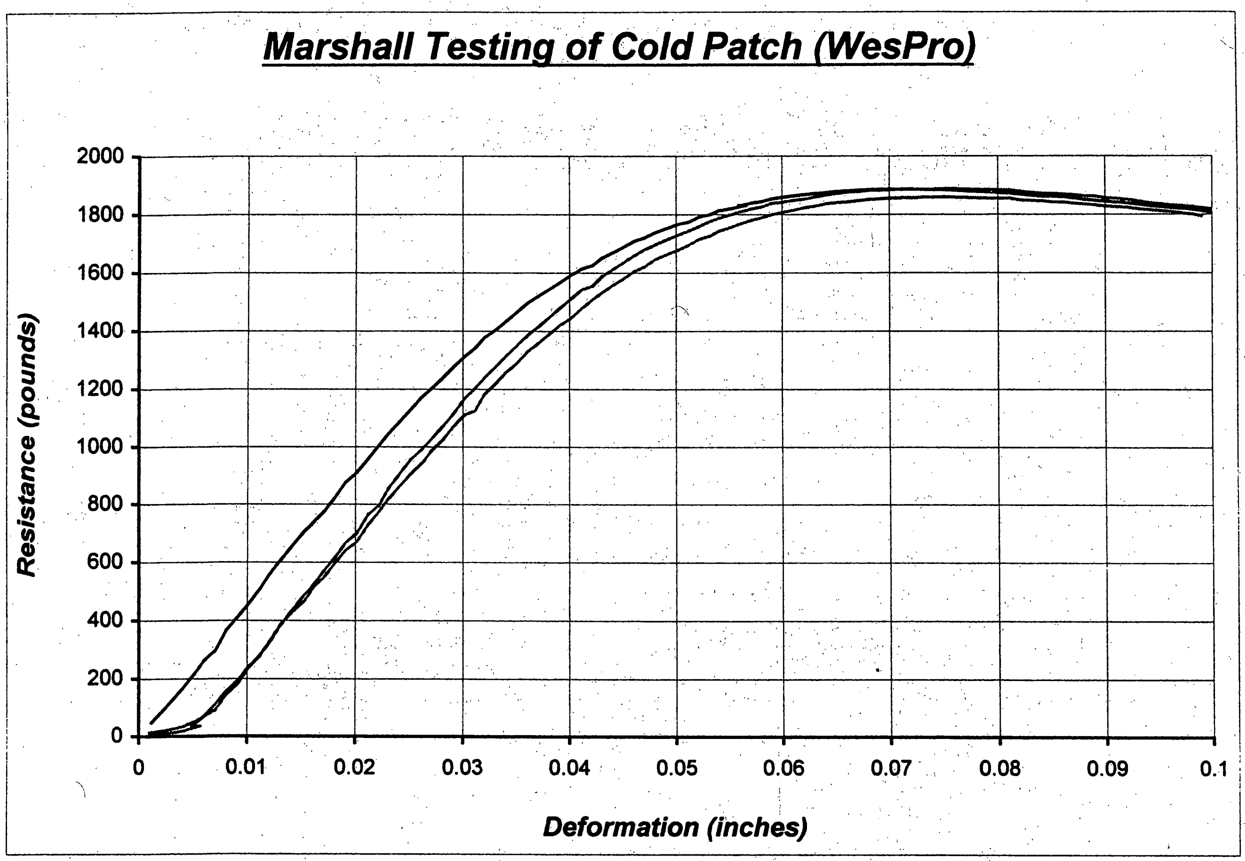

Figure 29. Marshall Testing of Cold patch (WesPro)

Table 14. Blade Penetration Testing of Cold Patch Materials

Material	Test Location	Max Load (pounds)	Prepared	Tested
QPR 2000	Forward	122.1	9/29/97	9/30/97
	Center	70.3		
	Aft	83.0		
	Forward	111.2		
	Center	67.3		
	Aft	56.2		
		85.0		
UPM	Forward	167.3	9/30/97	10/1/97
	Center	87.8		
	Aft	97.7		
	Forward	150.8		
	Center	103.9		
	Aft	213.3		
		136.8		
IAR	Forward	207.6	9/18/97	9/22/97
	Center	98.4		
	Aft	156.7		
	Forward	223.1		
	Center	105.2		
	Aft	109.9		
		150.2		
SuitKote	Forward	-	8/17/97	8/18/97
	Center	178.2		
	Aft	-		
	Forward	215.4		
	Center	233.3		
	Aft	145.1		
		193.0		
Performix	Forward	201.0	9/22/97	9/23/97
	Center	164.9		
	Aft	151.0		
	Forward	181.5		
	Center	220.0		
	Aft	151.8		
		178.4		
WesPro	Forward	166.3	9/23/97	9/25/97
	Center	125.4		
	Aft	96.6		
	Forward	122.4		
	Center	122.7		
	Aft	213.3		
		141.1		
PermaPatch	Forward	286.0	9/25/97	9/29/97
	Center	123.9		
	Aft	143.4		
	Forward	96.0		
	Center	72.7		
	Aft	70.0		
		132.0		

