

Detection of Voids under a Concrete Airfield Parking Apron using a Heavy Weight Deflectometer (HWD)

V. G Cervantes¹, L. J. Malvar²

Abstract

A series of incidents involving aircraft punching through pavements prompted the Navy to develop procedures for detecting voids on airfields. Initially, a successful void detection survey was completed at a Naval Air Station (NAS) where several voids were generated by leakage of large underground drainpipes. To determine the location of the voids, a procedure was developed which used a combination of methods such as internal videotaping of the pipes, heavy weight deflectometer (HWD) testing, ground penetrating radar (GPR), and dynamic cone penetrometer (DCP) testing. This procedure is now routinely applied at all 70 major Navy and Marine Corps airfields. This paper summarizes the methodology and presents a recent field case where a waterline ruptured under a concrete airfield parking apron. After evaluating an area of interest with a HWD possible voids were detected under a number of slabs which were then drilled to be able to take DCP measurements. Grout was used to fill in the voids and Pavement-Transportation Computer Assisted Structural Engineering (PCASE) analysis showed that the pavement should be able to support the estimated traffic levels of that airfield for the next 10 years.

Introduction

In 1999, the front gear of an aircraft broke through the pavement and fell into a 12-inch deep hole that had formed in a taxiway. A team of Navy engineers was assembled to determine the cause of the catastrophic failure. The investigation discovered that the pavement failure was due to the erosion of the pavement base layer and the subgrade from a leaking drainpipe. The Naval Facilities Engineering Service Center (NAVFAC ESC) and the Naval Facilities Engineering Command (NAVFAC) Southern Division were tasked to determine the extent of potential voids near all drainpipes under the runways, taxiways, and aprons at the NAS where the failure occurred. In addition, NAVFAC ESC was tasked to assess the available current technology for void detection under pavements, determine the optimum methodology, and prepare guidance for proactive detection of voids to prevent future similar failures. To reduce the cost of the assessments, a risk analysis was completed, establishing a work prioritization within each airfield, and providing a prioritization of all Navy and Marine Corps airfield pavements. The methodology that uses a HWD does not distinguish between an actual void and a weak area, since only the effect on load-carrying capacity is of interest.

Ten years later, at a different NAS, a water line ruptured under a recently reconstructed parking apron. Shortly before the rupture, two valves had been replaced upstream on the water line that runs under the concrete pavement. The water supply was closed off after water was seen leaking between the concrete slabs and the joint sealant. The local Public Works Department (PWD) requested support from NAVFAC ESC to determine if the high pressure leak caused any voids under the concrete pavement and to evaluate if the load carrying capacity of the parking apron had been affected. Visual inspection, ground penetrating radar (GPR) a HWD, and

soil penetration techniques were used to detect the weak areas of the pavement indicative of voids.

Void Detection Methodology

A review of the state-of-the-art non-destructive technologies applicable to void detection under airfield pavements was completed in 2000, including: (1) Electromagnetic (i.e., Ground Penetrating Radar, Microwave and Millimeter Wave, Infrared Thermography, Magnetic Fields, Electrical Resistivity/Conductivity, Spontaneous Potential, and including Visual Inspections); (2) Transient Load (i.e., Seismic Waves, Impact-Echo, Heavy Weight Deflectometer, Rolling Deflectometers, Vibratory Loading Systems, Rolling Dynamic Deflectometer, Ultrasound, Acoustic Reflection Sounding, Acoustic Emission, Audible Acoustic Reflection Sounding); and (3) Others, such as Video Taping, Quasi-Static Load-Deflection Devices, Gravitational, and Soil Penetration techniques, the latter including Dynamic Cone Penetrometer (DCP), Electronic Cone Penetrometer (ECP), and Standard Penetration Test (SPT).

