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Evaluation of the Iowa Vacuum Tester

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Final Report
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Prepared in cooperation with the
U.S. Department of Transportation
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Evaluation of joint seals has been a difficult job. It is time consuming, inefficient, and heavily dependent on the experience of the evaluator. The Iowa DOT has developed a testing system that gives a positive indication where there is a place where a joint seal leaks.

By wetting a joint with a soapy solution and applying a vacuum to the wetted area, ir is possible to locate and identify defecte in the seal. An area where there is a failure in the seal will allow air to pass through the seal causing the soapy solution to bubble. The test equipment can then be moved and the exact cause of the failure determined.

This study evaluates the Iowa Vacuum Testing System and copmares its results with those obtained by esperienced visual evaluators on several types of seals in concrete pavement.

Recommendations are made concerning use, maintenance, and possible changes in the system.

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Evaluation of the Iowa Vacuum Tester

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I. Background

Properly installed and functioning joint seals help prevent premature failure of concrete pavement. Tight seals keep water from getting into the base through the pavement. Water trapped in a base can lead to pumping which flushes out fine particles, leaving the pavement unsupported. Good joint seals also keep incompressible materials out of joints. Joints open and close due to thermal expansion. When a joint closes, material in the joint that cannot be compressed can cause cracks or spalls which allow water to penetrate the pavement. Failure of a joint seal can be caused by spalls, adhesion failure, cohesion failure, improper installation and construction practices, or damage by traffic.

Evaluation of joints and seals is usually done by visual examination and coring. In visual examination, areas of a joint that are spalled, or sealant that is improperly installed, damaged, or appears to have other problems must be probed to determine if the joint seal system has failed. Several factors, including the large linear footage and the possibility for several types of failure, make visual evaluation time consuming, and inefficient. It is also heavily dependent on the experience of the evaluator and ambient temperature at the time of the evaluation. When it is warm, thermal expansion of the pavement closes the joints and makes flaws in the sealant harder to see, so visual evaluations are best done in the winter when the joints are widest.

To check adhesion of the seal to the walls of the joint, a core can be taken over the joint. In the lab, slowly pulling the two halves of the core apart shows the adhesion of the seal to the walls of the joint. Obviously, coring is a destructive test method and only samples a small portion of the joint. It is highly localized, labor intensive, and requires specialized equipment. Damage to the integrity of the joint where a core has been taken is difficult to repair.

A new system, developed by the Iowa Department of Transportation, can, under certain conditions, positively locate flaws in a joint seal that will allow water to penetrate the seal. The Iowa Vacuum testing system (IA-Vac) gives a positive indication of any defect in a joint seal by applying a vacuum to a section of joint that has been wetted with a soapy water solution. Bubbles show the exact location and size of seal failures.

II. Description

Following is a description of the system equipment and its operation and maintenance.

A. IA-Vac system

The Iowa Vacuum system consists of the following equipment:

- Test chamber - A box, 1.22m long, 150mm wide, and 50mm high, with a clear top so the joint being tested is visible. (Figure 1)

- Vacuum pump - An electric pump to evacuate the air from the test chamber. (Figure 2)

- Reserve vacuum tank - A small tank to help establish the initial vacuum in the test chamber at the start of a test. (Figure 3)

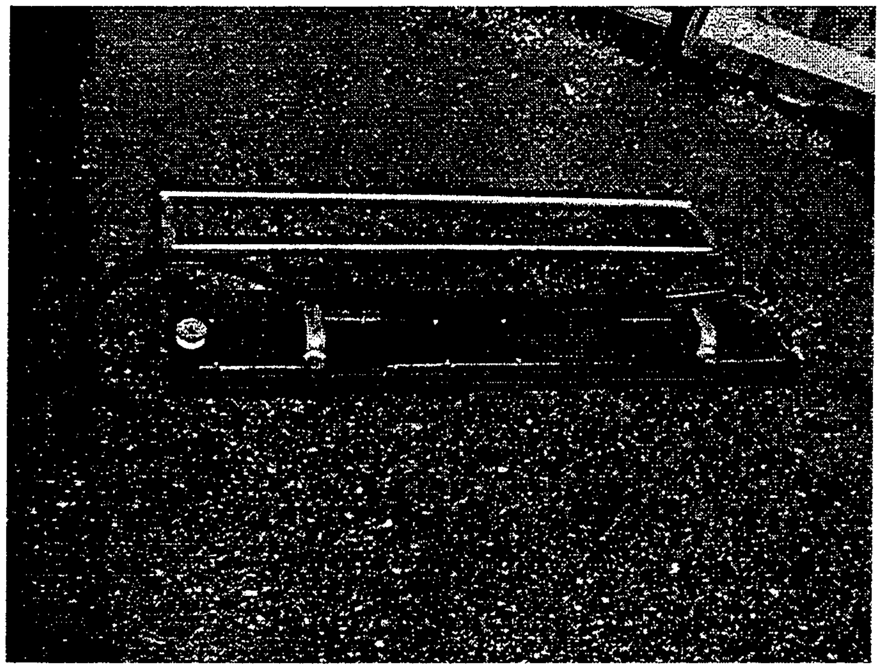

Figure 1 The test chamber has a vacuum gage on the left end. A valve with a quick-connect fitting on the right end connects to the reserve tank through a 7 meter long hose. The hose in the picture is used to regulate the vacuum level in the chamber by the operator opening or closing the end with a thumb. The seal protector/mold is at the rear of the photo.

- Hoses - To connect the vacuum pump, reserve vacuum tank, and test chamber.

- Sprayer with water and liquid soap - To wet the joint and surface of the pavement to help the test chamber make a good seal with the surface of the pavement and to make bubbles if there are openings in the joint seal.

- Generator - To provide electricity to operate the vacuum pump. For a more complete description of the system, see appendix A.

A van or pick-up truck is a convenient way to transport the IA-Vac system (Figure 4). The generator, vacuum pump, and reserve vacuum tank stay in the vehicle during testing. One person walks behind carrying the IA-Vac test chamber and doing the testing while another person moves the vehicle from one test location to the next.

