Infrared Thermographic Nondestructive Testing of HDPE Geomembranes Seams

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ABSTRACT: A preliminary evaluation of infrared thermography (IRT) as a method for nondestructively testing geomembrane seams is described. IRT will identify nonpenetrating defects within seams and shows potential for broadly assessing seam bond strength, thus potentially obviating the need to destructively test good seams.

1 INTRODUCTION

Seams fabricated in the field under uncontrollable ambient conditions are the Achilles heel of geomembrane liners. To ensure that seams are well made they are 100% nondestructively tested. NDT techniques simply monitor the continuity of the seam, they do not assess the bond strength. Conventional NDT methods, such as air channel pressure testing, vacuum box testing, and spark discharge testing are only capable of identifying penetrating holes through the seam.

To assess seam bond strength samples are cut out of a production seam approximately every 150 m for destructive peel and shear testing. The production seam, usually a thermal fusion seam, is repaired with a patch that is seamed with an extrusion seam of approximately three times the length of the fusion seam. Extrusion seams are generally considered to be inferior to fusion seams. In effect, we cut a hole to ensure that we are not likely to get a hole in the liner seam, and then we repair the original (probably acceptable) seam with a longer length of an inferior seam. There is, therefore, a major incentive to develop an NDT method of evaluating seam bond strength.

Additionally, there are many defects within seams, such as partially penetrating channels, partially penetrating cracks, interface dirt, and internal voids, that, while they are not detected by conventional NDT methods, have the potential, under service stresses, of initiating and developing into critical cracks that could cause ultimate liner leakage or major fracturing (Peggs et al., 1990). An NDT method capable of identifying internal seam defects may also be capable of assessing seam bond strength.

Ultrasonic methods of nondestructively testing seams have been investigated (Peggs et al., 1985). While multi-frequency ultrasonics clearly define internal defects under controlled laboratory conditions, the signals transmitted through the seam from one geomembrane to the other in the field contain so much background noise, and the scan rate is so slow, that the technique is impractical.

Infrared thermography (IRT) has been used for many years to locate thermal leaks in buildings, moisture under roofing membranes, and short locations in electrical equipment, simply by remotely measuring surface temperatures. It was thought that IRT may have some potential for locating holes in geomembranes, and defects within seams, just as it can be used to detect delamination and blistering in fiberglass composites.

2 BACKGROUND

HDPE geomembranes have a relatively low value of thermal conductivity and should, therefore, provide an thermal barrier such that the upper environment is at a higher temperature than the subgrade during the day, but at a lower temperature than the subgrade at night. There should, therefore, be a flow of heat through the geomembrane at all times. Such heat flow will be different through seams that contain voids, lack of bonding, or interface dirt, when compared to seams that are clean and well-bonded. The relative heat flow through seams of different bond strength should also be different, and perhaps measurable. Only fully bonded seams, where the weld material has the same structure as the parent material will have the same heat flow characteristics as the parent material. Hot or cold air flowing through holes in the geomembrane should also generate temperature variations in the geomembrane at the edges of holes. It was thought that a sensitive IR camera could "see" such temperature differences.

A preliminary test had been performed on a sample cut from a seam that had been repaired by multiple extrusion beads. The seam was known to be leaking at two locations. The sample was heated with a hair drier and the cooling monitored by an IR camera. The two leak locations could be clearly identified.

In early 1992, at the start of this feasibility study, the FLIR Model 2000F IR camera was capable of resolving temperature variations of 0.06°C. Discussions with the camera manufacturer suggested that a 0.5 mm diameter hole that disturbed the temperature of the geomembrane by 3.5°C should be detectable by a camera placed 4.3 m above the liner travelling at a speed of 3,2 km/hr. The path width of the liner examined would be approximately 1.5 m allowing a survey rate of approximately 4 ha/day.

The FLIR camera was used to perform two brief additional preliminary studies. From a distance of about 5 m, it successfully defined a surface blemish approximately 50 mm^2 in area on HDPE geomembrane, and it identified cracked strands in a geonet sandwiched between two layers of nonwoven geotextile. In the latter case only two adjacent broken strands were required for resolution by the IR camera.

3 THE TEST SITE

Arizona Public Service made available their Number 1 evaporation pond, with an area of 100 ha, that was being relined with a 2 mm smooth HDPE geomembrane. Approximately 5 km of seam were examined by IRT and by a geoelectric leak location method (Peggs, 1993) as the pond was being filled.