The experience of many Government agencies, State Departments of Transportation, academia, and private firms and all available applicable techniques was gathered and summarized. The following were conclusions derived from this knowledge:

1. No single technique is currently capable of providing a complete solution to the void detection problem.
2. A combination of technologies can, however, provide a cost-effective, reliable methodology to minimize the potential for accidental airfield pavement failure due to subsurface voids.
3. The optimum technology combination at the current time is a combination of visual, HWD, and DCP techniques, which can be completed by a single operator. The DCP can be replaced by an ECP or an SPT, but these techniques require additional manpower.
4. Complementary technologies include videotaping and GPR. Videotaping can detect pipe failures indicative of potential void problems, and even detect actual voids. Ground penetrating radar is very useful for determining pavement layer thickness (for use in HWD structural evaluation), and location of drainpipes (assuming favorable low conductivity subgrade characteristics), but is not very reliable when detecting voids.
5. Promising technologies include Rolling Weight Deflectometer, High Speed Deflectograph, Rolling Dynamic Deflectometer, and Infrared Thermography.

In some cases, when the area to investigate is large, using the HWD to perform a thorough coverage may not be possible. In that case, it is recommended that: (1) the HWD be used at any critical location within the area of concern; (2) the GPR be used to complete coverage of the area in an attempt to identify subsurface anomalies (assuming soil characteristics allow its use); (3) the HWD be used again at the discrete locations where the GPR identifies anomalies; and (4) DCP (or ECP or SPT) testing be completed where weaknesses were confirmed by the HWD.

Ground Penetrating Radar (GPR). One intended use of GPR is to detect voids. However, it is less effective at finding voids than other tools (Malvar, 2010). It is capable of showing a water saturated area or steel pipe because of the much higher dielectric constants of water and steel when compared to that of concrete or asphalt. For this project, the GPR was able to show an area which was highly saturated but could not distinctly find any voids or the broken water pipe under the apron.

Heavy Weight Deflectometer (HWD). The HWD system used by NAVFAC ESC is made up of a trailer mounted set of weights that may be dropped onto a set of rubber cushions that transfer the force to a load plate and then onto the pavement. The set of weights can be dropped from a height of up to 40 cm (15.7 inches) from its starting point to produce forces that range from 4,082 to 27,215 kgf (9,000 to 60,000 lbf). Geophones are placed at set distances in front and behind the loading plate in order to measure the velocity of the propagating dynamic load and derive the resulting deflection basin. The particular HWD that was used has seven geophones in front of the load plate (D1 through D7) and two behind the load plate (D8 and D9). The relative position of the D1 through D9 geophones with respect to the center of the load plate are 0, 30.5, 61, 91.5, 122, 152.5, 183, -23, -30.5 cm (0, 12, 24, 36, 48, 60, 72, -9, and -12 inches).

A known limitation of the HWD is the relatively small deflection basin area, about a 1.5 m (5-foot) radius, that is produced. In order to get accurate information on asphalt, readings have to be taken on a 3-by 3-m (10- by 10 foot) grid. For concrete airfield pavements whose slab dimensions are approximately 3.8 m x 4.6m (12.5 ft x 15 ft), a HWD measurement is taken at the center of each slab in the area of interest. The center of the slab is tested to minimize the influence of the surrounding slabs. If there are slabs within the area of interest that show a high degree of weakness, then soil testing using a DCP is performed to ensure subgrade soundness. The prediction methodology can be found in Malvar 2010.

Parking Apron Example

In the fall of 2009, NAVFAC ESC received a call from the PWD to determine if a high pressure water mainline rupture caused any voids under a recently reconstructed airfield parking apron. The established guidelines indicate that a visual inspection should be conducted, followed by HWD testing, and DCP testing of any area shown to be weak after analysis of the HWD testing. Ground Penetrating radar can be used to determine if the soil is saturated or to find a buried pipe. Due to the fact that the damage was caused by a water mainline rupture, a visual inspection was followed by GPR measurements to find saturated areas under the pavement. After that area was established, HWD measurements were taken of the area, which included cracked slabs. DCP measurements were taken under the weakest concrete slabs and a load capacity analysis was conducted for the row of slabs that showed the lowest impact stiffness modulus (ISM).

Ground Penetrating Radar. The area near where water was seen leaking between the joint sealant and the concrete slabs was visually inspected. Within the area of interest, there is a catch basin that was observed to be lower than the surrounding pavement and nine cracked slabs. A plausible reason for the lower catch basin is that the slabs near the basin were lifted uniformly which increases the possibility of voids being under the slab. Ground penetrating radar measurements showed that the area was saturated up to approximately 2 feet below the surface of the pavement. An effort to

find the broken pipe yielded no results because of the high water level. An area was determined to be of interest (Figure 1) and HWD data was collected. The catch basin is located in slab J-12 in Figure 1.

