Report No. CDOT-DTD-R-97-6

Evaluation of the Iowa Vacuum Tester

William (Skip) Outcalt
Colorado Department of Transportation
4201 East Arkansas Avenue
Denver, Colorado 80222

Interim Report
July, 1997

Prepared in cooperation with the
U.S. Department of Transportation
Federal Highway Administration

The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Colorado Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

ACKNOWLEDGMENTS

Special thanks to the Research Study Panel, who provided input for this study and peer review of this report. The Research Study Panel consists of: Ahmad Ardani (CDOT Research Branch), Dick Hines (CDOT Staff Materials), Gerry Peterson (CDOT Region 1 Materials), and Rich Zamorra (FHWA).

Thanks also to Mr. Lynn Evans of ERES Consultants, Inc. and Mr. Doug Frith of Nichols Consulting Engineers, Ltd for valuable help and input.

REPORT DOCUMENTATION PAGE

FORM APPROVED
OMB NO. 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	July 1997	Interim Report 1996-1997

4. TITLE AND SUBTITLE

Evaluation of the Iowa Vacuum Tester

5. FUNDING NUMBERS

6. AUTHORS(S)

William (Skip) Outcalt

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(S)

Colorado Department of Transportation
4201 E. Arkansas Ave.
Denver, Colorado 80222

8. PERFORMING ORGANIZATION REPORT NUMBER

CDOT-DTD-R-97-6

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(S)

Colorado Department of Transportation
4201 E. Arkansas Ave.
Denver, Colorado 80222

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

CDOT-DTD-R-97-6

11. SUPPLEMENTARY NOTES

Prepared in Cooperation with the U.S. Department of Transportation, Federal Highway Administration

12a. DISTRIBUTION/AVAILABILITY STATEMENT

No Restrictions: This report is available to the public through the National Technical Information Service. Springfield, VA 22161

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

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 indication where there is any defect in a joint seal.

By wetting a joint with a soapy solution and applying a vacuum to the wetted area, it is possible to locate identify defects 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 the failure determined.

. This study evaluates the Iowa Vacuum Testing System and compares its results with those obtained by an experienced visual evaluator on various types of joint seals in concrete pavement at several sites in Colorado during warm weather. Cold weather evaluations will be compared in the final report.

14. SUBJECT TERMS

Joint Seals
Seal Failure
Seal Evaluation

15. NUMBER OF PAGES

19

16. PRICE CODE

17. SECURTITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

Table of Contents

APPENDIX

Evaluation of the Iowa Vacuum Tester

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 that cannot be compressed can cause cracks or spalls which allow water to penetrate the pavement.

Evaluation of joints and seals is usually done by visually examining them. Areas that appear to have problems are probed to determine if the seal has failed and why.

Several factors, including the large linear footage and the possibility for several types of failure, make visual evaluation of joint seals difficult at best. This is especially true during the warm months when expansion of the pavement closes the joints and makes adhesion and cohesion failures harder to see. The procedure is time consuming, inefficient, and heavily dependent on the experience of the evaluator.

A common method checking adhesion of the seal to the walls of the joint is to take a 10 cm core sample over the joint and slowly pull the two halves of the core apart. Obviously, this is a destructive method and only samples a very small portion of the joint. Core sampling is labor intensive, localized, and requires specialized equipment. It is difficult to restore the integrity of the joint where a core has been taken.

The Iowa Department of Transportation has developed a vacuum testing system (IA-Vac) that gives a positive indication where there is even a very small defect in a joint seal. The IA-Vac applies a vacuum to a 1.2 m section of joint that has been wetted with a soapy water solution. Air pulled through a defect in the joint causes bubbles which show the exact location of a seal failure and its extent. If necessary the operator can examine the area to determine the exact cause and extent of the failure.

II. Description

A: IA-Vac equipment:

The Iowa Vacuum system consists of the following equipment: test chamber, vacuum pump, reserve vacuum tank, hoses, sprayer, and generator. Water and some type of liquid soap are also needed. For a more complete description of the equipment, see appendix A.