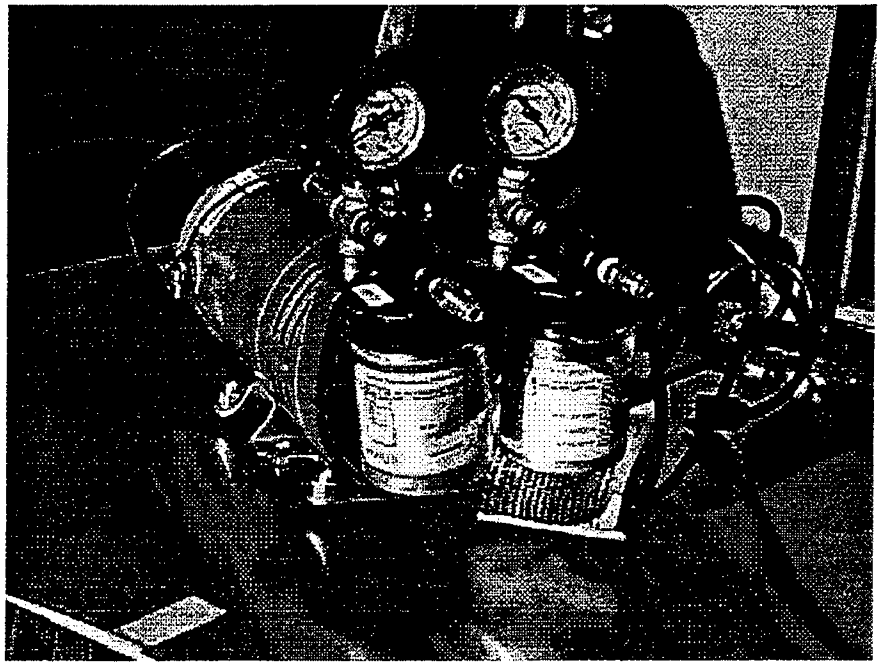

Figure 2 The pump supplied with the IA-Vac works as a vacuum pump or a compressor depending on which coupler is connected. There is a gage for each function.

Note: Never operate a gasoline generator in a closed space. If a van is used to transport the system, be sure all windows are open before starting the generator.

B. System Operation

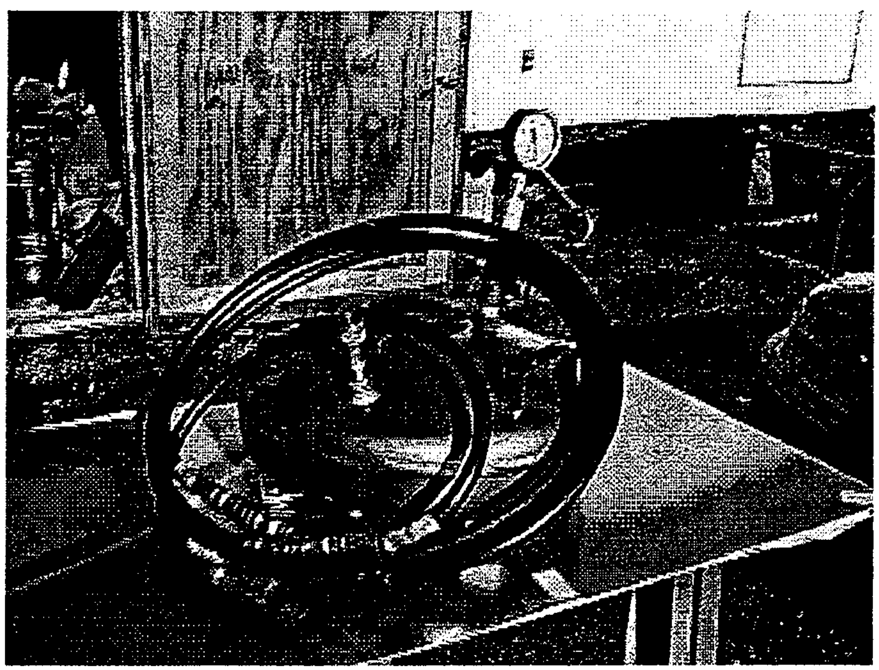

Figure 3 The reserve vacuum tank has a gage to show the vacuum level in the tank. A short hose connects the tank to the pump and a long (7 meter) hose connects to the test chamber.

Testing more than a few joints with the IA-Vac requires at least two people. Addition of a third person to operate the sprayer, and analyze and record the results while the system is moved improves the efficiency and rate of testing.

The Iowa Vacuum Tester is easy to operate. After a short learning period, the operator(s) develop a system of operation that makes the testing flow smoothly. Several gauges on the system make it easy to keep track of the vacuum level. Any joint seal can be tested quickly and thoroughly unless it is in such bad condition a vacuum cannot be established.

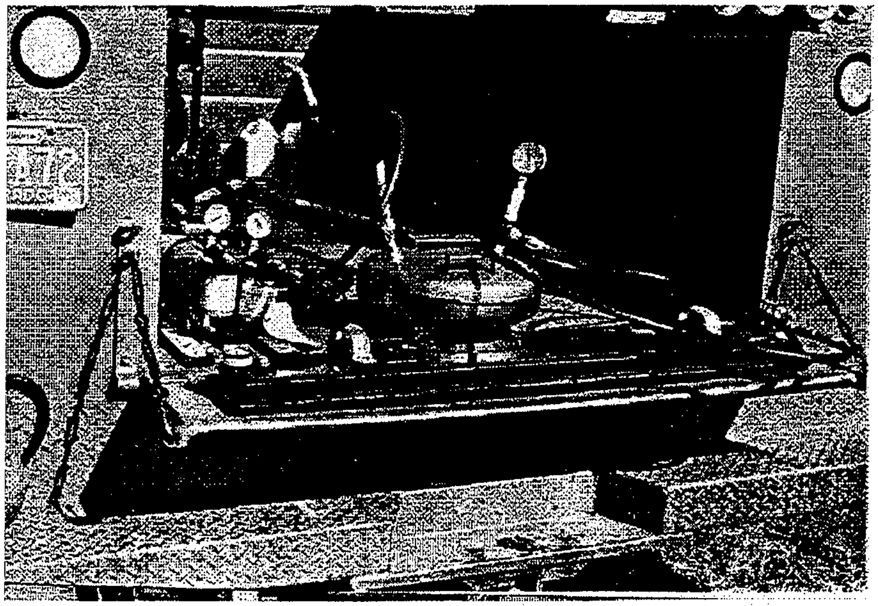

Figure 4 The system can be easily transported in a pickup truck. For testing, the chamber is placed on the pavement while the rest of the system remains in the bed of the truck. A 7 meter hose allows tests across one lane while the truck remains on the shoulder.

Test procedure:

1. Choose an area to test. If necessary, sweep the area to remove dirt and debris so the test chamber can make a good seal with the surface of the pavement. The joint itself should also be free of all loose material so the bubbles can be easily seen and their cause determined.

