DEVELOPMENT OF CLEGG IMPACT VALUE THRESHOLDS FOR MINIMIZING
RUTTING OF CEMENT-TREATED BASE MATERIAL
UNDER EARLY TRAFFICKING

By

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ABSTRACT
In order to avoid early-age damage such as rutting, cement-treated base (CTB) materials must be allowed to cure before the pavement can be opened to early trafficking. One instrument shown to be effective in assessing the suitability of a CTB for early-age trafficking is the Clegg impact soil tester. In previous research, a Clegg impact value (CIV) threshold was proposed. That testing was conducted in northern Utah and consequently has limited application in other locations and with different CTB materials. Therefore, the objective of this research was to investigate the suitability of that CIV threshold in other conditions. Specifically, data were collected in Georgia, Texas and Idaho to supplement the Utah data. Following the field testing, the data were reduced on a site-specific basis, and CIV thresholds were selected for each site. The results indicate that the threshold is clearly a function of the 7-day unconfined compressive strength (UCS) of the CTB material, and a chart was developed to assist engineers with selecting appropriate CIV thresholds based on a specified 7-day UCS.
INTRODUCTION

The integrity of a roadway depends on the strength and stiffness of the layers that comprise it. In order to improve the quality of the materials within the pavement section, roadway engineers frequently specify the use of portland cement as a stiffening agent in cement-treated base (CTB) layers. There are several commonly used methods for constructing CTB sections. Generally, portland cement is mixed with water and an aggregate base, which is then placed, graded, and compacted on a prepared subgrade or subbase layer. As portland cement cures, it forms chemical bonds that link aggregate particles together in a stiff matrix. The rate at which curing occurs is a function of the ambient air temperature, humidity, wind speed, and cement concentration (1, 2). Because these factors vary from site to site and from day to day, predicting the exact progression of the CTB curing is difficult. Once properly cured, however, CTB offers excellent support for the wearing course of a pavement structure.

Properly cured CTB can resist forces applied directly to it from early-age trafficking. Heavy vehicles, however, can mar the CTB surface if it has not properly cured. Because it is difficult to predict exactly when a CTB is sufficiently cured, many agencies specify conservative curing periods, 7 days for example, during which trafficking of the CTB is not permitted (3, 4). This approach ensures that early-age trafficking will not rut the CTB, but it can also waste valuable time and money on the part of construction contractors and the driving public who must wait for the time period to expire regardless of the curing condition of the CTB.

As an alternative to a time specification, agencies and engineers may specify physical testing of CTB. There are several methods for testing the stiffness of CTB in the field, many of which were evaluated by researchers at Brigham Young University (BYU). Those researchers found that the heavy Clegg impact soil tester (CIST), commonly referred to as a Clegg hammer, was the most efficient, cost effective, ergonomically friendly, and sensitive method for assessing the stiffness of CTB layers (3). This instrument consists of a 20 kg (44 lb) drop weight that is 12.7 cm (5 in.) in diameter and set within a thin-walled cylindrical guide tube. During testing, this weight is dropped from a height of 30.5 cm (12 in.), impacting the roadway surface. An accelerometer mounted on the drop weight measures the maximum rate of deceleration and reports the rate on a digital display in terms of a Clegg impact value (CIV), which is equal to the measured deceleration rate divided by 10 times the acceleration rate of gravity. Therefore, a CIV of 30 would indicate a deceleration rate of 300 times the rate of gravity (5, 6). The deceleration rate is directly proportional to the shear resistance and stiffness of the material that the weight impacts.

Research was performed at BYU to develop a rutting threshold for the Clegg hammer. This work was performed on one CTB construction site in northern Utah and showed that a CIV of 25 would ensure that a CTB could withstand early-age trafficking without unacceptable rutting (7). The methods and results of that research, while technically sound, have not been validated or expanded beyond materials and conditions similar to those found in northern Utah. The specific objective of this research was to investigate the suitability of that CIV threshold for conditions in other locations and with different materials.