4 THE EQUIPMENT

Figure 1 shows the basic equipment. The IR camera was mounted 3.7 m above the liner, on a tower on the front of a trailer. Its field of view was 1.4 m x 1.5 m. The camera could be rotated and tilted remotely. A miniature visible light camera was mounted 450 mm above the surface of the liner to view the same area as the IR camera. A 76 MJ propane powered IR heater was placed across the front of the trailer to heat the area of liner to be viewed by the IR camera. A video monitor was used to view the seam while the video and audio commentary were recorded on VHS tape. The trailer was pulled by a small tractor with a 4 kW generator attached, to power the equipment and charge the camera's batteries. Tractor and trailer tires exerted ground pressures less than 40 kPa.

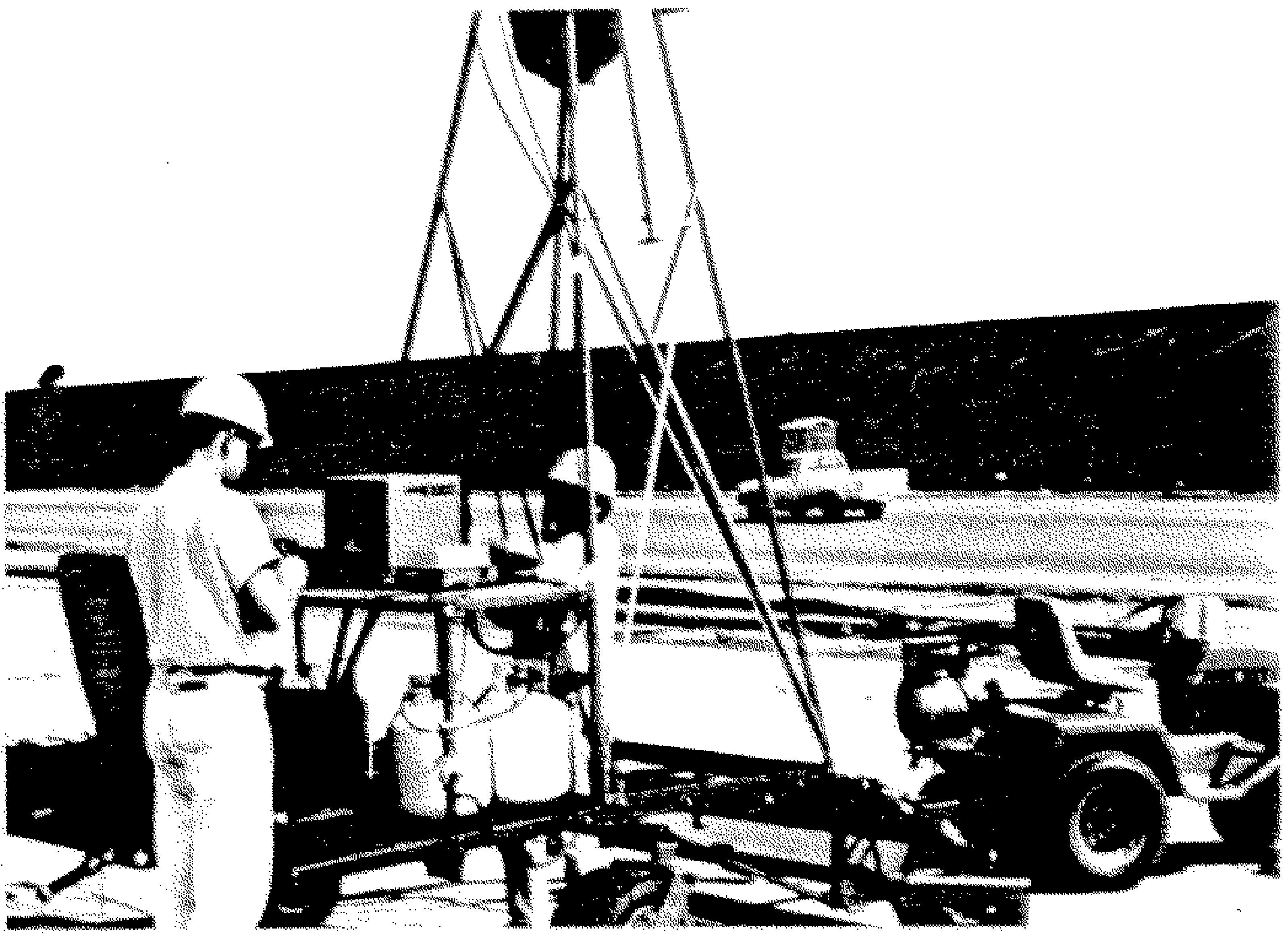

Fig. 1 IRT Mobile Test Rig

5 FIELD SURVEYS

The section of liner examined had been nondestructively tested by the installer and all repairs had been made. It was not possible for us to remove interesting sections of seams for further laboratory examination.

