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SUBJECT: Engineering Technical Letter (ETL) 12-7: Repair of Cement-Stabilized Soil (CSS) Surfaces

1. Purpose. This ETL outlines approaches for repairing failed cement-stabilized soil (CSS) surfaces on airfields. Procedures for removing and replacing Portland cement-stabilized materials as well as performing in-place repairs are presented.

2. Application: All Department of Defense (DOD) organizations responsible for maintaining and repairing CSS-surfaced airfields.

   2.1. Authority: Air Force policy directive (AFPD) 32-10, Air Force Installations and Facilities

   2.2. Coordination: Major command (MAJCOM) pavement engineers

   2.3. Effective Date: Immediately

   2.4. Intended Users:
   - Air Force Prime BEEF and RED HORSE units
   - Army Corps of Engineers
   - Organizations performing DOD airfield pavement evaluations and/or others responsible for airfield maintenance

3. Referenced Publications.

   3.1. Air Force:

   3.2. Joint:

   3.3. Army:

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED
- D1557-09, *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort* (56,000 ft-lbf/ft$^3$ (2,700 kN-m/m$^3$))
- D558-11, *Standard Test Methods for Moisture-Density (Unit Weight) Relations of Soil-Cement Mixtures*
- D559-03, *Standard Test Methods for Wetting and Drying Compacted Soil-Cement Mixtures*
- D560-03, *Standard Test Methods for Freezing and Thawing Compacted Soil-Cement Mixtures*

4. Acronyms and Terms:

°C – degree Celsius
°F – degree Fahrenheit
AFPD – Air Force policy directive
ALZ – assault landing zone
ASTM – American Society for Testing and Materials
CSS – cement-stabilized soil
DOD – Department of Defense
ETL – Engineering Technical Letter
FM – Field Manual
FOD – foreign object damage
ft$^2$ – square foot
lbs – pounds
lbs/ft$^3$ – pounds per cubic foot
MIP – mix-in-place
OMC – optimum moisture content
Prime BEEF – Prime Base Engineer Emergency Force
RED HORSE – Rapid Engineer Deployable Heavy Operational Repair Squadron Engineers

5. Background. The U.S. Army Engineer Research and Development Center (ERDC) was tasked to develop a method for repairing Portland cement-stabilized surfaces. Test sections were constructed according to the criteria outlined in UFC 3-250-11, *Soil Stabilization for Pavements*, for cement-stabilized silty sand (SM) soil and different repair methods were performed. The repair methods tested were: 1) sawcut, remove, and replace with original soil mixed with cement (small patch size only); and 2) milling and in-place remixing with cement and water. Repair sizes were full depth (6 inches) for two 8-foot by 8-foot square areas for one test lane (Lane 1) and one 18-foot by 40-foot area for another test lane (Lane 2). Lane 1 did not receive traffic prior to the repair while Lane 2 was trafficked until failure prior to the repair being performed. Traffic was applied using a C-17 six-wheel load cart.

6. Soil Stabilization. Soil stabilization is generally defined as making major improvements to the engineering properties of soils by amending the natural soil with an additive. These additives may include other soils or materials such as Portland cement,
lime, fly ash, asphalt cement, polymers, and fibers. Traditionally, additives such as bitumen, cement, and lime have achieved widespread use. Bitumen is typically used as a soil surface treatment to limit dust and loss of fines. Cement is used to provide strength to soil. Lime is often used in clay soils to control plasticity. The long-term performance of pavements constructed using CSS is influenced by the characteristics of the soil, the type and quantity of stabilization additive, construction practices, pavement system design, loading frequency and magnitude, and the local climate/environment.