To accomplish this objective, three additional CTB construction sites were investigated during the summer of 2007. The first site was in the state of Georgia along the Statesboro Bypass on U.S. Highway 301 (US-301). The second site was in north central Texas on Farm to Market Road 219 (FM 219). The final site was near the eastern border of Idaho on U.S. Highway 26 (US-26). The data from these three states have been compared with the data collected in Utah on U.S. Highway 91 (US-91) near Smithfield during the summer of 2005 (7).
BACKGROUND
The following sections contain a brief overview of the equipment and methodologies devised in the previous work and followed in this work with minor variation.

Equipment
The purpose of the original CTB rutting research was to establish a correlation between CIV and rut depth. A heavy wheeled rutting device (HWRD) was developed to rut the CTB in a consistent manner. The HWRD has been described in detail in the previous work (7). It essentially consists of a set of wheels that together weigh approximately 90.7 kg (200 lbs) and each have a footprint of approximately 6.5 cm² (1 in.²). The HWRD was designed so that each wheel produces a pressure of about 690 kPa (100 psi), equal to the contact pressure associated with an equivalent single axle load. This cart is designed to be pushed by hand over the roadway surface during testing.

To ensure consistency and accuracy in measuring rut depths, BYU researchers developed a measuring board system (MBS) (7). The MBS consists of a rigid wooden board that is set on two blocks that serve as a base. Together the blocks and the board provide a stable mounting location for a micrometer that is inserted into the board for measuring rut depth. Researchers found that inserting a small metal disk over the measured surface each time a measurement was taken served to eliminate errors from minute surface variations associated with small variations in measurement location.

Methodology
Researchers at BYU developed a protocol for collecting rut depth and CIV data. In cooperation with the construction contractor, the researchers selected several HWRD test sites. To ensure that the testing would yield a full range of results, the researchers selected some sites that were freshly compacted and others that had cured for a few days. Once a suitable site was located, a team of two researchers began the process of creating and measuring ruts using the HWRD and the MBS (7).

To perform the testing, researchers situated the support blocks on either side of the intended test site and placed the MBS across the tops of the blocks. Initial micrometer readings were recorded, with two replicate measurements taken in each wheel path. The HWRD was then situated so that the wheels were aligned with the micrometer mounting locations on the MBS. The MBS was then removed, and the HWRD was manually rolled over the surface in sets of 10 passes each. A pass consisted of one traverse of the wheels. The steps of rolling and measuring were repeated for five sets of 10 and then one set of 50, making a total of 100 passes per test site. At the conclusion of this rutting procedure, CIVs were measured following the guidelines set forth in ASTM D5874 at three locations immediately adjacent to each wheel path (7).

Approximately 90 sites were investigated in the previous work. Operator and measurement errors necessitated a systematic and logical data reduction plan, which was applied consistently to all the data collected in the field. Approximately 27 percent of the rutting measurements taken during the field work at US-91 were eliminated through this process (7). As mentioned previously, the results of this previous work are referenced in the presentation of the current work.

The previous work addressed selection of an appropriate rut depth threshold and concluded that a rut depth greater than 0.25 cm (0.1 in.) would be unacceptable (7). This
threshold is consistent with several other rut testing methods (8, 9, 10) and is used in the current research as well.

**EXPERIMENTAL METHODOLOGY**

The protocol and methodologies set forth by the previous researchers were carefully followed at each of the new sites, but certain improvements were implemented. First, as previous researchers reported that using a single micrometer was both time consuming and a source of potential error, two micrometers, of the exact same type and precision, were used instead of only one. Second, the small metal disks used to prevent the micrometer tip from penetrating the CTB surface were replaced with screw-in micrometer tips specifically designed and constructed for this research by the BYU Precision Machining Laboratory. The tips measured 1.3 cm (0.5 in.) in diameter, which is the same diameter as the metal disks used previously. Third, three measurements with the micrometer, rather than only two, were averaged as one observation. This approach reduced the effects of a bad measurement but did not greatly increase the time required for each set of measurements. All three of these measures account for the reduction in the data rejection rates in Georgia, Texas, and Idaho compared to Utah.

Once the data were collected at each of the new sites, they were reduced using the same procedure as described in the previous work (7). After data reduction, each rut depth was plotted against the average CIV taken along the wheel path associated with the measurement. Linear trend lines were developed for each set of points corresponding to a given set of 10 passes within the general construction site. These lines provides a means of analyzing the data trends. Using the same 0.25 cm (0.1 in.) rut depth threshold used in the previous analysis, CIV thresholds for each site were chosen. The following sections describe the four sites for which data are presented.

