NONDESTRUCTIVE EVALUATION METHODS FOR ASSESSING THE QUALITY OF SEAMS IN SINGLE-PLY MEMBRANES

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The feasibility of using the ultrasonic pulse echo method and the infrared thermography method for detecting the presence of voids and delaminations in adhesive-bonded seams in single-ply membranes was investigated in laboratory and field exploratory studies. Preliminary results suggest that these methods could be used to locate voids and delaminations in seams.

The durability of a single-ply membrane is dependent on the performance of both the membrane and the seams. Some of the problems occurring with single-ply membranes are attributed to failures of field-fabricated seams.[1] The quality of these seams often is only assessed by visual inspection. Large bubbles and "fish mouths" can readily be found by visual inspection. Other inspection methods that are occasionally used for geomembranes are the air lance and the pick test.[2] These methods, however, do not detect many of the typical voids or delaminated areas that occur in the interior portions of seams, which can lead to seam failures. Failure of a seam can result in moisture penetration through the membrane system, causing loss of thermal efficiency of the roofing insulation and water damage to other building components.

The feasibility of using non-destructive evaluation (NDE) methods to detect voids and delaminations in adhesive-bonded seams of single-ply roofing membranes is being investigated at the National Bureau of Standards. Ultrasonic pulse echo and infrared thermography methods have been used to detect voids and delamination in materials such as concrete,[3] metals[4] and geomembranes,[2] and were considered to be among the most promising methods for inspecting seams in roofing membranes. Therefore, they were selected for evaluation in the present study. Preliminary results obtained using these NDE methods for detecting voids and delaminations in both laboratory and field-fabricated seams are presented in this report.

PRINCIPLE OF NDE METHODS

Ultrasonic Pulse Echo

In the ultrasonic pulse echo method, sound waves beyond the audible range are induced in a seam by a piezoelectric transducer, and waves reflected off discontinuities such as voids and cracks and from interfaces such as between membrane and thermal insulation or air are recorded. A completely bonded seam would produce an echo signal that passed through two membrane layers, while if the region of the seam being inspected was unbonded, the echo only would pass through one layer (*Figure 1*). Therefore, the echo signal would require twice the time to pass through a bonded region of a seam.

The penetrating ability of the ultrasonic pulse and the minimum size of detectable flaws are influenced by the frequency of the generated waves. High-frequency waves have less penetrating abilities but better sensitivity in detecting small voids than do low-frequency waves. In the present study the piezoelectric transducer had a frequency of 1.0 megahertz.

Ultrasonic waves are reflected at interfaces between air and denser materials. Water usually is used (as in this study) as a coupling medium between the transducer and the object being inspected.

Multi-reflections can occur when an ultrasonic wave is induced in a material, which complicates the interpretation of the echo pattern. In the present study, only the first echoes (first order echoes) were recorded.

Infrared Thermography

An object having a temperature above absolute zero degrees Kelvin will emit energy in the form of thermal photons. Around room temperature, these photons will be in the infrared region. The photons can be recorded using an infrared camera and displayed on a cathode ray tube. By using the infrared camera, surface temperature differences of less than 1C can be measured while temperature differences of less than 1C can be measured while a seam is rapidly being scanned. If the temperature of a roof is changing, the presence of voids, bubbles or delaminations in a seam can cause the surface temperature directly above the defect to be at a different temperature than that of a defect-free region (*Figure 2*). The infrared camera used in the present study could detect temperature differentials of 0.2C.

SEAM FABRICATION

Laboratory Seams

Seams were fabricated from a commercial EPDM (ethylene-propylene-diene terpolymer), using a cleaning process and contact adhesive recommended by the supplier of the EPDM. After the EPDM surfaces were cleaned and coated with the adhesive and the adhesive had dried, the seam layers were pressed together at 0.69 mPa for 10 seconds in a hydraulic press. Also, to simulate field fabrication, some seams were pressed together with a roller supplied by the EPDM supplier. The pressures exerted using the roller were measured to be around 0.69 mPa. Voids of known size were created in seams by placing tape over a desired area of the EPDM surfaces prior to the adhesive application and removing the tape after the adhesive had dried. The voids were squares with areas of 161, 361, and 645 millimeters. Completed seams were placed on 25 millimeter insulation board, which provided a substrate during testing.

