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EXECUTIVE SUMMARY

The Light Weight Deflectometer (LWD) is a device that plays a vital role in checking the quality of highway foundations and base installations for sports facilities, such as football pitches and athletic tracks. National Highways and Transport Scotland commissioned WSP, in partnership with AECOM, to assess the performance of LWD devices operating in the UK.

The report describes the second annual UK LWD correlation trial, which was undertaken between the 12th and 15th September 2022. The test site for the correlation trial was located within AECOM's Pavement Test Facility (PTF) based in Nottingham, and the report describes the test pit design, installation, and material testing carried out prior to the correlation trial. Machines and operators from 42 organisations attended the correlation trial. In total, 97 LWD devices were compared against a pre-calibrated Falling Weight Deflectometer (FWD).

The report describes the details of the trial, including a description of the devices, trial site, correlation exercise, testing programme and summarises the analysis undertaken. The main output of the trial involved the issue of a LWD Correlation Certificate for each device tested, where a sufficient correlation with the FWD was deemed to exist. Additional data analysis was undertaken to examine the difference between the two permitted approaches described in MCHW Series 800 (Clause 885), Procedure A and Procedure B, and the spread in data produced by each device.

The 2022 LWD correlation trial can be summarised as follows:

- Ninety-seven LWD devices took part in the correlation trial and followed Procedure A, by applying a standard target stress, and Procedure B, applying a range of applied stresses.
- An examination of surface modulus results produced using Procedure A and Procedure B showed that the methods were not significantly different at the 95% probability level.
- Ninety-six LWD devices were deemed to show a sufficient correlation with the pre-calibrated FWD, and adjustment factors were issued for use on materials covered by range 1, i.e. surface modulus between 25 MPa and 120 MPa.
- Some machines (10%) were considered to have produced an excessive number of outliers. Owners were contacted and alerted to this with a view to reviewing and improving the operation and use of the LWD.

Recommendations include the continued use of Procedure A and reviewing the current correlation requirement between FWD and LWD for future correlation trials.

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INTRODUCTION

1. INTRODUCTION

1.1. OVERVIEW

The Light Weight Deflectometer (LWD) is a device that plays a vital role in checking the quality of highway foundations. It is also used to control the quality of base installations for sports facilities, such as football pitches and athletic tracks. The LWD is used during construction to measure the effective surface foundation modulus and the consistency of the foundation support along a site length. Sufficient stiffness provides an assessment of adequate compaction and subsequent resistance to deformation. It is therefore essential that there is confidence in the repeatability of the measurements and that it has been calibrated against a recognised standard or measurement.

1.2. BACKGROUND

In accordance with BS 1924-2:2018[1], LWD devices are required to be correlated against a pre-calibrated Falling Weight Deflectometer (FWD). Two options are provided in the standard: a site-specific correlation, or an annual off-site correlation. The first annual UK off-site correlation trial was carried out in 2021. The trial was commissioned by National Highways and Transport Scotland, and carried out by a partnership consisting of WSP and AECOM.

In total, 78 LWD devices were compared against a pre-calibrated FWD. The main output of the trial comprised the issue of LWD Correlation Certificates for each device tested. An analysis of the collected data was also undertaken to examine the spread in data produced by each device and proposals were made to improve the precision of the LWD devices[2].

1.3. 2022 TRIAL OBJECTIVE

As part of the 2021 correlation trial, LWD devices were used to take measurements following the procedure known as Procedure A, which targets a peak stress of 100 kPa as per BS 1924-2:2018. LWD Correlation Certificates for each device tested were issued where a sufficient correlation with the FWD was deemed to exist. The 2022 trial aims to repeat the previous trial objective. However, additional data will be collected using Procedure B, which involves targeting a range of stresses centred around 100 kPa. This data will be examined to determine whether improvements can be made to the annual correlation exercise and improve the precision of the LWD devices.

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[1] BS 1924-2:2018. Hydraulically bound and stabilized materials for civil engineering purposes. Part 2: Sample preparation and testing of materials during and after treatment. BSI Standards Limited

[2] Gordon M (2022).WSP Report No. 70061041 – 101. https://www.transport.gov.scot/publication/light-weight-deflectometer-lwd-correlation-trial-report/

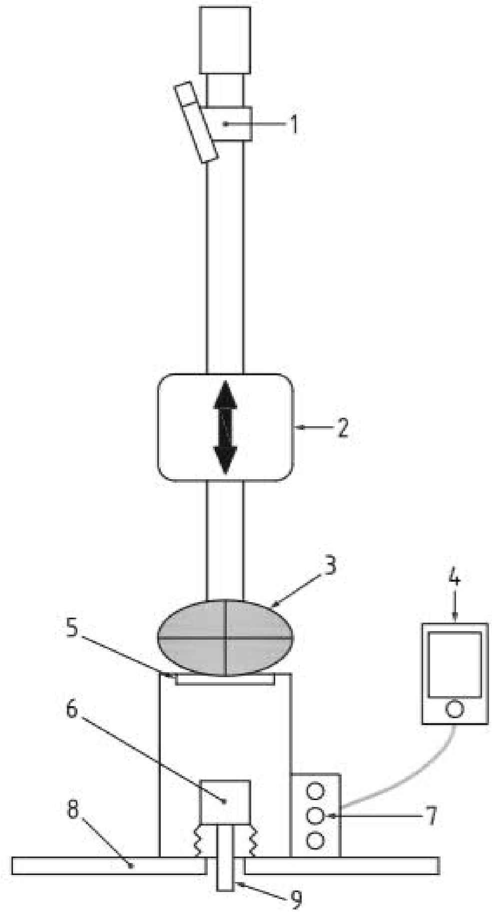
2

LWD & FWD DEVICES

2. LWD & FWD DEVICES

2.1. LIGHT WEIGHT DEFLECTOMETER

The LWD is described in BS 1924-2:2018 as a device that is used to determine the in-situ foundation surface modulus. Figure 2-1 shows an extract from the standard and illustrates the typical configuration of a LWD and key components, viz. loading plate; load cell; falling weight; deflection sensor; buffer; and data storage system.



Key

1	Weight release with adjustable drop height (max. 850 mm)
2	Drop weight (10 kg, 15 kg or 20 kg)
3	Position of buffer(s)
4	Personal digital assistant (PDA) display unit to display and store data
5	Load cell with a range of (1 ±0.01) kN to (15 ±0.15) kN
6	Deflection sensor (velocity transducer) with geophone range 2 200 µm, geophone accuracy better than ±2%, and one to three geophones
7	Communication port (option for wireless data transfer)
8	Bearing plate 100 mm, 200 mm or 300 mm in diameter
9	Geophone foot

Figure 2-1 - Typical Light Weight Deflectometer (BS1924-2:2018)

The LWD measures in-situ foundation surface modulus by applying a known stress to the top of the pavement foundation and measuring the response of the underlying structure. The in-situ foundation stiffness modulus is the composite modulus derived from the response of the foundation layers in the zone of influence of the test. The zone of influence is affected by several factors including applied load, plate diameter and material parameters.

2.2. FALLING WEIGHT DEFLECTOMETER

The FWD is regarded as a tried and tested device and is seen as the definitive method that other dynamic plate tests should be assessed against. It comprises a vehicle towed, non-destructive testing device that consists of a drop weight mounted on a vertical shaft and housed in a trailer that can be towed by most conventional vehicles. The FWD can be used on both bound and unbound materials.

Figure 2-2 shows a schematic of the FWD in operation. The device applies impulse loading to a circular plate in contact with the pavement surface, which approximates to the high-amplitude dynamic loads imposed by heavy goods vehicle traffic. The FWD load signature is similar to that of a standard (40kN) half-axle travelling at typical highway speeds i.e. 50 to 80 km/h. Thus, the measured pavement response is considered to be a realistic measure of the pavement response to real traffic. The load pulse is approximately that of a half sine wave form. The drop weight is hydraulically lifted to predetermined heights ranging from 50-510 mm. The weight is usually dropped onto a 300 mm diameter loading plate resting on a 5.6 mm thick rubber buffer.