6.1. CSS is often used as a base layer for pavements since it improves the strength of the soil. However, when used as a surface layer, it may suffer from durability problems. The durability problems arise from the inherent susceptibility of the natural soil and the relatively lower amounts of cement used for soil stabilization combined with less-than-ideal moisture and curing conditions in most cases. The durability of cement-stabilized materials is addressed in UFC 3-250-11 through ASTM D559-03, Standard Test Methods for Wetting and Drying Compacted Soil-Cement Mixtures, and ASTM D560-03, Standard Test Methods for Freezing and Thawing Compacted Soil-Cement Mixtures (depending on project climate), by establishing criteria for weight loss after simulated weather cycling. Additional information may be found in Army FM 5-410, Military Soils Engineering, Chapter 9, “Soil Stabilization for Roads and Airfields.”

6.2. Several cement-stabilized military airfields have been constructed in the continental United States: Holland Assault Landing Zone (ALZ) at Fort Bragg, North Carolina, All American ALZ at Little Rock AFB, Arkansas, and Fullerton Landing Zone and Self Landing Zone at Fort Polk, Louisiana. Holland ALZ was removed from service due to foreign object debris (FOD) issues and All American ALZ also suffered severe FOD issues due to CSS surface degradation. The CSS airfields at Fort Polk are reported to be performing well.

6.3. The problems at Holland ALZ appeared to be primarily related to construction techniques. Considerable cracking and spalling were evident at longitudinal “cold” joints where adjacent lanes from the stabilizer machine abutted. There is evidence that some lanes may have been allowed to cure for a significant period before constructing the adjoining lane. This prevented adequate compaction and bond at the joint and possibly degraded the cured material due to the compactor —bridging— from the cured side into the uncured material. In many locations, it appeared that a thin layer of CSS was placed to achieve final grade. The thin layer failed to adequately bond to the underlying material, resulting in large sheets of CSS delaminating and becoming a serious FOD issue. No evidence of an emulsion coating was observed. An emulsion coating (such as asphalt or polymer) serves two functions. First, applied immediately after mixing and compaction, it serves to hold moisture within the pavement, allowing it to react with the cement. Second, it serves as a barrier to external moisture, minimizing CSS softening and freeze-thaw damage.
6.4. The problems at All American ALZ were deemed to be both construction and material related. Problems resulting from placing thin layers of CSS, similar to those observed at Holland ALZ, were also observed at this site. In addition, durability testing was not conducted during design, which likely led to a reduced design cement content and an inadequate mix design. It was also noted in discussions with base personnel that the source of the borrow soil was changed in the middle of construction without verifying the mixture design’s adequacy. It was determined that moisture contents may not have been properly controlled during construction. Degradation of the pavement also appeared to be the result of moisture intrusion and freeze-thaw damage. This may have been exacerbated by not maintaining a moisture barrier (such as asphalt or polymer emulsion). Construction records indicated that an asphalt emulsion was applied after construction. However, it was not clear if the emulsion was applied immediately after completion of each portion of the surface or was applied to the completed runway. The moisture barrier should have been applied to each completed portion of the pavement and a final coat applied to the entire surface when the project was completed. The moisture barrier should also have been periodically reapplied based on surface wear from traffic and/or degradation due to weathering.

6.5. Properly designed and constructed CSS airfields, such as those at Fort Polk, are performing well. However, proper maintenance—such as reapplying emulsion coatings (asphalt or polymer) to prevent water intrusion (especially in freeze-thaw areas) and spot-repair of failed areas—is necessary to prevent CSS degradation.

7. Repair Procedures.

7.1. Remove and Replace.

7.1.1. The remove-and-replace method is analogous to a full-depth repair of a concrete pavement. It may be used to repair small areas (localized damage of less than an 8-foot by 8-foot area) or large areas; however, this method is probably feasible only for repairs of less than 2,000 square feet if a reclaimer/stabilizer is not available. A concrete saw may be used to cut the sides of the repair area and a jackhammer or backhoe can be used to remove the failed material. For larger areas, it may be more feasible to use a reclaimer/stabilizer device or a front-end loader mounted miller (fitted with carbide cutting teeth). If milling is used, the sloped ends of the milled area created by the milling drum will need to be sawcut vertically to avoid feathering the edge of the repair. The exposed base course will also need to be smoothed and repaired if any damage is evident after removing the failed CSS. Typically, the depth of repairs should not exceed 6 to 7 inches for compacted soil (8 to 9 inches for loose fill).