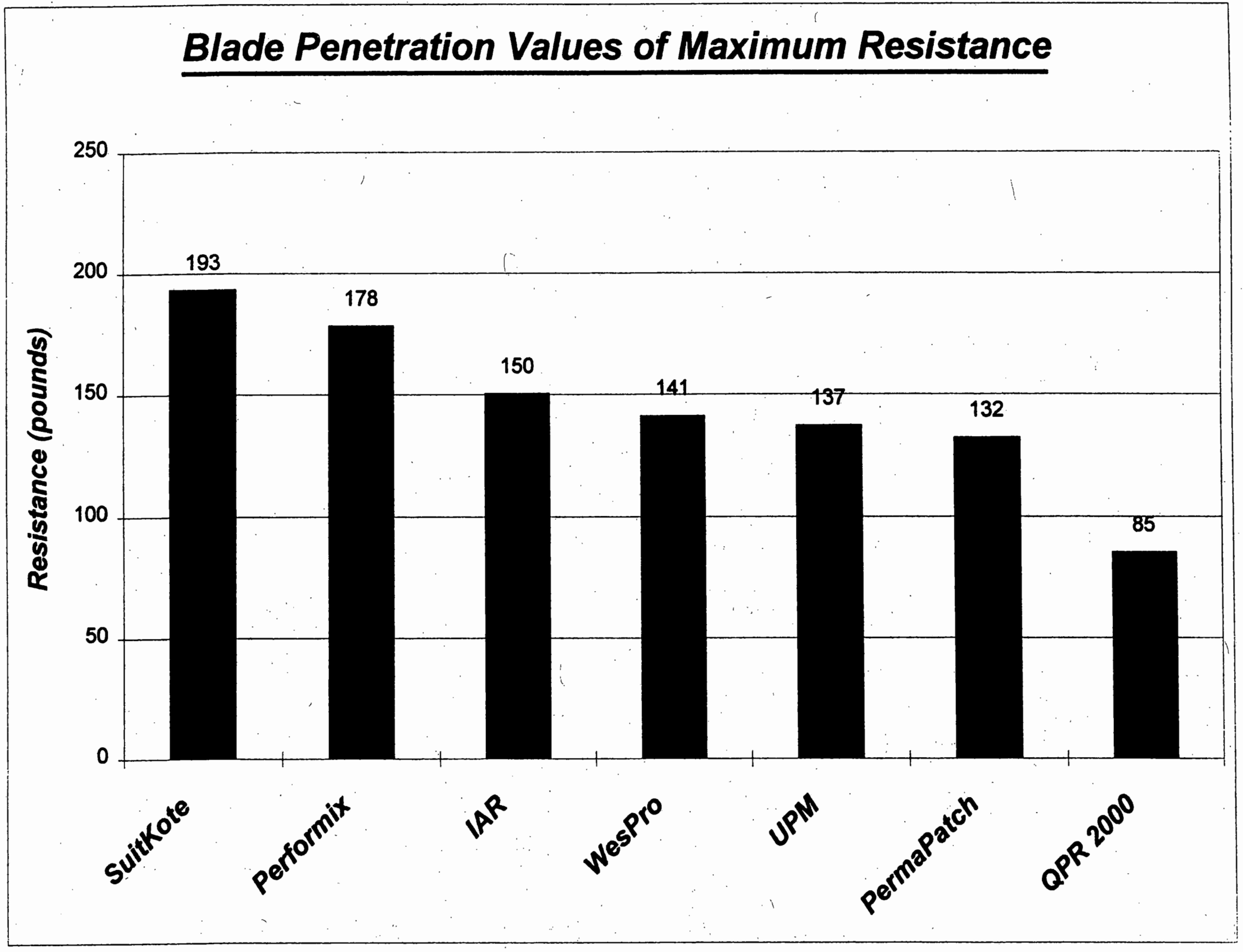

Figure 30. Blade Penetration Values of Maximum Resistance

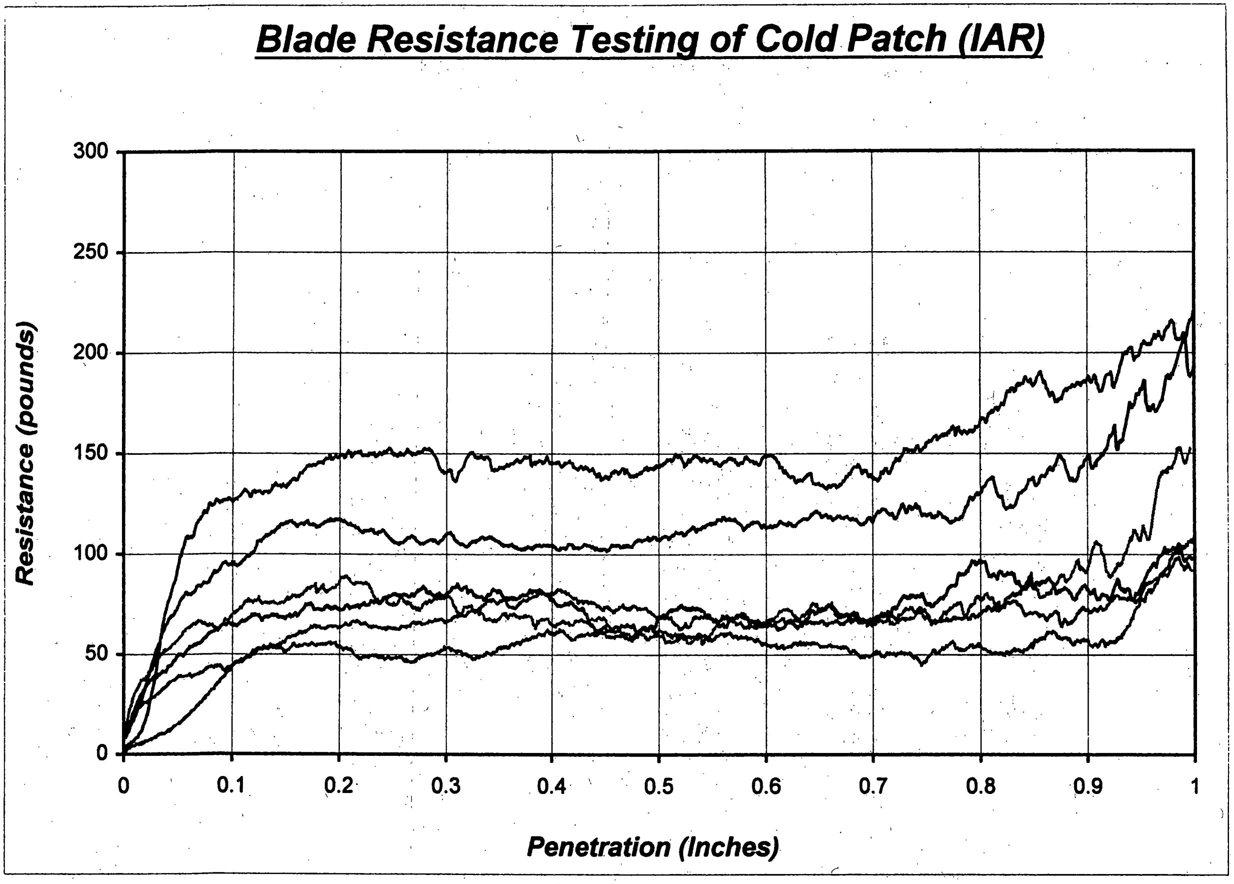

Figure 31. Blade Resistance Testing of Cold Patch (IAR)

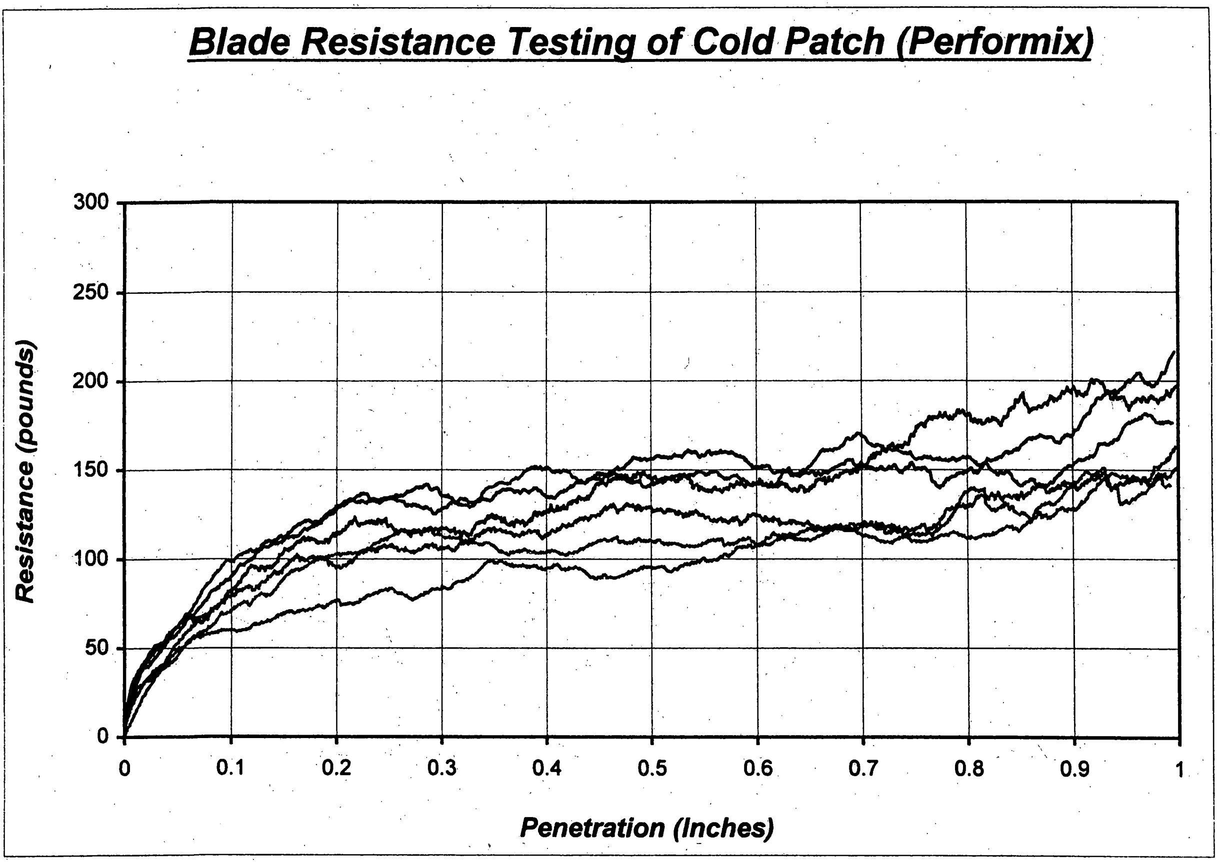

Figure 32. Blade Resistance Testing of Cold Patch (Performix)

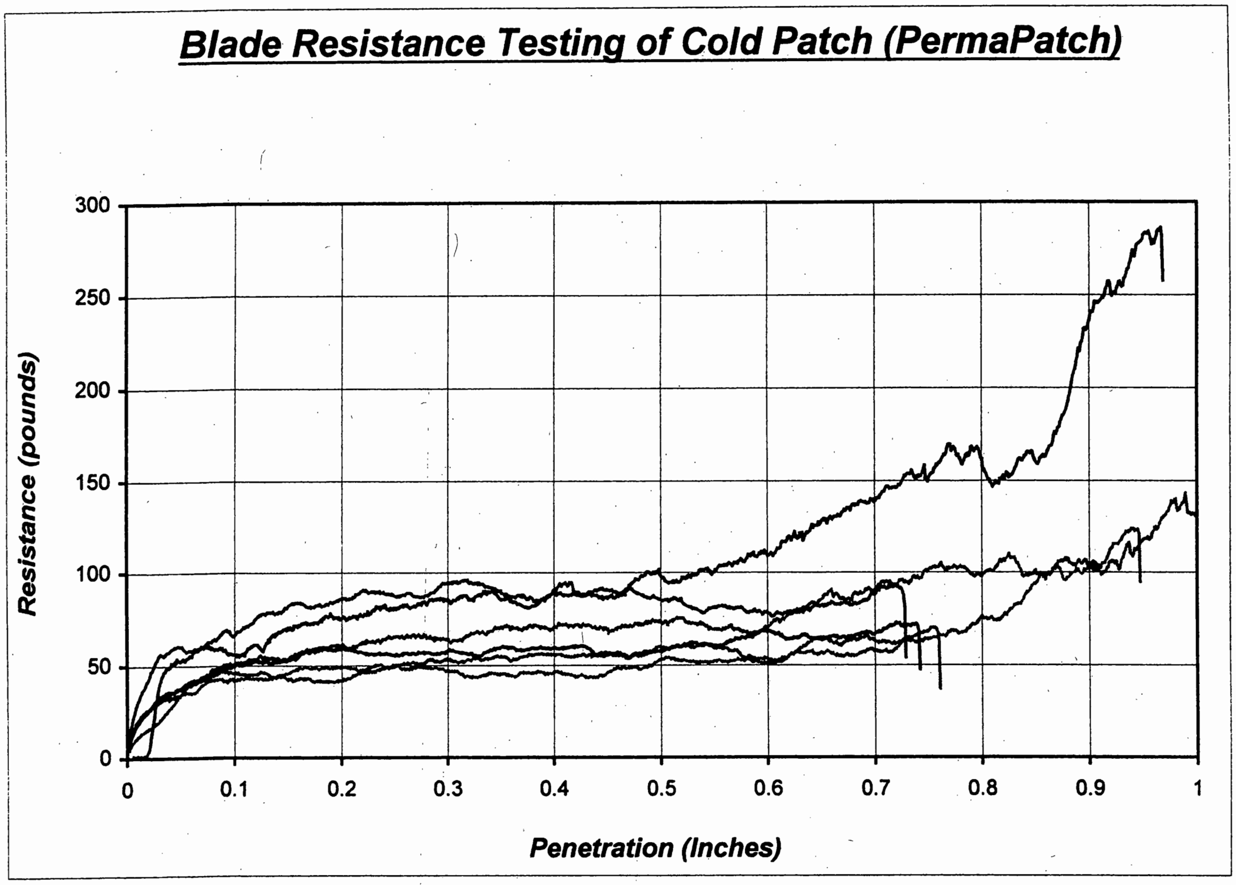

Figure 33. Blade Resistance Testing of Cold Patch (PermaPatch)