**Utah Site**

As described in detail in the previous work (7), researchers selected a CTB site along US-91. They reported an average daytime temperature of 29.5°C (85°F) with an average relative humidity of 37 percent. This highway was completely reconstructed as part of a widening project. After subgrade excavation, embankment construction, and widening were completed, the roadway was overlain with a 20.3 cm (8 in.) layer of high quality limestone base material. Next, 2.0 percent portland cement by weight of dry aggregate was placed in powder form and mixed with the base material and water using a reclaimer to form the CTB. Finally, the layer was graded and compacted.

A sample of the limestone aggregate base was collected and classified in the laboratory as A-1-a (11) and as SW-SM (12). The material had a maximum dry density of 2191 kg/m³ (137.8 pcf) and an optimum moisture content (OMC) of 7.0 percent. The material had a 7-day unconfined compressive strength (UCS) of 5000 kPa (725 psi).

**Georgia Site**

The Georgia Department of Transportation (DOT) specified the use of CTB as a base layer for the pavement section constructed for a truck bypass route around the city of Statesboro along US-301. The new bypass consisted of two new lanes constructed adjacent to existing bypass lanes. Researchers worked for two days at the site, where the average daytime temperature was 31.7°C (89 °F) and the average relative humidity was 57 percent. Figure 1 shows the testing in progress.
On this site, base material was mixed in a pug mill and then trucked to the site and spread. A pneumatic roller was employed to compact the layer. Following compaction, the CTB was allowed to cure for approximately one day before it was sealed with a prime coat. Because the construction took place adjacent to operating traffic lanes, no general traffic passed over the new CTB until it was paved sometime later.

Georgia DOT officials reported that the OMC of the material was 12.8 percent. To strengthen the aggregates, cement power was added at a rate of 5.0 percent by dry weight of aggregates. The compacted in-situ density of the material was 2105 kg/m$^3$ (131.4pcf).

A representative sample of untreated base was analyzed in the laboratory. One set of three 1.22 cm (4 in.) diameter UCS samples were prepared using 5.0 percent cement by dry weight of aggregate. Consistent with the previous research, the specimens were cured for 7 days at 20°C (70°F) and 100 percent humidity. Following the curing period, the specimens were capped with a high-strength gypsum compound and subjected to compression testing at a constant strain rate of 0.05 in./minute ($\frac{1}{20}$). The material had an average UCS of 986 kPa (143 psi) with an average moisture content of 12.0 percent at the time of testing. The material was classified as A-3 (I1) and SP (I2).

In Georgia as well as at all the other general construction sites, test locations were selected to ensure a wide range of CIV values. For the most part, tests were performed within the future driving lane, although some were taken on the shoulders of the road. One team of two researchers operated the HWRD, MBS, and CIST. Forty-six sites were investigated in Georgia. In the data reduction process, only 21 percent of the measurements were rejected.

**Texas Site**
The Texas site was located along FM 219 in north central Texas. Researchers were on site for two days, during which time the average daytime temperature was 27.8°C (82°F) and the average relative humidity was 75 percent. During these two days, research work had to be stopped twice due to rain.

The reconstruction process involved spreading virgin aggregates over the existing flexible pavement and then pulverizing and mixing the two together using a reclaimer. Calculating the...
exact percentage of reclaimed asphalt pavement (RAP) in the final mixture was not possible, but that percentage was estimated by the contractor at approximately 10 percent. A second pass of the reclaimer was necessary to mix in the cement and water. The OMC for the mixed material was 9.3 percent by weight of the dry aggregate. Texas DOT personnel specified 3.9 percent cement by dry weight of aggregate for this CTB. Once the materials had been thoroughly mixed by the reclaimer, they were graded to the approximate elevations required by the specifications. Both vibratory and pneumatic compactors were employed to compact the material. The compacted in-situ density of the mixture was reported to be 2193 k/m$^3$ (136.9 pcf).

As in Georgia, a sample of the untreated material was obtained and characterized in the BYU Highway Materials Laboratory. Three replicate specimens were treated with 3.9 percent cement and compacted at OMC to the in-situ density. After compaction, these specimens were cured and tested in the same fashion as the samples from Georgia and yielded an average UCS of 1641 kPa (238 psi) at an average moisture content of 9.0 percent at the time of testing. The material was classified as A-1-a (11) and SW (12).

