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ERDC 6.2 Boreal Aspects of Ensured Maneuver (BAEM)

Using the Light Weight Deflectometer in Winter Climates

A. Menke, W. Wieder, and S. Shoop

August 2020

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U.S. Army Engineer Research and Development Center (ERDC)
Cold Regions Research and Engineering Laboratory (CRREL)
72 Lyme Road
Hanover, NH 03755-1290

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Preface

This study was conducted for the Assistant Secretary of the Army for Acquisition, Logistics, and Technology under project number 465395, "Boreal Aspects of Ensured Maneuver (BAEM)," which is part of the U.S. Army Engineer Research and Development Center (ERDC) 6.2 Remote Assessment of Infrastructure for Ensured Maneuver (RAFTER) Program managed by Ms. Danielle Whitlow, ERDC Geotechnical and Structures Laboratory (GSL).

The work was performed by the Force Projection and Sustainment Branch (CEERD-RRH) of the Research and Engineering Division (CEERD-RR), U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-CRREL). At the time of publication, Mr. Jimmy Horne was Acting Chief, CEERD-RRH; and Mr. Jimmy Horne was Chief, CEERD-RR. The Deputy Director of ERDC-CRREL was Mr. David B. Ringelberg, and the Director was Dr. Joseph L. Corriveau.

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COL Teresa A. Schlosser was Commander of ERDC, and Dr. David W. Pittman was the Director.

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Using the Light Weight Deflectometer in Winter Climates

A. Menke
ERDC-CRREL, Hanover, New Hampshire, USA

W. Wieder, Ph.D.
ERDC-CRREL, Hanover, New Hampshire, USA

S. Shoop, Ph.D.
ERDC-CRREL, Hanover, New Hampshire, USA

ABSTRACT: The light weight deflectometer (LWD) was designed to test the compaction or bearing capacity of in-place aggregate base-course materials. This study evaluated the LWD at temperatures near and below freezing, below of its typical temperature range for road construction. Initial field LWD tests were run on a variety of compacted snow surfaces over asphalt pavement, gravel, and soil in the winter of 2018 in both Montana and Michigan. The LWD measures load and deflection, enabling calculation and backcalculation of stiffness parameters for the test surface layers. The field results were reasonable for the snow layers analyzed. However, the results indicated LWD may also have issues with the effects of low temperature testing on its components, specifically the rubber load buffers. Therefore, in the fall of 2018 a series of LWD tests were performed in cold rooms to evaluate the equipment without the variability of the snow surfaces as a parameter. This series of controlled tests determined that the LWD could be operated in conditions as cold as -25 °C. However, care must be taken in interpreting the results of tests conducted at cold temperatures. The ambient temperature and the duration of the LWD's exposure to these conditions will affect the accuracy of testing. Significant changes in the LWD test results occurred after 24 hours of exposure to 0 °C, after two hours of exposure to -10 °C and after only one hour of exposure to -20 °C or a half hour of exposure to -25 °C. The LWD should not be stored in freezing temperatures prior to testing, and temperature and length of exposure should be monitored and recorded during field testing.

KEY WORDS: Bearing capacity, pavement, snow, temperature.

1 INTRODUCTION

The light weight deflectometer (LWD) is a portable version of the larger, typically trailer-mounted, falling weight deflectometer (FWD). The LWD was developed to estimate the in situ stiffness modulus of soils and is typically used for quality control and quality assurance, and structural evaluation of mechanically compacted earthwork and pavement layers (Senseney and Mooney 2010). The LWD is not usually operated on snow or ice surfaces as it is used more typically as a construction or pavement layer (i.e. base course, subbase or subgrade) evaluation tool. In temperate regions, those activities are usually during the summer construction season.

As part of a larger program evaluating test equipment for potential use characterizing the mechanical properties of snow, testing was conducted with the Dynatest 3031 LWD on a variety of groomed snow surfaces at two field sites, in Montana and Michigan, during the winter of 2017-2018. The results of these field tests led to questions concerning the temperature sensitivity of components of the LWD in temperature ranges below freezing. Therefore, a set of controlled cold room tests were designed to evaluate and quantify the effect of freezing conditions on LWD testing. That work is presented in this paper.