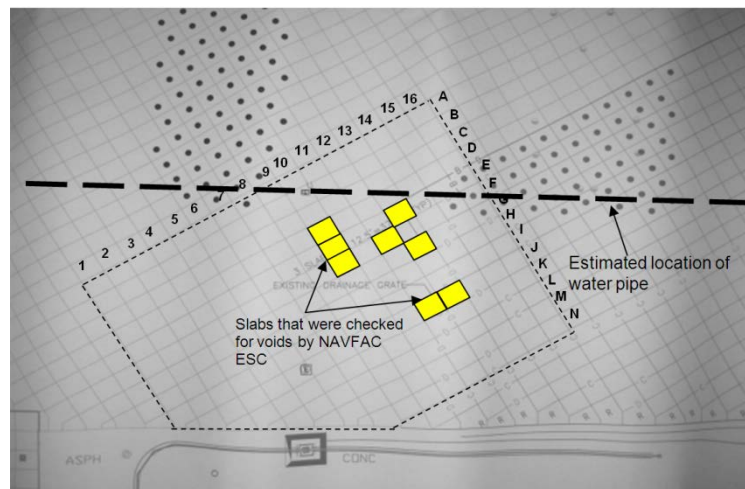


Figure 1. Map of the area evaluated by HWD

Heavy Weight Deflectometer. Once the pavement had been visually inspected and the area of interest established with the help of the GPR, HWD testing was conducted. A map of the test area consists of Rows A through N with approximately 16 stations in each row.

For each drop, the HWD records the applied load (P_{HWD}) and the measured deflection at each of the nine sensors ($\delta_{measured}$). The ISM value is calculated by dividing the recorded load by the measured deflection as is shown in Equation 1.

$$ISM = \frac{P_{HWD}}{\delta_{measured}} \quad (1)$$

All the ISM values are plotted together to determine the weakest areas. In accordance with Malvar, 2010, the following are key things to look for:

- For asphalt pavements, an absolute ISM 1 value below about 52.5 MN/m (300 kips/inches) is of concern (or represents a weak pavement)
- For concrete pavements, an absolute ISM 1 value below 175 MN/m (1,000 kips/inches) is of concern
- An absolute ISM 7 value below 525 MN/m (3,000 kips/inches) is of concern
- A relative ISM decay indicates an unexpected weakness
- A relative weakness in ISM 1 indicates a possible shallow void
- A relative weakness in ISM 7 indicates a possible deep void (1 to 6 meters, or about 3 to 20 feet)
- A relative weakness in both ISM 1 and ISM 7 indicates a general lack of support.

The ISM plots before and after grouting of sensors D1 and D7 are shown in Figures 2 and 3, respectively. On each of the plots, there is an area that has no color on the lower left corner. This is an area that was not tested because it was outside the

concrete apron area. For this case study, analysis focuses on ISM 1 and ISM 7, because they represent the deflections near the surface and at the subgrade level respectively. Figure 2 shows areas that lacked support. The general area is on the right side of the grid, in between rows C and K and stations 9 and 14.