7.1.2. For smaller patch areas, the material should be prepared outside of the patch recess and then placed. The amount of soil to be used can be estimated based on the patch dimensions, depth, and maximum density at the optimum
moisture content (OMC). Excess soil should be mixed and placed to allow for surface trimming of the patch after compaction. Prepare the soil to be used in the repair by drying, if necessary, or by adding water to obtain the proper moisture content. A front-end loader can be used to fold the soil repeatedly while wetting. Once the appropriate uniform moisture content has been obtained, the cement should be added and mixing continued until a uniform mixture is obtained. Once mixed, the cement will begin to cure with the moisture in the soil so work as quickly as possible. Immediately place the soil-cement mixture into the excavation and spread uniformly with a substantial overfill of 3 to 4 inches. To obtain a fully compacted 6-inch soil layer will require approximately 8 inches of loose, uncompacted soil. After compaction, the patch area should be immediately trimmed to match the grade of the adjoining pavement and covered or sprayed with an emulsion to seal the surface to prevent excess moisture loss. If using Type I cement, a minimum of seven days of curing should be allowed for temperatures above 40 degrees Fahrenheit (°F) (4 degrees Celsius [°C]). For Type III cement (high early strength), a minimum of 24 hours of cure should be allowed for temperatures above 40 °F (4 °C). The surface should be protected from freezing temperatures during the curing period. At temperatures below 40 °F (4 °C), Portland cement is not recommended.

7.2. Mix In Place (MIP).

7.2.1. The MIP method would typically be used for repairs where a large area of pavement needs repair and mixing soil cement outside the repair area is not practical. This method is feasible only for repairs of greater than 2,000 square feet. A reclaimer/stabilizer machine is recommended for the MIP process, although a milling drum mounted on a front-end loader may be used. The reclaimer/stabilizer machine may also be used to mill the damaged CSS for removal or reuse. The area to be repaired should be milled at a speed of less than 30 feet per minute to allow for efficient cutting of the damaged CSS. Care must be taken to properly set the depth of the reclaimer/stabilizer to prevent base course damage. The milled material should be discarded and replaced with the same or similar soil unless time and material constraints dictate otherwise.

7.2.2. After milling, the sloped edges created by lowering and raising the milling drum at the beginning and end of the milling process will need to be cut vertically to avoid feathered edges on the repair. If reusing the millings, it may be necessary to add some fresh soil to the millings to increase the volume of material. After compaction, it will be necessary to trim the repair area to grade, which requires some overfill of the repair area. Ideally, the milled material should be sampled and tested to determine the moisture-density relationship (ASTM D1557-09, Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft³ (2,700 kN-m/m³))) that will define the optimum moisture content for compaction. When testing is not practical, such as in a contingency environment, then the OMC of the millings, new soil, and cement must be estimated based on field tests and engineering judgment.
7.2. Calculations.

7.2.1. Calculations are required to determine the amount of cement and water to add for a given repair area and depth. The calculations are based on the maximum dry density of the material (based on Standard or Modified Proctor), soil volume, optimum moisture content of the soil, cement content, and moisture content prior to construction. If using cement bags, determine the spacing of the cement bags over the repair area to achieve the target stabilizer content. If a reclaimer/stabilizer machine outfitted with a spraybar inside the cowling is being used for the MIP procedure then water pump rates must be determined based on ground speed to achieve the target moisture content. The cement bag spacing within the reclaimer/stabilizer mixing lane must also be determined.