2 FIELD TESTING

Two field campaigns in January and February of 2018 used the LWD on groomed snow surfaces in Montana and Michigan. The snow surfaces varied greatly in the way they were groomed and compacted. Temperatures during testing ranged from approximately -14 °C to 1.5 °C, and testing was performed in a range of weather conditions including falling snow, overcast, sun and night-time operations.

The first phase of this testing, in Montana, was used to develop the LWD procedure to be used for the remaining field tests. This included determining the configuration for the LWD that best captured data for the groomed snow conditions that were found in Montana.

The configuration was as follows:

- The 300 mm diameter plate, with the center plug in. Running the LWD with the center annular plug removed caused a significant divot in the snow, indicating that the center geophone was digging into or compressing the snow under it.
- The 10 kg load package.
- The rubber LWD mat.
- Four drop heights, with 3 drops at each height:
  - Drop height 1: 15 cm (6 in.)
  - Drop height 2: 30 cm (12 in.)
  - Drop height 3: 46 cm (18 in.)
  - Drop height 4: 61 cm (24 in.)
- Only the center geophone was used, as the outer radial geophones did not register a deflection on the initial snow surfaces tested.

During both field campaigns, the LWD was stored in either a heated office trailer or garage. At the start of testing, the LWD was loaded into the back of an open truck to transport it around the site, and then transferred to a plastic sled to move between test points.

In Michigan, morning LWD tests would take place within an hour of the LWD coming out of the heated garage. However, afternoon tests occurred after the LWD had been sitting at ambient outside temperature for several hours. In Montana, the LWD testing usually spanned a shorter time frame, and often took place at night.

During the processing of LWD data we noticed that the LWD measured impact load varied between the morning and afternoon tests on groomed snow road surfaces (Figure 1) even though the weight package and the drop heights were not changed. The air temperature on the day of testing had increased slightly from -1.1 °C in the morning to -0.4 °C in the afternoon, with freezing rain and snow in the morning followed by overcast skies in the afternoon. Other researchers have reported a change in load associated with a change in stiffness of the LWD's buffers (Vennapusa and White 2009, Adam and Kopf 2004, and Siekmeier et al. 2009). Though use of the LWD at below freezing temperature is not common, other agencies have protocols that address temperature variability with the LWD. The Minnesota Department of Transportation addresses this issue as follows: "LWD devices should not be used when the temperature falls below 5° C to ensure the device's components, particularly the rubber buffers, work as intended." (Siekmeier et al. 2009)

For the larger FWD the Federal Highways Administration's (FHWA) FWD manuals indicate that the stiffness of the device's rubber buffers affects the measured load. During the course of testing, the buffers may warm or change stiffness. The FHWA recommends operators minimize these variations by conditioning the buffers prior to testing as follows (Schmalzer 2006): in ambient temperatures above 10 °C perform one drop at each of the first three drop heights, and then four drops at height 4, all repeated eight times for a total of 56 drops. In cold weather, ambient temperatures below 10 °C, the FHWA recommends an additional 32 drops at drop height 1 for a total of 88 drops.

The procedure suggested by the FHWA is not likely to be applicable to testing with the LWD in below freezing temperatures. Since the LWD weight is raised and released manually, 88 drops would be an onerous requirement. It seems more logical that the buffers would need to be kept at a consistent cold temperature, or in a range of cold temperatures, to ensure they had the same stiffness and thus were delivering the same load throughout a given test program.