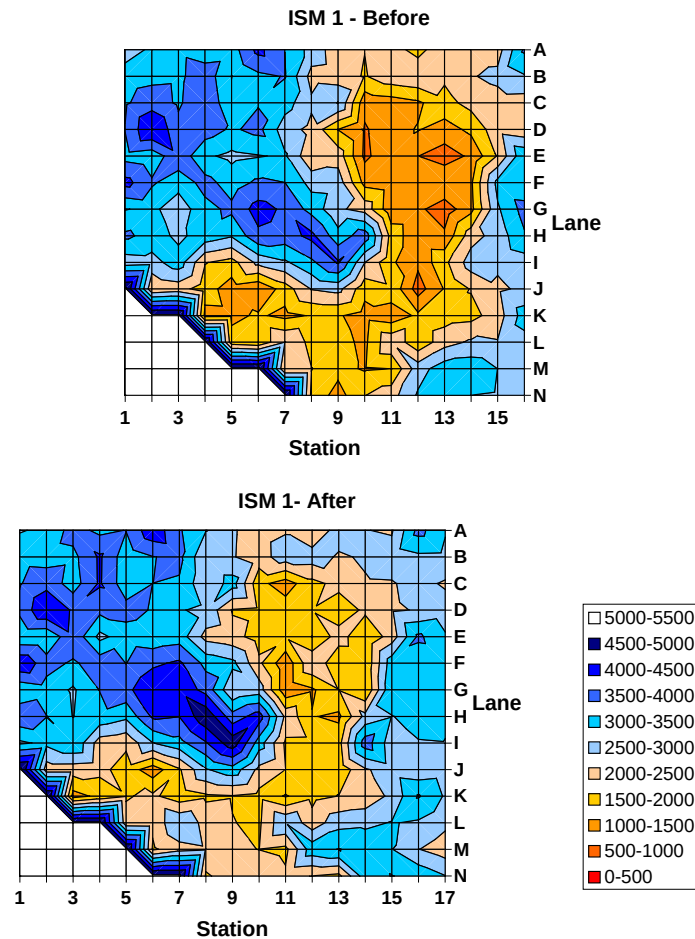


Figure 2. HWD ISM 1- Before and after grouting.

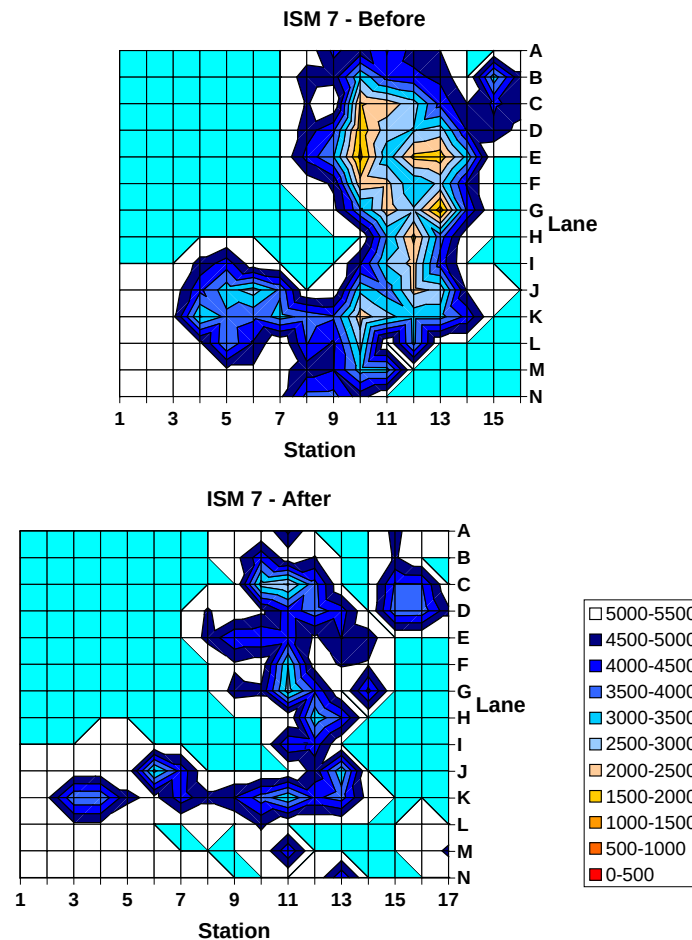


Figure 3. HWD ISM 7 – Before and after grouting.

Once the slabs of interest were determined, they were drilled to verify if there were voids and to take DCP readings. Drilling showed that the concrete pavement was approximately 20 cm (8 inches) thick and the cement treated base (CTB) was about 28 cm (11 inches) thick. Later coring showed that the concrete slabs were about 23 cm (9 inches) thick. Voids were typically found between the concrete and the CTB and some voids were detected between the CTB and the subgrade. The results of the DCP testing showed that the voids exist and that the subbase is, for the most part, above a California Bearing Ratio (CBR) of 10. Thus pumping of grout was recommended to fill in the voids. HWD testing was executed after grouting and ISM plots were created for ISM 1 and ISM 7 values as shown in Figure 3. After grouting, all the values were above the recommended minimums.

Grouting. A local contractor was hired to pump grout under 20 concrete slabs. Figure 4 shows slabs D-13 and E-13. E-13 was grout filled using 9 holes and D-13 was filled using 2 holes. There was an area east of the catch basin that had ponding water, which was also grouted to elevate the slabs to the correct grade.



