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Evaluation of In-Place Asphalt Recycling for Airfield Applications

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Abstract

Over the last few decades, in-place recycling of asphalt pavements has seen increased use by the highway industry, primarily to take advantage of potential cost and logistical savings compared to conventional reconstruction. More recently, the U.S. Navy and Federal Aviation Administration have allowed recycling to be used on airfields with lighter traffic. This report contains a discussion of in-place recycling design considerations obtained from a literature review of its use in the highway industry. Observations developed from a review of airfield pavement projects that have utilized recycling is also included. A structural analysis was performed using the Pavement-Transportation Computer Assisted Structural Engineering (PCASE) tool to determine typical stiffness values that recycled layers must achieve to support various types of military aircraft traffic for different pavement structures. Overall, in-place recycling is recommended for consideration as a rehabilitation technique for military airfield pavements, and further investigation is recommended before it is implemented it into design guidance.

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Preface

This study was conducted for the U.S. Army Headquarters Installation Management Command under the Army Transportation Infrastructure Inspection Program, MIPR 11141371000001.

The work was performed by the Airfields and Pavements Branch (GMA), U.S. Army Engineer Research and Development Center (ERDC), Geotechnical and Structures Laboratory (ERDC-GSL). At the time of publication, Ms. Anna M. Jordan was Chief, GMA; Mr. Justin S. Strickler was Chief, GM; and Ms. Pamela G. Kinnebrew, GZT, was the Technical Director for Military Engineering. The Deputy Director of ERDC-GSL was Mr. Charles W. Ertle II, and the Director was Mr. Bartley P. Durst.

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

1 Introduction

1.1 Background

Over the last few decades, in-place recycling of asphalt pavements has seen increased use by the highway industry, primarily to take advantage of potential cost and logistical savings compared to conventional reconstruction. More recently, the U.S. Navy and Federal Aviation Administration (FAA) have allowed in-place recycling to be used on airfields with lighter traffic. The two most common in-place recycling techniques used when heat is not applied are typically referred to as either cold in-place recycling (CIR) or full-depth reclamation (FDR). CIR is often defined as recycling the existing asphalt concrete layer(s), while FDR frequently refers to recycling all existing asphalt layer(s) as well as incorporating some of the underlying layers, which are usually granular. Berthelot et al. (2000) reported that these terms have regularly been used interchangeably; however, the distinction between the two appears to have become clearer in recent years.

CIR or FDR typically involves pulverizing an existing, distressed asphalt pavement, adding a stabilizer (e.g., cement, emulsion, or foamed asphalt), and re-compacting the material to use as a base layer for new asphalt pavement layer(s). For this report, cement refers to Type I portland cement, and emulsion refers to asphalt emulsion. Since CIR is typically limited to the asphalt layers, it is commonly used on pavements that exhibit distresses, occurring near the pavement surface (e.g., asphalt rutting, low-temperature cracking, top-down fatigue cracking, etc.). FDR is conventionally used as a solution when pavement exhibits deeper structural problems indicative of base issues where limiting rehabilitation to the asphalt layers alone would not be appropriate (e.g., unbound layers rutting, bottom-up fatigue cracking, freeze-thaw expansion, etc.). A variety of research studies have been performed to address the type of stabilizer that is most appropriate, moisture content determination, mix design procedures for one additive and multiple additives, and best practices for construction.

1.2 Objective and scope

The objectives of this report are to:

- Conduct a literature survey of in-place asphalt recycling use in the highway industry to determine general best practices for construction and preferred methods for selection of design moisture content, binder type, and binder dosage rate(s)
- Investigate in-place recycling use on airfields and summarize findings
- Develop recommendations for selecting the best candidates for in-place recycling use on military airfield pavements
- Perform a structural analysis to determine what stiffness values would be required by a recycled layer to withstand various types of military airfield traffic for a variety of pavement structures
- Summarize overall conclusions and provide recommendations for in-place recycling use and future research.

1.3 Outline of chapters

Chapter 2 of this report provides a discussion of various design considerations for in-place recycling, along with other findings from literature. Chapter 3 contains a detailed description of case studies involving use of in-place recycling on military airfield pavements. Chapter 4 contains a structural analysis, which includes a listing of assumptions, results, and a discussion. Chapter 5 provides conclusions and recommendations. References are also provided, along with Appendix A, which contains raw data from the structural evaluation.