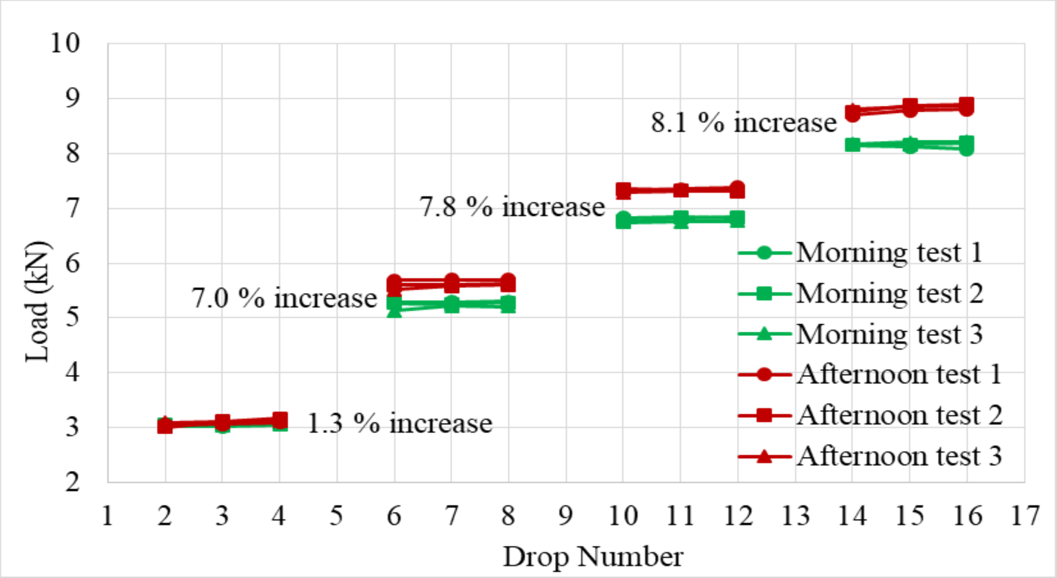

Figure 1. Load levels recorded by the LWD in Michigan indicating a change in loading conditions between morning and afternoon tests.

Based on questions raised during the field testing and subsequent data analysis, we designed a series of controlled tests in a cold room environment which were conducted in December 2018 at the Cold Regions Research and Engineering Laboratory (ERDC-CRREL).

3 COLD ROOM TESTS

In order to evaluate the variability in LWD test results, a series of experiments were conducted in a controlled environment. To simulate a surface with the appropriate stiffness for the LWD, a block of ultra-high molecular weight (UHMW) polyethylene was used. This block, with the dimensions 5” x 24” x 24”, was seated on a neoprene sheet ¾” x 36” x 36” which in turn rested on the concrete floor of the cold room and was not moved for the duration of testing. This configuration was selected to provide a stable surface that would not be degraded by repeated impacts, providing material properties as consistent as possible throughout the series of tests.

During testing, the LWD was brought into the cold room environment from warm storage and a series of tests was conducted immediately; the test procedure was performed again after 30 minutes, 1 hour, 90 minutes and 2 hours of exposure to the cold. The LWD was left in the cold room to fully acclimate and a final test was performed after 24 hours of exposure to the test temperature. The cold room environment was adjusted to nominal temperatures of 0 °C, -10 °C, -20 °C, and -25 °C, as well as a “warm” temperature of 20 °C considered the baseline. Actual temperatures varied by ±1 °C during the course of testing. The full 24-hour series of testing was performed at each temperature, except for the warm baseline during which time of exposure was not a factor. The palm pilot used with the LWD was not exposed to the cold.

Configuration of the LWD was not identical to configurations used during field testing, as it was selected to achieve test results within or near the manufacturer’s recommended range for stress level, deflection, and pulse time. The configuration and test procedure were consistent at each temperature during the controlled environment phase, with a few additional tests conducted in order to provide insight into the effect of individual components. To provide consistency, the same operator performed all tests.

The configuration was as follows:

- The 150 mm diameter plate, without the center annular plug.
- The 10 kg load package.
- 2 grey (higher density) under 4 black (lower density) buffer pads
- No rubber LWD mat.
- Four drop heights, performed lowest to highest, with 4 drops at each height:
    - Drop height A: 33 cm (13 in.)
    - Drop height B: 48 cm (19 in.)
    - Drop height C: 64 cm (25 in.)
    - Drop height D: 79 cm (31 in.)
- Only the center geophone was used.

The effect of increasing and prolonged exposure to cold conditions was evaluated by observing the change in recorded force as well as the deflection measured by the device. The ASTM E2583 *Standard Test Method for Measuring Deflections with a Light Weight Deflectometer* specifies that peak load levels must not vary by more than ±3% during calibration and recommends that variations of more than ±3% at one test point should be noted (ASTM 2015). Based on these guidelines, unexplained variations of 4% or more at a given temperature and drop height were considered significant in this study.

3.1 LWD Force

The force applied to the test surface by the LWD is controlled by the weight package and drop height selected. The results of testing at 0 °C and -10 °C did not exhibit significant changes in the measured force, even after 24 hours of exposure. Some variations occurred, but these results differed by less than 4% from the equivalent test performed under warm conditions – the "baseline" test.