Figure 4. Slabs after being grouted.

Load Carrying Capacity Analysis. After the grouting was completed, the HWD results showed that the ISM 1 for all of the tested slabs was greater than 175 MN/m (1,000 kips/inch). The ISM plots for the D1 and D7 sensors after grouting are shown in Figures 2 and 3, and show the improvements. Load carrying capacity analysis was then conducted in order to determine if it was safe to taxi aircraft on the parking apron. The PCASE software package was used to evaluate the pavements load carrying capacity on the weakest slab after grouting. Figure 5 shows the evaluation and back calculation iteration plot, which show that even the weakest slab can sustain more than 5,700 passes of the equivalent aircraft compared to the 271 passes before grouting.

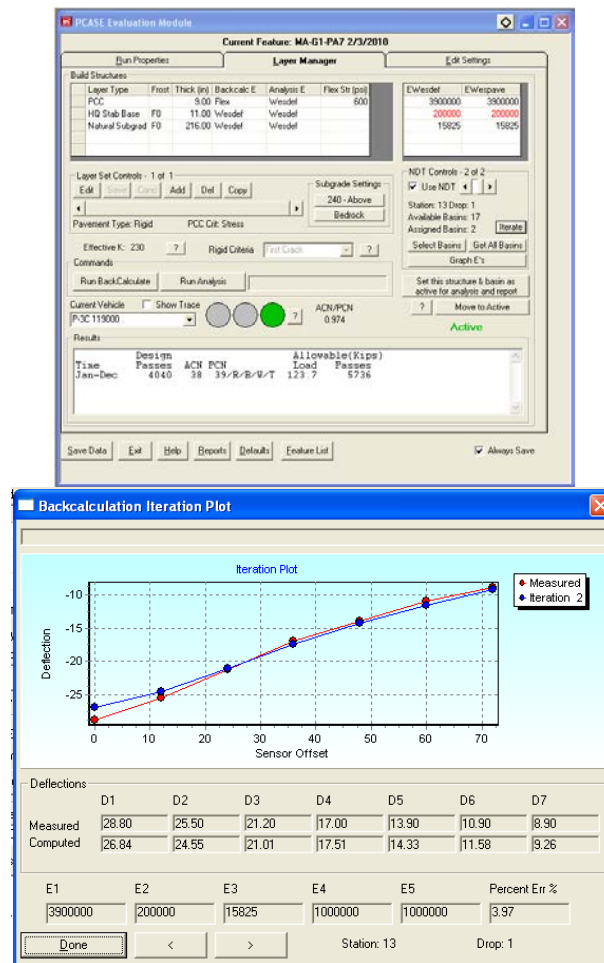


Figure 5. PCASE evaluation and backcalculation iteration plot – Slab G-13 – P3 Aircraft – After Grouting.

The PWD asked to have an additional load carrying capacity analysis done because in the previous 5 years, three C-5s a year have been placed on that parking apron. The parameters for the analysis were the C-5 gear configuration, with a load of 348,818 kg (769,000 pounds), 50 passes for the next 10 years, and the deflection basins for slabs G-13 (Figure 6) and G-11 (Figure 7) after grouting. G-13 was used because it was the weakest slab before grouting and G-11 (ISM 1125) is the weakest slab after grouting. As is shown in Figure 7, the weakest slab in the evaluation area was calculated to sustain more than 170 passes of the C-5.