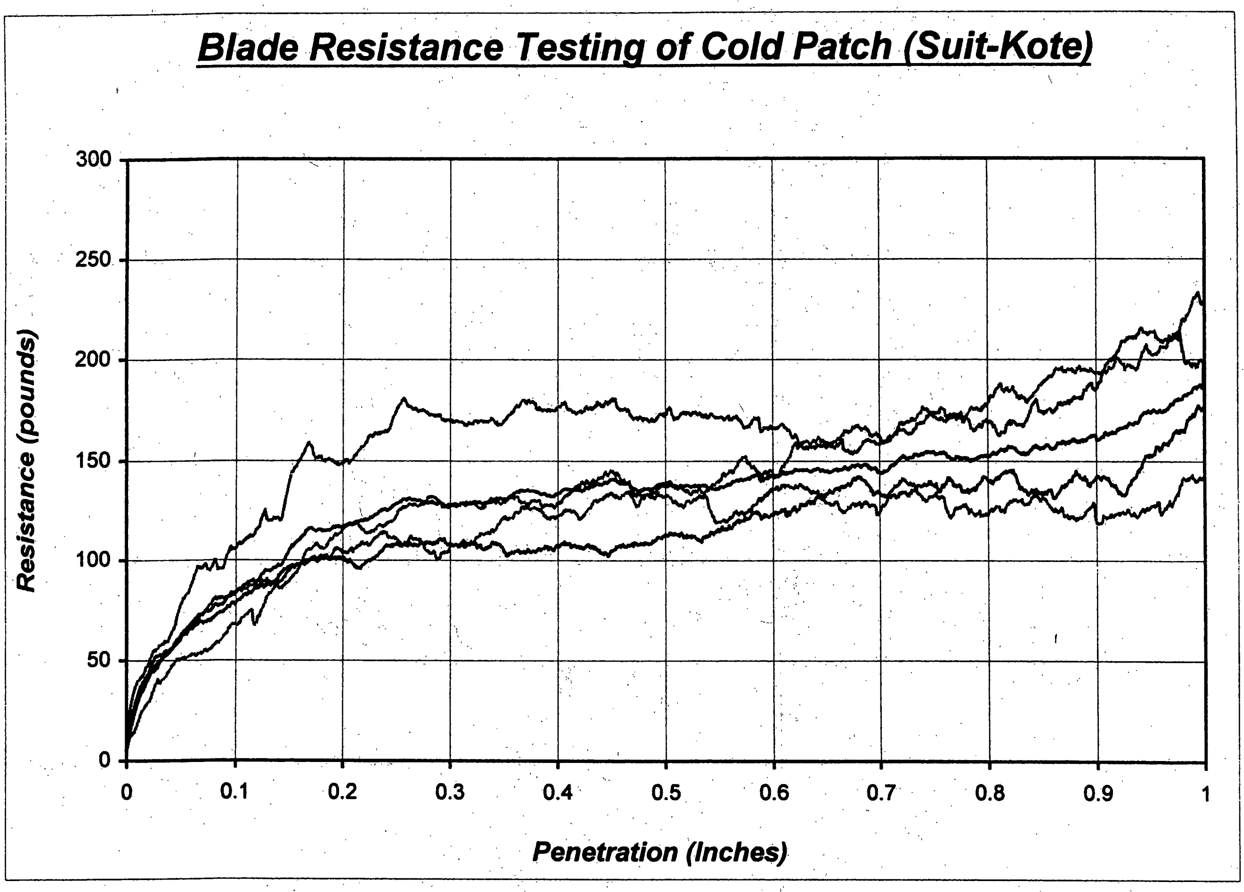

Figure 34. Blade Resistance Testing of Cold Patch (SuitKote)

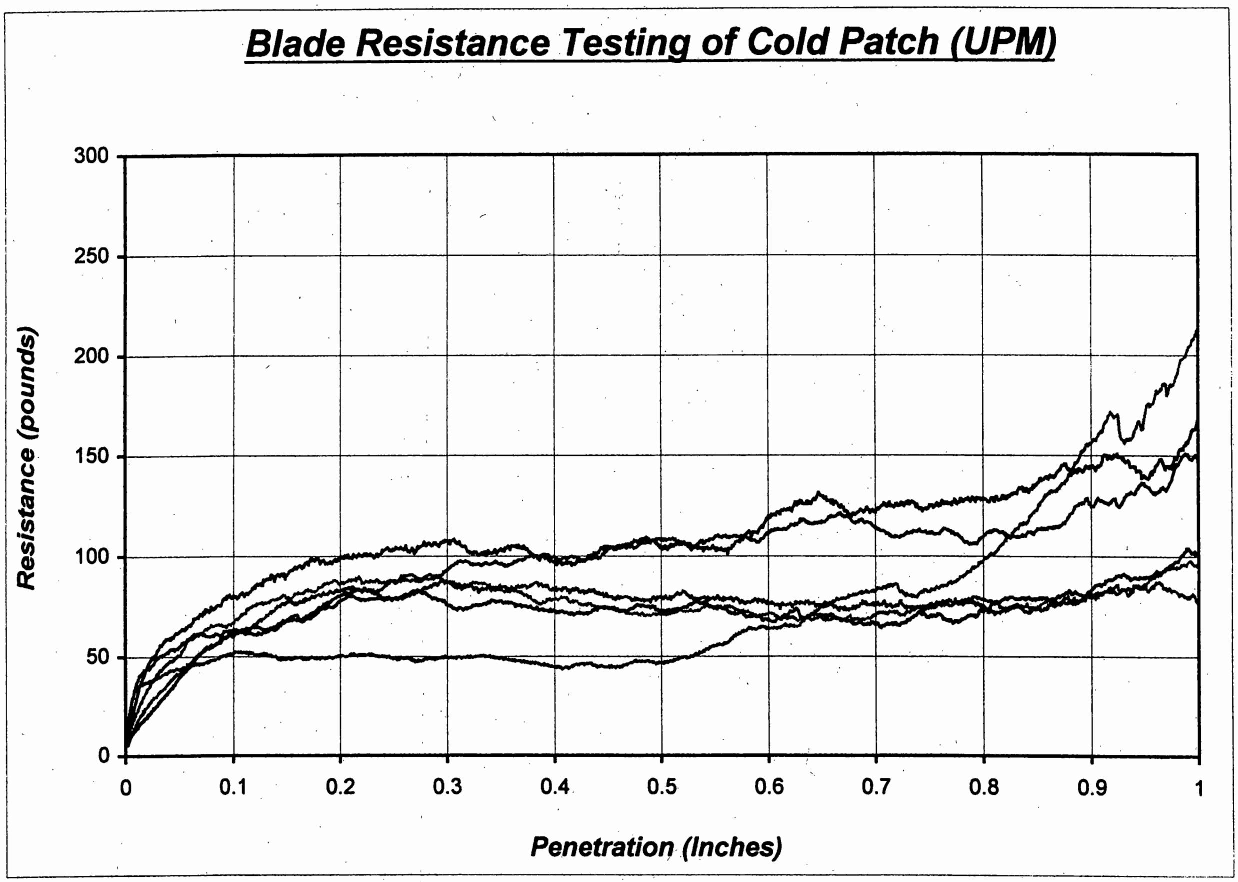

Figure 35. Blade Resistance Testing of Cold Patch (UPM)