While the selected test sites were generally in the main traffic lanes or in the adjacent shoulders, some sites were in intersections. Figure 2 shows deep ruts that occurred in one of the intersections. The researchers collected data from 41 sites, with a data rejection rate of only 5 percent.

![FIGURE 2 Deep ruts achieved with the HWRD in Texas.](image)

**Idaho Site**

The final data collection site was located in Irwin, Idaho, approximately 80 km (50 miles) east of Idaho Falls, Idaho. From Irwin east to the Wyoming border, the Idaho DOT was reconstructing US-26. Researchers were on site for a day and a half, during which time the average daytime temperature was 30.0°C (86°F) and the average relative humidity was 42 percent. Light rain fell on the site during the first afternoon, but the second day was sunny. Figure 3 shows the testing in progress.

The reconstruction of this pavement section involved no new aggregates and was estimated to be between 75 and 100 percent RAP. Idaho DOT personnel required the contractor to mix 6.0 percent water and 2.0 percent cement by dry weight of the constituents into the aggregate.
mixture. Once the CTB had been mixed and rough graded into place, a compaction rolling
density of 2162 kg/m$^3$ (135.0 pcf). The
time between completion of compaction and application of a prime coat was approximately four
hours. US-26 is a heavily traveled road and is the only access to the area; therefore, a very
aggressive construction schedule was required, sometimes with paving occurring within 24 hours
of the asphalt pulverization.

A sample of the untreated base material, mostly RAP, was collected and characterized at
BYU. Three replicate specimens of 1.22 cm (4 in.) diameter were constructed using that
material; however, even with compaction effort exceeding modified Proctor, only 96.5 percent of
the in-situ density could be achieved. These specimens were cured and tested in a manner
consistent with the Georgia and Texas specimens and yielded an average UCS of 669 kPa (97
psi) with an average moisture content of 6.5 percent at the time of testing. The RAP was
classified as A-1-a ($I_I$) and GW ($I_2$). In burn-off testing, the RAP was determined to have 6.0
percent asphalt cement.

Due to the accelerated pace of the contractor in Idaho, there were few test sites older than
24 hours. Also, due to space constraints and contractor scheduling requirements, the vast
majority of the test sites were necessarily located within the main traffic lanes. One team of
three researchers collected data from 43 test sites, with a final data rejection rate of 16 percent.

RESULTS AND ANALYSIS

The results and analysis of the work performed in Georgia, Texas, and Idaho are presented with
some of the results of the previous work completed in Utah, for reference. Specifically, Figure
4(a) is repeated from previous work, while Figures 4(b), 4(c), and 4(d) show the work from
Georgia, Texas, and Idaho, respectively. In order to visually identify a CIV rutting threshold
value, each figure includes a curve that follows the outer edge of the data until it connects with
the 0.25 cm (0.1 in.) rut depth threshold line. Linear trend lines have been included for each set
of 10 HWRD passes at each site. The equation for each of the trend lines was determined using
Equation 1:
RD = m*CIV + b                     (1)  

where:  
RD = predicted rut depth at a given CIV, cm  
m = slope of the trend line  
CIV = measured CIV at a particular CTB site  
b = theoretical rut depth corresponding to CIV = 0  

Table 1 gives a summary of the equations for the trend lines and includes the results of a statistical analysis performed on the data collected in the field. The p-value is the result of a t-test in which the null hypothesis states that the slope of the line is equal to zero, or that there is no statistical relationship between CIV and rut depth (14). With a Type I error rate of 0.05 specified in this research as the tolerable level of error for the experimentation, the results presented in Table 1 indicate that in every case the null hypothesis can be rejected. This leads to the conclusion that a statistical relationship exists between CIV and rut depth. The \( R^2 \) value shown in the table indicates how much of the variation in rut depth can be explained by variation in CIV. The comparatively low \( R^2 \) values shown in the table indicate that factors beyond CIST measurements contribute to rut depth. The table also shows that, generally, the slopes increase as the number of passes increases. This trend indicates that weaker aggregates are likely to rut to a greater depth with an increase in the number of passes than are stronger aggregates and that, at some point, CTBs can reach a stiffness at which no amount of trafficking will cause rutting. The theoretical CIV at which the rut depth is 0.0 cm (0.0 in.) has also been back-calculated for each trend line and is indicated in the table.  