However, at -20 °C and -25 °C significant changes in measured load occurred. Variations greater than 4% from baseline were noted after two hours exposure to -20 °C and after 90 minutes exposure to -25 °C, shown in Figure 2. The most significant impact was seen after 24 hours of exposure to the coldest temperature (-25 °C), at which time loads were recorded more than 25% above the baseline results. The most significant changes were seen at the highest drop heights, and thus at the highest loads.

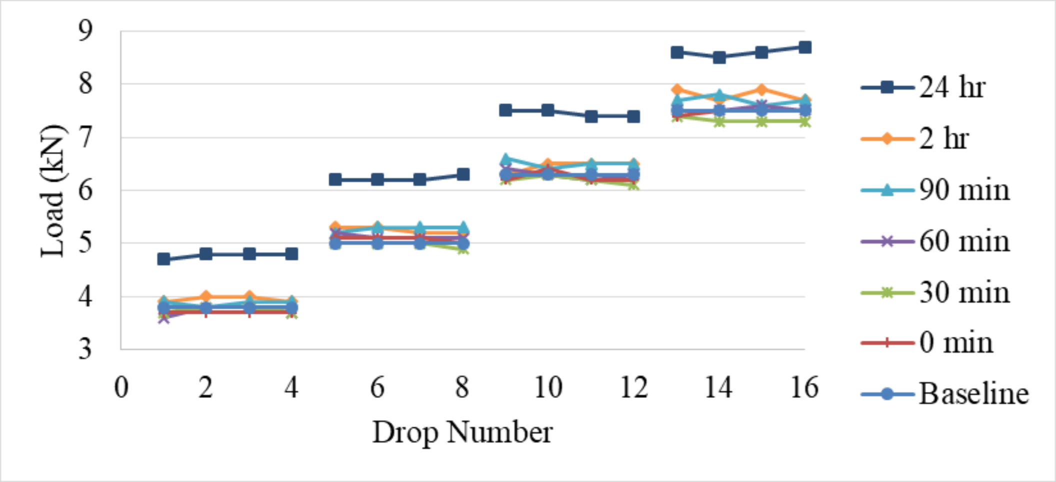

Figure 2. Changes in impact load sensed by the LWD after exposure to -25 °C.

3.2 LWD Deflection

The deflection of the target surface, recorded by the LWD in microns, is a function of the force or load based on drop height and plate diameter, and the properties of the surface material being tested, in this study a UHMW polyethylene block. The block and cold room were allowed to stabilize for at least 24 hours at the test temperature before the LWD was brought into the cold room and testing was performed. Thus, the properties of the polyethylene would be constant at a given temperature since it was cold soaked and held at the same temperature throughout each series of tests.

A change in the properties of the polyethylene test material is expected to accompany a change in temperature. Since this can result in different deflection readings, unrelated to the accuracy of the LWD, deflection was not used to compare the results of tests performed at different temperatures. At a constant temperature, however, a change in deflection readings after prolonged cold exposure could be an indicator of degraded performance.

Testing at 0 °C, -10 °C and -20 °C showed some significant variations in deflection, but these included both increases and decreases without a clear trend. For each test temperature, the average of four drops at each drop height was compared to the initial test performed with zero minutes cold exposure. The most consistent and dramatic trend was found at -25 °C with increases in deflection of up to 24%, shown in Figure 3.