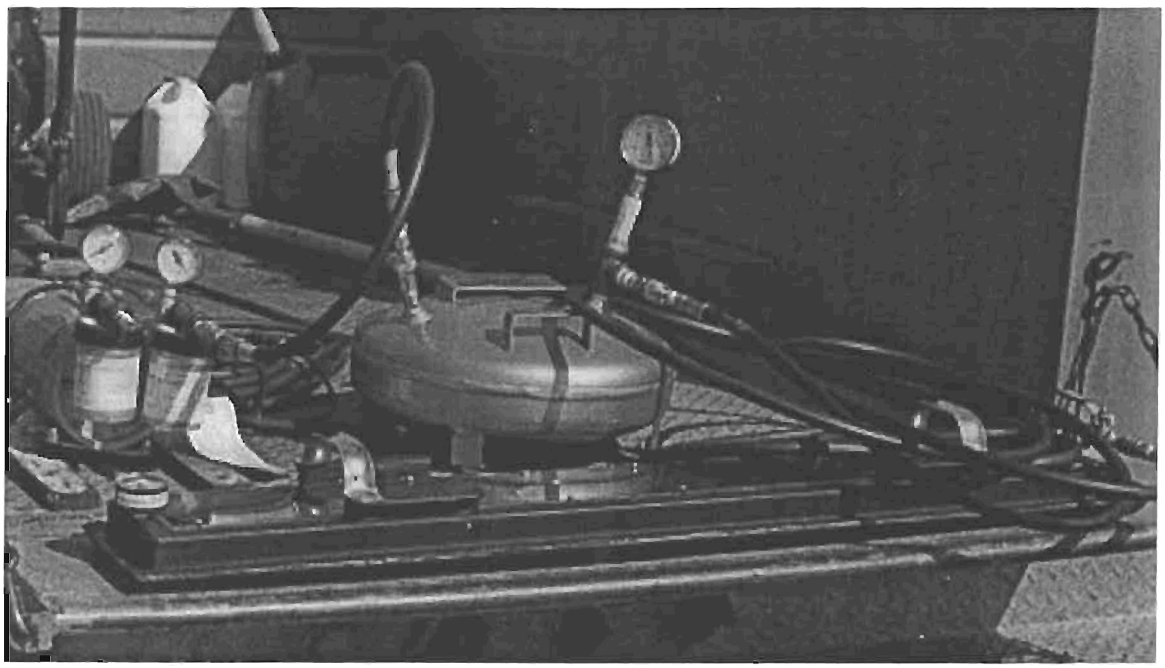

Figure 1 The Iowa Vacuum Testing System. The pump, to the left, has two gauges, It can be used as either a compressor or a vacuum pump. The storage tank also has a gauge to show the pressure level in the tank. The test chamber is on the tailgate of the truck. The gauge on the left end lets the operator keep the vacuum at the proper level. Next to the silver handles are foot rests for the operator to stand on to help the chamber seal to the pavement. At the right end is the vacuum valve which is opened to apply vacuum to the chamber. The 10 ft. supply hose connects the storage tank to the chamber through the valve. A 6 ft. hose that is open at the end connects to the chamber side of the valve. The operator regulates the vacuum level in the chamber by opening and closing the end of the hose with his thumb.

B. System Operation:

A van or pick-up truck is a convenient way to transport the IA-Vac. The generator, vacuum pump, and vacuum storage tank stay in the vehicle during testing. One person walks behind carrying the IA-Vac and doing the testing while another person moves the vehicle from one test location to the next. The 7 m long hose from the chamber to the vacuum storage tank makes it possible to test two joints or test completely across a 3.6 m lane without moving the vehicle.

Testing with the IA-Vac requires at least two people if more than a few joints are to be tested. One person drives the vehicle carrying the generator, pump, and reserve vacuum tank. The other does the testing. Addition of a third person to spray the joints increases the rate of testing. With three people, it is possible to perform 100 tests in one hour according to the designers.

Test procedure:

1. Choose an area to test. If necessary, sweep the area to remove dirt and debris. The pavement needs to be fairly clean so the chamber can make a good seal. The joint should be free of all loose material so leaks can be seen and their cause determined.

2. Wet the joint seal completely. Also wet the area where the test chamber will sit to help

Figure 2 Wet the joint and the pavement surface for about 4" on each side.

the chamber make a good seal with the pavement.