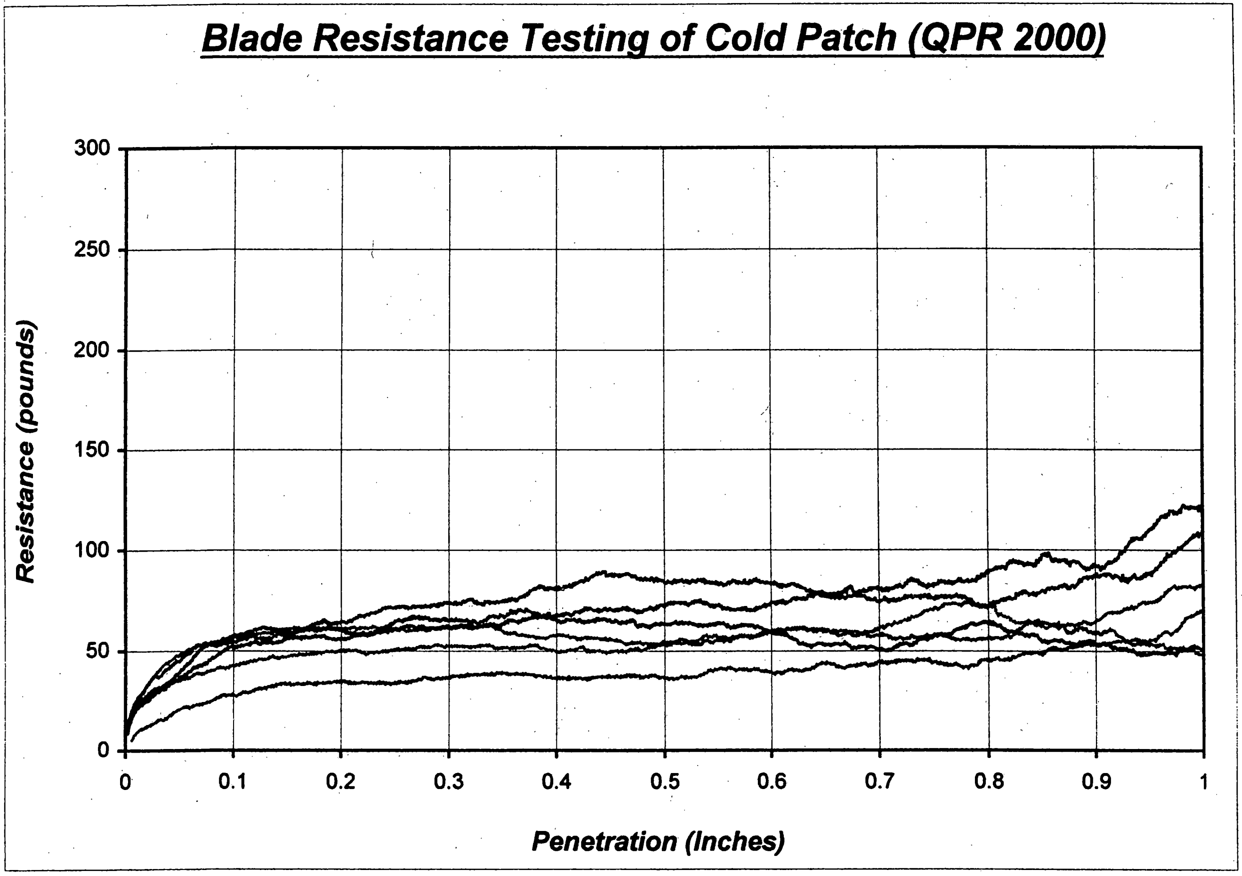

Figure 36. Blade Resistance Testing of Cold Patch (QPR 2000)

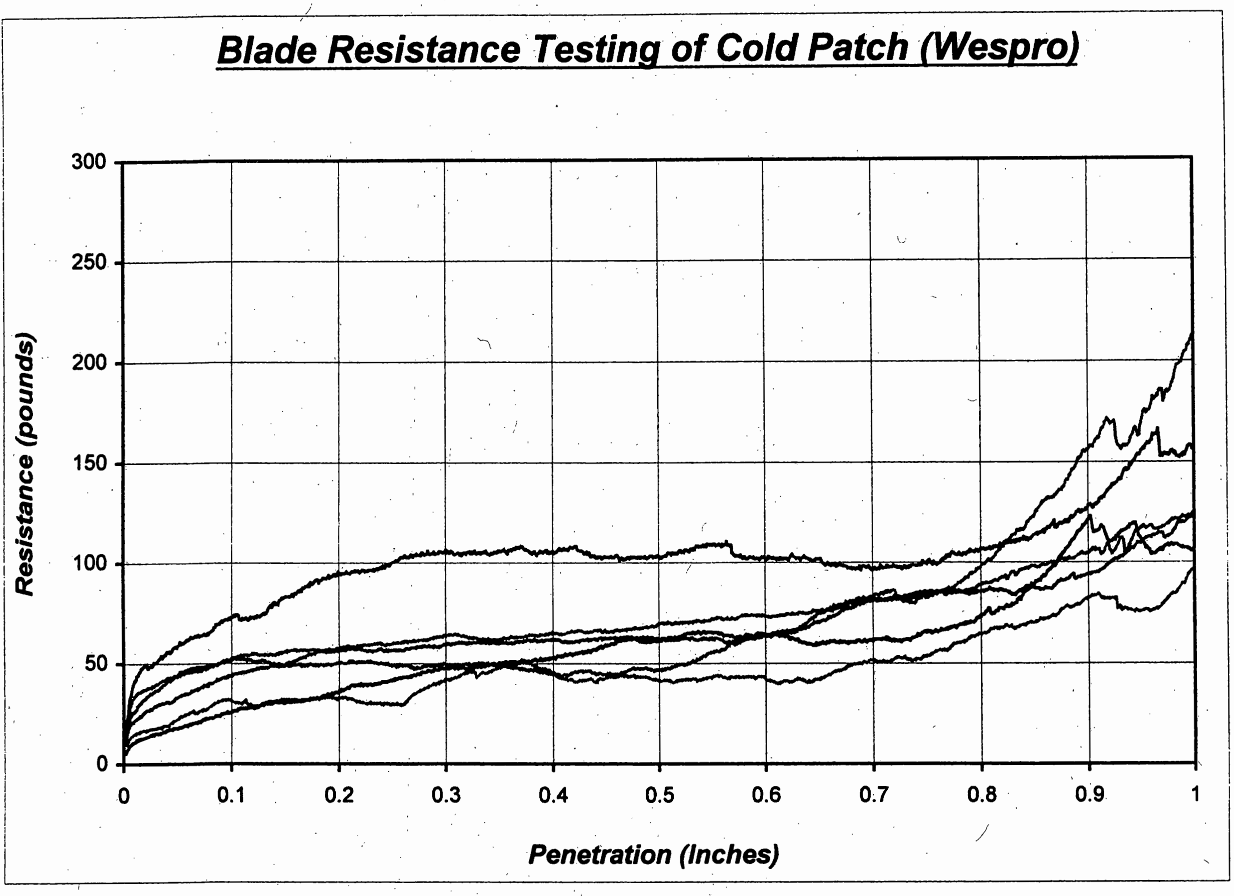

Figure 37. Blade Resistance Testing of Cold Patch (Wespro)

Table 15. Rolling Sieve Testing of Cold Patch Materials

Material	Sample	Mass Retained (grams)	Mass Passing (grams)	Percentage Retained (%)
	1	58	769	7.0%
Wespro	2	68	808	7.8%
			Average	[illegible]
	1	254	644	28.3%
UPM	2	104	670	13.4%
	3	192	622	23.6%
			Average	[illegible]
	1			N/A
IAR	2			N/A
	3			N/A
			Average	[illegible]
	1	808	41	95.2%
SuitKote	2	830	36	95.8%
	3	722	31	95.9%
			Average	[illegible]
	1	766	10	98.7%
Performix	2	746	12	98.4%
	3	842	19	97.8%
			Average	[illegible]
	1	676	47	93.5%
QPR	2	684	49	93.3%
	3	669	42	94.1%
			Average	93.6%
	1	722	61	92.2%
PermaPatch	2	775	74	91.3%
	3	665	62	91.5%
			Average	[illegible]

Notes:

(1) IAR material was unresponsive to providing more material to perform this test

(2) 2 Samples were tested for Wespro

Figure 38. Performix- 2 Month Inspection, Rt. 21 SB MP 11.8 Passaic

Figure 39. Performix 6 Month Inspection, Rt. 21 SB MP 11.8 Passaic

Figure 40. Performix 6 Month Inspection, Rt. 21 SB MP 11.8 Passaic

Figure 41. Performix 6 Month Inspection, Rt. 21 SB 11.8 Passaic

Figure 42. Permapatch 2 Month Inspection, #1 Rt. 21 NB Passaic, #2 Rt. 1&9 NB MP 49.5 Passaic