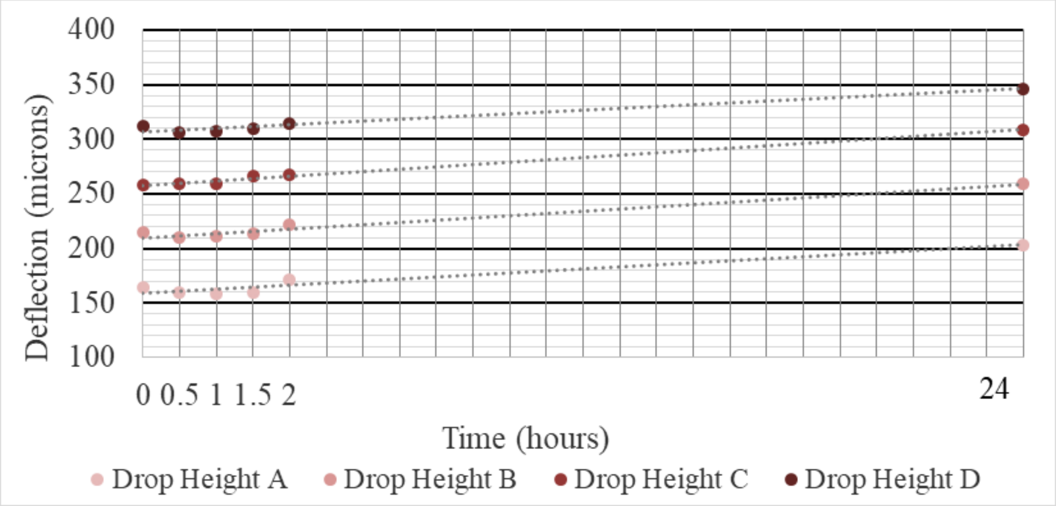

Figure 3. Changes in LWD average deflection with exposure to -25 °C.

3.3 Impulse Stiffness Modulus (ISM)

In addition to actual deflection, the Impulse Stiffness Modulus (ISM) was analyzed. The ISM is used by the U.S. Army and Air Force as a pavement evaluation parameter (U.S. Army Corps of Engineers [USACE] 2001). It provides a qualitative measure of stiffness which accommodates some variations in force, as it is based on both force and deflection. The ISM is calculated simply as load divided by deflection in kips per inch.

The most significant effects were again seen at the coldest temperatures, -20 °C and -25 °C. During testing at 0 °C, significant increases in ISM were only noted after 24 hours of exposure. The results of testing at -20 °C (Figure 4) were very consistent, with an increase in ISM occurring after longer periods of exposure and with greater drop heights, but with significant impacts after as little as one hour exposure. Increases in ISM were also evident at -10 °C, with a pattern similar to that seen at -20 °C. At -10 °C the impacts became significant after two hours of exposure.

The results of testing at -25 °C, shown in Figure 5, did not exhibit the same general pattern found at warmer temperatures. During testing at -25 °C, errors which caused the test data to be recorded incorrectly became more frequent, often requiring repeat attempts to obtain usable data. The inconsistency of these results may be due to failure of the LWD's components in extreme cold.

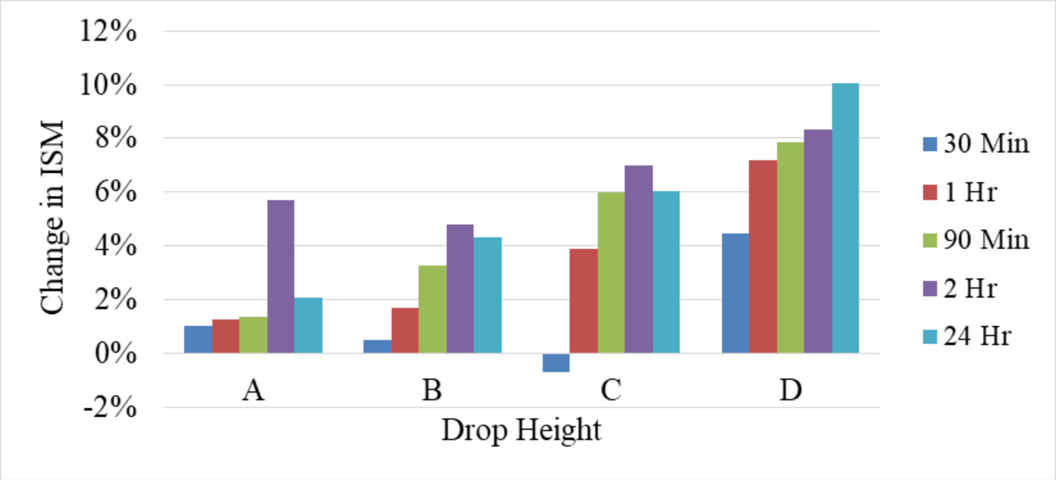

Figure 4. Average change in ISM compared to the initial measurement (zero minutes exposure) for tests conducted at -20 °C.