Careful examination of the trend lines also shows that the vertical spacing on the left side of the charts between each line decreases with each subsequent set of passes, indicating, for example, that the rutting created after 10 passes is deeper than the additional rutting created between 50 and 100 passes. This trend is illustrated for selected Utah cases in Figure 5, which shows that the slope of the line relating rut depth to number of passes drastically decreases with increasing numbers of passes for a range of CTB stiffness values. One explanation for this trend is that the density of the CTB increases with each pass, causing increasing resistance to further rutting.
FIGURE 4(a) Clegg impact value and rut depth correlation from Utah work (7).
FIGURE 4(b) Clegg impact value and rut depth correlation from Georgia work.
FIGURE 4(c) Clegg impact value and rut depth correlation from Texas work.
FIGURE 4(d) Clegg impact value and rut depth correlation from Idaho work.
### TABLE 1 Results of Statistical Analysis

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<th>Site</th>
<th>Wheel passes</th>
<th>m</th>
<th>b (cm)</th>
<th>$R^2$</th>
<th>$p$ - value</th>
<th>CIV at rut depth of 0.0 cm</th>
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Careful examination of the data in Figure 4 does not yield a single CIV threshold value, but rather a range of values. One of the specific purposes of this research was to investigate the suitability of the CIV threshold value of 25 found in Utah by applying the same protocol developed there in other locations under different conditions. Clearly, a threshold value of 25 is not sufficient in every case to guard against rutting of CTB under early-age trafficking. Of particular interest to this research, then, was evaluating the relationship between the CIV threshold and the 7-day UCS of the CTB material as measured in the laboratory as previously described; the 7-day UCS was treated as a material property independent of the curing regime that may occur in the field during construction. Figure 6 shows a plot of the average 7-day UCS of each CTB versus the CIV threshold value obtained for each case from Figure 4. The figure includes a logarithmic trend line with an associated $R^2$ value of 0.91. The relatively high $R^2$ value indicates that much of the variability shown in CIV threshold values can be attributed to variability in UCS. The equation for this line is given in Equation 2:

$$CIV = -4.6594 \ln(UCS) + 63.905$$  \hspace{1cm} (2a)$$

where:

- $CIV =$ required minimum CIV to open CTB to traffic
- $UCS =$ design 7-day UCS, kPa

or, alternatively, in English units,

$$CIV = -4.6594 \ln(UCS) + 54.909$$  \hspace{1cm} (2b)$$
where:

\[
\text{CIV} = \text{required minimum CIV to open CTB to traffic}
\]

\[
\text{UCS} = \text{design 7-day UCS, psi}
\]

Rather than simply applying a single CIV threshold to every CTB, an engineer should use Equation 2 to find a recommended CIV threshold based on the 7-day UCS of the material specified for the project.

**FIGURE 6** Correlation between Clegg impact value threshold and unconfined compressive strength.

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**CONCLUSION AND RECOMMENDATIONS**

Because CTB will rut if excessively trafficked while in the early-age curing phase, agencies often require conservative waiting periods during which trafficking of the CTB layer is not permitted. While these practices do prevent pavement damage, they can also waste valuable time if the CTB has cured before the specified time has expired. Therefore, a more attractive option is to specify physical testing of the CTB using the CIST as recommended in this research.

To write an appropriate specification for the use of the CIST for assessing the rutting susceptibility of a CTB, an engineer should follow three basic steps. First, the design 7-day UCS of the material should be determined. Second, the appropriate CIV threshold should be chosen from Figure 6. Third, the number of measurements in a given section should be specified based on the maximum acceptable tolerance as described in previous work, although in no case should less than 15 sites be obtained for a given CTB section (15). After the curing period of interest, the CTB should be tested with a CIST by an educated inspector according to the specification. In the testing, one CIST measurement should be the average CIV from three separate tests taken within a 0.2 m² (2 ft²) area. Taking a CIST measurement in this fashion can be accomplished in...
less than one minute. When the average CIV for the given CTB section exceeds the selected 
CIV threshold, the CTB layer can be opened to trafficking.

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