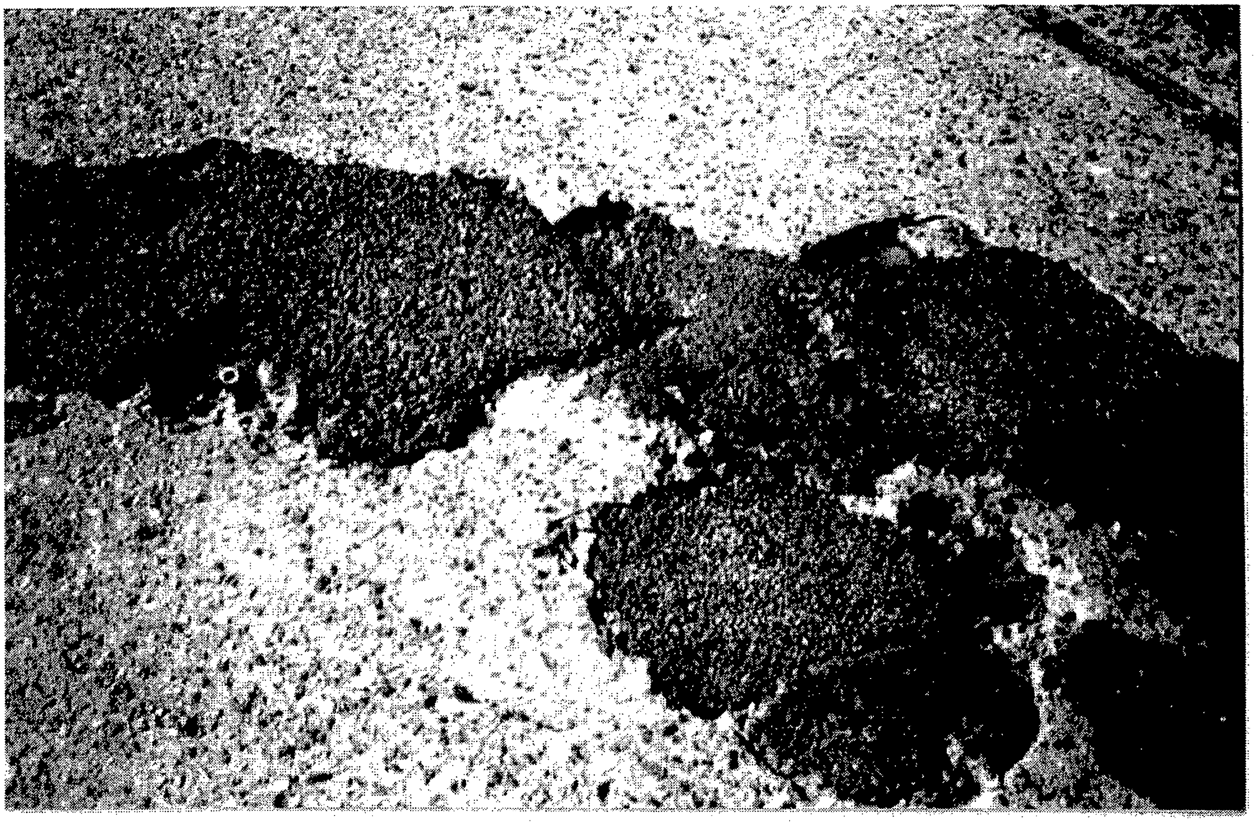

Figure 43. QPR 2 Month Inspection, Rt. 21 SB MP 12.0 Passaic

Figure 44. QPR 2 Month Inspection, Rt 21 SB MP 12.0 Passaic

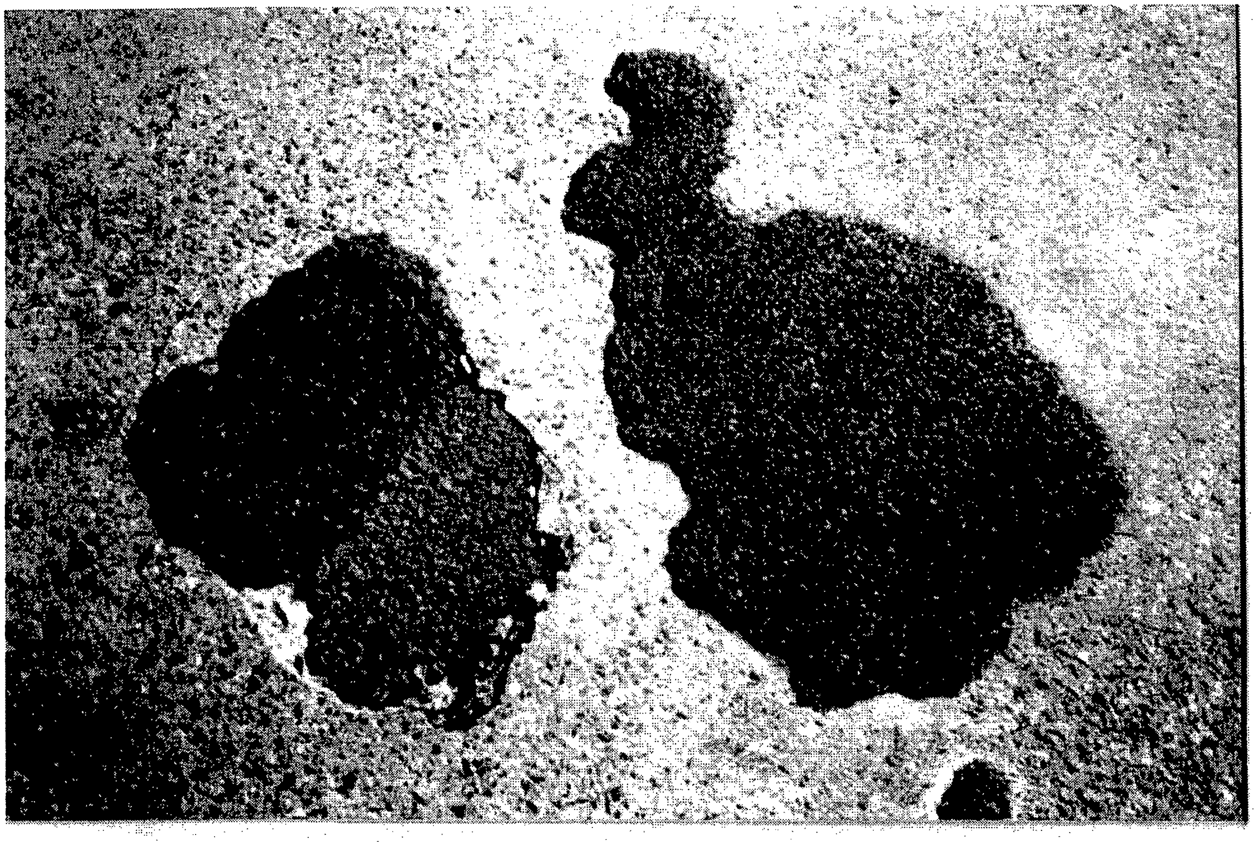

Figure 45. QPR 2 Month Inspection, Rt. 21 SB MP 12.0 Passaic

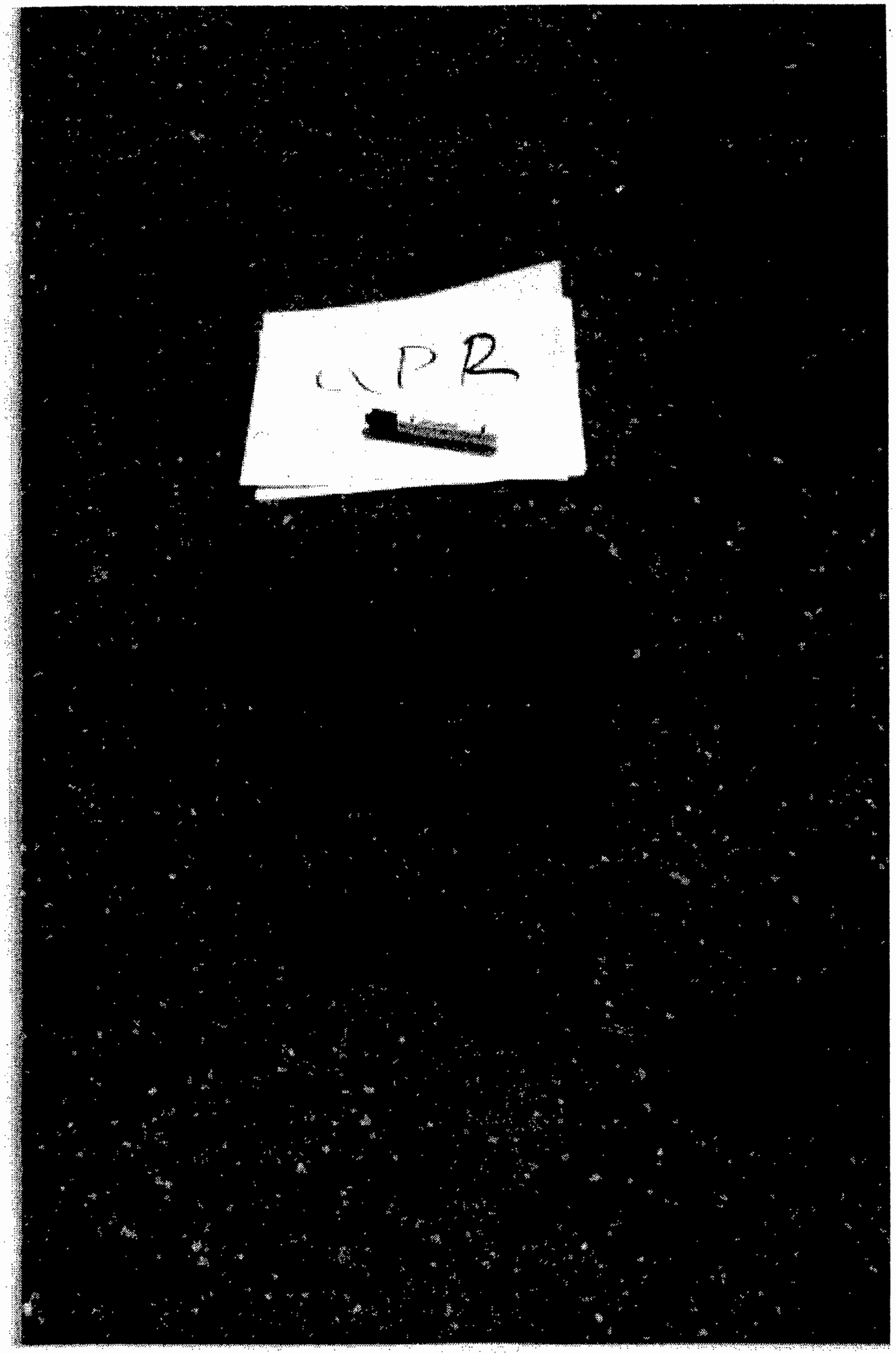

Figure 46. QPR 6 Month Inspection, Rt. 21 SB MP 12.0 Passaic

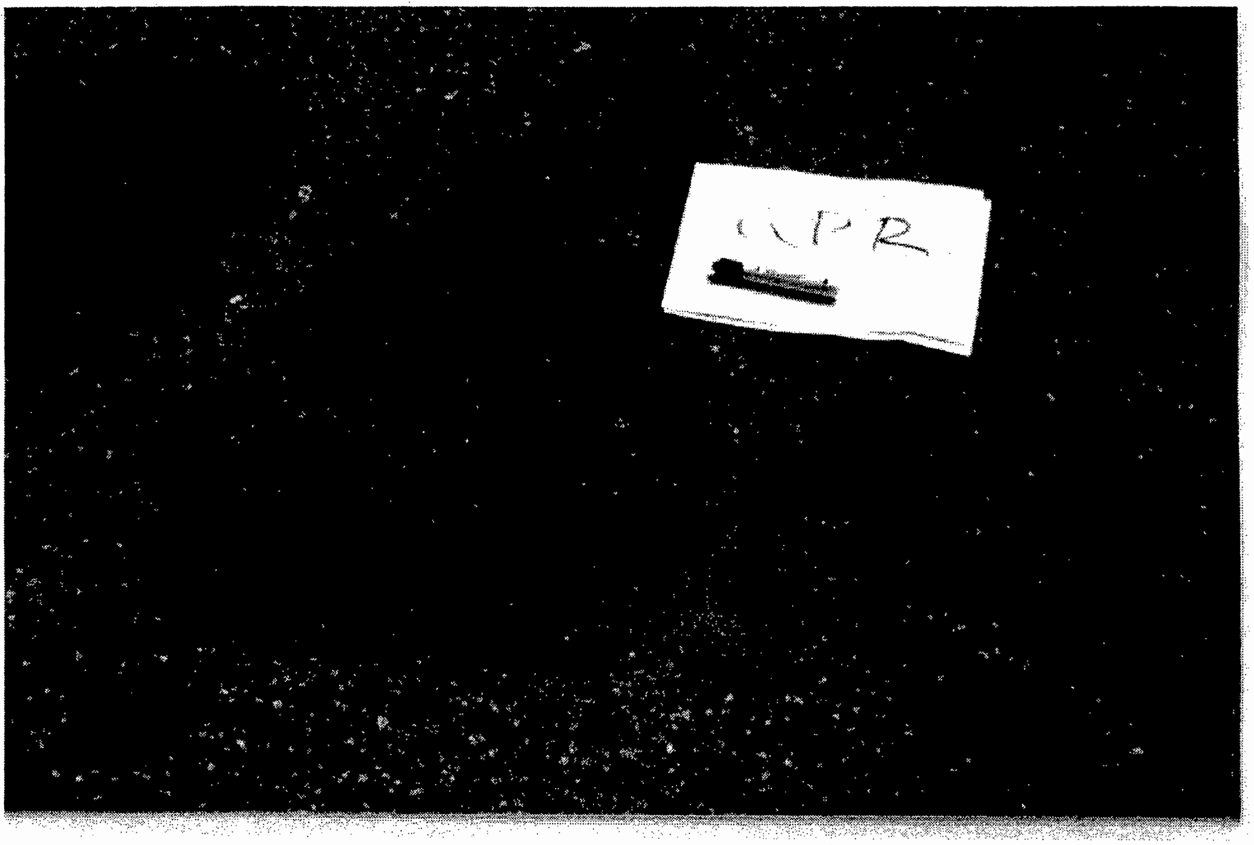

Figure 47. QPR 6 Month Inspection, Rt. 21 SB MP 12.0 Passaic