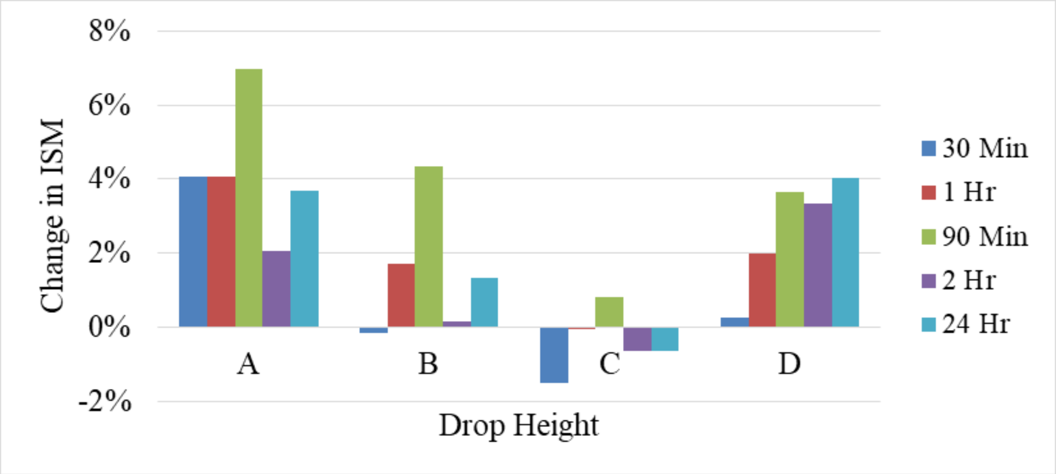

Figure 5. Average change in ISM compared to the initial measurement (zero minutes exposure) for tests conducted at -25 °C.

3.4 LWD Buffer Conditioning

In addition to the standard test series performed at each temperature point, several attempts were made to determine the effect of buffer stiffness on the accuracy of the

LWD test results. Since buffer conditioning is recommended as a measure to ensure accuracy during FWD testing in cold conditions, buffer stiffness has been proposed as a source of variation in LWD testing at cold temperatures. Two methods of buffer conditioning were used: performing numerous repeated drops, and physically removing the buffers from the cold environment to warm them and observe any change in subsequent test results.

To test the first method of buffer conditioning, four full tests of 16 drops each were conducted in quick succession at 0 °C; no significant change in recorded stress was observed (Figure 6). Another variation was attempted, with 35 drops performed rapidly from drop height C at -25 °C. This revealed only a slight downward trend in the recorded stress and associated ISM, as shown in Figure 7.

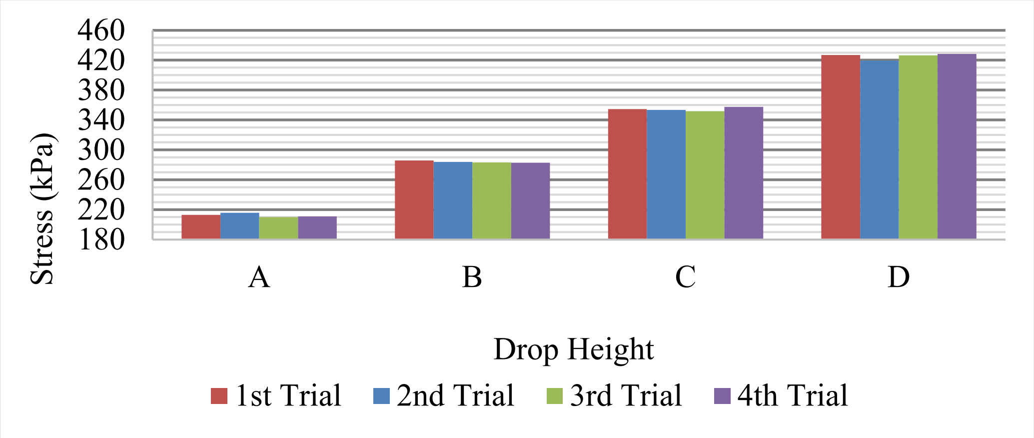

Figure 6. Buffer conditioning used at 0 °C.