The first survey was performed during daylight hours in sunshine. The tower cast shadows on the geomembrane, and wrinkles had warm sides and cold sides. The wrinkles also caused the liner to move as the mobile test rig (MTR) passed by. There was too much background "noise" for an effective survey. Heating the geomembrane with the heater proved to be ineffective.

A second survey was performed at night when the geomembrane had cooled down and contained few wrinkles. There were no thermal shadow problems at night. It was found necessary to heat the geomembrane surface through about 15°C, under which conditions the liner could be surveyed with manual monitoring for defects, at a speed of about 5 km/hr. Calibration holes between 1 and 3 mm in diameter were placed in the geomembrane and were evident in the IR monitor. However, with the correct artificial light the holes could all be more easily seen by the visible light camera. At this point it was decided to concentrate the IR cameras on the seams and to leave parent geomembrane surveying to visible light cameras. This would permit a significant increase in the magnification of the seam, at this point less than unity. The camera magnification was increased to about 1.25 and several long seams examined. It was found that an even higher magnification would be desirable, and that it would be necessary to move the heater further forward, to allow more thermal energy to penetrate the geomembrane surface prior to it being surveyed. It was also noted that IRT was ineffective where there was standing water, and even condensation, on the surface of the geomembrane.

The heater was moved to the front of the tractor and aligned along the length of the seam. The camera was lowered to 1.6 m above the geomembrane. At one point the installers identified a section of seam that had not been able to pass an air pressure test; the IRT equipment was able to locate the leak in the seam within a few seconds, as shown in Figure 2. No obvious leaks were found in the seams examined on the remaining section of the liner. However, the following interesting features were observed:

- Holes in the geomembrane under patches
- Probable voids within seams where patch seams intersect sampled seams
- Probable voids within run-out beads from patches to, and along, original seam
- Lack of bond width on inner track where geomembrane overlap has been insufficient
- Amount of panel overlap
- Distinct features at many, but not all, "T" intersections between seams and the longitudinal fold in blown film geomembrane.