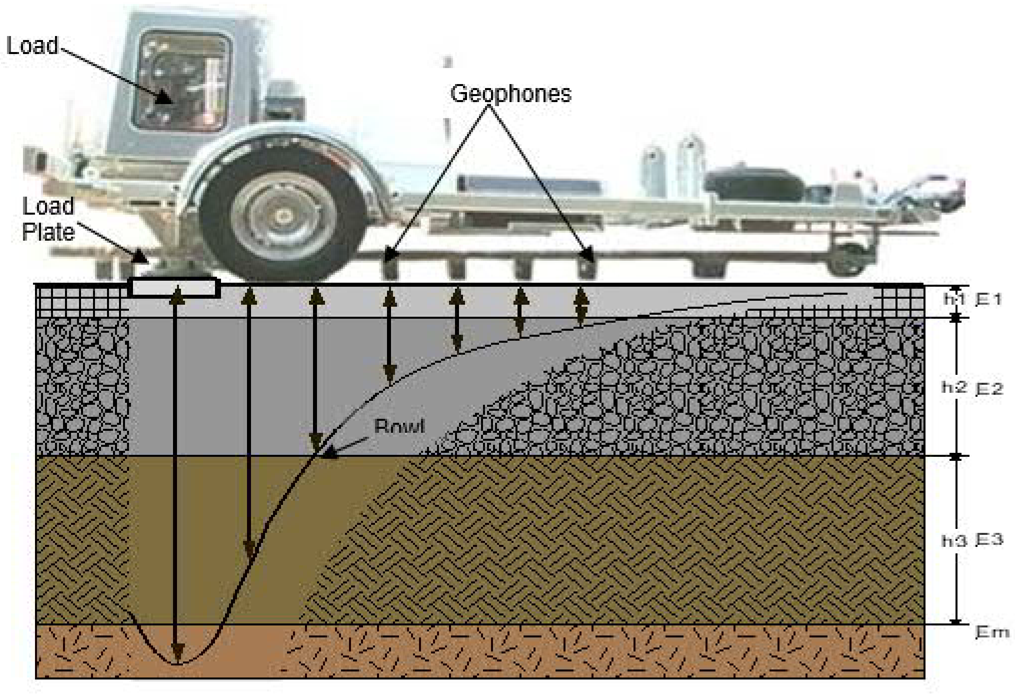


Figure 2-2 - FWD and idealised deflection bowl

3

TRIAL DESIGN

3. TRIAL DESIGN

3.1. PARTICIPANTS

Machines and operators from 42 organisations attended the correlation trial between the 12th and 15th September 2022. In total, 97 LWDs were compared against an accredited FWD. Further Information about the accreditation trial can be found on the UK Road Liaison Group website[3]. To maintain confidentiality, each participating LWD was assigned a unique ID number.

The participating devices were owned, in alphabetical order, by the following organisations:

ACS	-	1 x LWD	Labosport	-	2 x LWD
AECOM	-	3 x LWD	Lincolnshire C C	-	1 x LWD
AWK	-	1 x LWD	MATtest	-	6 X LWD
BAM Ritchies	-	5 x LWD	Major Diamond serv.	-	1 x LWD
Balfour Beatty	-	6 x LWD	Norse Group	-	3 x LWD
BB Vinci	-	9 x LWD	OCL Regeneration	-	1 x LWD
Breedon	-	1 x LWD	PMS Ltd.	-	1 x LWD
Celtest	-	2 x LWD	PTS	-	2 x LWD
CMT Labs	-	3 x LWD	Rincent	-	1 x LWD
Costain	-	1 x LWD	SIMTEC	-	3 x LWD
CTS	-	8 x LWD	SOCOTEC	-	9 x LWD
Devon	-	1 x LWD	Soil Property Testing	-	2 x LWD
DMH Testing	-	1 x LWD	Sports Labs	-	3 x LWD
Dynatest	-	3 x LWD	Stabilised Pavements	-	1 x LWD
Eurotest	-	1 x LWD	Stangers	-	1 x LWD
G&H	-	1 x LWD	Surrey C C	-	1 X LWD
Harrison Group	-	1 x LWD	Tarmac	-	1 x LWD
i2 Analytical	-	1 x LWD	TD construction	-	1 x LWD
Kiwa CMT	-	1 x LWD	Tensar	-	1 x LWD
JLUK	-	2 x LWD	Tonkin	-	1 x LWD
JMS Contractors	-	1 x LWD	Wills Bros	-	2 x LWD

[3] https:// ukrlg.ciht.org.uk/ukrlg-home/guidance/road-condition-information/data-collection/dynamic-plate-test-devices-dpt

3.1.1. DEVICES

Participants were asked to provide manufacturers' calibration certificates for all the LWD devices used in the trial. Five different makes of LWD were used in the trial, namely: Dynatest, SWECO, TerraTest and Rincent MiniDyn. Figure 2-1 shows examples of four of the different LWD devices that took part in the trial. The fifth device was a Rincent Hybrid Prima 100 which incorporates different electronics to the SWECO Prima 100.

Dynatest

SWECO

Rincent MiniDyn

TerraTest

Figure 3-1 - LWD manufacturer types

3.2. TRIAL SITE

The test site for the correlation trial was located within AECOM's Pavement Test Facility (PTF) based in Nottingham. The PTF comprises a concrete test pit that is located within a spacious hangar. A copy of AECOM's report[4] has been reproduced in Appendix B. The report describes the test pit design, installation, and material testing carried out prior to the correlation trial.

The concrete test pit dimensions were 10m x 3.5m x 1.5m. Figure 3-2 shows a 3D illustration of the materials contained within the test pit and a general view of the pit following construction. Material testing was carried out to ensure the compacted material layers produced an unbound foundation that was comparable to a Foundation Class 2 (CD 225)[5].

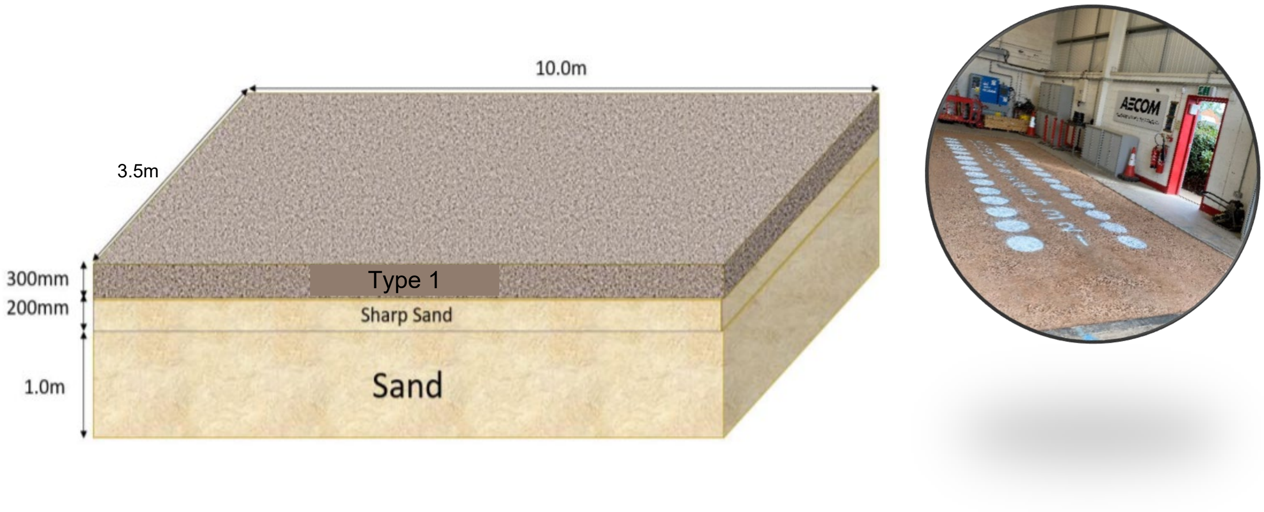


Figure 3-2 - Pit construction dimensions and general view on completion

Once the construction was completed, 30 test locations were marked on the surface. To minimise the effect of material confinement due to the presence of the concrete test pit walls, all test marks were located at least one metre from the test pit edges. A schematic of the test locations can be seen in Figure 3-3.

The test locations were laid out in two lanes, marked run "A" and run "B". Each run contained 15 test locations, namely A1 to A15 and B1 to B15. Both runs started from the righthand side of the test pit, which was close to the shutter doors in the PTF.

[4] AECOM (2021) LWD Correlation Trials - Test Pit Material Installation and Initial Testing. Project No: 60667475.
[5] National Highways (2020). CD225 Design for new pavement foundations. DMRB. Rev 1.