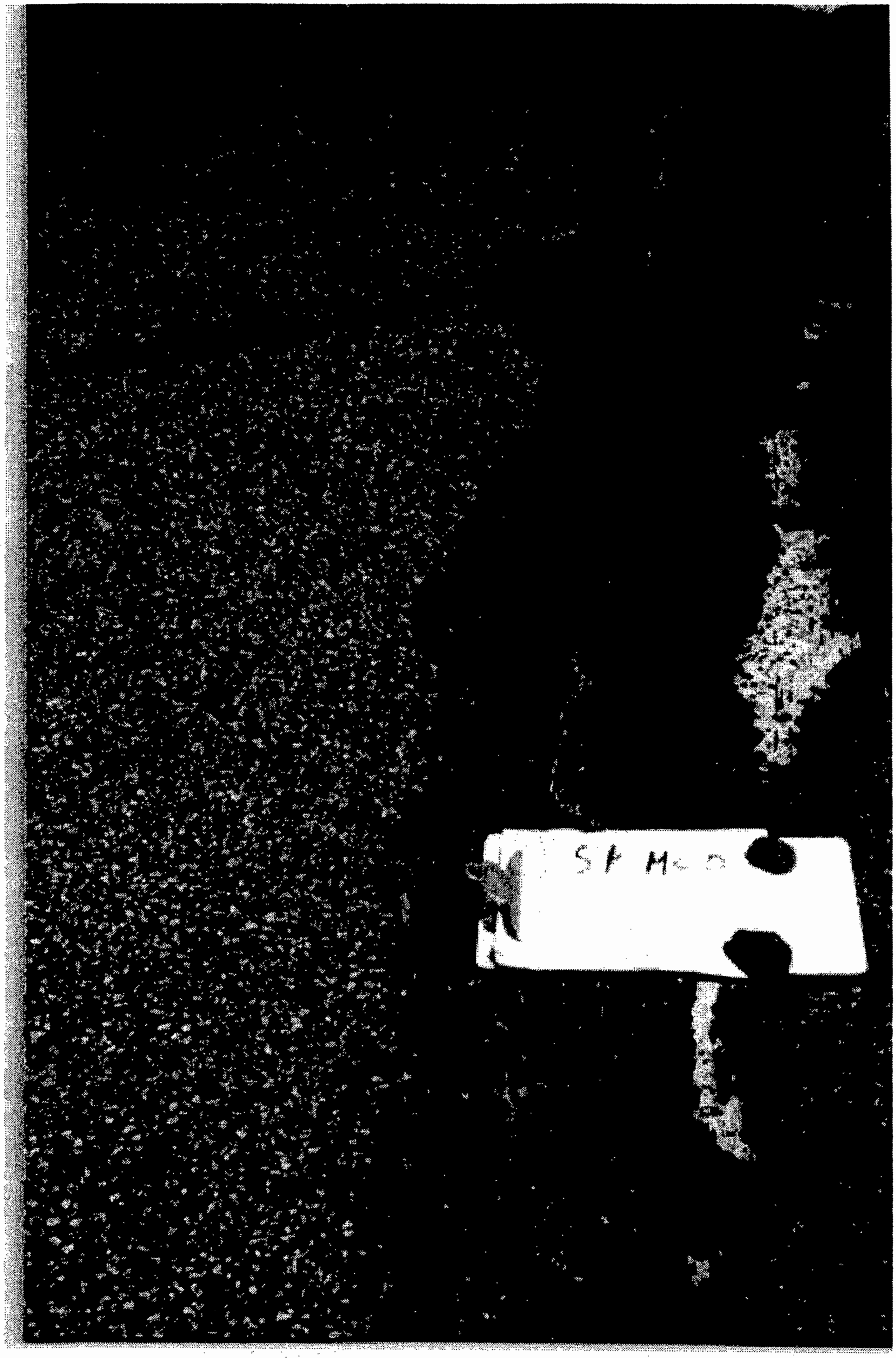

Figure 48. SuitKote 6 Month Inspection, Rt. 3 WB Ramp to Rt. 21 NB Clifton

Figure 49. SuitKote 6 Month Inspection, Rt. 3 WB Ramp to Rt. 21 NB Clifton

Figure 50. SuitKote 6 Month Inspection, Rt. 3 WB Ramp to Rt. 21 NB Clifton

Figure 51. SuitKote 6 Month Inspection Rt. 3 WB Ramp to Rt. 21 NB Clifton

Figure 52. UPM 2 Month Inspection, Rt. 120 SB MP 2.65 over Rt. 17 East Rutherford