3. Put the test chamber in position over the wetted joint. If the joint seal is more than about 3 mm below the surface of the pavement, a short section of backer rod or silicone seal placed in the joint below each end of the chamber seal will help it seal to the pavement.

4. Stand on the foot rests on top of the chamber, close the end of the vent hose with your thumb, and open the vacuum valve. When the chamber gauge indicates vacuum (about 5 seconds), 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 3 The operator stands on the chamber to help it seal to the pavement. The hose in his right hand regulates the vacuum level in the chamber.

NOTE: When there is no vacuum applied to the chamber the vacuum gauge on the test chamber used for this study reads 5 in. Hg Vac. Presumably , this is because Denver is 5000 feet above sea level. It is important to be sure that the <u>change</u> from static position on the chamber gauge does not exceed 12.5 cm Hg vac. 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. If there are no bubbles, but there is a wet spot on the glass there is probably a large failure that allows too much air to pass for bubbles to form. This can occur at a large spall in the joint or a tear in the seal.

6. Close the vacuum

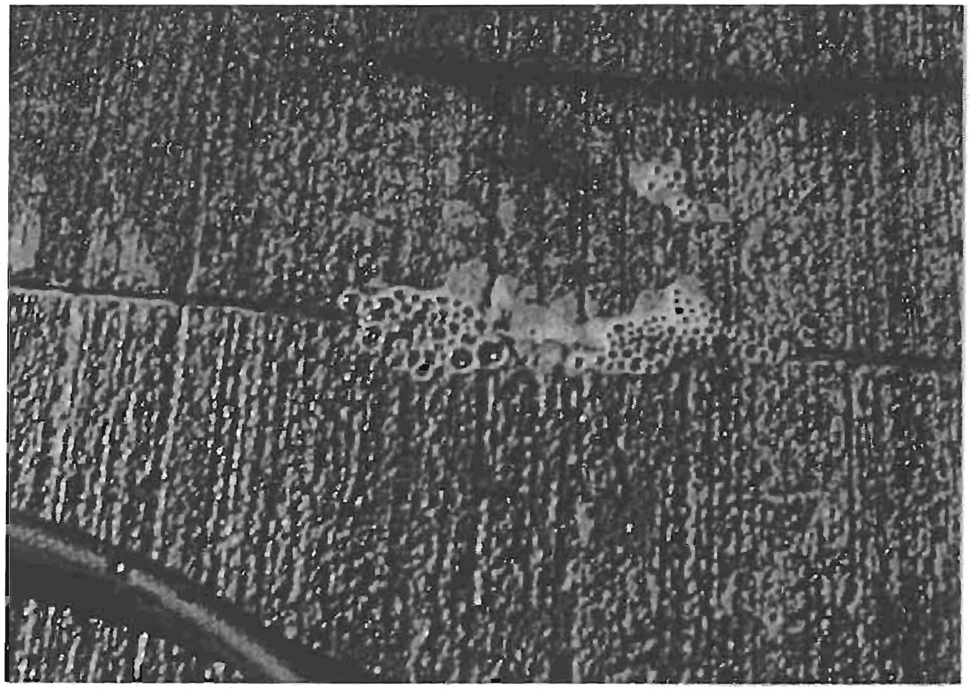

Figure 4 Two groups of bubbles indicate two leaks in the joint.

Figure 5 The drops in the center of the chamber show a severe leak. The air flow through the failure can't bubble; it just sprays the solution on the bottom of the window. This can also happen if the vacuum level in the chamber is too high with a smaller leak.

valve to release the chamber. Move the chamber and determine the cause of the failure at the marked locations.

C. Maintenance:

Maintain the oil level in the reservoir on the vacuum pump with special attention to using the proper viscosity.

Check the seal on the test chamber for tears and damage. If it is necessary to replace it, 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. After the new seal has cured, it can be bonded to the test chamber using the same Dow Corning 890 SL silicone. Silicone sealant or weatherstrip adhesive may be used.

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. This is especially important with a new seal.

Clean the glass with a soft cloth.

D. Cautions

Be sure to keep the oil reservoir on the vacuum pump filled with the proper oil.