2. Use the sprayer to wet the joint and the surface

Figure 5 The joint to be tested and the pavement surface where the test chamber will sit are sprayed with a soapy water solution. It is important to wet the joint thoroughly.

of the pavement where the test chamber seal will sit (Figure 5). Wet the joint thoroughly. Wetting the surface of the pavement helps the chamber make a good seal. If the pavement surface is heavily textured, the chamber will occasionally have problems sealing. This can be helped by wetting the area again or by moving the chamber slightly.

3. Put the test chamber in position over the wetted joint. If the joint seal is more than about 2 mm below the surface of the pavement, a filler may need to be placed in the joint under each end of the test chamber. This allows the chamber seal to span the joint without leaking. The filler can be piece of backer rod or a piece of silicone seal. Pieces of seal material of different sizes are included with the system.

4. Stand on the foot rests on top of the chamber (Figure 6). This will compress the seal on the bottom of the chamber to help provide the initial seal with the surface of the pavement. Close the end of the vent hose with your thumb and open the vacuum valve on the chamber. When the chamber gauge indicates vacuum, you can step off the chamber. Open and close the end of the vent hose to regulate the vacuum in the chamber so it does not exceed 125 mm Hg (about 2.5 psi).

Figure 6 The operator stands on the test chamber to help seal it to the pavement surface. The vacuum level in the chamber can be regulated by opening and closing the end of the hose.

NOTE: The vacuum gauge on the test chamber used for this study reads 5 in. Hg with no vacuum applied to the chamber (Figure 7). It is important to be sure that the change from static position on the chamber gauge does not exceed 125 mm Hg during testing. Higher vacuum can damage the chamber seal by causing it to roll and tear away from the base of the chamber.

5. Mark locations on the pavement at the side of the chamber if specific analysis of the causes of bubbles is to be made. Size of the bubbles (Figure 8) is a good indicator of the size of the failure.

The IA-Vac will occasionally locate very small leaks that make bubbles that look like a small pile of shaving cream 25 - 50 mm back from the edge of the joint. These small leaks are not usually significant. If there are several of them in a small area they may indicate micro cracking. Micro cracks can develop into spalls.

A wet spot on the bottom of the glass (Figure 9) and no bubbles on the joint probably indicate a large failure that passes so much air that bubbles can not form. Usually a failure this large will be easily seen

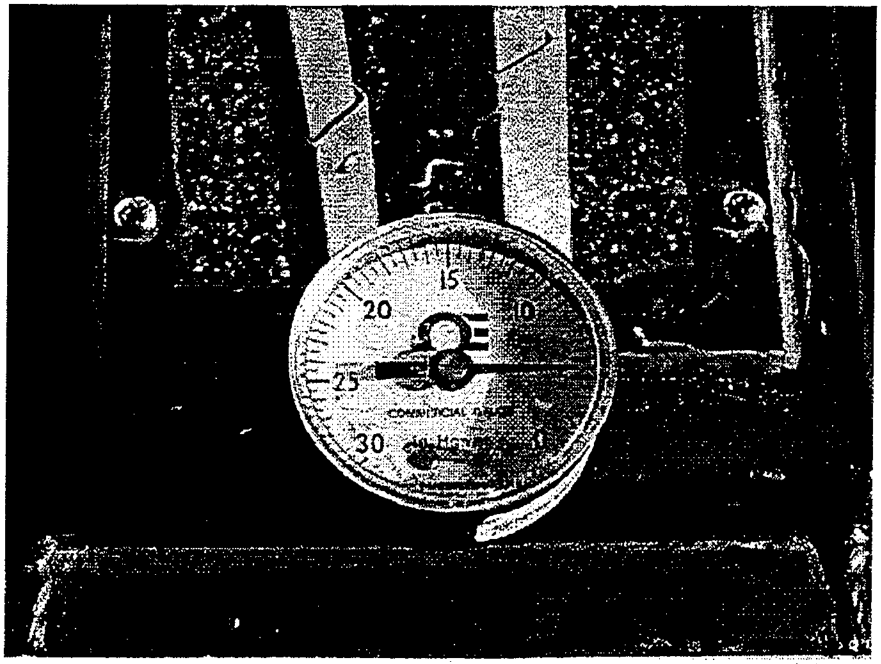

Figure 7 The vacuum gage on the test chamber reads 5 in. Hg when the system is disconnected. If possible, it should be re-calibrated. If it is used in this condition the vacuum level in the chamber must be read as the change in the gage reading when vacuum is applied.

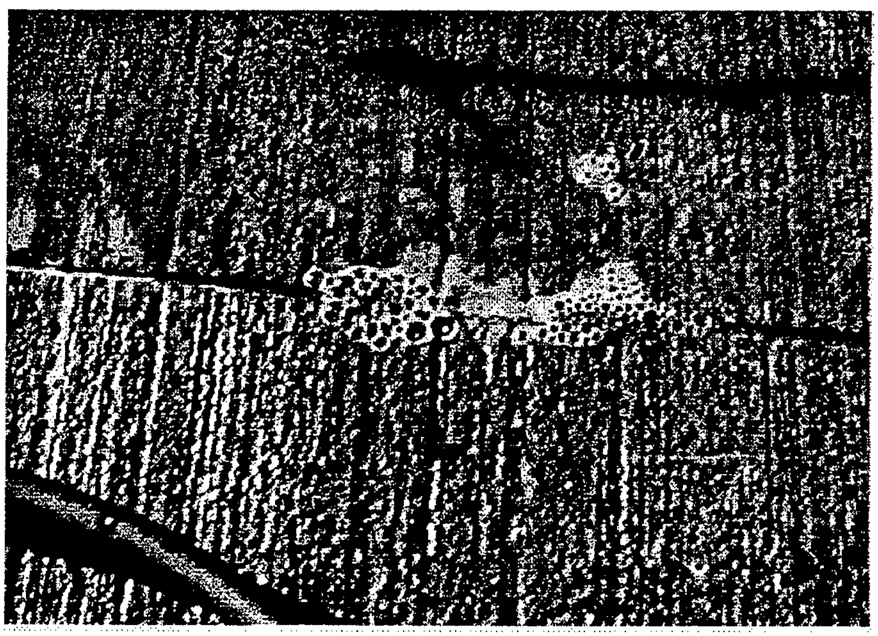

Figure 8 Bubbles show a leak in the seal. The larger bubbles to the left indicate a larger leak than the one to the right. The small bubbles to the rear of the joint may indicate a pinhole in the concrete or a micro crack that could develop into a spall.

(Figure 10).