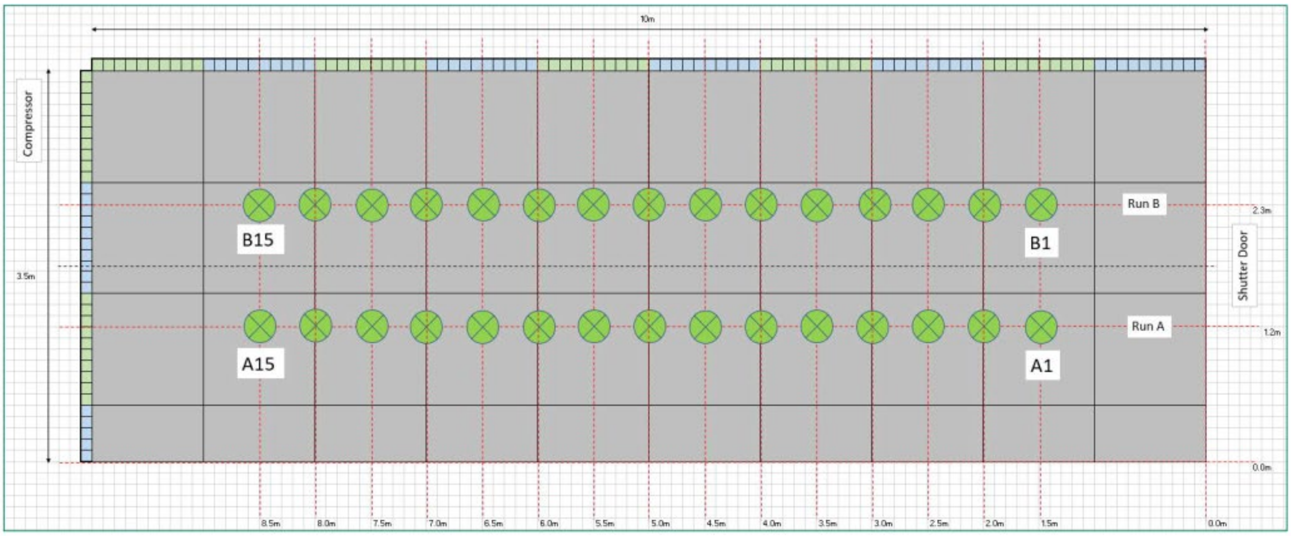


Figure 3-3 - Plan view of LWD test locations

3.3. CORRELATION EXERCISE

The correlation exercise followed the guidance contained in BS 1924-2:2018 for an annual off-site correlation certificate. The standard states that the LWD can be tested on individual ranges of surface modulus, viz.:

- range 1: ≤25 MPa and ≤120 MPa;
- range 2: >120 MPa and ≤200 MPa; and
- range 3: >200 MPa to 300 MPa.

Range 1 was selected for the correlation trial. The trial involves measuring surface modulus values with the LWD and FWD for a minimum of 25 measurement points. The values are then compared, and the square of the correlation coefficient (R^2) is calculated. The standard states that if this value exceeds 0.45 then it is deemed that a sufficient correlation exists between the two devices. Using all the data collected, an adjustment factor is calculated as the mean of the ratios of each FWD value to LWD value. Subsequent readings for each LWD device readings are adjusted by the correction factor for all further readings carried out on materials that are covered by range 1.

3.3.1. TEST PROCEDURE

Series 800 of the MCHW states that LWD testing can be undertaken using one of the following procedures:

i. Procedure A – use of a standard target stress as per BS 1924-2; or
ii. Procedure B – a range of applied stresses centred around 100 kPa to determine stress dependency.

Procedure A was selected for the 2021 correlation trial, which involved targeting the peak stress of 100 kPa with three test drops. In addition, operators were asked to use Procedure B, which involved targeting a range of stresses centred around 100 kPa to determine stress dependency. The results from both methods were examined and compared with a view to improving the precision of the LWD measurements and the results are discussed in Section 5.

4

TESTING PROGRAMME

4. TESTING PROGRAMME

4.1.1. GENERAL

The LWD correlation trials took place between Monday 12th September 2022 and Thursday 15th September 2022. Each machine was assessed by a WSP team member to ensure it conformed to the requirements of the manufacturer, BS 1924-2:2018 and assigned a unique ID number. As shown in Figure 4-1, the devices were then used to take measurements on the 30 points marked on the test panel surface.

4.1.2. FWD

At the start of each day, the 30 test points were tested with a pre-calibrated FWD using three drops to ensure the plate is seated followed by three test drops targeting the peak stress requirements of 100 ±10 kPa. At the end of each day's testing the surface of the trial panel material was compacted by means of plate compactor in a single pass.

4.1.3. LWD PROCEDURE

Prior to carrying out a test for the first time, each participant was asked to carry out 10 drops of the weight to "warm up" the LWD buffer(s).

Participants were then asked to undertake the following:

Procedure A

- Three initial "seating" drops at 100 kPa; and
- Three further drops from the 100kPa test height - these individual drops were recorded and the mean test result was used to calculate the normalized surface modulus value.

Procedure B

- One drop at a low height position (≈ 40kPa);
- One drop at a medium height position (≈ 60kPa); and
- One drop at a high height position (≈ 100kPa) - these individual drops were recorded and the test results were used to assess the stress dependency of the material tested. The results were then used to estimate the surface modulus value at 100kPa.

Figure 4-1 - LWD testing

5

DATA ANALYSIS

5. DATA ANALYSIS

5.1. FWD SURFACE MODULUS

The test bed was tested daily using a FWD device and the surface modulus results are shown graphically in Figure 5-1. Box plots have been used to describe the distribution of results from the 30 test points. Each box shows the upper (Q3) and lower (Q1) quartile, median mid-point line (Q2) and average (x). The vertical bars or whiskers show the maximum and minimum values. One of the results collected on Wednesday was assessed to be an outlier.

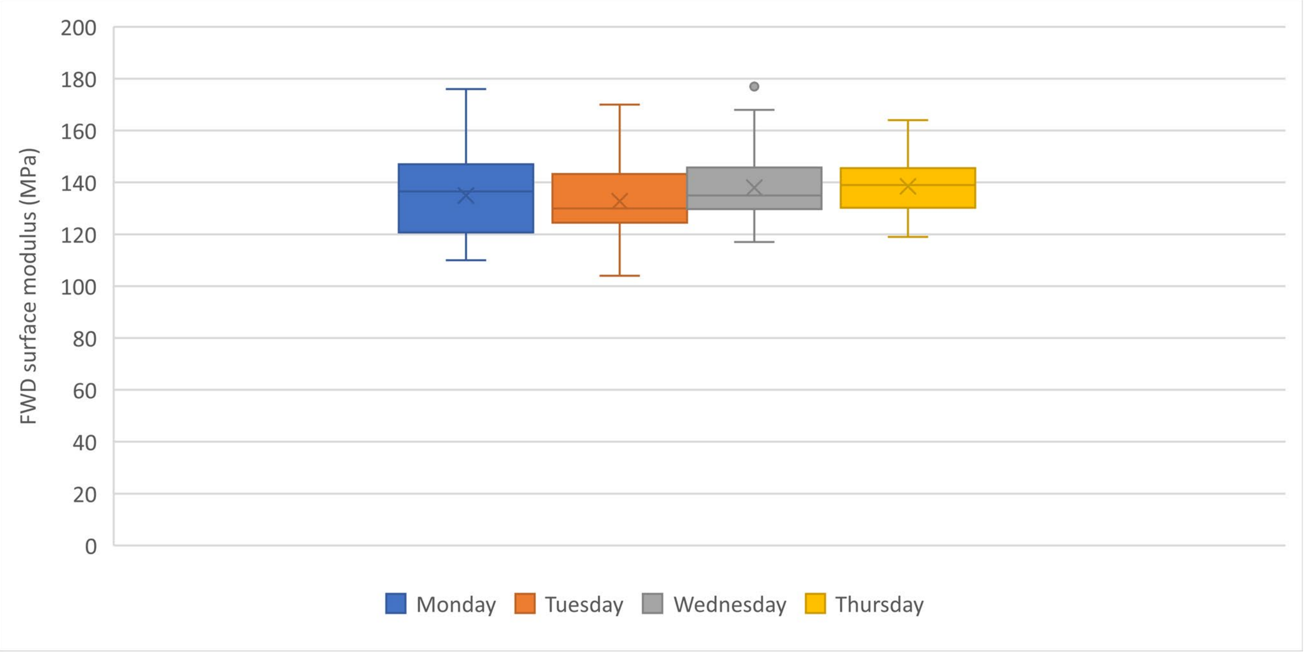


Figure 5-1 - FWD surface modulus results

In general, the surface modulus increased slightly over the four days of testing. The daily average surface modulus varied from 134 MPa on the Monday to 139 MPa on the Thursday, with the spread of data reducing over the week's testing. It can be seen from Figure 5-1 that there was a slight dip in the average result for Tuesday of 133MPa. The highest average surface modulus was measured on the Thursday at 139MPa and the test results were more tightly clustered. The probable causes for daily variations in surface modulus measurements, including outliers, are related to factors such as moisture variation (drying out), the effect of physical LWD device testing on each day, and the application of a single pass using a plate compactor at the end of each day's testing.