Field Seams

In a preliminary experiment, field-fabricated seams in an installed EPDM membrane system also were inspected using both the ultrasonic pulse echo and infrared thermography methods. Some of the seams in this membrane system had disbonded and, therefore, provided an opportunity to evaluate the performance of the NDE methods.

RESULTS AND DISCUSSION

Ultrasonic Pulse Echo

The echo patterns of a single EPDM layer and laboratory-fabricated, adhesive-bonded seams, all laid over a thermal insulation board, are shown in Figure 3. A single echo was observed for a single membrane layer, or at a location of a void in an adhesive-bonded seam (*Figure 3A*). Voids which were intentionally produced in the laboratory-fabricated seams were easily detected by the ultrasonic pulse echo method. The echo obtained while testing a seam fabricated using a laboratory press had a transit time about twice that of a single sheet, which implied that a tightly bonded seam had been produced in the tested specimen (*Figure 3B*). The method also was used to examine seams in specimens fabricated using a roller. The echo pattern varied across the length of the seams. For many locations, the pattern was similar to that for the laboratory-pressed seam. However, at some other locations echo patterns similar to that produced by a single sheet or void were observed. This is depicted in Figure 3C, which shows echo patterns using solid and dashed lines. The echo pattern having the solid line was the predominant response observed over many locations on the seam. The dashed line represents the response observed at a few other locations. Reasons for these observations regarding the seams made using the roller need further investigation. In the field test, some of the seam areas located in the installed membrane system gave echo patterns similar to that observed for either a single sheet or a laboratory-pressed seam. However, echo patterns taken at other locations in the field system were too complex to interpret without additional studies.

Results of the laboratory and field exploratory studies do suggest that with further research the ultrasonic pulse echo method could become a reliable method for detecting voids and delaminations in seams. Techniques to make the method practicable for field investigations also need to be developed.

Infrared Thermography

The effectiveness of three methods for causing temperature differentials on the surface of seams were investigated. In the first method used, the back side of a seam was heated to 25C above ambient temperature and the surface temperature of the reverse face was measured by the infrared method. The presence of voids in the laboratory-prepared seams with known voids was not detected and this method was not investigated further. Heating the top surface of a seam to 25C above ambient temperature was found to produce a measureable temperature differential when voids were present. The resulting infrared thermograph is shown in Figure 4A, with the white regions in the seam image corresponding to voids. In the third method, the seam surface was heated to 25C above ambient temperature and then was immediately cooled with an air blower for one minute. The infrared thermograph was recorded within one minute after the cooling process. Voids appear as dark areas in the resulting thermograph (*Figure 4B*).

Results of the preliminary infrared thermography inspections of the EPDM roof membrane were encouraging. In this field experiment, the temperature differential was created by heating the surface of the seam using a laboratory heat gun. In one case, at a location where the seam contained an obvious delamination at its edge, the delaminated area was observed using thermography. In another case, a section of a heated seam which showed no obvious defect produced an infrared thermographic image that was similar to that given in the laboratory by a seam containing a void. Although the indication was that a void perhaps was present, it was not possible to verify the presence of a void because the membrane could not be cut during the field examination.

One practical difficulty encountered during the field test was the heating of the seams using the laboratory heat gun. It was difficult to raise the surface temperature of the seams sufficiently on the roof top under the weather conditions (windy, cool, overcast) during the day of the test. Nevertheless, these preliminary results suggest that the infrared thermography method can be used to identify the presence of voids in seams. Further studies are needed to optimize the process of creating temperature differentials and to determine the minimum void size which can be detected.