7.2.2. Stabilizer Calculations.

- \( A \) = area, square feet
- \( D \) = depth of cut, feet
- \( \text{OMC} \) = optimum moisture content, %
- \( \text{MSM} \) = measured soil moisture content, %
- \( \text{MDD}_{\text{OMC}} \) = maximum dry density at optimum moisture of the unmodified soil, lbs/ft\(^3\)
- \( P_{\text{Cement}} \) = percentage of cement by dry weight of soil, %
- \( W_{\text{Soil}} \) = weight of soil to be stabilized, lbs
- \( W_{\text{Cement}} \) = weight of cement to be added to soil, lbs
- bag spacing = number of cement bags/area, bags/ft\(^2\)
- \( V_{\text{Water}} \) = volume of water needed to reach OMC, gallons

The weight of cement, \( W_{\text{Cement}} \), required for the mixture is calculated from the volume of soil, the maximum dry density, and the percentage of cement to be used based on UFC 3-250-11. The \( \text{MDD}_{\text{OMC}} \) for the soil-cement mixture should be determined according to ASTM D1557-09 and ASTM D558-11, *Standard Test Methods for Moisture-Density (Unit Weight) Relations of Soil-Cement Mixtures*. If the \( \text{MDD}_{\text{OMC}} \) is not known for the mix but only for the unmodified soil, a rule of thumb is that for every 5% of cement added, increase by 1% the amount of water needed to reach OMC. For example, if the \( \text{MDD}_{\text{OMC}} \) is 9% of the unmodified soil, for a 7% cement addition, the \( \text{MDD}_{\text{OMC}} \) of the modified soil would be estimated at 10%. If 11% cement was being added, the estimated \( \text{MDD}_{\text{OMC}} \) of the modified soil would be 11%. This increase in the OMC results from the increased fines present in the cement and the need for extra water to hydrate the cement. The cement bag spacing is then determined by dividing \( W_{\text{Cement}} \) by the weight of cement bags divided by the area (typically either square feet or square yards). The volume of water necessary to reach the OMC for the soil-cement mix is determined from the weight of soil, \( W_{\text{Soil}} \), and the OMC.
7.2.2.1. Remove and Replace.

7.2.2.1.1. As an example of the remove-and-replace method, 7% cement is being used to make a 10-foot-wide by 10-foot-long by 6-inch-deep repair with a silty sand (SM) soil having \( \text{MDD}_{\text{OMC}} = 130 \text{ lbs/ft}^3 \). The OMC of the unmodified soil is 9% and the MSM = 4%. Using the equations above:

\[
W_{\text{Soil}} = A \times D \times \text{MDD}_{\text{OMC}} \\
W_{\text{Cement}} = W_{\text{Soil}} \times P_{\text{Cement}} \\
\text{Number of Bags} = \frac{W_{\text{Cement}}}{\text{Bag Weight}} \\
\text{Bag Spacing} = \frac{\text{Number of bags}}{A} \\
V_{\text{Water}} = \frac{(W_{\text{Soil}} + W_{\text{Cement}}) \times (\text{OMC}-\text{MSM})}{8.33}
\]

7.2.2.1.1. The weight of soil is 6500 pounds, resulting in a cement weight of 455 pounds. For 94-pound bags of cement (typical in the United States), 4.84 bags are needed. Always round up to the nearest whole number so five bags of cement (bag spacing = 1 bag per 20 square feet) would be needed to repair the area. For 7% added cement, the OMC for the soil-cement mix would be 10% (OMC of the soil = 9% + 1% added for extra water needed for 5% to 10% cement dosage) and using the MSM, leads to \( V_{\text{Water}} = 50 \text{ gallons} \) to reach a 10% OMC target. The water should be evenly mixed with the soil before mixing the cement. After the cement is well mixed, the material should immediately be evenly placed in the repair recess with a 3- to 4-inch overfill and well compacted.

7.2.2.2. MIP.

7.2.2.2.1. For the MIP method the calculations are the same. However, the cement needs to be spread in the mixing lane of the reclaimer/stabilizer machine. The target moisture content may be reached by surface addition of water to the area or by spraybar, if equipped. Surface water addition is the simplest approach as this avoids the complications of using the spraybar method. When using the spraybar approach, a nurse truck with water tank is required, and the pump rate
(typically in gallons/minute) must be controlled according to the total gallons of water required over the area, the speed of the machine, and the width of the cutter head. Overlap of adjacent lanes must be minimized to avoid overwatering the overlap area and lane spacing must be coordinated to match the size of the repair area.