The FWD data showed that the surface modulus of the test panel was equivalent to a Foundation class 2 on each day of testing, and that the test panel provided a stable test bed for the comparative LWD testing that was carried out over the five days.

5.2. LWD TESTING

Following the procedures described in Section 4.1.3, this section describes the analyses undertaken on the collected LWD, including: removal of outliers; the strength of a relation between FWD and

LWD; observed differences in calculating adjustment factors using Procedure A or Procedure B, and variability in LWD machines.

5.2.1. REMOVAL OF OUTLIERS

In accordance with BS 1924-2:2018, the mean of the ratios of each FWD value to LWD value were used to determine an adjustment factor. Prior to calculating the adjustment factor, the ratio of each FWD value to LWD value was examined to determine whether any individual values fell outside of the overall pattern of the 30-point data set. The existence of any outliers was determined using the Inter-Quartile Range (IQR) Rule, i.e., the lower bound was set at ‘Q1 - 1.5 x IQR’ and the upper bound as ‘Q3 + 1.5 x IQR’. Any ratio observed to be less than the lower bound or more than the upper bound was considered as an outlier.

In general, the majority of the individual calculated ratios, or 30 point data sets, were assessed to contain zero or only a small number of outliers, typically one or two. However, around 10 of the devices (10.3% of total) recorded five or more outliers and for some devices the removal of outliers resulted in the generation of additional outliers.

Standard outlier detection is typically based on the assumption that the data is normally distributed. Figure 5-2 shows the distribution of calculated FWD/LWD ratios for a LWD device that possessed no outliers and a device with > 5 outliers. It can be seen that the distribution of LWD with no outliers appears as a "bell curve" which is associated with a normal distribution. In contrast, it can be seen that the distribution for the device producing outliers has a flatter or steeper dome and contains some extreme values. The latter is typical of a non-uniform distribution.

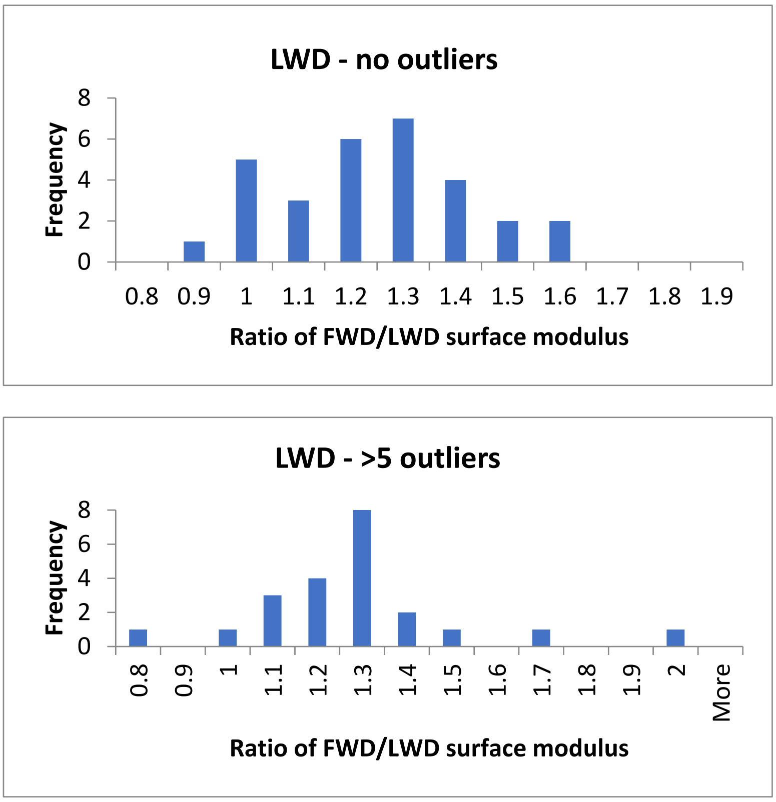


Figure 5-2 - Distribution of calculated ratios for two LWD devices

It is likely that the data variability was caused by various factors, such as equipment specification (e.g. spring stiffness) or the test methodology adopted by the user. A common example of the latter could be due to issues associated with plate stability during testing, e.g. the plate has not been seated properly due to surface condition. Owners of the ten devices that produced a high number of outliers were issued with Correlation Certificates and Correction Factors but alerted to the fact that their machine produced variable data compared to the other machines that took part in the trial.

5.2.2. CALCULATION OF RELATION BETWEEN FWD & LWD

Following the removal of outliers, the surface modulus results from FWD and LWD were compared and the square of the correlation coefficient (R^2) was calculated. An example of this process using data from the correlation trial is shown in Figure 5-3.

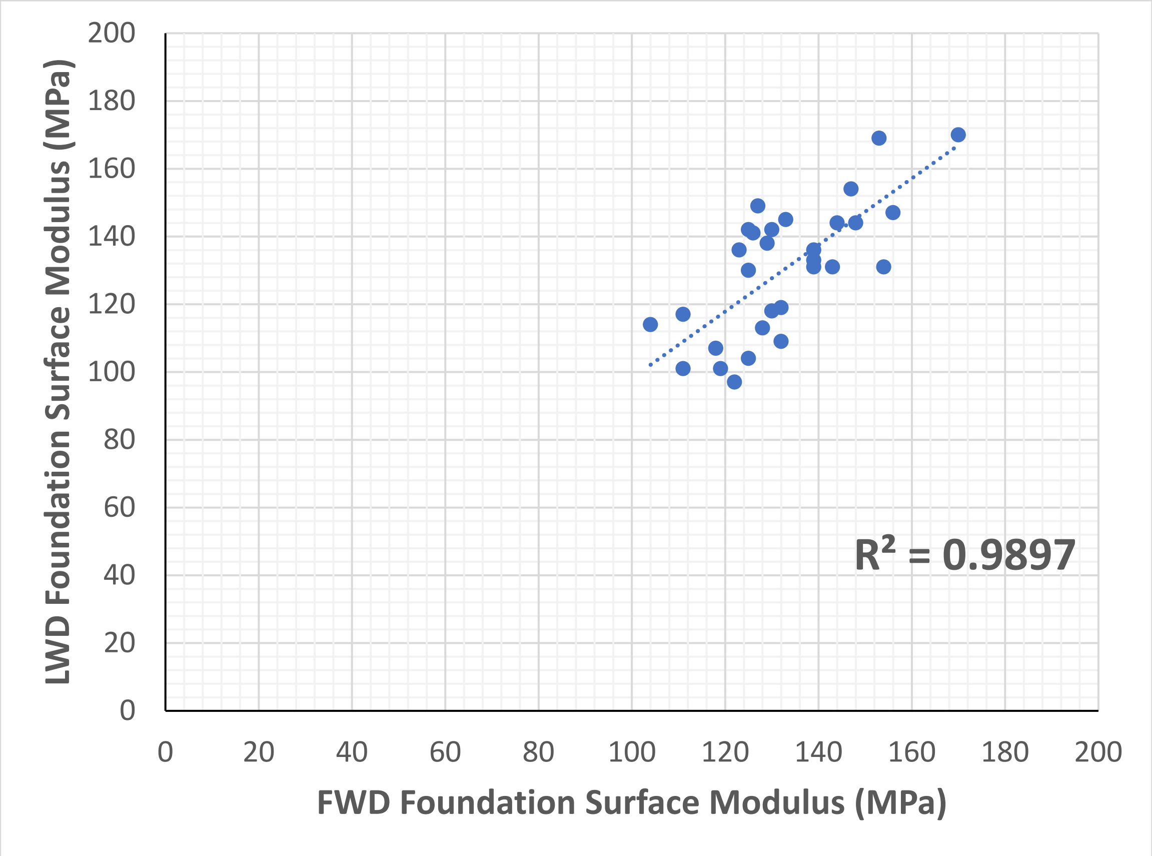


Figure 5-3 - Example calculation of R-squared

It can be seen from Figure 5-3 that a very good correlation exists. In this instance the mean of the ratios of the FWD and LWD values produced an adjustment factor of 1.029. Henceforth, the LWD device in this example, would be adjusted by this factor when testing material considered to fall into range 1, i.e. ≤25 MPa and ≤120 MPa. In this particular example, the correlation trial indicates that the LWD device produces a surface modulus reading that is approximately 3% lower than the pre-calibrated FWD. For the 97 devices tested, R^2 ranged from 0.941 to 0.998 and adjustment factors ranged from 0.827 to 1.549. An example of a certificate that was issued for each machine is shown in Appendix A.