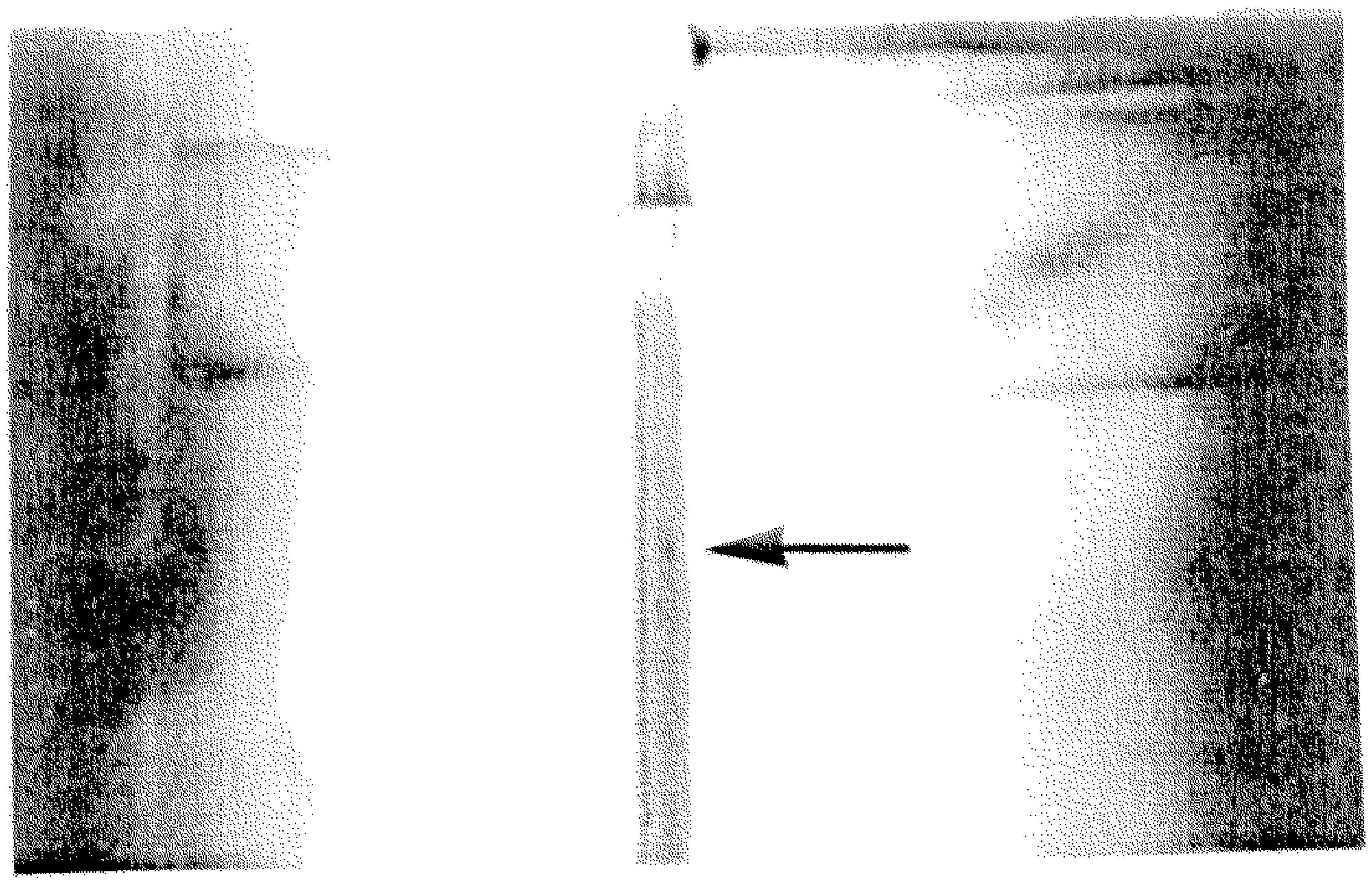

Fig. 2 Seam leak (arrowed).

It seems evident that the technique can identify consistent "unique" features that are not normally responsible for liner failures. It, therefore, will become important to define those features that are not a problem and those are cause for concern.

At a later date, when water covered this section of a liner, an electrical leak survey was performed over the same seams, but no leaks were found.

During the investigation a trial seam in a polypropylene/EPDM alloy geomembrane was examined and shown to display light to dark shading towards one end of the seam and on each track of seam. Strips across the seam were cut and subjected to peel testing, displaying different amounts of peel separation on each track and along the length of the seam, consistent with the shading. The darker (colder) shades were associated with the most peel separation. Thin slice microsections of the seams were also prepared and examined by transmitted light microscopy; they showed a broad poorly defined weld zone in low peel areas, and narrow sharp weld zones where complete separation occurred. These microstructural observations are consistent with the IR thermograms, thus providing convincing preliminary evidence that IRT may have the potential to broadly define seam bond strengths.