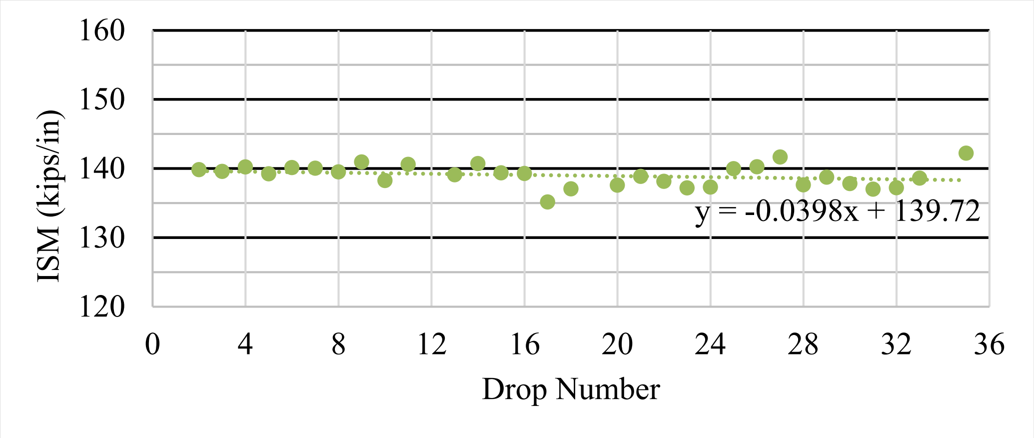

Figure 7. Buffer conditioning used at -25 °C with linear trend line.

To test the alternate method of buffer conditioning, the buffer pads were physically removed, warmed to at least 20 °C, and replaced on the LWD immediately prior to testing. All other components of the LWD were cold soaked and remained in the cold room. The results of this test are shown in Figure 8 as “warm buffers.” The results of the warm buffers test were comparable to those obtained after 24 hours exposure without special treatment of the buffers, indicating that this method of buffer conditioning was not effective. Buffer stiffness does not appear to be the primary source of change in LWD test results at cold temperatures. Buffer conditioning is therefore not recommended as a strategy to mitigate the effects of cold exposure.

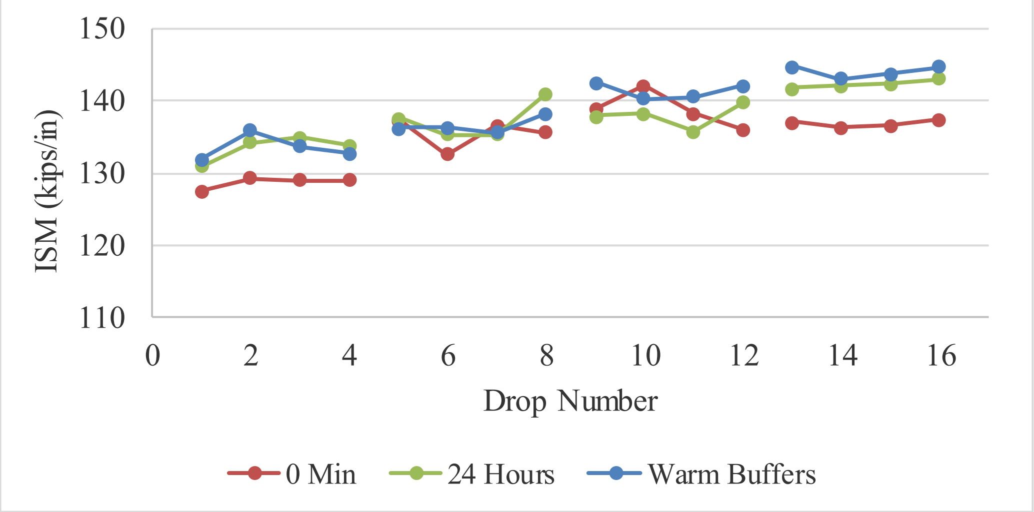

Figure 8. Testing of individually warmed buffers at -25 °C.

4 CONCLUSIONS

Freezing conditions, particularly after prolonged exposure, clearly impacted LWD testing. This series of controlled tests determined that the LWD could be operated in conditions as cold as -25 °C. However, the accuracy of the results from these tests, with regard to the response of the test surface versus a variation in the LWD components, is questionable. Significant changes in the LWD test results were observed at every freezing temperature tested. Changes in either force or ISM exceeded the recommended ±3% (ASTM 2015) occurred after:

- 24 hours of exposure to 0 °C,
- two hours of exposure to -10 °C,
- one hour of exposure to -20 °C, and
- one half hour of exposure to -25 °C.

With this in mind, comparing LWD data taken at different low temperatures may be problematic, as the variation between tests may arise from the LWD and not the test surfaces.

The LWD should not be stored in freezing temperatures prior to testing, and temperature and length of exposure should be monitored to ensure accuracy of the LWD. Based on our results, buffer conditioning does not appear to be an effective method of counteracting the effects of cold weather on LWD test results. In future cold weather field testing, temperature and time of exposure should be recorded for each test.

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14. ABSTRACT

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