2 Overview and Design Considerations

2.1 Overview

Before the existing asphalt can be stabilized and compacted, the material must first be pulverized, which is typically performed using a reclaimer/stabilizer (Figure 1). This device is able to pulverize the existing asphalt and any underlying layers. Before cement addition, a water truck may be used to spray enough water over the section to reach the desired moisture content. Next, the reclaimer/stabilizer is used to blend the cement with the pulverized material. However, occasionally the contractor may wish to spread the cement directly on the distressed asphalt in order to pulverize and blend all in one pass. Most reclaimer/stabilizers also have the capability to be coupled with a water truck and/or binder tank truck to enable water/binder injection and mixing while the machine is blending the cement.

Figure 1. Reclaimer/stabilizer.

Pulverization and mixing can occur to varying depths depending on the in-place recycling method being used (FDR or CIR). Also, at times it could be desirable to mill and remove part of the existing asphalt before stabilization to adjust grade depending on the thickness of the overlaying new layer to be constructed. Cox and Howard (2013) surveyed the reported recycled layer depths from 35 CIR references and 10 FDR references with the average depths being 3.3-in and 8.5-in for CIR and FDR, respectively.

2.2 Types of stabilizers

The most common stabilizers used for CIR and FDR projects are cement, asphalt emulsion, and foamed asphalt. Other stabilizers that have been investigated include hydrated lime and fly ash. Asphalt emulsions and foamed asphalt are more commonly used for CIR, while cementitious binders (portland cement, hydrated lime, and American Society for Testing and Materials [ASTM] Class C or Class F fly ashes) are most often observed for FDR (Cox and Howard 2013). The various stabilizers affect the properties of the reclaimed layer in different ways. Cement is usually the most cost-effective stabilizer and provides the greatest stiffness. The drawback of using cement is the potential for shrinkage cracking to develop and reflect through the overlying asphalt layer. Asphalt emulsion and foamed asphalt pose much less reflective cracking potential, but provide much less stiffness compared to cement. Combinations of multiple binders are often used for CIR and FDR projects in an attempt to optimize stiffness and resistance to cracking. This concept is discussed further in the mix design section of this paper.

FDR and CIR are occasionally performed without a stabilizer. For this technique, the existing pavement is simply pulverized and compacted, which causes the material to somewhat mimic the properties of a granular base. Jones et al. (2014a) evaluated the performance of FDR without stabilizer using accelerated pavement testing for two different asphalt thicknesses (2.3-in and 4.7-in). The FDR section without stabilizer was reported to perform satisfactorily, with the asphalt thickness having a controlling effect on the results. The section with an asphalt thickness of 2.3 mm withstood approximately 490,000 equivalent single axle loads (EASLs) before failure (0.5 in of rutting), while the 4.7-in thick asphalt section withstood over 21 million EASLs.

2.3 Design moisture content

One of the key components of CIR and FDR mix design is determining the moisture content of the mixture that should be used during construction. For FDR projects, it is more common to determine an optimum moisture content (OMC) using Proctor curves instead of recommending a maximum moisture content as observed for CIR projects. Determination of an OMC in the laboratory is more appropriate for FDR mixes since they do contain some granular material from base and subbase layers. An example can be found in Jones et al. (2014b) wherein the optimum moisture content was determined in conjunction with construction of a test section for accelerated pavement testing. Lewis et al. (2006) reported that the Georgia Department of Transportation (DOT) also uses a proctor-based approach to determine the appropriate moisture content to use.

One unique approach that is more seldom used is to employ the Superpave Gyratory Compactor (SGC). Since many DOT laboratories have SGC's to perform asphalt mix designs, the SGC could be used to perform FDR and CIR mix designs as well. However, at higher OMCs, excess water is usually expelled during compaction. Some have felt it necessary to perforate SGC compaction molds and base plates to facilitate this free water (e.g., Mallick et al. 2002); however, this step is generally not required.

Several different methods have been used to select the moisture content used for CIR projects. One method involves simply using a standardized moisture content from previous experience as discussed in Kim et al. (2011) and Mallela et al. (2006). However, the reporting of the moisture content used is very inconsistent in literature. For example, Kim et al. (2007) reported an overall moisture content of 4.0% when conducting CIR laboratory tests with foamed asphalt. This amount included any moisture present in the existing asphalt and any amount that was added to get the material up to 4.0%.