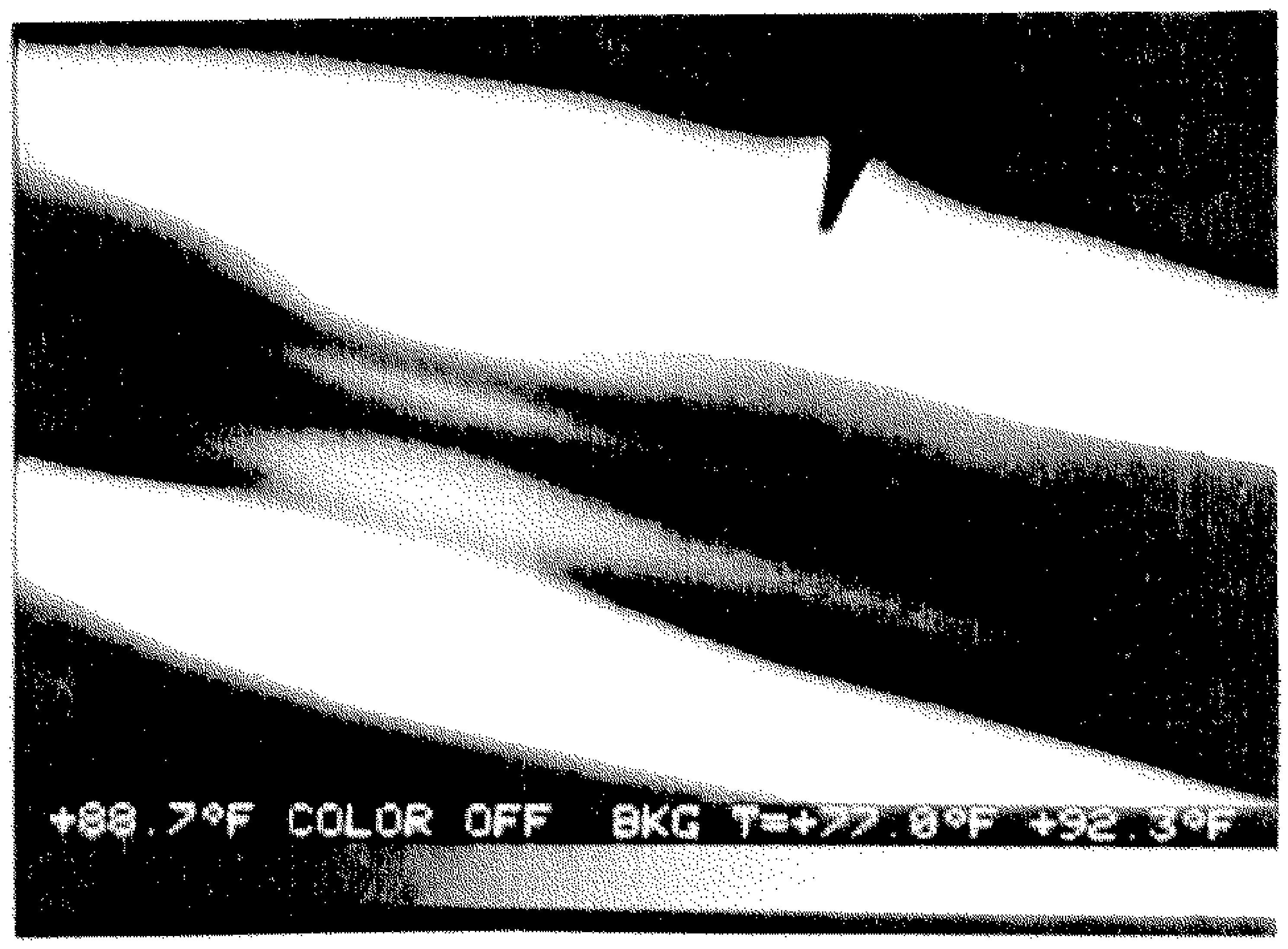

Fig. 3 White glare at soil within seam.

Subsequent laboratory work on additional seam samples containing various artificially induced defects showed that IRT can clearly detect moist soil within the seam (Figure 3), and a thin (< 1.0 mm diameter) piece of wire within a seam (Figure 4). The wire was placed across the seam with the intent of removing it to leave a hole , but the wire could not be removed. The wire was clearly bent within the seam. At the location shown in Figure 5 the outer track is lighter than the inner track. Specimens cut across the seam showed more peeling at the inner track. As the shading changed along the length of the seam so did the amount of peel separation. Work is continuing, using an IR camera with a temperature resolution of 0.002°C, to relate IRT signal to actual bond strength (strength during peeling) over a length of seam of known variability, as assessed by peel testing and microstructural examination.