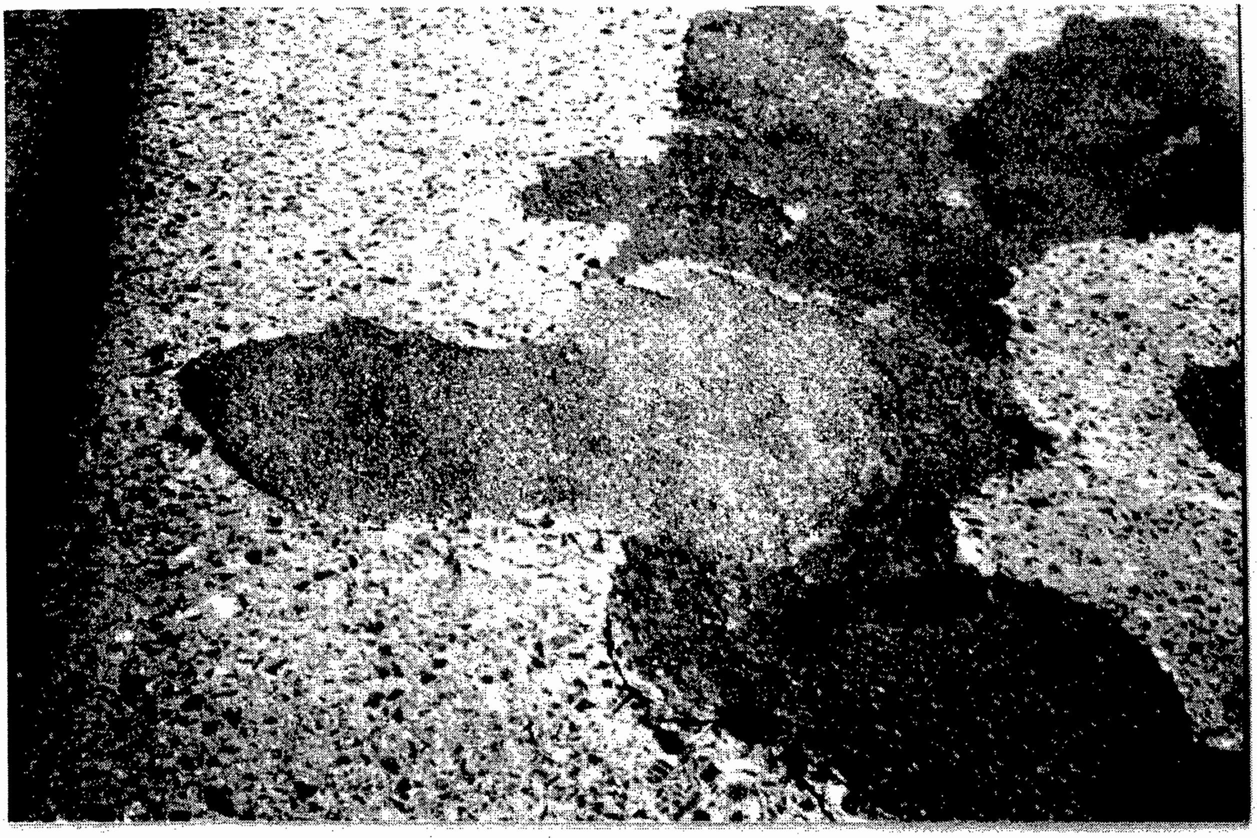

Figure 53. UPM 2 Month Inspection, Rt. 120 SB MP 2.65 over Rt. 17 East Rutherford

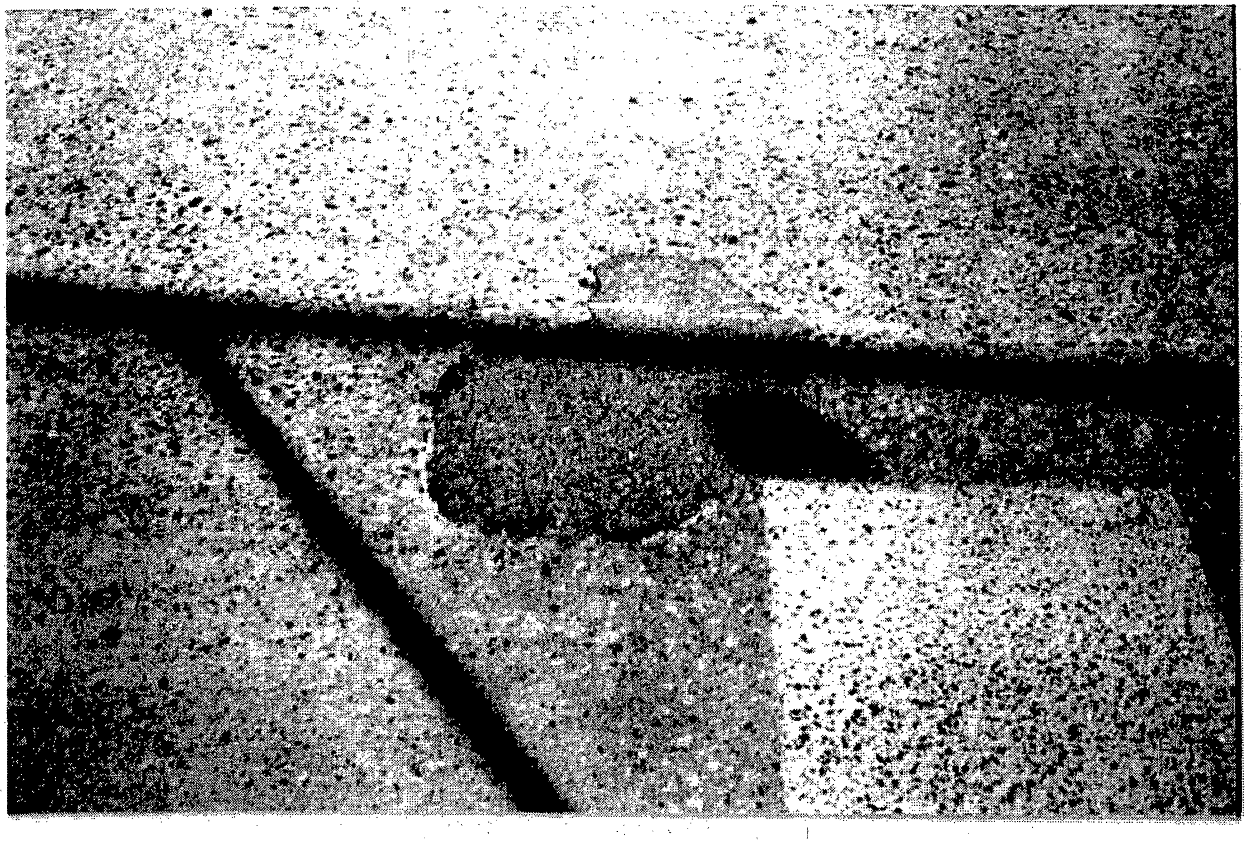

Figure 54. UPM 2 Month Inspection, Rt. 120 SB MP 2.65 over Rt. 17 East Rutherford

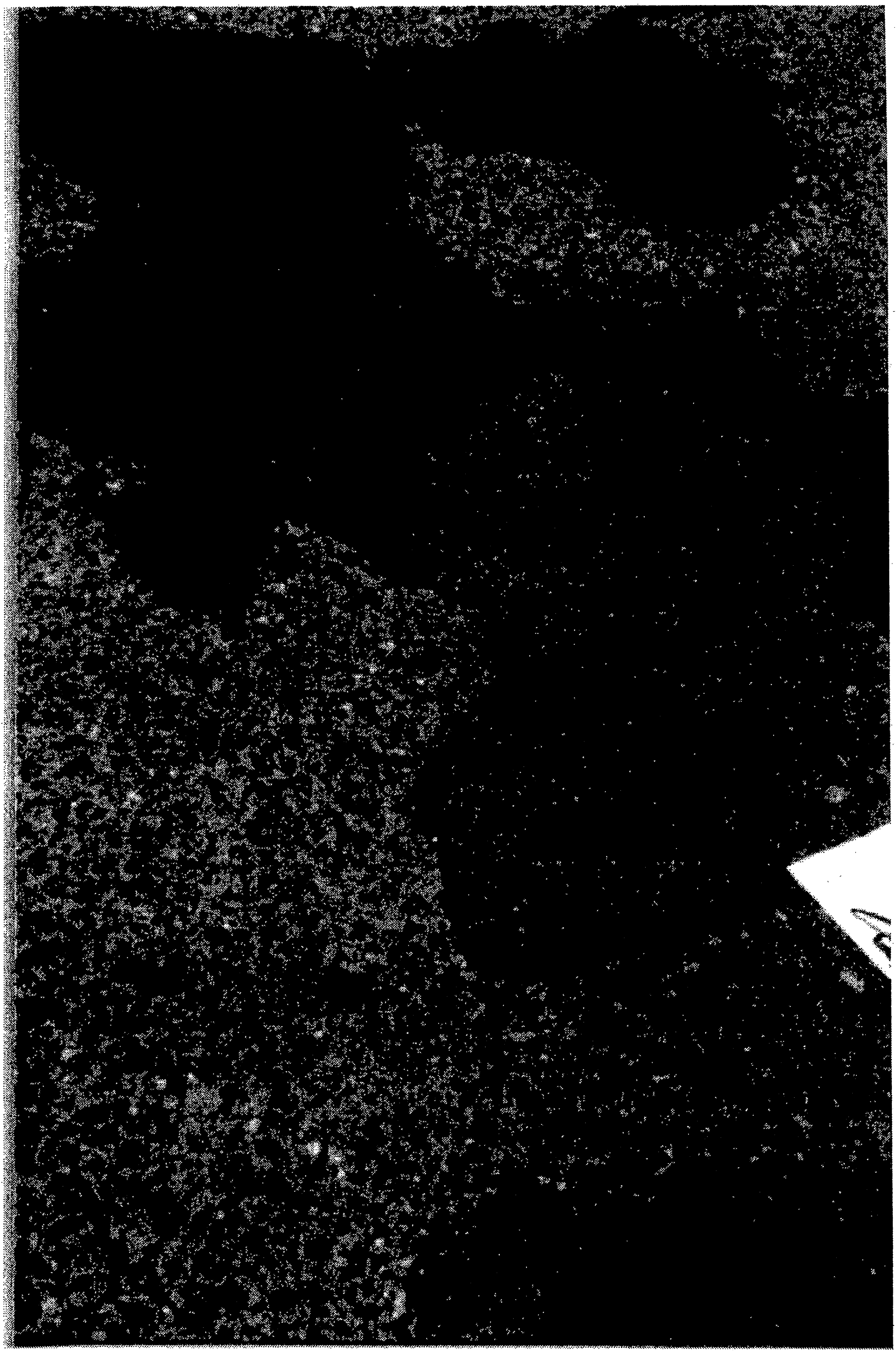

Figure 55. UPM 6 Month Inspection, Rt. 120 SB MP 2.65 over Rt. 17 East Rutherford