5.2.3. PROCEDURE A & PROCEDURE B

Following a recommendation from the 2021 correlation trial report, the 2022 trial collected data using both Procedure A and Procedure B. The former process involved using drops at a fixed height and the latter used a range of drop heights (high and low loads) to assess the stress dependency of the unbound aggregate. The data was collected to determine whether one method produced a more consistent surface modulus measurement when compared to the other.

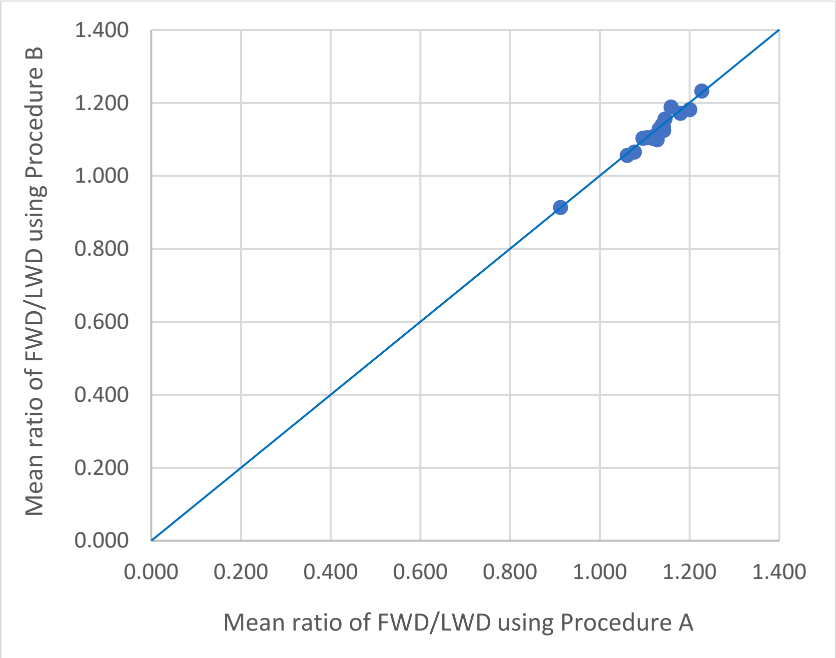


Figure 5-4 - Monday results comparing procedures A & B

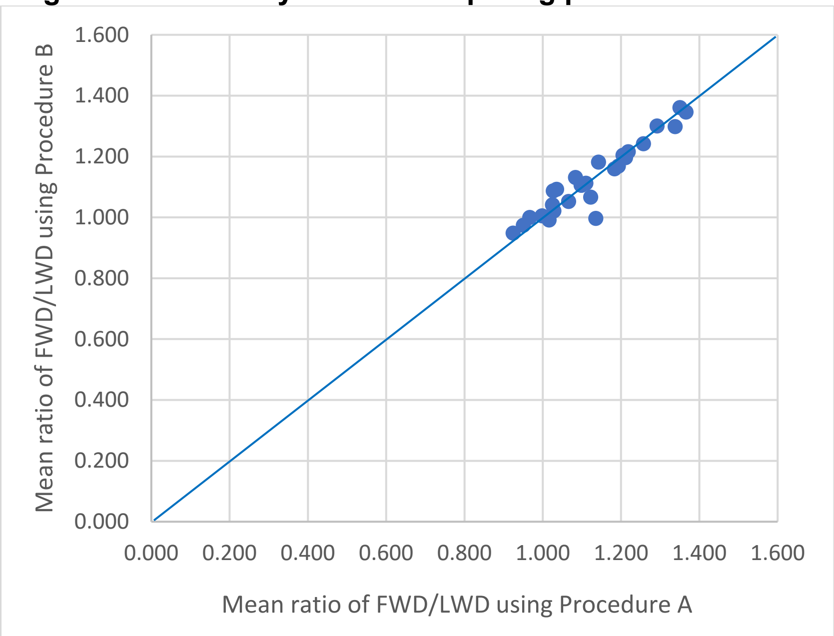


Figure 5-5 - Wednesday results comparing procedures A & B

Figure 5-4 and Figure 5-5 show the results of testing for Monday and Wednesday using both methods. It can be seen that the data points are tightly clustered around the line of equivalence indicating little difference in the method used. The Student's t-test was carried out on the data that was collected daily using the two methods. The t-test confirmed that the methods produced results that were not significantly different at the 95% probability level. Based on this analysis it was decided to adopt Procedure A for calculating correlation coefficients and adjustment factors.

5.2.4. VARIATION IN LWD RESULTS

In order to describe the degree of variation in results from one LWD device to another during each day's testing, the Coefficient of Variation (CV) was calculated for each device. The CV is normally expressed as a percentage and is simply the ratio of the standard deviation to the mean of each data set. The greater the coefficient of variation, the greater the spread of data is around the mean. Figure 5-6 shows the CV (blue column) for 17 LWDs and the FWD (yellow column) collected during one day of testing. It can be seen that the LWD devices generally produced a greater spread of data (higher CVs) than the FWD, i.e., LWDs ranged between 11.4% and 22.2%, FWD was 11.6%. The CV for the LWDs varied over the week's testing and ranged from 9.5% to 29.7%. The results were broadly comparable the 2021 correlation trial.

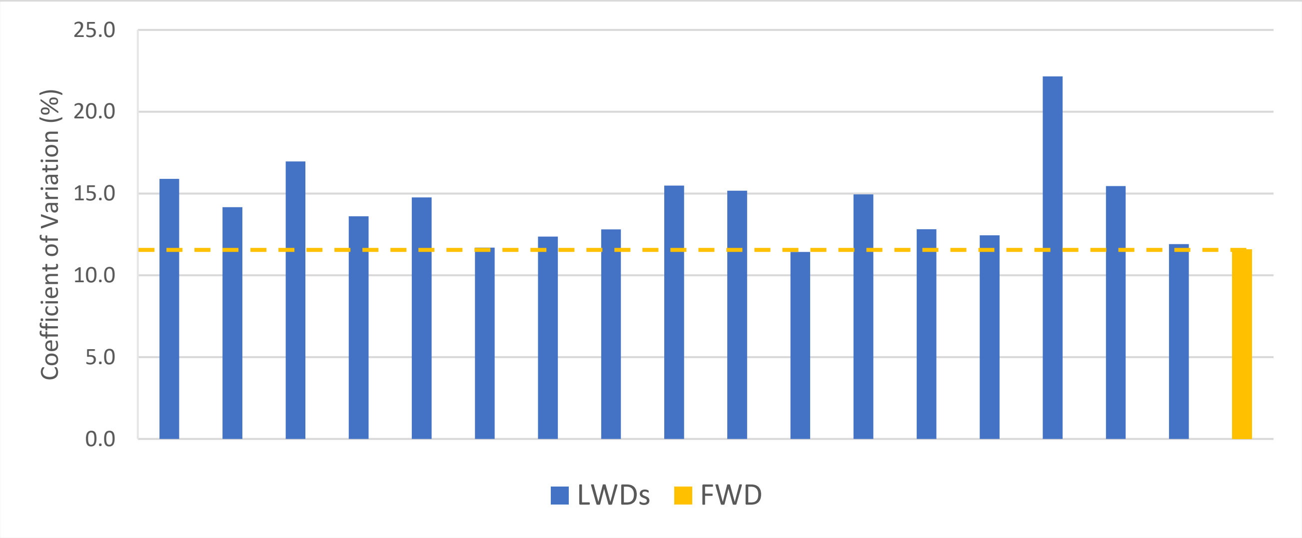


Figure 5-6 - Comparison of coefficient of variation for each LWD and FWD

For the same data, Figure 5-7 shows the mean surface modulus determined by the LWD devices (blue line) and the mean surface modulus once adjusted (orange line) using the calculated correction factors. The figure shows that the individual LWDs can provide a similar mean value to the FWD (135MPa). However, it should be noted that the adjustment technique is based on the average of at least 28 data points and will be much less effective when a smaller number of tests is carried out.