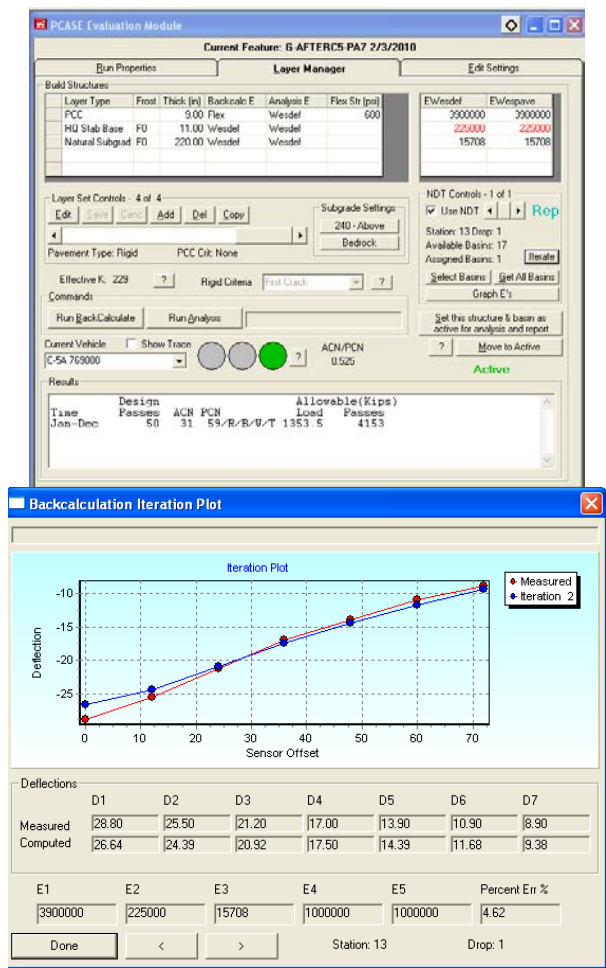


Figure 6. PCASE evaluation and backcalculation iteration plot – Slab G-13 – C5 Aircraft – After Grouting.

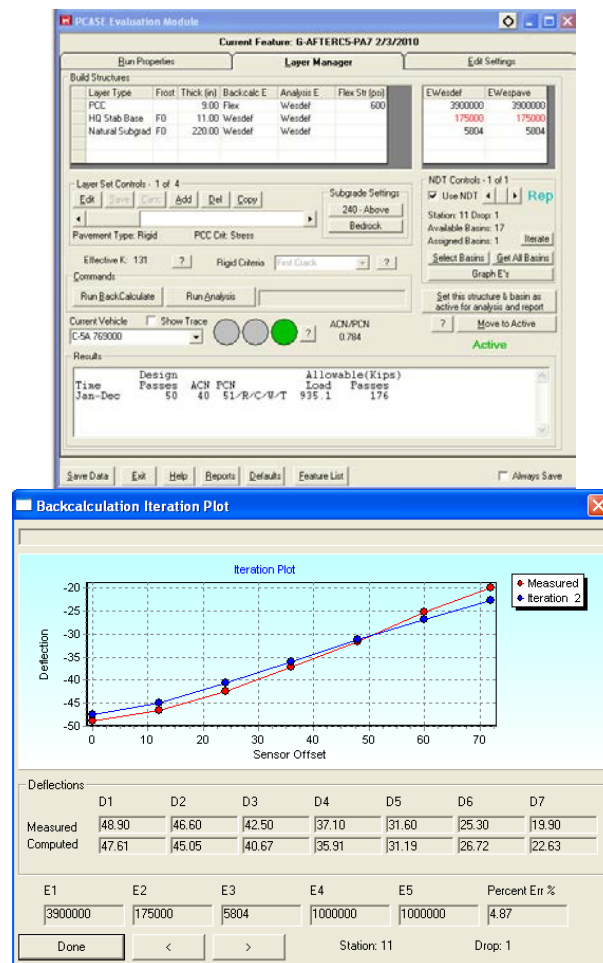


Figure 7. PCASE evaluation and backcalculation iteration plot –
Slab G-11 – C5 Aircraft –
After Grouting.

Conclusions

Aircraft gears punching through airfield pavements prompted the Navy to develop a method for locating weak areas under pavements near leaking drain pipes that are indicative of voids. This method has been integrated into a pavement evaluation program. The void detection procedures were recently used in an unforeseen situation when a water line rupture under a parking apron caused water to leak between the concrete slabs and the joint sealant.

Ground penetrating radar evaluation determined a saturated area where possible voids could be located which was verified using a HWD and via drilling into the slabs to take DCP measurements. It was suggested that grout be pumped under the slabs to fill the voids. After the weakest slabs were grouted, HWD data and a load carrying capacity analysis showed that all of slabs on the test area had an ISM 1 value that is greater than 175MN/m (1,000 kips/inch) and that the parking apron should be able to support the number of passes estimated for the P-3 and the C-5 aircraft in the next 10 years.

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References

1. Malvar, L. J., (2010)“Detecting Voids Under Pavements: Update on the DOD Approach.” *Transportation Research Record: Journal of the Transportation Research Board.*,28-35.