For project specifications, the maximum amount of moisture allowed in the existing asphalt is sometimes specified. Mallela et al. (2006) described numerous CIR projects in Arizona; typically, the amount of mix water used was reported, along with the maximum amount allowed in the existing aggregate. If emulsion was used, the dosage rate was reported, but the amount of water present was not specifically reported even though it would contribute to the overall mixture moisture content. Cox and Howard (2013) summarized the total moisture contents used in several CIR projects and found that the average was approximately 3.5%, and a maximum moisture content of 6% was recommended. A moisture content over 6% would likely result in excess water being present on the recycled surface during field compaction.

2.4 Determination of binder content

2.4.1 Single component binder systems

Along with the design moisture content, determination of the additive content is central to the CIR and FDR design process. Design procedures for the typical additives used for FDR (cement, emulsion, foamed asphalt, etc.) can be slightly different since the stabilization mechanisms are not the same. When cement is the sole additive used, typically specimens are compacted at varying cement contents at OMC and the lowest cement content yielding the design unconfined compressive strength is selected as the design cement content.

Fly ash content is typically determined in a method similar to that of cement where varying fly ash contents are tested at OMC. Fly ash can be an economical option as an additive, but the high contents needed could offset the potential economic benefits and cause logistical problems during construction. Bang et al. (2011) conducted FDR laboratory testing at three different fly ash contents (10, 12, and 15% by weight of dry aggregate), and Cross and Young (1997) used even higher contents (11, 15, and 19%). Hydrated lime was not observed as a stand-alone additive in literature but is commonly used in combination with emulsion or fly ash to help a mixture resist moisture damage.

For asphalt emulsion, a similar method to that of cement is used where multiple specimens are compacted at OMC for varying asphalt emulsion contents and the content that provides the highest strength and density is selected. Asphalt emulsion contents are typically lower since higher contents result in mixture instability and premature failure. Of the CIR projects using asphalt emulsion only, cited in Mallela et al. (2006), the asphalt emulsion contents used ranged from 1 to 2% by total weight of the mixture. More commonly, asphalt emulsion is used in conjunction with another additive such as portland cement or lime to increase strength. Additional discussion of use of multiple binders in FDR and CIR mix design is provided in the next subsection.

Foamed asphalt is also used as a stand-alone additive, mostly for CIR projects. FDR projects typically require some active filler such as portland cement or fly ash in order to produce a stable mixture. Examples of foamed asphalt design in conjunction with active fillers is discussed in the next subsection. Considerations other than the additive content are required when using foamed asphalt. The optimal amount of foaming water used with the asphalt binder should be selected based on the amount of foaming water that produces the maximum expansion ratio and half-life. Expansion ratio is defined as the maximum volume divided by original volume. The foam half-life is defined as the time it takes for foam to achieve half of its maximum volume. According to Jones and Fu (2009), two methods are currently used by designers to determine half-life. One method measures the time it takes for the foam to decrease to half its original volume from its maximum volume, while the other measures the time starting when the foaming device is turned off. The second of these two methods was recommended.

Kim et al. (2007) outline a mix design procedure for use of foamed asphalt as the lone stabilizer used in CIR. Once the optimum foaming water content is determined, the OMC to be used during mixing and compaction is determined using modified Proctor curves. Next, the mixture is compacted using the SGC for 30 gyrations and the specimens are allowed to cure for two days at 60°C. Afterward, the specimens are saturated under a vacuum before being subjected to indirect tensile (IDT) strength testing. Five foamed asphalt contents are typically tested between 1.0% and 3.0% at 0.5% increments, and the foamed asphalt content that produces the highest IDT strength is selected.

2.4.2 Multiple component binder systems

As discussed previously, in many cases it may be useful to use multiple additives for CIR and FDR projects in order to take advantage of the benefit that each different additive can provide. For example, Sebaaly et al. (2004) presented a mix design for CIR projects using asphalt emulsion and hydrated lime. Specimens were mixed and compacted at the optimum moisture content using three different moisture contents with and without hydrated lime. Then the specimens were subjected to resilient modulus and moisture sensitivity testing, and the optimum binder content was selected as the one that provides a good level of early stability (resilient modulus above 150 ksi) and a good resistance to moisture damage (retained strength ratio above 70%).