The part of the joint to be tested and the area where the test chamber seal will sit should be free of sand, dirt, and dust. Dirt in the joint may prevent the solution from wetting the joint seal. A failure in the area that is not wet will not bubble and may not be apparent. Debris on the pavement can prevent the chamber from sealing.

Be sure to stand only on the foot rests on the top of the test chamber.

The vacuum level in the chamber is the reading when vacuum is applied <u>minus</u> the reading at rest. Keep the vacuum level in the chamber below 12.5 cm of mercury. This level must be read as the change in the chamber gauge after the vacuum valve is opened. A stronger vacuum level will cause the chamber seal to roll to the side, pulling it off the base of the chamber or tearing it. A high vacuum level will not help locate more leaks; it may make large leaks pass air too rapidly to allow bubbles to form and cause them to be completely overlooked.

If a test shows no bubbles (not uncommon on new seals) and the gauge shows that there is vacuum in the chamber, check carefully to be sure that there is not a large failure that is allowing air into the chamber without making bubbles. Often in this case there will be a wet spot on the bottom of the glass where the air is blowing the soap solution out of the joint onto the glass.

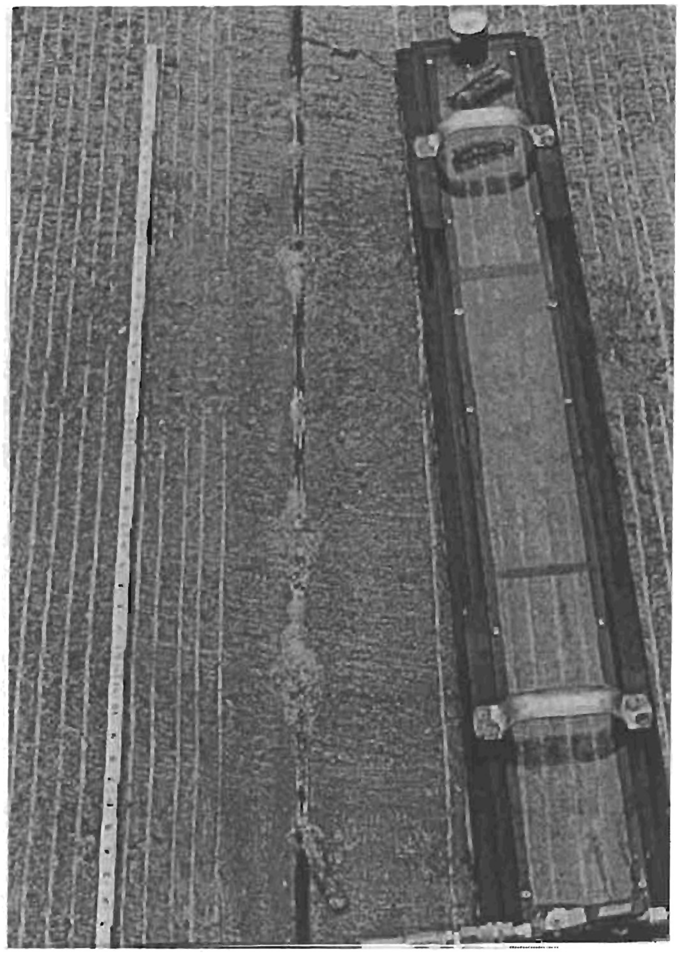

Figure 6 This is where tie IA-Vac excels. This is a compression seal with several leaks. It is very difficult to find adhesion failures visually. However, as this picture shows, the IA-Vac finds them easily. The quantity and size of a group of bubbles indicates the severity of the leak.

III. Evaluation:

A. Visual Testing

A common way to check the overall condition of seals and joints is by visual evaluation. This is usually done in cold weather when thermal contraction has opened the joints as much as possible. Spalls and some construction problems are easily located visually and can be probed with a tool like a dull knife blade to determine the extent of failure. However, adhesion of the seal to the sides of the joint is not always easy to locate by this method. Joints that had dust or moisture on their walls when they were sealed are very likely to have problems with the sealant not adhering. The surface of the seal may look good but unless it is pulled to the side, adhesion problems may not be apparent.