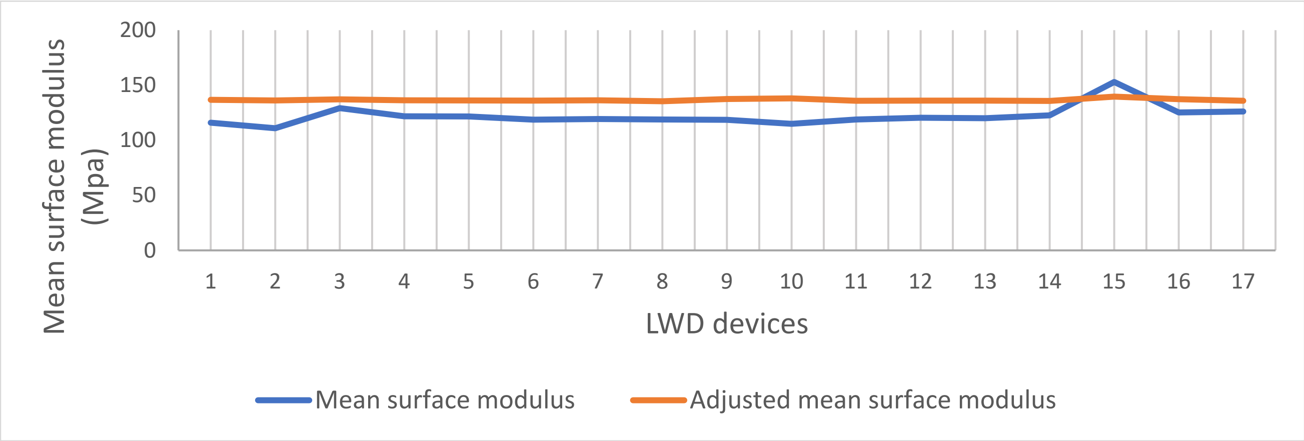


Figure 5-7 – Example of measured mean and adjusted surface modulus for LWDs

6

SUMMARY OF TESTING

6. SUMMARY OF TESTING

6.1. SUMMARY

The 2022 LWD correlation trial can be summarised as follows:

- The LWD correlation trial was held at AECOM's PTF between Monday 12th September 2022 and Thursday 15th September 2022.
- Collected data showed that the surface modulus of the PTF test panel was equivalent to a Foundation class 2 on each day of testing, and that the test panel provided a stable test bed for the correlation exercise.
- Ninety-seven LWD devices took part in the correlation trial and all devices were used to take 30 measurements following the procedure known as Procedure A, applying the standard target stress and Procedure B, a range of applied stresses, as per BS 1924-2:2018.
- The LWD devices were deemed to show a sufficient correlation with the pre-calibrated FWD, and adjustment factors were issued for use on materials covered by range 1, i.e. surface modulus between 25 MPa and 120 MPa.
- An examination of surface modulus results produced using Procedure A and Procedure B showed that the methods were not significantly different at the 95% probability level.
- Some machines (10%) were considered to have produced an excessive number of outliers. Owners were contacted and alerted to this with a view to reviewing and improving the operation and use of the LWD.

6.2. RECOMMENDATIONS

Based on data analysis and observations made during the correlation trial the following recommendations are made:

- Procedure A should be the preferred approach to be used as part of future correlation trials owing to its familiarity with operators and the results of analyses carried out as part of this study.
- Owing to the high correlation coefficient (R^2) values achieved during the trial, consideration should be given to amending the British Standard requirement to $R^2 > 0.85$ for LWD correlation trials that are conducted in a controlled environment. The existing requirement of > 0.45 for site trials should remain unchanged.

7

ACKNOWLEDGEMENTS

7. ACKNOWLEDGEMENTS

This study was carried out for National Highways and Transport Scotland. WSP and AECOM would like to thank all those individuals who organised and assisted with the trial. We would also like to thank all of the LWD operators from the participating organisations.

Appendix A

EXAMPLE: LWD CORRELATION CERTIFICATE

EXAMPLE: LWD CORRELATION CERTIFICATE

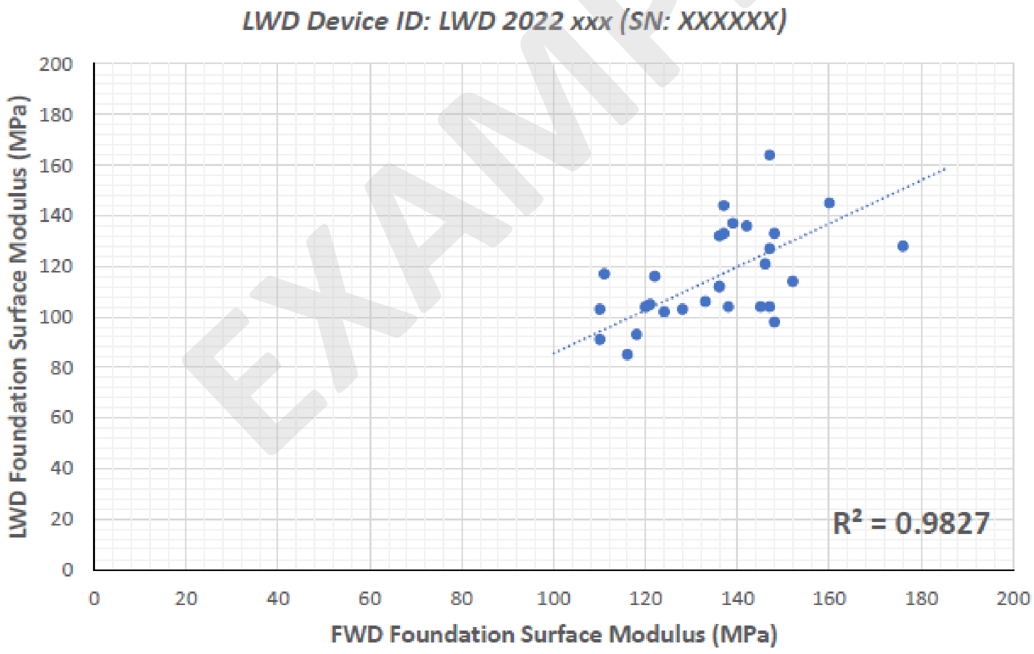
LWD Correlation Certification 2022

Introduction:

As part of the second annual UK LWD correlation trial, a calibrated LWD device (LWD 2022 xxx) has been compared with a FWD in accordance with BS 1924-2:2018. The results of the correlation exercise are shown below and the calculated adjustment factor shall be used when undertaking measurements using the LWD

LWD Device ID:	LWD 2022 xxx
LWD Serial Number:	XXXXXX
LWD Manufacturer:	XXXXXX
LWD Model:	XXXXXX
LWD Operator:	XXXXXX

Date of Correlation:	12/09/2022
Certificate Valid Until:	**31/12/2023**



As R2 ≥ 0.45 there is considered to be sufficient correlation between the FWD and LWD

The adjustment factor for this device has been calculated to be 1.022

The value is the mean of the ratios of each FWD value to LWD value

Appendix B

AECOM: TEST PIT MATERIAL INSTALLATION AND INITIAL TESTING

LWD Correlation Trials

Test Pit Material Installation and Initial Testing

Project number: 60658793

October 2022

Delivering a better world

Quality information

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Revision	Revision date	Details	Authorized	Name	Position
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1. Introduction

AECOM, in collaboration with WSP were commissioned by National Highways to host the annual Light Weight Deflectometer (LWD) correlation trials. The objective of the trial was to correlate all available LWDs across the UK with a calibrated Falling Weight Deflectometer (FWD) on a known stiffness, purpose-built test material. The LWD and FWD apparatus are briefly described in Section 2.

The material selected for the trial was an unbound granular pavement subbase material. For this, AECOM sourced a Mountsorrel Type 1 from Tarmac's Mountsorrel quarry. The laboratory certificates for this material batch are included in Appendix A. The material was installed in accordance with Series 800 of the Manual of Contract Documents for Highway Works (MCHW) (National Highways, 2016) and such that the resulting construction meets the requirements for a Foundation Class 2 (FC2), in accordance with CD225 (National Highways, 2020).