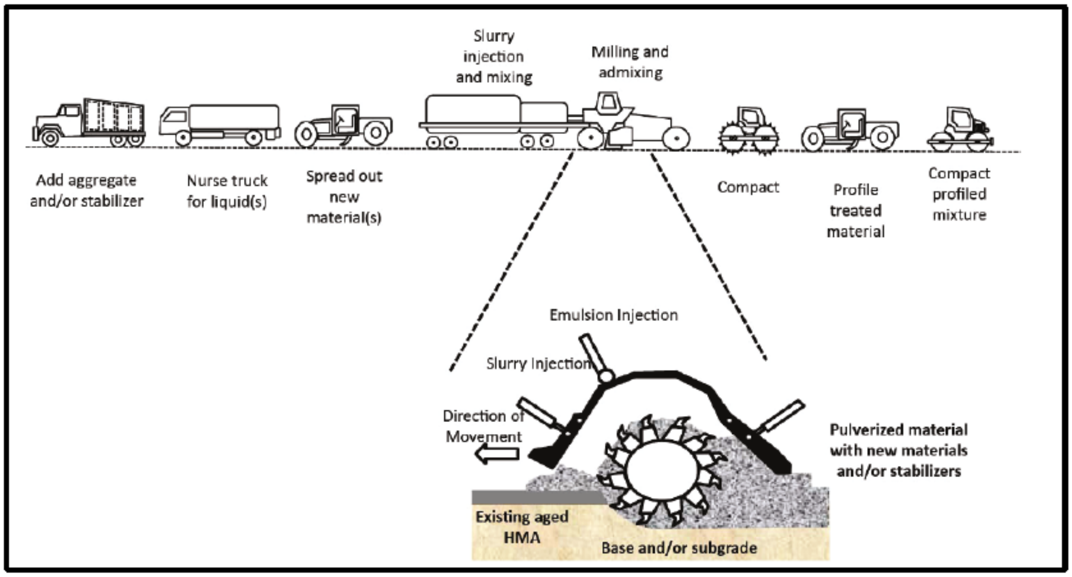
Cement and asphalt emulsion are commonly used in combination to take advantage of the increased strength provided by the cement and the resistance to reflective cracking offered by asphalt emulsion. Cox and Howard (2015) suggested selecting an OMC based on experience and then spending more resources testing various blends of cement and asphalt emulsion to obtain an optimal mix design. This recommendation was developed from testing multiple combinations for rut resistance using the asphalt pavement analyzer (APA) and crack resistance using the fracture energy results obtained from calculating the area under an IDT stress-strain curve.

Jones and Fu (2009) detailed a mix design using foamed asphalt and an active filler (e.g., cement). The optimum asphalt binder content and the active filler content are determined separately. For the asphalt binder, an untreated specimen and specimens at three different binder contents are mixed and compacted using 75 blows of the Marshall hammer. After curing, the specimens are subjected to IDT testing and the content with the highest IDT strength is selected. To determine the active filler content, mixtures are prepared using the optimum asphalt binder content at three different active filler contents, and the mixtures are compacted and tested in the same manner previously described. The results are analyzed and the lowest active filler content to create a strength improvement of 30 psi compared to the control is selected. If none meet this criterion, an alternate active filler is tested. Typical ranges of asphalt binder and active filler contents are 2.0 to 4.0% and 1.0 to 2.0%, respectively.

2.5 Construction procedures

Use of proper construction procedures during CIR and FDR can be vital to project success. Figure 2 shows a typical recycling train for CIR and FDR projects (Stroup-Gardiner 2011). Depending on project requirements, some asphalt material may need to be milled and removed. Once the proper starting grade is achieved, the pavement is reclaimed/pulverized, and the spreading of any dry cementitious additives is conducted. The material is then mixed using a reclaimer/stabilizer and any liquid additives are typically sprayed inside the mixing drum. Water may also be added at this point instead of prior to mixing. It is important at this stage to visually inspect the material in order to detect any areas where the additives are not thoroughly mixed into the material. This inspection can also be conducted during a test section, before the project begins, if possible. After mixing, the material is compacted, commonly with a pneumatic tire roller for CIR and a sheep's foot (pad foot) roller for FDR. Compaction is typically delayed slightly when emulsion is used until it begins to break, whereas compaction commences immediately if cement is involved. Grading is then carried out to ensure a proper grade before finish rolling using a steel-wheel roller and/or a rubber-tire pneumatic roller. For cementitious mixtures, a tack coat is usually applied to the surface to seal in moisture during curing before placement of an asphalt surface layer. Some agencies opt to use the reclaimed surface as a temporary wearing course in higher traffic areas, since construction can occur only during nighttime hours and closing an entire lane during a curing period of seven days or more is not logistically feasible (Caltrans Division of Maintenance 2013).