This method is slow and inefficient and it is easy for even an experienced person to miss small failures. It can also be a problem in a new product evaluation where the same seal is to be rechecked several times over a long period. Changes in personnel performing the evaluation or changes in the skill level of one evaluator can give inconsistent results. Correctly used, the IA-Vac will always find the same leaks.

The testing for this evaluation was done with the help of Mr. Lynn Evans,of ERES Consultants, Inc. Mr. Evans is one of the principal evaluators of the SHRP SPS-4 joint seal study. The Colorado SPS-4 site has nine different test sections, as shown in the following table. Each section is repeated twice.

	Joint Width		
Seal Type	3.2 mm	6.4 mm	9.5 mm
Neoprene Compression		X	X
Self Leveling Silicone	X	X	X
Tooled Silicone	X	X	X
Unsealed	X		

Each year in November 12 of the joints in each section are carefully examined visually and all of the failures recorded as inches of failure per foot of joint. For the IA-Vac evaluation, the first three joints used by the SHRP study in each section were tested to see how the IA-Vac results compared to the SHRP data. Joints tested with the IA-Vac were tested for 1.22 m from 0.3 m inside the shoulder stripe to 1.62 m inside the shoulder stripe.

The following table compares failures observed during the SHRP visual evaluation done in November 1996 with IA-Vac data collected during May 1997. Each data column represents 0.3 m of the joint. The left column begins 0.3 m from the shoulder stripe.

Section Number Joint width Seal Material	Joint Number-test method	Length and cause of failure: C=Cohesion S=Spall, A=Adhesion, I=Intrusion, D=Construction, B=Bubble, P=Partial depth (see appendix B)			
455 9 mm Joints Crafco RS902 Silicone tooled	5 IA Vac		25 mm C 25 mm S	25 mm S	
	5 Visual	25 mm AP	25 mm C	50 mm SP 25 mm AP	
	16 IA Vac				
	16 Visual				
446 9 mm Joints Crafco RS903 Silicone Self Leveling	3 IA Vac				
	3 Visual	25 mm SP			
	4 IA Vac				
	4 Visual		25 mm SP		25 mm S
	5 IA Vac				
	5 Visual			25 mm SP	25 mm SP
415 9 mm Joints Crafco RS902 Silicone tooled	4 IA Vac				
	4 Visual				
	6 IA Vac				
	6 Visual	25 mm SP	25 mm SP		
	7 IA Vac				
	7 Visual		25 mm SP	25 mm SP	

445 6 mm Joints Crafco RS903 Silicone Self Leveling	6 IA Vac		25 mm A		25 mm A
	6 Visual		50 mm AP	50 mm AP	
	8 IA Vac			50 mm S	
	8 Visual			25 mm SP 50 mm S	
	9 IA Vac		25 mm S	25 mm S	25 mm S
	9 Visual		50 mm SP 50 mm S	25 mm SP	
414 6 mm Joints Crafco RS902 Silicone tooled	8 IA Vac		25 mm S		
	8 Visual	25 mm SP			
	11 IA Vac		25 mm S*	25 mm S*	25 mm S*
	11 Visual		50 mm SP	25 mm S	25 mm S
	12 IA Vac				25 mm S 25 mm D
	12 Visual				
444 3 mm Joints Crafco RS903 Silicone Self Leveling	4 IA Vac			25 mm S	
	4 Visual	25 mm SP		25 mm SP	
	5 IA Vac	25 mm S	25 mm S	25 mm S	50 mm S
	5 Visual	75 mm AP	25 mm AP 25 mm S	25 mm S 150 mm AP	25 mm SP
	6 IA Vac		25 mm S	50 mm S	25 mm I**
	6 Visual	75 mm AP	50 mm SP 125 mm AP	50 mm S	

413 3 mm Joints	3 IA Vac		25 mm D	25 mm S	25 mm S
Crafco RS902	3 Visual		25 mm C		25 mm SP
Silicone	5 IA Vac	25 mm S	25 mm S	25 mm A	
tooled	5 Visual	25 mm SP		1 B 25 mm SP	
	7 IA Vac				
	7 Visual		25 mm S 25 mm SP 25 mm C *	25 mm S 25 mm SP	25 mm SP
452 9 mm Joints	3 IA Vac	Failed for about 50% of tested area			
D.S. Brown	3 Visual	25 mm SP			25 mm SP
Compression seal	5 IA Vac	50 mm S	50 mm S	75 mm unknown	25 mm S
	5 Visual	25 mm P			50 mm SP 25 mm S
	6 IA Vac		25 mm S		25 mm S
	6 Visual		25 mm SP		

*These were large failures identified visually - The IA-Vac was unable to get a vacuum.