This report details the construction and initial testing undertaken as part of the 2022 LWD correlation trials. This trial is the second of its kind to be held at AECOM's full scale test pit facility in their Nottingham laboratory.

2. LWD and FWD apparatus

2.1 LWD Apparatus

The LWD is a non-intrusive and non-destructive handheld apparatus that is used to test pavement foundations.

It consists of a falling weight of 10Kg that is manually lifted and dropped down a guide shaft onto buffers, transmitting the load through a 300 mm diameter plate. The deflection and approximate stiffness at the test location are measured by a velocity transducer and stored via Bluetooth on a handheld device. Figure 1 shows an LWD apparatus in operation.

Figure 1 - LWD Apparatus

2.2 FWD Apparatus

The FWD is also a non-intrusive and non-destructive test typically towed by a 4 x 4 vehicle (See Figure 2 - FWD Apparatus); however, it can be used in isolation from the towing vehicle if required. The FWD tests at discrete locations on the pavement. Each test consists of an initial seating drop followed by three loading cycles.

It consists of a falling self-weight of 50Kg (once all the FWD weights have been removed) that is lifted hydraulically and dropped down a guide shaft onto buffers, transmitting the load through a 300 mm diameter plate. The deflection and approximate stiffness at the test location are measured by a velocity transducer and stored onto an external hard drive. Figure 2 shows an FWD apparatus in operation.

Figure 2 - FWD Apparatus

3. Test Pit Design

AECOM's Nottingham laboratory has a full scale test pit facility, formed of concrete and integrated into the floor of a spacious hangar. This hangar/test pit is referred to as the Pavement Test Facility (PTF). Prior to the works of this trial, the PTF was used for a stone mastic asphalt (SMA) surfacing research project in which stone mastic asphalt (approx. 100mm depth) was laid upon pre-existing Mountsorrel Type 1 (approx. 0.2 m depth), sharp sand (approx. 0.2 m depth) and building sand (approx. 1 m depth). The dimensions of the pit are presented below in Figure 3.

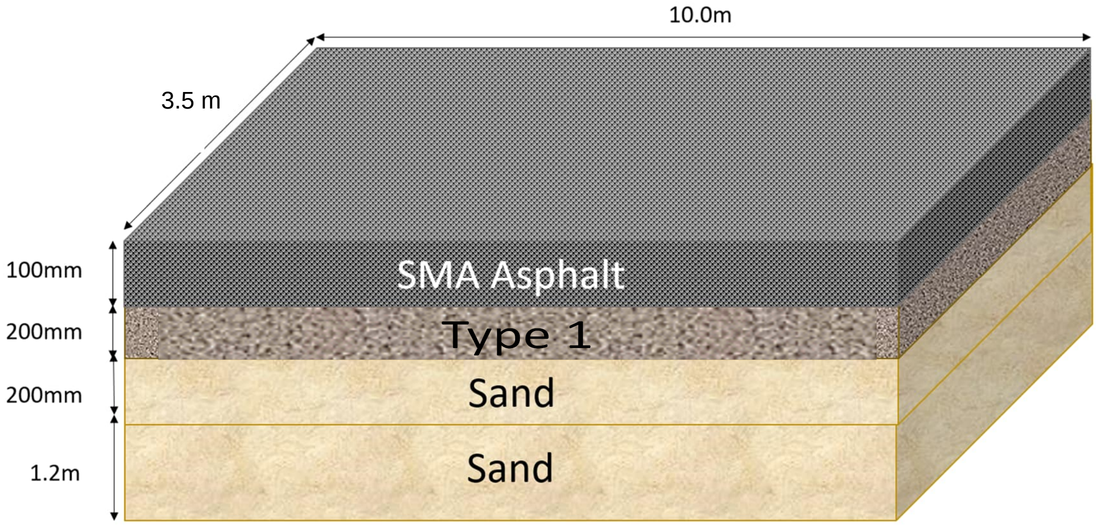


Figure 3 - Test Pit Construction Prior to Trials

3.1 Initial Excavation

For the trials, the 100mm of stone mastic asphalt was removed by a third-party contractor using a pneumatic pecker. The pit in its condition before the excavation is presented below in the left image of Figure 4. The right image shows the Type 1 material after delivery.

Figure 4 - Test Pit Prior to Trials and Type 1 Material

3.2 Construction

Type 1 subbase was sourced from Tarmacs Mountsorrel Quarry and was installed and compacted with a plate compactor by the third-party contractor. The type 1 was installed on the 6th September 2022. The material was delivered during a day of heavy rain and then stored outdoors, for this reason a moisture content was not recorded.

The image below in Figure 5 shows a cross section of the pit construction before and after the new material was installed. Figure 6 provides an image of the completed test pit ready ahead of the corellation trial.

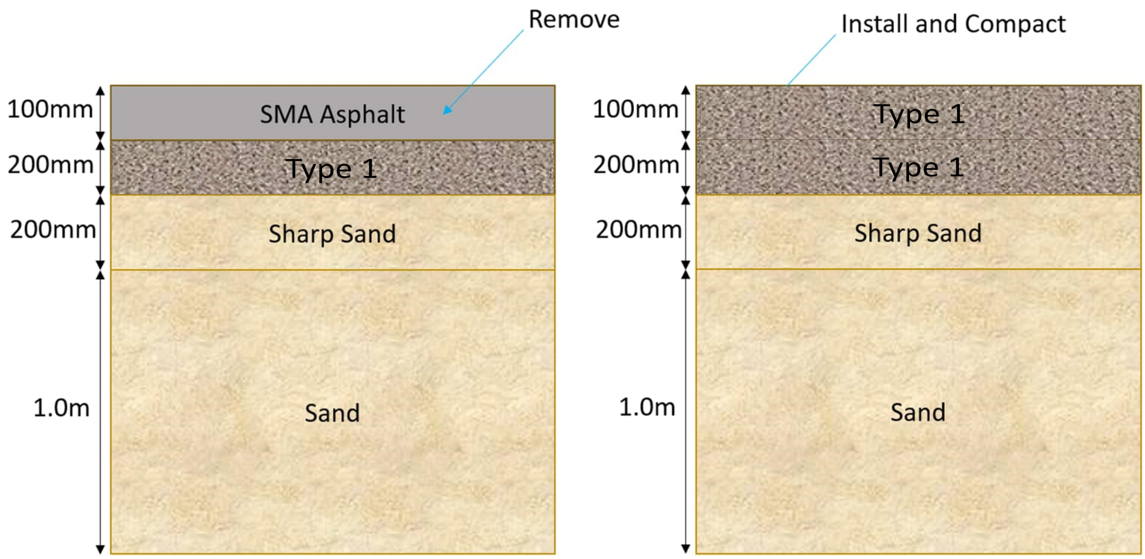


Figure 5 - Pit Cross Section Before and After Construction

Figure 6 - Completed Test Pit with Test Locations

4. Post Construction Testing

Initial testing was required to ensure that the compaction applied during construction was sufficient for the material to achieve a surface modulus comparable with an FC2 material (CD225 (National Highways, 2020)).

Once the construction was completed 30no. test locations were marked to ensure the test locations remain consistent throughout the correlation trials. To ensure that the results were not influenced by confinement from the concrete walls of the pit, all tests were undertaken >1.0 m away from the edges of the pit. The test location configuration can be seen overleaf in Figure 8.

The initial testing included FWD and LWD runs undertaken on Friday 9th September. Results from this testing indicated an FC2 material in accordance with CD225 (National Highways, 2020). Photographs from the testing are presented below in Figure 7.

Figure 7 - Post Construction Testing

Figure 8 (overleaf) shows the LWD Correlation Trial locations. The test locations are laid out in 2 No. runs “A” and “B”, each run has 15 no. test locations (A1-A15 and B1-B15). These start at the right closest to the shutter door in the PTF.