6. Close the vacuum valve to release the chamber from the surface of the pavement. Move the chamber and determine the cause of the failure at the marked locations. Moving the test chamber without releasing the vacuum may cause the seal to tear away from the base of the chamber. It can also result

Figure 9 The drops on the glass show a large failure that is passing air too rapidly for bubbles to form. A failure this large is usually easily seen.

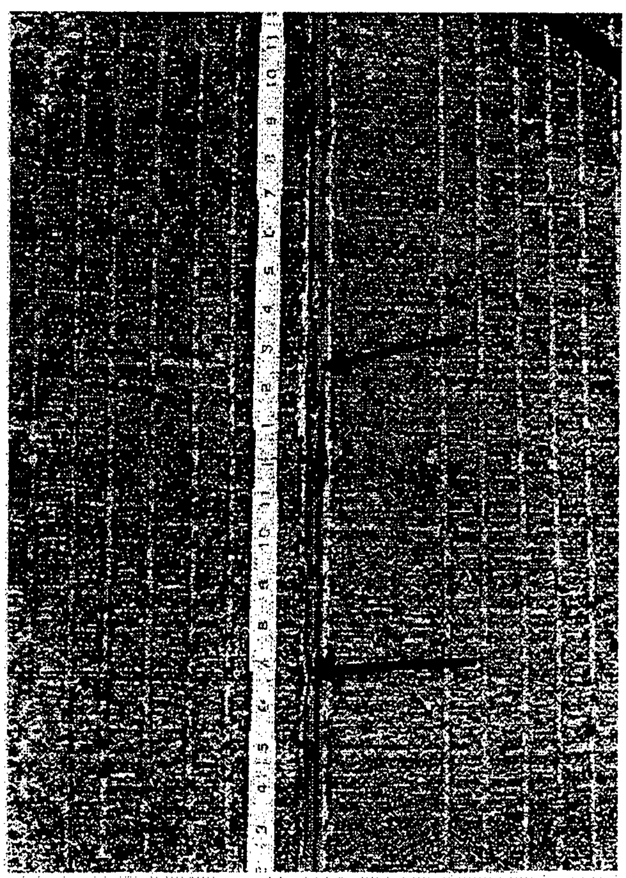

Figure 10 Both of these failures are too large to allow bubbles to be made. A cohesion failure (at the top arrow) was caused by the sealant being too thin. A spall (at the bottom arrow) has left a large opening through the seal. Openings this large may pass so much air that no other failures in the area will bubble. It may be necessary to move the chamber if the adjacent section of seal needs to be tested.

in damage to the operator since the test chamber is quite a bit "heavier" than normal when it is under vacuum.

7. Record the results of the test and move to the next location to be tested.

C. Maintenance

The system requires no special maintenance beyond cleaning and common sense care in storage and handling. However, a few things need to be pointed out in case the operators are not familiar with this type of equipment. These things will help to assure system reliability and reduce the chances of problems developing during a test session. See appendix C for complete maintenance information.

III. System Evaluation

A common way to check the overall condition of seals and joints is by visual evaluation. This is easiest in cold weather when thermal contraction of the pavement has opened the joints as much as possible. Large spalls and some construction problems such as improper tooling of the seal, or seals too high or too low are easily located visually. Finding adhesion and cohesion problems and determining whether they have an effect on the function of the seal requires pushing and pulling on the entire seal to locate adhesion and cohesion problems. A knife with a

Figure 11 During a visual inspection of new seals, the only way to check for adhesion of the seal to the walls of the joint is to probe the seal and watch for it to move away from the wall. It is also necessary to probe spalls to see if they extend below the seal.

dull blade is a good tool for this (Figure 11), but it requires crawling along the entire length of the seal. Then, when a problem is found, there is no reliable way to determine if it extends all the way through the seal. A seal with a failure extending only part way through will still function properly. However, probing to check the depth of a problem can pull the seal away from the joint wall, making it a full-depth failure.

Another drawback to a thorough visual examination is the fact that a considerable amount of time is spent determining whether a given problem extends all the way through the seal. A partial depth problem may indicate future problems, but the joint and seal will still function properly until the failure penetrates the seal completely.

This evaluation of the IA-Vac was done with the help of Mr. Lynn Evans and Mr. Chuck Weinrank of ERES Consultants, Inc. in Champaign, Illinois. They are the principal evaluators of the SHRP SPS-4 supplemental joint seal study, which has sites in several states including Colorado. The Colorado SHRP SPS-4 site is ideal for the evaluation of the IA-Vac; it has nine different joint/seal combinations as shown in table 1.

	Joint Width		
Seal Type	3.2 mm	6.4 mm	9.5 mm
Neoprene Compression, D. S. Brown		X	X
Self Leveling Silicone, Crafco 930 SL	X	X	X
Tooled Silicone, Crafco 902	X	X	X
Unsealed	X		

Table 1

The nine combinations of joint width and seal type that are used in the SHRP SPS-4 test site on US 287 in southeastern Colorado

The SHRP study consists of a thorough visual evaluation of a predetermined set of joints in each of the test sections. To find out how the IA-Vac would compare to the results of a thorough visual evaluation by two national experts, several of the joints used by the SHRP team were tested with the IA-Vac.

Since the test sections were new and the joints were in good condition, we decided to concentrate on the area beginning .3-m in from the shoulder joint and extending 1.2-m across the right wheel path.

Several joints had no failures in the area tested with the IA-Vac. In 23 joints the totals of the failures located with the IA-Vac were:

625-mm of spalls

75-mm of adhesion failure

50-mm of construction-related failures

All of these were full-depth failures that would allow water to get under the pavement. No cohesion failures were found.

In the same locations the totals of the failures found by the SHRP evaluators were:

350-mm of spalls

75-mm of construction-related failures

675-mm of partial-depth spalls

600-mm of partial-depth adhesion failures

The SHRP evaluators found a total 1700-mm of failures, of which 425 mm were listed as full-depth failures - where the seal in the joint would leak. For the same location, the IA-Vac found 750-mm of failures where the joints did leak. Approximately 75% of the time that was spent doing the SHRP evaluation was used checking things that were not actually failures.

The IA-Vac eliminates time spent trying to see if a problem extends completely through a seal. Everything it locates is a place where water definitely can penetrate the pavement.

According to the designers of the IA-Vac, it is possible to perform 100 tests per hour, covering 120 m, with three people. During our evaluation with two operators, a rate of about 20-30 tests per hour was normal when time was taken to determine the types of failures and compare them with the findings of the SHRP team. One person can operate the system alone if necessary but the testing will be very slow.

Two things that slowed operations were surface texture and the level of the sealant in the joint. At locations where the seal was below the surface of the pavement more than 2-3 mm a short piece of seal was placed in the joint under the ends of the chamber to fill the gap.