SUMMARY

The feasibility of using the ultrasonic pulse echo method and the infrared thermography method to detect the presence of voids and delaminations in seams was investigated in this study. The preliminary results suggest that both methods were successful under certain conditions to locate voids and delaminations in roofing seams. In the laboratory, voids intentionally incorporated in seams were readily detected using both methods. In the field, the results were less conclusive. The ultrasonic pulse echo method produced echo patterns that were for the most part difficult to interpret. The infrared thermography detected delaminations which were visible at the edge of the seam, and in one case, gave a thermographic image that indicated that a void was possibly present in the interior of the seam. Since the methods were found to be successful in the laboratory, it is believed that their application to field analysis could be developed through further research.

To use the infrared thermography method to locate voids and delaminations, a surface temperature differential must exist or be created between bonded and unbonded areas. Such temperature differentials were created in the present study by heating the surface of seams or by cooling heated areas. Both processes were found to create a sufficient temperature differential so that unbonded regions could be detected by observing their infrared thermographs.

Both the ultrasonic pulse echo and the infrared thermography methods need further research before their reliability in locating defects can be ascertained and their results more fully interpreted.

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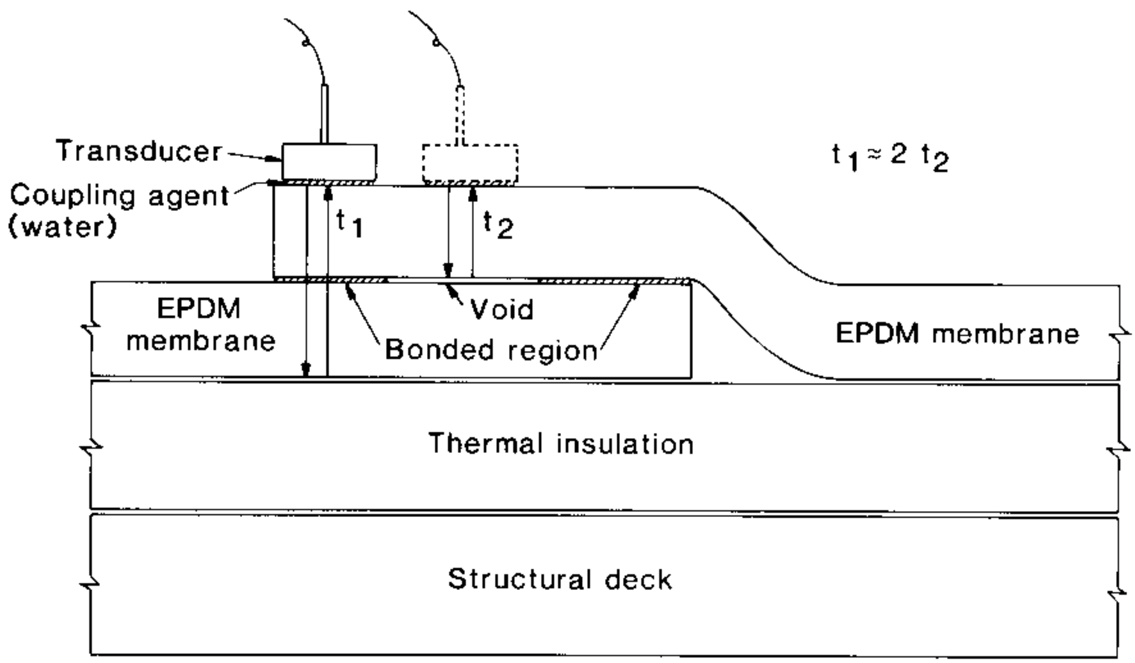

Figure 1 Ultrasonic pulse echo method. Echo times t_1 and t_2 is proportional to the thickness of the membrane or seam through which the wave propagates