** Something had been pressed into the seal before it cured. It was later pulled out leaving a hole. This failure was not located during the SHRP visual evaluation.

The visual evaluation missed 50 mm of full depth adhesion failure, called 325 mm of full depth spalls partial depth, and missed 225 m of full depth spalls. All of these were located by the IA-Vac.

The Iowa Vacuum Tester is easy to operate. After just a few tests a "rhythm' establishes itself and testing flows very smoothly. The system is equipped with several gauges so it is easy to keep track of the vacuum level. The system will easily locate all of the leaks in any seal unless it is in such bad condition that a vacuum cannot be established.

It is possible to perform 100 tests per hour with 3 people, according to the designers of the IA-Vac. During our evaluation with 2 operators, a rate of about 20-30 tests per hour was normal when time was taken to determine the types of failures discovered.

Two things that slowed operations were surface texture and sealant level in the joint. Areas where the seal was below the surface of the pavement (as it should be) required a filler in the joint under the ends of the chamber. The varying widths of the joints required the use of different widths of filler rods. If the gap is not sealed the chamber will not be able to pull a vacuum. Bubbles at the end of the chamber could be either the joint seal or a leak in the chamber seal at the joint. If pressing on the filler in the joint gap changes the bubbles it is probably a leak in the chamber seal. If there is no change it is advisable to check the joint seal further.

The IA-Vac can detect very small leaks. The size of the bubbles is a good indication of the relative size of leak. 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.

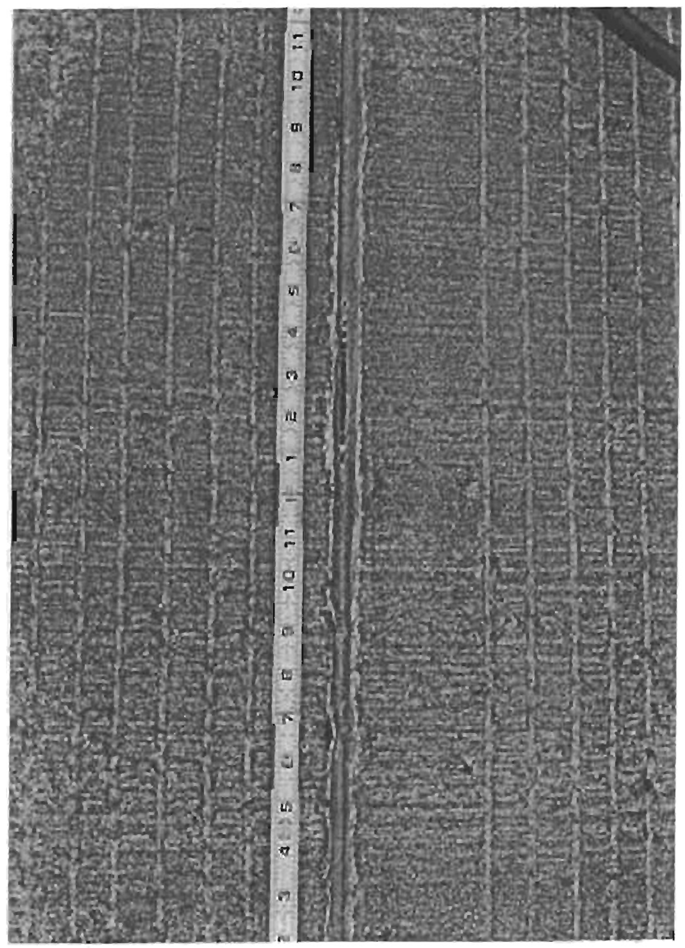

Figure 7 A severe spall at 7" and a cohesion failure at 1' 3" will not bubble. These two severe joint failures allow so much air to pass that other failures in the area cannot be detected.