Figure 2. Example in-place reclying train.



Even when proper construction procedures are followed, sources of variability can easily become apparent. For example, Howard et al. (2015) documented an FDR project where mixing was conducted with thicknesses ranging from 12 to 19.5 in with an average of 15.3. A large variability in the amounts of fines along the route was also observed, which could have considerable consequences on the performance of the completed pavement.

One unique construction technique that is gaining popularity is intentionally induced microcracking. Shrinkage cracks observed on CIR and FDR layers that are stabilized with cementitious material are one of the major challenges associated with these recycling techniques. The cracks reflect upward, causing premature cracking of the newly placed asphalt surface layer. Microcracking is intended to reduce shrinkage cracking by intentionally causing very small cracks to occur on the reclaimed surface by applying several passes of a vibratory roller. The California Department of Transportation (Caltrans) recommends performing microcracking 48 to 72 hr after finished grading to create a network of small cracks to prevent wider cracks from forming, thus reducing the likelihood of reflective cracking through the asphalt layer (Caltrans Division of Maintenance 2013).

3 Case Studies of In-Place Recycling for Airfield Applications

While in-place recycling has been implemented by many state DOTs, as discussed in Chapter 2, its use on airfield projects has been limited. The FAA has allowed the use of in-place recycling for regional airfields with relatively smaller-design aircraft. The FAA has also released a new specification for FDR (FAA 2018), which is discussed in this chapter. For military applications, only two airfield projects were found to have used in-place recycling: Naval Air Station (NAS) Whiting and Naval Station (NS) Mayport. Available information concerning these two projects is discussed in this chapter.

3.1 Mayport NS

FDR was implemented on several sections at NS Mayport after several sections with relatively new asphalt overlays were performing poorly. This section provides a full construction history, along with a discussion of the performance of select asphalt sections over several years. The FDR design process used at Mayport is also discussed in detail.

3.1.1 General layout and construction history

NS Mayport is located in Mayport, FL, and was originally commissioned in 1942. Mayport contains a primary runway and several primary and secondary taxiways to support a variety of rotary and fixed-wing aircraft. A history of the initial airfield construction was provided in a report documenting a pavement investigation performed by a contractor. Before initial construction began, a subgrade material surcharge was applied and then removed before construction in an attempt to consolidate the underlying existing salt marsh layer. Despite the surcharge, asphalt leveling courses were applied in the 1950s to account for settlement of soft underlying layers. By the early 2000s it was concluded that the marsh layer had reached full consolidation. For this report, select asphalt sections were of most interest, and the construction history and pavement structure for these are listed in Table 1.

Table 1. Mayport construction history and pavement structure.

Branch ID	Section ID	Historical Data
Runway RW05-23	R03C	2016 – 4.0” mill and overlay 2005 – 2.0” mill and overlay 1985 – 1.5” AC 1967 – 1.0” AC & leveling [1]1952 – original construction
	R04D	2016 – 8” FDR and 4” AC overlay 2005 – 2.0” mill and overlay 1985 – 1.5” AC 1967 – 1.0” AC & leveling [1]1952 – original construction
Taxiway TWA	T01A	2016 – 8.0” FDR and 4” AC overlay 2009 – 2.0” mill & overlay 1985 – 1.5” AC [1]1952 – original construction
Taxiway TWB	T02A & T03A	2016 – 8.0” FDR and 4” AC overlay 2009 – 2.0” mill & overlay 1985 – 1.5” AC [1]1952 – original construction
Taxiway TWF	T08A	2016 – 8.0” FDR and 4” AC overlay 2009 – 2.0” mill & overlay 1985 – 1.5” AC [1]1952 – original construction
Taxiway [2]TWG	T10A	2016 – 8.0” FDR and 4” AC overlay 2009 – 2.0” AC overlay 1985 – 1.5” AC 1969 – 1.0” AC & leveling [1]1952 – original construction

[1] 1952 original construction: 12” compacted subgrade; 9” stabilized sub-base; 12” sand shell base and 3” AC