Wherever there is an opening through a joint there will be bubbles. Their size is a good indication of the size of the leak. Larger leaks allow more air to pass causing larger bubbles. A large failure can pass so much air that the system cannot establish a vacuum. When this happens, there will be no bubbles and the chamber will need to be repositioned away from the large leak to analyze the rest of the joint.

The IA-Vac can detect very small leaks. It is often possible to pull a very small amount of air though tiny holes in the pavement near the joint. The bubbles at these locations will be extremely small and may look like small piles of shaving cream. These tiny holes are usually insignificant. If there are many of them, however, they may be an indication of micro cracking near the joint.

IV. Testing with the IA-Vac

Testing with the IA-Vac can have a variety of objectives. The three general types of testing discussed below are where the system would probably be most useful.

A. Post Construction Evaluation

The IA-Vac could be very useful as a method of evaluating the joints and joint seals on new construction. Joints that are not properly cleaned and completely dry before the application of the sealant can develop adhesion problems that are very hard to locate and evaluate using visual techniques alone. The IA-Vac will locate all of the areas where there are problems. The time that would have been spent checking areas that look questionable can be used to determine the cause of known problems.

One of the CDOT study panel members originally felt that measurements taken with the IA-Vac would be too subjective to be used for a construction specification. This evaluation made it clear that the IA-Vac can reliably locate all existing problems. Its results are repeatable, and, with a little experience, an operator can determine the size and cause of a failure rapidly and reliably. The IA-Vac provides a way to evaluate construction practices and techniques. Results obtained from the system are not dependent on experience level and are easily repeatable.

Problems experienced during construction of the neoprene joints at the SHRP site described earlier in this report left several of the seals twisted in the joint (Figure 12). The

IA-Vac, or a similar method, may be the only reliable way to evaluate the function of this type of seal. Visual examination clearly indicated the twisting problem but there was no way to determine if the seals were performing properly. The IA-Vac tests showed that while some of the twisted seals did leak, some of those that were severely twisted had no leaks at all at 70°F. (At lower temperatures the neoprene seals may leak.)

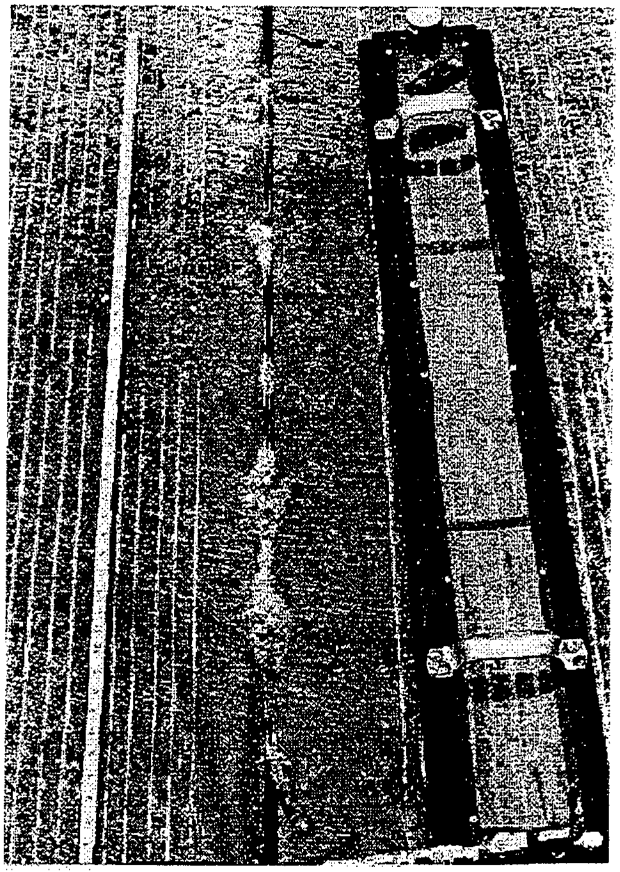

Figure 12 This is a neoprene seal. As the bubbles show, there are eight leaks in the seal. During a visual inspection these failures would be extremely hard to locate. This particular seal was twisted during installation. Twisting does not always cause leaks. Other seals that were also twisted showed no leaks when tested with the IA-Vac.

By combining random sampling with the IA-Vac with pull tests (see appendix B) and visual checks, a dependable prediction of the performance of the joint seals in a project should be possible. The IA-Vac will provide information on the workmanship of the joints and general condition of the seals. The pull test will show conditions below the surface - adhesion, cohesion, and seal depth. And the visual check will verify proper height of the seal relative to the surface of the pavement, correct depth of the seal and backer rod, and condition of the pavement at the joint.

B. New Product Evaluation

Better materials and methods are continually being developed for sealing joints. There has not been a reliable, easily repeatable way to evaluate them in the field other than the visual inspection and destructive testing discussed earlier.

Testing with a system that is not dependent on operator experience increases the accuracy of the tests. By eliminating the human factor, the IA-Vac system will remove many of the variables and help provide an unbiased comparison of products and methods. The fact that the results are repeatable makes the IA- Vac particularly well suited to this type of use. Careful recordkeeping is essential, but the effects of operator experience and prejudices are effectively eliminated.

C. Rehabilitation Evaluation

The IA-Vac is not well-suited for evaluating old deteriorated joints for rehabilitation. As joints and seals age, seal failure levels rise, and there is too much air flow to obtain a reading. Because of the wide variation in the types and degrees of distress that occur in joints, it is probably not reasonable to try to set a "maximum testable level of failure". If the seal adhesion fails it may be possible to test and get bubbles along the entire length of the chamber, but a large spall or piece of missing sealant may make the IA-Vac unable to test a particular area of joint.

However, by keeping track of the normal deterioration of joint seals after installation, an accurate prediction of the effective life of the seals in a particular location could be made. The rate of deterioration of a known selection of joints could be determined by periodically monitoring them beginning immediately after construction or rehabilitation. The information from those joints could be used to predict the need for future rehabilitation for the entire project.

V. Conclusions

For purposes of testing new products and methods, determining if the seals in a new project will perform adequately, or forecasting the need for future work on a project, the IA-Vac should be a major time-saver. It will locate areas where water can penetrate the pavement and won't waste time with areas where there is no problem.

The system is easily operated and is a reliable, repeatable method for evaluating the condition of joints and seals. It is better than visual inspections and core sampling because it eliminates the human factor of visual inspections and the destructive factor of coring.