IV. Recommendations:

A. Post Construction Evaluation:

As a method of evaluating the joints and joint seals on a new construction site the IA-Vac would be very good. It would locate problems caused by sawing and problems with the joints being wet or too dirty for proper adhesion of the sealant to the joint walls.

If a specification of the allowable amount of leakage per joint could be written, the IA-Vac could provide a way to determine if joints meet the specification. One of the CDOT study panel members felt that measurements would be too subjective to be used for a specification.

Random sampling through a project with the IA-Vac combined with pull tests (described below) and visual checks should provide a dependable way to predict the performance of the joint seals. The IA-Vac will provide information on the workmanship and general condition of the seals, the pull test will show conditions below the surface, and the visual check will verify the height of the seal and look for spalls, cracks, and improper installation of the seal.

A pull test is usually performed on a joint on the shoulder 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 to the side of the joint as possible 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.

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 method discussed above.

By establishing test sections and carefully monitoring installation and performance of new products, it is possible to determine which ones will best do the job in a given situation. Careful record keeping and testing using a system that is not dependent on operator experience increases the accuracy and value of the tests. Use of 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 suited to this type of use.

C. Rehabilitation Evaluation

The IA-Vac is not well suited to evaluating joints for rehabilitation because, at a seal failure level above about 20%, there will probably be too much air flow to obtain a reading. However, it could be used to track the normal deterioration of joint seals. A known selection of joints monitored from the time of construction or rehabilitation will show a rate of deterioration. The information from those joints could be recorded and used to make predictions for future rehabilitations.

D. Possible Modifications for Production Testing

The IA-Vac system that the Colorado Department of Transportation received from the FHWA has evolved considerably from its original form. Here are a few changes that the operators thought might increase its durability and improve its ease of operation and efficiency:

The hose on the sprayer leaked and fell out of the handle when the tank was pressurized. This allowed water to spray out randomly; a very unpleasant experience when the temperatures are low and the wind velocity is high. A tank with a metal nozzle that has provisions for a positive attachment of the hose would be worthwhile.

An adjustable valve on the chamber to prevent the vacuum level from exceeding 12.5 cm Hg would eliminate the need for the hose from the chamber vent. It would also make it easier for one person to keep the vacuum level in the chamber at an acceptable level while checking the window for bubbles in the chamber.

A measurement device on the outside edge of the chamber would make it easier to identify locations of specific failures. This would apply more to a product evaluation type of testing, where exact locations need to be found and recorded so tests can be repeated. It would be easy to put a metric scale on one side of the frame and an English scale on the other side.

The plexiglass window is held down with screws around the edge spaced 27.5 cm apart. It is sealed to the chamber with silicone but can warp and leak. A 25 mm wide flat metal frame around the edge of the window would distribute the pressure of the screws. It would hold the plexiglass flat and maintain the seal on the top of the chamber. The frame would also help protect the glass from scratches during transport and handling.

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 9 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.

Appendix A

IA-Vac equipment:

1. Test Chamber: A lightweight metal box 15 cm wide, 122 cm long, and 5 cm high. The top of the chamber is plexiglass so the joint being tested is visible. Around the bottom of the chamber a triangular 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 which is also used to cast a new seal when the old one is damaged. The test chamber has handles for carrying, foot rests to stand on to help with the initial seal, 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 L per minute of airflow and generate a vacuum of about 80 mm of Hg (about 1.5 psi).

3. Reserve Vacuum Tank: A 14 L 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 is opened the tank can provide 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. Both hoses, the pump, the reserve tank, and the test chamber are fitted with quick connect couplers.

5. Sprayer: A 12 L (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

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

The seal failure categories used in this report and their descriptions are:

Cohesion: 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.)

Spall: A chip off the corner of the surface of the pavement along the joint. A spall may extend below the seal or end in or above the seal. If it ends in or above the seal the IA-Vac will not find it. However, it is not a seal problem then.

Adhesion: Failure of the seal material to adhere to one or both 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 as soon as possible.

Intrusion: A foreign object that has become imbedded in the seal material before it was 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.

Construction: Nearly all of the failure types are caused by poor construction practices. The ones that are listed in the chart as construction failures were definitely due to poor construction techniques, such as tooling too thin or improper backer rod placement.

Bubble: A bubble in the seal material.

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