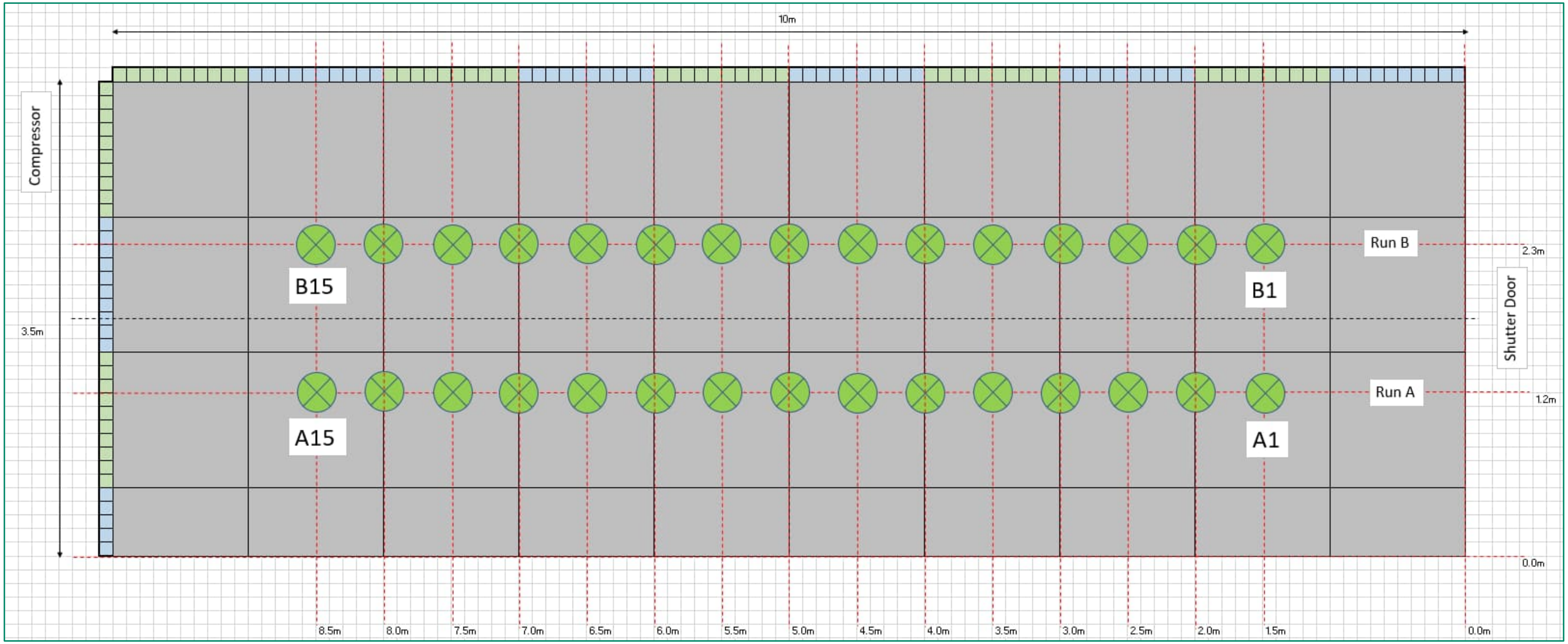


Figure 8 - Plan of Test Locations

5. LWD Correlation Trials

The LWD correlation trial took place between Monday 12th September 2022 and Thursday 15th September 2022. Figure 9 shows the LWD trial with operators from various companies taking part.

Figure 9 - Photographs from Trials

During the trials, the material was tested with the FWD after each day and then compacted (via plate compactor) in a single pass. The material was then tested again the following morning using the FWD to monitor the stiffness of the Type 1 Class 2 foundation performance.

6. References

National Highways. (2016, February). Manual of Contract documents for Highways Works - Series 800.

National Highways. (2020, April). CD225 Design for new pavement foundations. Design Manual for Roads and Bridges. Rev 1.

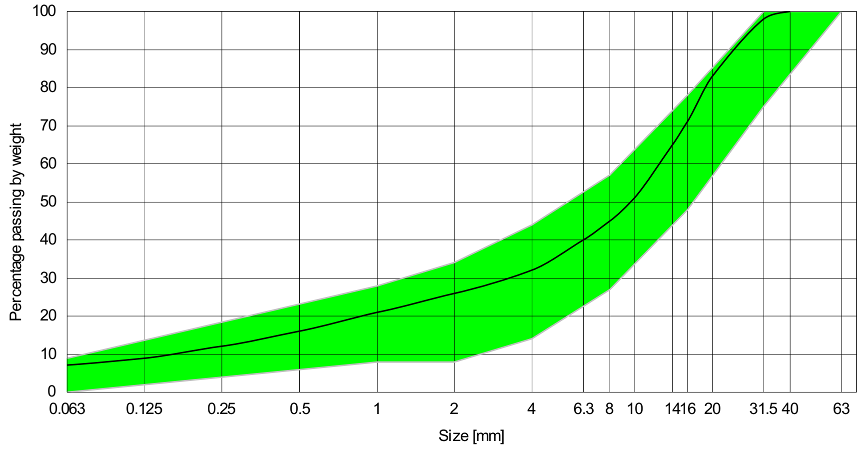
Appendix A Tarmac Laboratory Sheets

GRADATION ANALYSIS TEST REPORT

Product: TYPE 1 SUB-BASE CL803.
Material Code: 110A801
Supplied by: MOUNTSORREL QUARRY
Customer:
Site Address:
Material type: SHW 803 / Granite

Sampled to: LPM 3.2 Methods for sampling aggregates
Prepared to: LPM 3.3 Aggregate reduction to test portion from a bulk sample
Test method: BS EN 933-1: 2012

Sample number	584
Ticket No	
Sampled by	BAILEY
Date Sampled	23/09/2022
Sample location	TIPPED ON STOCK
Weather Conditions	
Remarks	



Sieve Size (mm)	Percent passing	Specification	Complies (Spec)	Control limits	Complies (Ctrl)
63	100	100 - 100	Yes	-	-
40	100	-	-	-	-
31.5	98	75 - 100	Yes	-	-
20	83	-	-	-	-
16	71	48 - 78	Yes	-	-
14	65	-	-	-	-
10	51	-	-	-	-
8	45	27 - 57	Yes	-	-
6.3	40	-	-	-	-
4	32	14 - 44	Yes	-	-
2	26	8 - 34	Yes	-	-
1	21	8 - 28	Yes	-	-
0.5	16	-	-	-	-
0.25	12	-	-	-	-
0.125	9	-	-	-	-
0.063	7.2	0 - 9.0	Yes	-	-
Moisture content (%)	2.0				
Uniformity Coefficient	86				

Size fraction d/D	Percent passing	Specification	Complies (Spec)
4/8	13	7.0 to 30.0	yes
8/16	26	7.0 to 30.0	yes

Sampled By: BAILEY Tested By: Date Tested: 26/09/2022

Product Data Sheet

Tarmac - Central

Mountsorrel B626

SHW Series 800 ,Road Pavements Unbound , Cement and other Hydraulically Bound Materials

Clause 803 , Type 1 Unbound Mixture

Conformity Requirements, Table 8/2			
	Requirements	Declaired Value	
Crushed or broken and totally rounded particles	$C_{90/3}$	C	90/3
Resistance to Fragmentation , Los Angeles Test	LA_{50}	LA	21
Resistance to Wear , micro-Deval test	M_{DE} NR	M_{DE}	7
Resistance to Freezing and thawing - Magnesium Sulphate Soundness	MS_{35}	MS	4
Water Absorption	WA_{24} NR	WA_{24}	0.5
Plasticity Index	Non-Plastic	Non-Plastic	
Frost Heave	Less than 15	2.7	
Constituent Parts	NR	NR	

Grading Requirements , Table 8/5			
Sieve	Declared SHW Requirements	Supplier Declaired Requirements	Supplier Declared Target
63mm	100	100	100
31.5mm	75-100	75-100	99
16mm	43-81	48 - 78	63
8mm	23-66	27 - 57	42
4mm	12-53	I4 - 44	29
2mm	6-42	O8 - 34	21
1mm	3-32	O8-28	18
0.063mm	0-9	0 - 9	6.0
Passing 16mm Retained 8mm	7-30		22
Passing 8mm Retained 4mm	7-30		13

Chemical Test Data BS EN1744			
Water Soluble Sulfate	mg/L SO_4		<50mg/l
Total Sulfur	% S		<0.1
Acid Soluble Sulphides	% SO4	Note 1	0.27
pH			9.8

Additional Test Data			
Mean CBR Value	%		220
Water Soluble Sulphate	mg/L SO_4	TRL	17
Oxidisable Sulphides	% SO_4	TRL	0.01
Optimum MC	%		5.6
Max Dry Density	Mg/m3		2.32

Note 1 New BS EN1744 SHW requirement <0.06% as SO4 - If deposited within 500mm of Metallic Structural Elements

Notes
1. The above data is provided in good faith as a guide to typical values and does not constitute a specification
2. The company reserves the right to revise the data at any time
3. Individual Certification available on request

Issued By :

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