Appendix A

IA-Vac System Equipment

1. Test Chamber: A lightweight metal box 150 mm wide, 1.22 m long, and 50 mm high. The top of the chamber is clear plastic so the joint being tested is visible. Around the bottom of the chamber, an 18-mm thick soft gasket of silicone sealant provides a seal between the chamber and the pavement. In storage and transport, the seal is covered by a protector/mold that is also used to cast a new seal when the old one is damaged. The test chamber has carrying handles, foot rests, a valve to apply vacuum, a vacuum gauge (calibrated in inches of mercury on the one tested) and a hose to regulate the level of vacuum in the chamber during testing.

2. Vacuum Pump: A 246 watt (0.33 HP) pump that can supply 128 liters per minute of airflow and generate a vacuum of at least 80 mm of Hg (about 1.5 psi).

3. Reserve Vacuum Tank: A 14 liter tank to provide the initial vacuum to the chamber when a test is started. The vacuum in the reserve tank is allowed to build to a higher value than is used for testing. When the valve on the test chamber is opened the tank provides a quick initial evacuation of air from the test chamber to help it seal to the pavement. The tank quickly re-evacuates when the valve on the test chamber is closed after a test is completed.

4. Hoses: One .6-m hose to connect the vacuum pump to the reserve tank and one 7-m hose to connect the reserve tank to the test chamber. It is possible to test completely across a lane without moving the vehicle. The hoses, pump, reserve tank, and test chamber are fitted with quick connect couplers to make the system easier to set up and take down.

5. Sprayer: A 12 liter (3-gal) pump up type garden sprayer to apply soap solution to the joint. The soap solution is made by adding a small amount of concentrated soap to the sprayer full of water. Shampoo, dish soap, or bubble blowing solution will work.

6. Generator: Provides electric power for the vacuum pump.

Appendix B

Terminology

Adhesion Failure: Failure of the seal material to adhere to the sides of the joint. This type of failure is the hardest to locate during a visual inspection. It may also be one of the most important to locate since it is often an indication of problems with the installation process. Adhesion loss can be caused by dirty or wet joints. If these conditions are common on a project, the cause must be found and corrected.

Cohesion Failure: A failure in the seal material itself. The failure in the photo on page 9 could be cohesive. (It could also be a construction problem if the seal was tooled too thin or the backer rod was too high, resulting in a thin seal. Close investigation is necessary to determine the actual cause.)

Construction Failure: Nearly all types of failures can be caused by poor construction practices. Failures identified as construction failures are definitely due to poor construction techniques, such as tooling the sealant too thin, improper backer rod placement, incorrect sawing, etc.

Intrusion: A foreign object that becomes imbedded in the seal material before it is fully cured. Seal material is displaced and a thin spot in the seal results. This is usually caused by having vehicles on the pavement while the seals are curing. Their tires press debris into the joint causing a potential failure. Occasionally seal materials do not cure properly or soften in hot weather. This can also lead to intrusion failure.

Partial Depth Distress: This is a description of distress rather than a type of failure. Distress found during a visual inspection that does not extend below the bottom of the seal is listed as partial depth. Spalls and adhesion are the most likely type of partial-depth distress. The IA-Vac will not locate partial-depth distress since it will not allow air to pass through the joint seal.

Pull Test: A pull test is can be performed on a transverse or longitudinal joint in a traffic lane or on the shoulder. The procedure is as follows: On the seal make three marks spaced 25 mm apart. Use a narrow sharp knife to cut across the seal at one end mark and along both sides of the seal as close as possible to the side of the joint for 50 mm to the other end mark. Free the cut end of the seal. Firmly grasp the free section of seal at the middle mark and pull up slowly and evenly at a 45-degree angle. Note how much the seal elongates before failure and the type of failure. The seal will fail cohesively (break) or adhesively (pull loose from the sides of the joint). How much the seal stretches before failure indicates the relative ability of the seal to withstand joint expansion. Some of the joint seals tested during this evaluation stretched 1200% (from 25 mm to 300 mm) before they broke. The removed section of seal can then be examined to determine the thickness of the seal, how well it is adhering to the sides of the joint, and the position and condition of the backer rod.

Spall: A spall is a broken place in the top edge of the pavement at a joint. The piece may be missing or may still be present. A spall may extend below the seal or end in or above the seal. If a spall ends in or above the seal (a partila depth distress), the IA-Vac will not find it. However, a partial depth distress is not a seal problem.

Appendix C

System Maintenance

Warning: A gasoline generator should never be operated in a closed area. Always open all of the windows if the vehicle being used is a type where the generator is in the passenger compartment.

The system requires no special maintenance beyond cleaning and common sense care in storage and handling. However, a few things should be pointed out in case the operators are not familiar with this type of equipment. These things will help to assure system reliability and reduce the chances of problems developing during a testing session.

Maintain the oil level in the reservoir on the vacuum pump with special attention to using oil of the proper type and viscosity. Be sure to use non-detergent oil if that is what is called for in the instructions of the pump manufacturer.

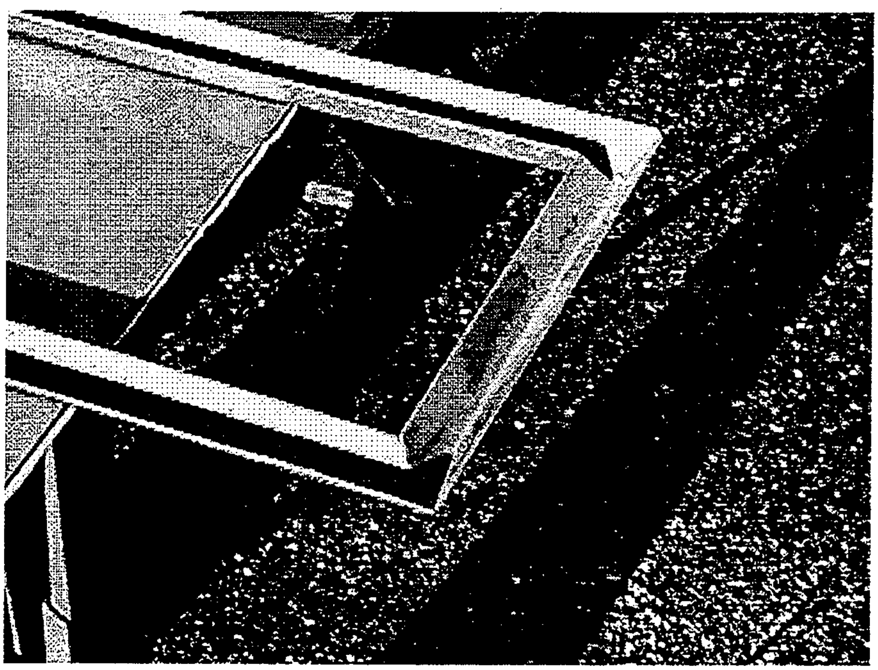

Figure 13 This is a close-up of the seal protector/mold. It should be kept over the chamber seal whenever the system is not in use to prevent damage to the seal. It is also a form for making a new seal.