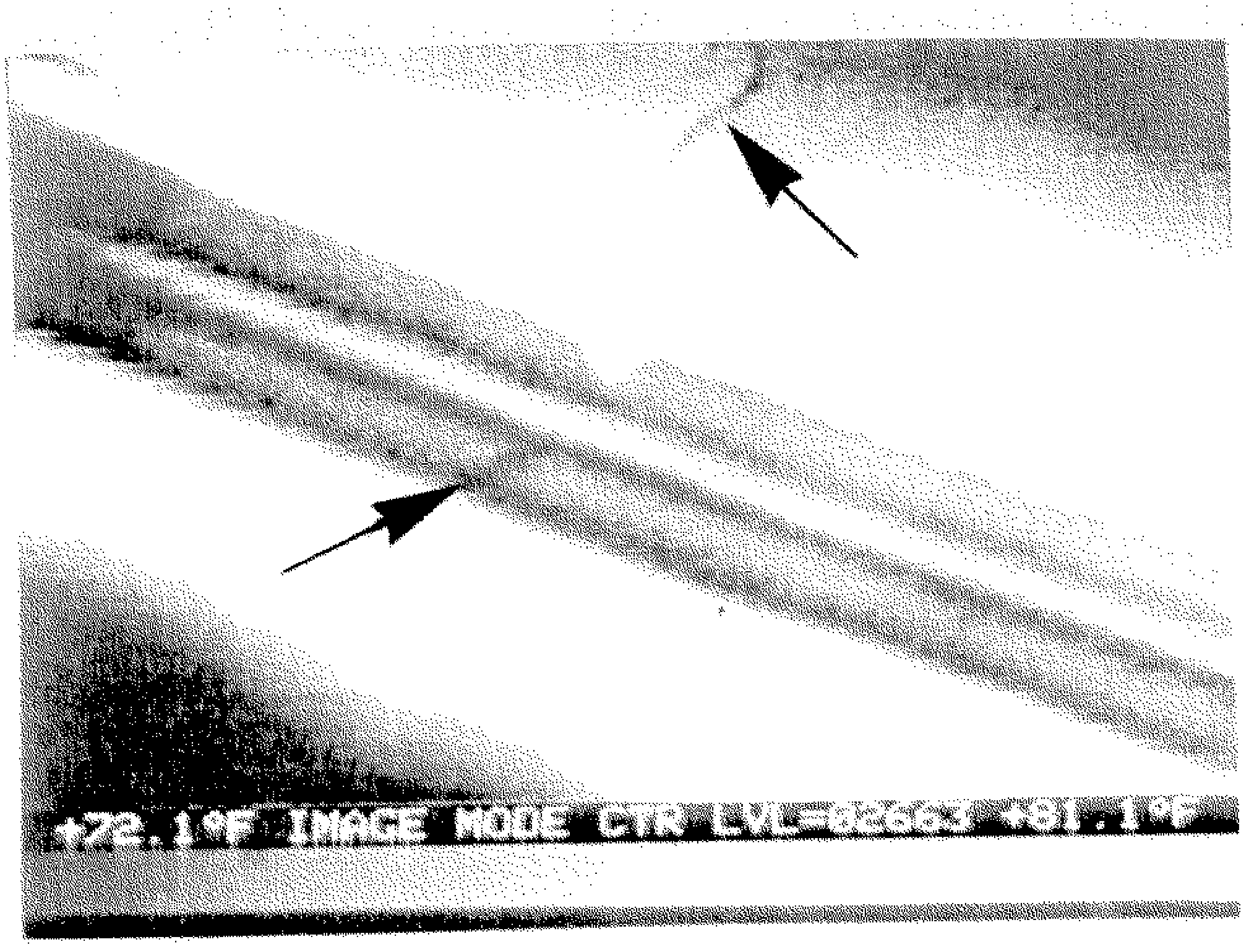

Fig. 4 Wire (arrowed) within seam.