\[
\text{Bag Spacing/Lane} = \frac{A}{\text{CHW} \times \text{Number of Bags}}
\]

\[
\text{Pump Rate} = \frac{V_{\text{Water}} \times \text{CHW} \times \text{Machine Speed}}{A}
\]

\(A = \text{area, square feet}\)

\(\text{CHW} = \text{cutter head width, feet/lane}\)

\(\text{PR} = \text{pump rate needed to reach optimum moisture, gallons/minute}\)

\(\text{bag spacing/lane} = \text{bag spacing in mixing lane, feet}\)

\(\text{machine speed} = \text{feet/minute}\)

7.2.2.2. As an example, a 100-foot by 100-foot area needs to be repaired using the MIP method. The same soil and cement conditions as in the previous example will be used. According to the previous equations, \(W_{\text{Soil}} = 650,000\) pounds and \(W_{\text{Cement}} = 45,500\) pounds. For 94-pound bags of cement (typical in the United States), 484 bags are needed. The bag spacing would be the same as the previous example: one bag per 20 square feet. For the MIP method, it is best to spread these in the mixing lane. The cutter head width of 6 feet is used to yield a bag spacing/lane of 3.44 feet. Thus, a bag of cement would be placed about every 3.5 feet in a 6-foot-wide mixing lane. The cutter head width yields the number of machine lanes of 16.7, which is rounded up to 17. The \(V_{\text{Water}} = 5,010\) gallons to reach a 10% OMC target. Assuming a machine speed of 30 feet/minute, a pump rate of approximately 90 gallons/minute is needed to reach OMC.

7.3. Compaction. For proper compaction and to achieve proper grade, the repair recess must be overfilled. This process is similar to a cold joint compaction method for asphalt pavement repair. The filled material should be placed or arranged to overlap the repair area a few inches and then raked back inside the edge to create a raised area of new repair material around the perimeter of the repair (Figure 1). A steel wheel roller in static mode should be used to initially compact or pinch the edges and corners. The raised edge should remain above the surrounding grade at all times during compaction. When operating the compactor inside the patch area, care should be exercised to compact as closely as possible to the edges and in the corners of the patch recess without getting the compactor drum or plate outside the patch area. This is especially critical if using vibration or a heavy drum compactor, as this may damage the surrounding pavement. Vibration should be used to compact the material to density. After compaction, the patch area should be trimmed with a grader to match the grade of the adjoining pavement. Static operation of a steel wheel roller may be used to remove roller marks or a rubber tire roller may be
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8. Repair Location. The location of the repair may dictate the size of the repair needed. If the damaged area is outside the aircraft wheel path in the runway, a small patch may

Figure 1. Replacement, Preparation and Compaction of Soil Cement for a Patch Repair
be appropriate. However, if the damaged area is in the wheel path of the aircraft, it must be repaired on both sides of the centerline such that the patch condition encountered by the aircraft gear is the same (Figure 2).

**Location of Repairs**

- Distressed area patches located outside of wheel-paths shall be repaired with a small patch.
- Distressed area patches located within wheel-paths shall extend across the full width of the gear plus allowance for wander. Soil conditions encountered by the aircraft wheels should be the same for both sides of the landing gear.

Figure 2. Wheel Paths and Location of Repairs
9. Additional Considerations. Further research may be needed to validate these repair methods under full-scale testing conditions for different CSS pavement thicknesses, repair sizes, types of soils, and cement contents. Environmental factors such as wet-dry and freeze-thaw conditions exacerbate CSS degradation, especially if strict construction specifications and routine maintenance are not followed. A research study of surface treatments that will prevent moisture intrusion, retain frictional characteristics, provide a wearing course, and act as curing membranes may also be warranted.

10. Point of Contact. Questions or comments regarding this ETL are encouraged and should be submitted to the Pavements Engineer, HQ AFCESA/CEOA, 139 Barnes Drive, Suite 1, Tyndall AFB, FL 32408-5319, DSN 523-6439, commercial (850) 283-6439, e-mail afcesar@tyndall.af.mil

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