Periodically check the seal on the bottom of the test chamber for tears and damage. If it is severely damaged and needs to be replaced, a new seal can be made by coating the seal protector/mold with a release agent, then filling it with Dow Corning 890 SL (Self-Leveling) Silicone (Figure 13). After the new seal has cured, it can be bonded to the test chamber using the same Dow Corning 890 SL silicone or silicone caulking or weather strip adhesive. The silicone takes some time to cure. It may be a good idea to cast a new seal before the old one is worn or damaged beyond usefulness so testing time is not lost while waiting for a new seal to cure.

It is possible for part of the seal to pull loose from the test chamber without being damaged otherwise (Figure 14). If this happens, a thin coat of silicone caulking applied to the base of the chamber will provide a quick way to reattach it. The system can be used with a short portion of the seal loose from the base of the chamber. However, extra care must be taken to prevent tearing the seal when it is unsupported. It should be re-glued to the chamber as soon as possible.

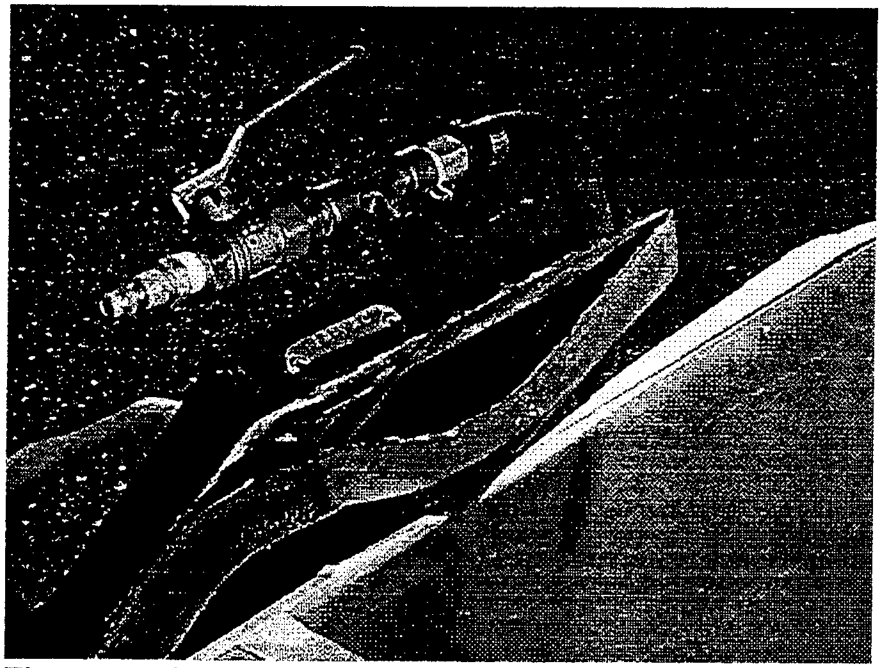

Figure 14 The seal can pull loose from the base of the chamber during normal use. A thin film of silicone caulking applied to the base of the chamber makes a quick, semi-permanent repair. This happens fairly often and does not prevent testing. However, it should be repaired as soon as possible to prevent further problems. The system can be used while the caulking cures.

When the IA-Vac is being stored or transported the protector/mold should be kept over the seal to protect it. The protector/mold should be lightly coated with talc to prevent adhesion to the seal. The talc is especially important with a new seal because the silicone stays quite tacky for some time. Use extra care when removing the protector if the system has been stored for some time. Even if talc was applied inside the protector, the seal tends to stick to it. If the protector is not removed carefully, it can pull the seal loose from the bottom of the chamber. Clean the clear top of the test chamber inside and out with a piece of soft cloth. This may need to be done often during a testing session.

When the system will be stored for more than a day or two, be sure that the surfaces of the chamber seal and its protector are thoroughly dried to prevent rust from forming on the protector. When rust does begin to form inside the protector, it can be removed with a wire brush and the protector re-painted to slow its reformation. Be sure the paint has dried completely before storing the system.

Appendix D

Modifications

The IA-Vac system that the Colorado Department of Transportation received for this evaluation has evolved considerably from its original form. Here are a few changes and/or additions that the evaluators thought might improve its ease of operation and increase its durability and efficiency:

The window on the top of the test chamber is held down with screws spaced 27.5 cm apart around the edge. It can warp and separate from the chamber frame and leak air. A flat metal frame 3 mm thick and 18 mm wide on top of the edge of the window would distribute the pressure of the screws more evenly around the window and hold it flat. The frame would also help protect the glass from scratches during transport and handling.

A measurement device on the outside edge of the test chamber would make it easier to identify locations of specific failures. It would be very useful for product evaluation testing where exact locations would need to be found and recorded so tests could be repeated. A piece of cloth measuring tape with the desired measuring system could be glued to the bottom flanges of the chamber.

A vacuum regulator valve on the chamber would make it easier for one person to keep the vacuum at an acceptable level while checking for bubbles. The valve would not let the vacuum in the chamber exceed the preset level; then the operator would not have to worry about regulating the vacuum while identifying leaks.

Legs inside each corner of the chamber and midway along the long sides could prevent over-compression of the seal. The legs could be threaded to be adjustable. By projecting below the metal base of the chamber about nine mm, they would allow the seal to compress and seal to the pavement. They would stop over- compression of the seal and hold the chamber in place laterally, reducing the tendency for the seal to roll and tear away from the base of the chamber when too high a level of vacuum is used.

A sprayer with a nozzle that has provisions for a positive attachment of the hose would be worthwhile. The sprayer we had leaked and the hose fell out of the handle when the tank was pressurized. A random spray of cold water is a very unpleasant experience when the temperatures are low and the wind velocity is high.