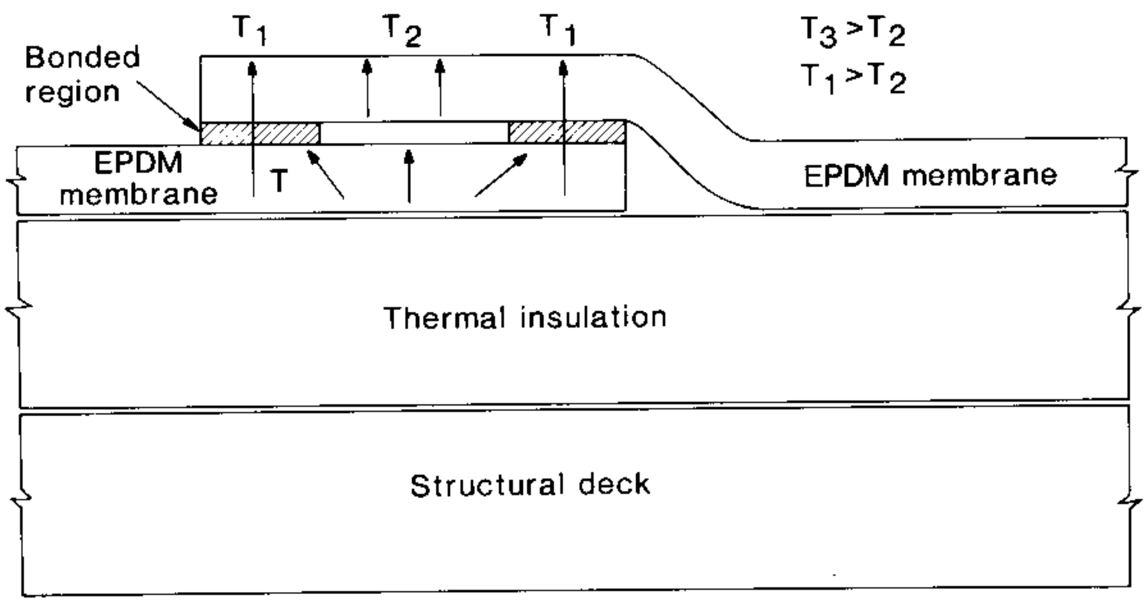

Figure 2 Infrared thermography method. Temperature is indicated by the symbol T

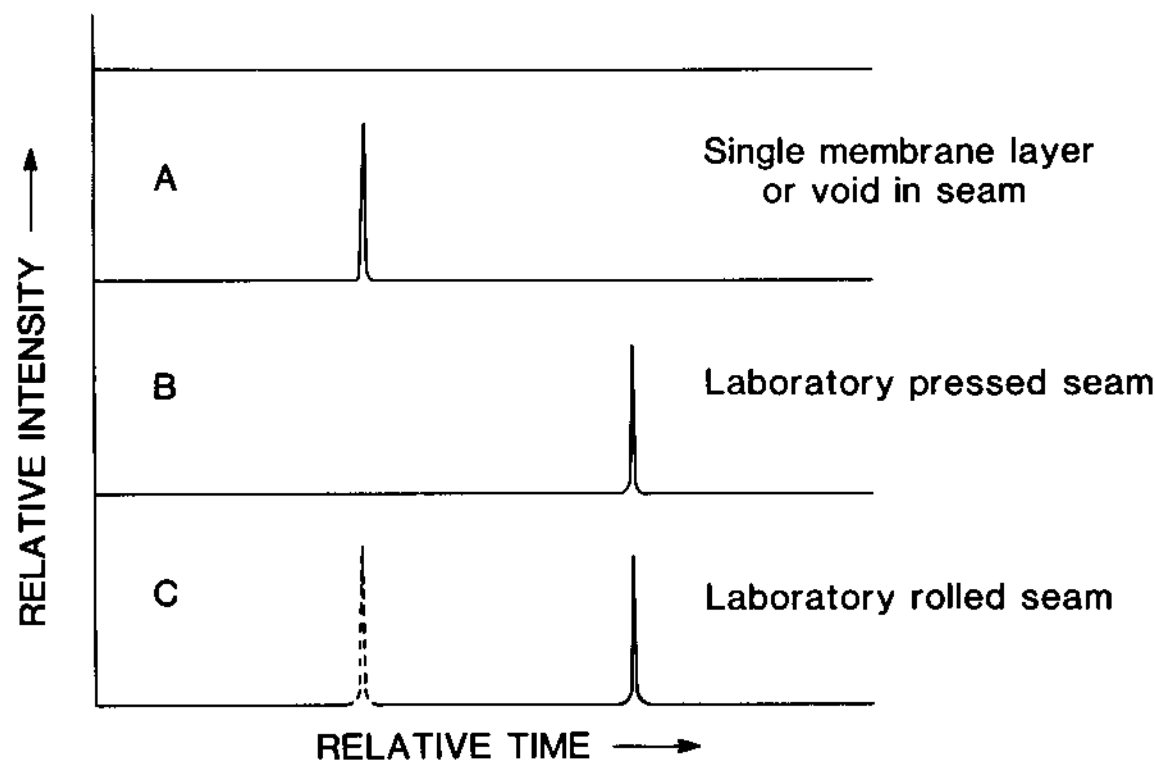

Figure 3 Ultrasonic pulse echo patterns of membrane, seams and voids in seams

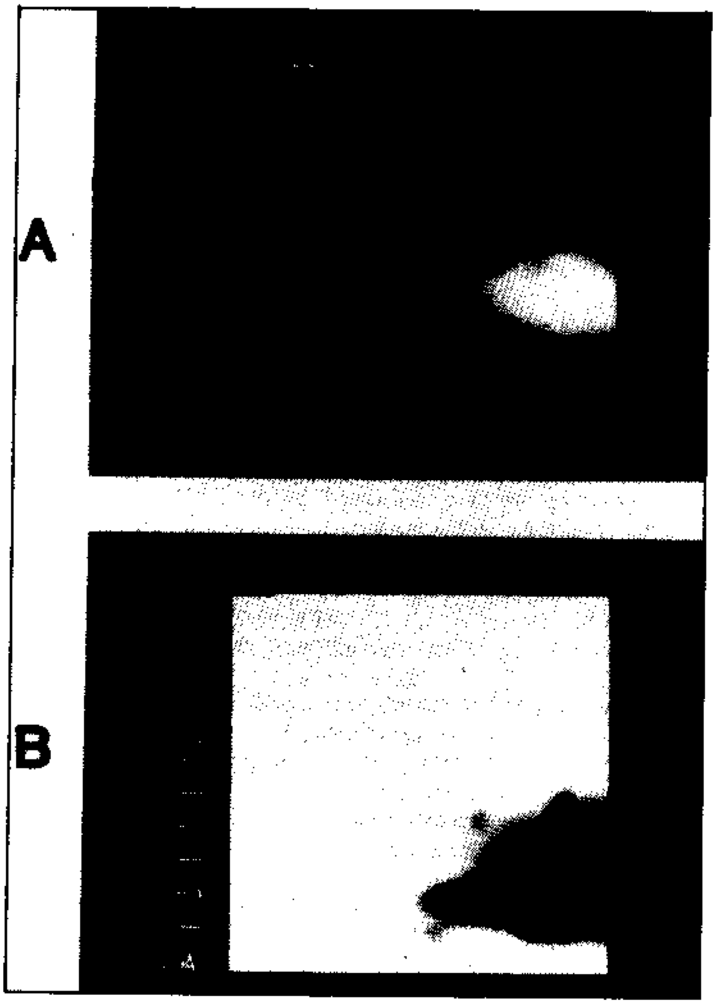

Figure 4 Infrared thermograph.
A. Top surface heated to 25C above ambient temperature with the white region indicating the presence of a void.
B. Seam heated to 25C above ambient temperature and then rapidly cooled. The dark region in this case indicates the presence of a void.