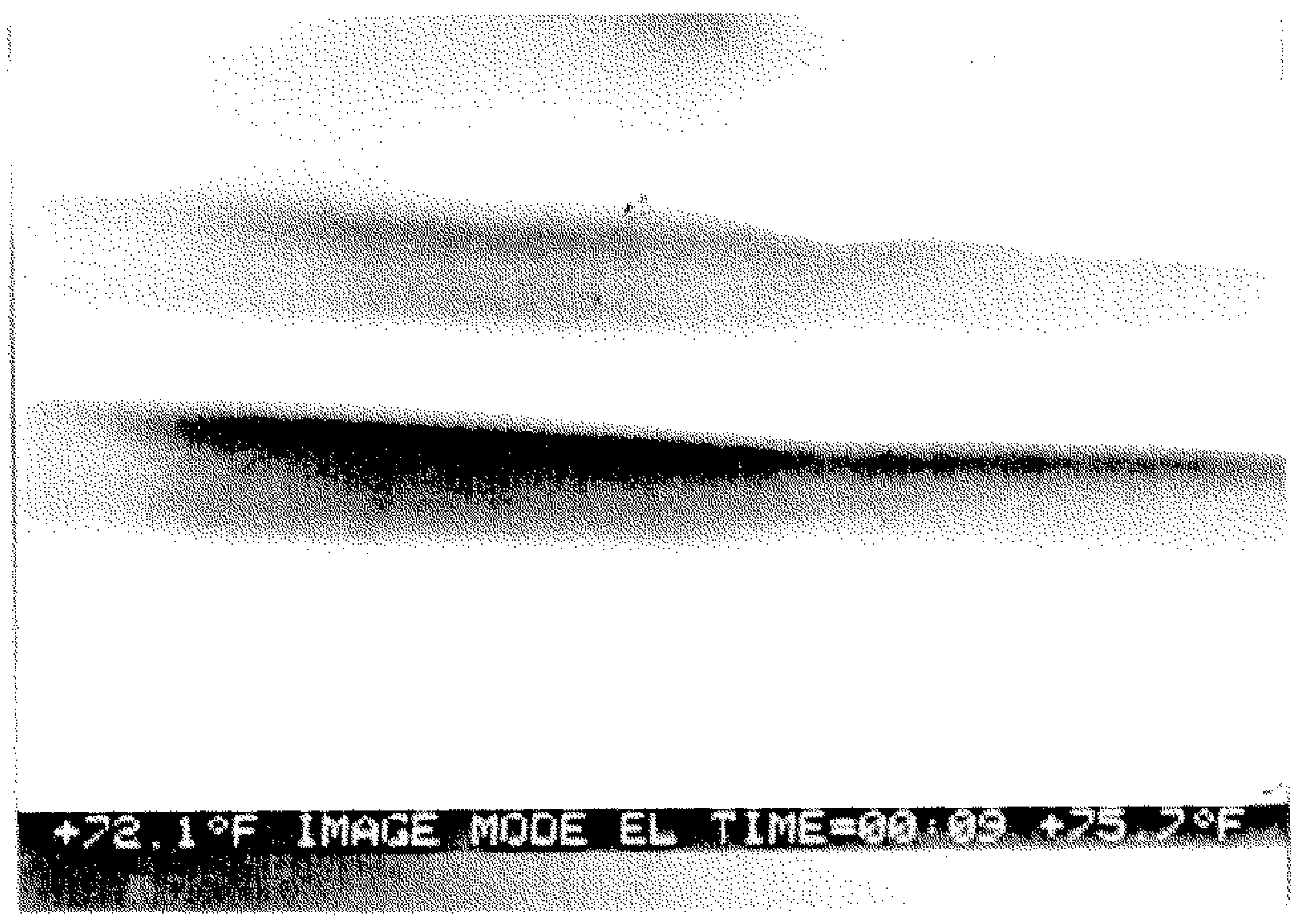

Fig. 5 Darker inner track which peeled.

6 ARTIFICIAL INTELLIGENCE

During the field project the video screen was manually monitored for seam defects while the MTR was travelling at approximately 5 km/hr, however, such manual monitoring would not be possible for even moderate periods of time without missing significant seam features due to operator boredom and fatigue. Experts in artificial intelligence (AI), at Fortesque Corp. were consulted. They acknowledged that AI could be developed that would facilitate a significantly higher survey speed and that could not only identify unacceptable seam defects, but could also, in real time, identify the type of defect and mark the geomembrane with an appropriate spot of colored paint. However, in order to do this, the AI must be instructed as to what type of defect is unacceptable. In addition, the concept of the "critical" defect must be adopted, since only those features that compromise the service lifetime of the installation will need to be identified. Sub-critical defects (unusual features) are of no concern. This opens a whole new area of geosynthetics technology, as initiated by Kanninen et al. (1993).

7 CONCLUSION

IRT has the potential for being a viable nondestructive method for testing geomembrane seams. Even in its present stage of development it is capable of identifying seam features that conventional NDT techniques cannot. IRT can, in fact, identify many more features than are cause for concern. With the appropriate development of AI, IRT could be combined with visible light techniques to examine approximately 5 ha of geomembrane per day.

In addition to locating penetrating leaks, IRT is capable of identifying nonpenetrating defects within a seam that could propagate into leaks during service. There is evidence that IRT has the potential for broadly classifying seam bond strengths. Unlike existing NDT methods a hard copy (videotape) of the survey data is generated.

8 ACKNOWLEDGEMENTS

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