CDOT Research Report Publication List

91-1 Industrial Snow Fence vs. Wooden Fences
91-2 Rut Resistant Composite Pavement Design (Final Report)
91-3 Reflective Sheeting (Final Report)
91-4 Review of Field Tests and Development of Dynamic Analysis Program of CDOH Flexpost Fence
91-5 Geotextile Walls for Rockfall Control (canceled)
91-6 Fly Ash in Structural Concrete
91-7 Polyethylene Pipes for Use as Highway Culverts
91-8 Ice Detection System Evaluation
91-9 Evaluation of Swareflex Wildlife Warning Reflectors
91-10 analysis and Design of Geotextile Reinforced Earth Walls, Vol III Parametric Study and Preliminary Design Method

92-1 Colorado Department of Transportation Asphalt Pavement White Paper
92-2 Expansive Soil Treatment Methods in Colorado
92-3 Gilsonite - An Asphalt Modifier
92-4 Avalanche Characteristics and Structure Response - East Riverside Avalanche Shed, Highway 550, Ouray County Colorado
92-5 Special Polymer Modified Asphalt Cement - Interim report
92-6 A User Experience with Hydrain
92-7 Chloride Content Program for the Evaluation of Reinforced Concrete Bridge Decks
92-8 Evaluation of Unbonded Concrete Overlay
92-9 Fiver Pave, Polypropylene Fiber
92-10 Description of the Demonstration of European Testing Equipment for Hot Mix Asphalt Pavement
92-11 Comparison of Results Obtained From the French Rutting Tester With Pavements of Known Field Performance
92-12 Investigation of the Rutting Performance of Pavements in Colorado
92-13 Factors That Affect the Voids in the Mineral Aggregate In Hot Mix Asphalt
92-14 Comparison of Colorado Components Hot Mix Asphalt Materials With Some European Specifications
92-15 Investigation of Premature Distress in Asphalt Overlays on I 70 in Colorado

93-1 Dense Graded Concrete
93-2 Research 92- Reality and Vision, Today and Tomorrow (Status Report)
93-3 Investigation of the Modified Lottman Test to Predict the Stripping Performance of Pavements in Colorado
93-4 Lottman Repeatability\
93-5 Expert System for Retaining Wall System Phase I
93-6 Crack Reduction Pavement Reinforcement Glasgrid
93-7 A Case Study of Elastic Concrete Deck Behavior in a Four Panel Pre-stressed Girder Bridge Finite Element Analysis
93-8 Rehabilitation of Rutted Asphalt Pavements (Project IR-25-3(96)
93-9 Cold Hand Patching

93-10 Ice Detection and Highway Weather Information Systems
93-11 Comparison of 1992 Colorado Hot Mix Asphalt With Some European Specification
93-12 Curtain Drain
93-14 Type T Manhole(Experimental Feature)
93-15 SHRP Seasonal Monitoring Program in Delta
93-16 DOT Research Management Questionnaire Response Summary
93-17 In Service Evaluation of Highway Safety Devices
93-18 Courtesy Patrol Pilot Program
93-19 I 70 Silverthorne to Copper Mountain: A History of Use of European Testing Equipment
93-20 Analytical Simulation of Rockfall Prevention Fence Structures
93-21 Investigating Performance of Geosynthetic-reinforced Soil Walls
93-22 Influence of Testing Variables on the Results from the Hamburg Wheel-Tracking Device
93-23 Determining Optimum Asphalt Content with the Texas Gyratory Compactor

94-1 Comparison of the Hamburg Wheel-Tracking Device and the Environmental Conditioning System to Pavements of Known Stripping Performance
1-94 Design and Construction of Simple, Easy, and Low Cost Retaining Walls
94-2 Demonstration of a Volumetric Acceptance Program for Hot Mix Asphalt in Colorado
2-94 The Deep Patch Technique for Landslide Repair
94-3 Comparison of Test Results from Laboratory and Field Compacted Samples
3-94 Independent Facing Panels for Mechanically Stabilized Earth Walls
94-4 Alternative Deicing Chemicals Research
94-5 Large Stone Hot Mix Asphalt Pavements
94-6 Implementation of a Fine Aggregate Angularity Test
94-7 Influence of Refining Processes and Crude Oil Sources Used in Colorado on Results from the Hamburg Wheel-Tracking Device
94-8 A Case Study of Concrete Deck Behavior in a Four-Span Prestressed Girder Bridge: Correlation of Field Test Numerical Results
94-9 Influence of Compaction Temperature and Anti-Stripping Treatment on the Results from the Hamburg Wheel-Tracking Device
94-10 Denver Metropolitan Area Asphalt Pavement Mix Design Recommendation
94-11 Short-Term Aging of Hot Mix Asphalt
94-12 Dynamic Measurements of Penetrometers for Determination of Foundation Design
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94-14 Preliminary Procedure to Predict Bridge Scour in Bedrock (Interim Report)

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95-2 PCCP Texturing Methods
95-3 Keyway Curb (Construction Report)
95-4 EPS, Flow Fill and Structure Fill for Bridge Abutment Backfill
95-5 Environmentally Sensitive Sanding and Deicing practices
95-6 Reference Energy Mean Emission Levels for Noise Prediction in Colorado
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95-18 Widened Slab Study

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96-4 Re-vegetation of MSB Walls
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96-6 Evaluation of Slope Stabilization Methods (US 40 Berthoud Pass) (Construction Report)
96-7 SMA (Stone Matrix Asphalt) Colfax Avenue Viaduct
96-8 Determining Asphalt cement Content Using the NCAT Asphalt Content Oven
96-9 HBP QC & QA Projects Constructed in 1995 Under QPM1 and QPM2 Specifications
96-10 Long-Term Performance of Accelerated Rigid Pavements, Project CXMP 13-006-07
96-11 Determining the Degree of Aggregate Degradation After Using the NCAT Asphalt Content Oven
96-12 Evaluation of Rumble Treatments on Asphalt Shoulders

97-1 Avalanche Forecasting Methods, Highway 550
97-2 Ground Access Assessment of North American Airport Locations
97-3 Special Polymer Modified Asphalt Cement (Final Report)
97-4 Avalanche Detection Using Atmospherical Infrasound
97-5 Keyway Curb (Final Report)
97-6 IAUAC -(Interim Report)
97-8 HBP Pilot Void Acceptance Projects Completed in 1993-1996 (Interim Report)
97-9 QC & QA Projects Constructed in 1996 Under QPM2 Specifications (Fifth Annual Report)
97-10 Loading Test of GRS Bridge Pier and Abutment in Denver, CO
97-11 Faulted Pavements at Bridge Abutments

98-1 I-76 Truck Study
98-2 HBP Pilot Void Acceptance Projects in Region 2 in 1997
98-3 1997 Hot Bituminous Pavement QC for Day Pilot Project with Void Acceptance
98-4 Hot Bituminous Pavement QC & QA Project Constructed in 1997 Under QPM2 Specifications
98-5 Evaluation of the Iowa Vacuum Tester (Final Report)