Figure 56. UPM 6 Month Inspection, Rt. 120 SB MP 2.65 over Rt. 17 East Rutherford

Figure 57. UPM 6 Month Inspection, Rt. 120 SB MP 2.65 over Rt. 17 East Rutherford

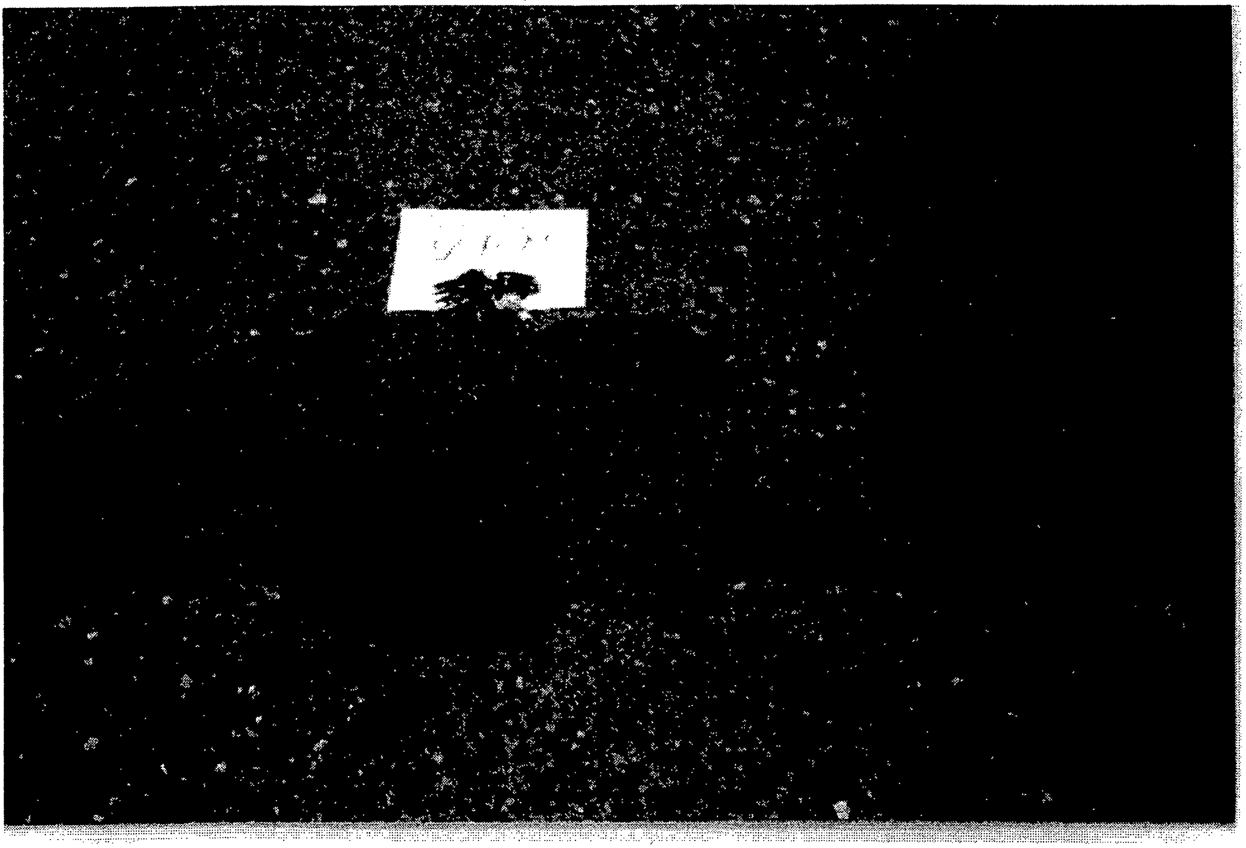

Figure 58. UPM 6 Month Inspection, Rt. 120 SB MP 2.65 over Rt. 17 East Rutherford

Figure 59. UPM 6 Month Inspection, Rt. 120 SB MP 2.65 over Rt. 17 East Rutherford

Figure 60. Wespro 2 Month Inspection, Rt. 21 SB MP 12.36 Passaic

Figure 61. Wespro 2 Month Inspection, Rt. 21 SB MP 12.36 Passaic

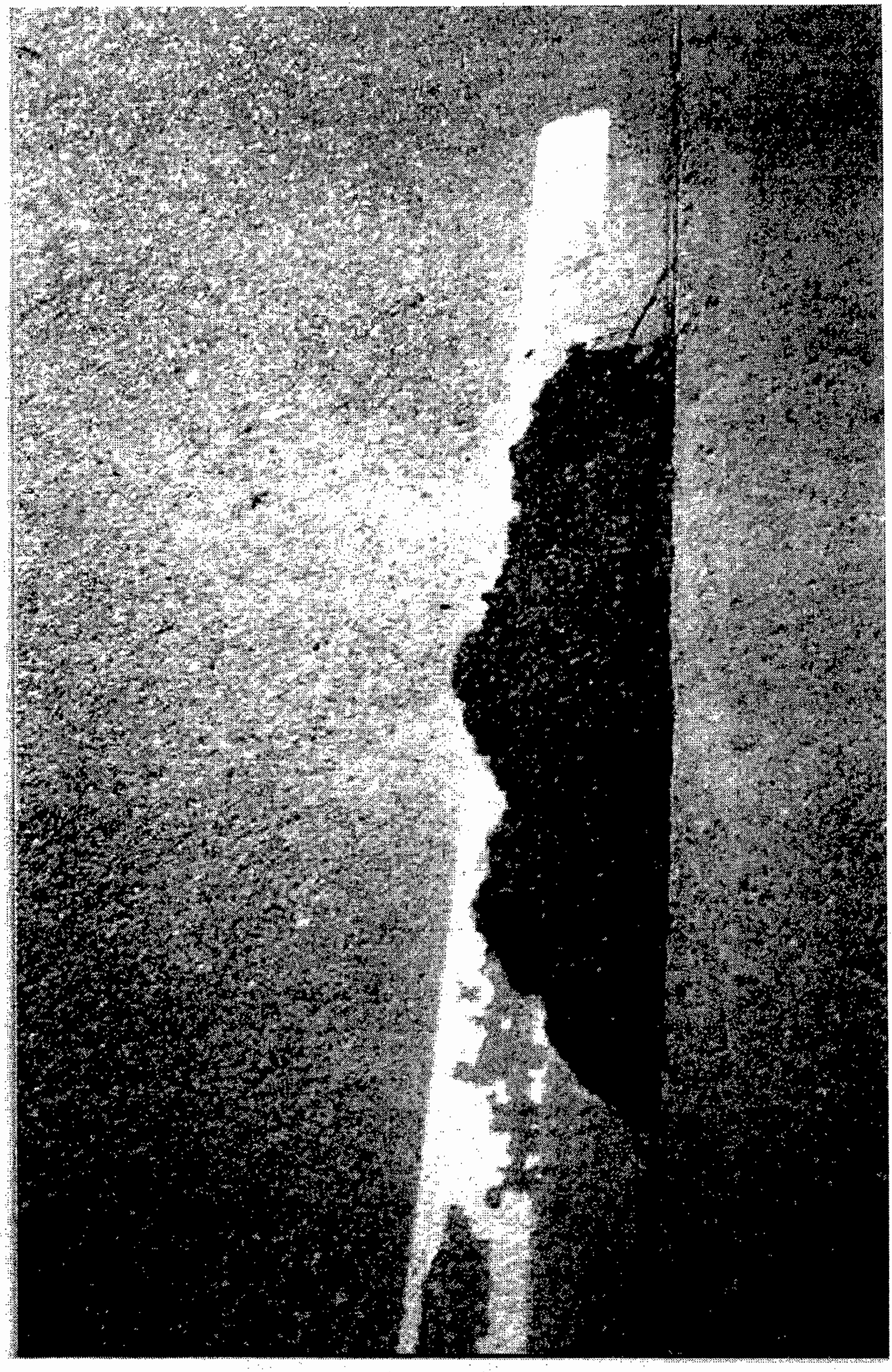

Figure 62. Wespro 2 Month Inspection, Rt. 21 SB MP 12.36 Passaic

Figure 63. Wespro 2 Month Inspection, Rt. 21 SB MP 12.36 Passaic