[2] TWG was referred to as TWP in Condition Survey Reports from 2001 to 2011

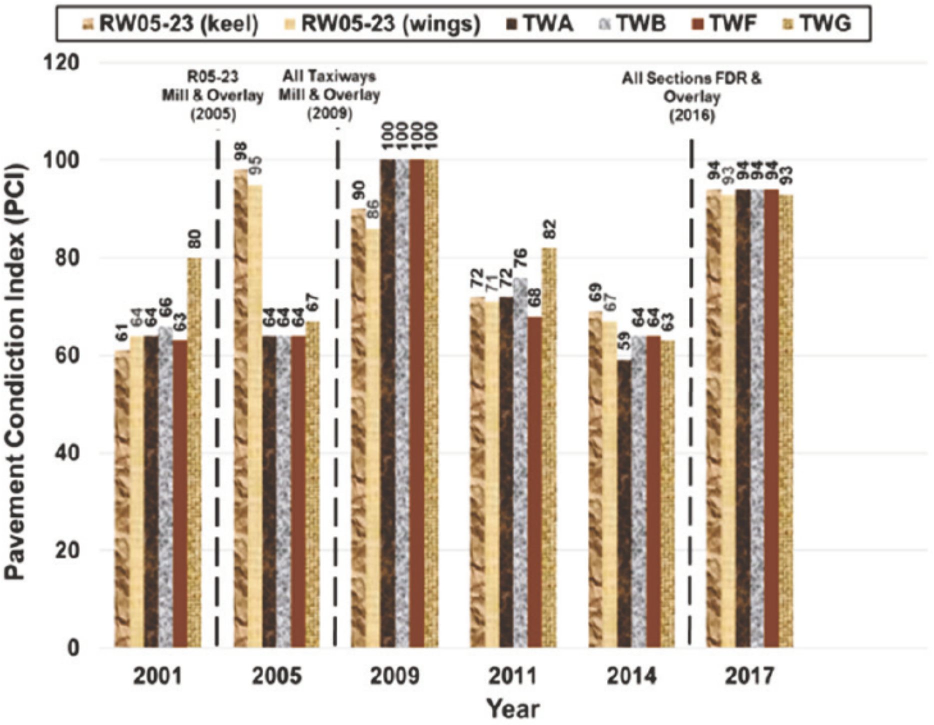
3.1.2 Findings from condition surveys 2001-2014

The condition of the airfield pavements at NS Mayport were surveyed periodically over the period of interest (2001 to present) with inspection reports published in 2001, 2005, 2008, 2011, 2014, and 2017 (NAVFAC 2001, 2005, 2008, 2011, 2014, and 2017). The pavement condition index (PCI) data for each of these reports for the pertinent sections can be found in Figure 3. The 2001 report indicated the keel portion of Runway RW05-23 (Section R03C) had a PCI of 61, and the wings section (R04C) has a PCI of 64. Since the runway PCI was less than the required minimum of 70, a 2-in. mill and overlay was conducted in 2005. Taxiways A, B, and F were just over the minimum PCI of 60 for taxiways in 2001, while Taxiway G exhibited a much higher PCI of 80.

By 2005, the recent mill and overlay on RW 05-23 was performing well, as exhibited by PCIs of 90 and 86 for sections R03C and R04D, respectively. However, all the taxiways were now deteriorated to the point that each was approaching the minimum PCI of 60. To address this issue, all taxiways were resurfaced in 2009 with a 2-in. asphalt concrete (AC) layer. According to the PCI reports, some sections were milled before the overlay and some were not, perhaps to maintain grade. The 2009 inspection reflected the new resurfacing on the taxiways, with all PCIs being 100. RW05-23 sections were still performing relatively well after being resurfaced in 2005.

During the 2011 PCI inspection, both RW 05-23 sections were just above the minimum PCI, and the PCI for sections on Taxiways A, B, F, and G had dropped substantially after being resurfaced just 2 yr earlier. These findings were echoed in the 2014 inspection report, as the PCI of the runway sections had fallen below the minimum value and the condition of the taxiway pavements continued to deteriorate. The 2014 inspection report recommended 1 in. of milling, followed by crack sealing and a 2-in. AC overlay for all sections shown in Figure 3 in order to restore the pavement condition to acceptable levels.

Figure 3. NS Mayport PCI Data 2001-2017 from select pavement sections.



3.1.3 2016 rehabilitation using full-depth reclamation

In order to address the findings in the 2011 and 2014 pavement condition reports, a major rehabilitation project at NS Mayport was initiated in 2015. A separate pavement investigation was performed to propose options for the design of the upcoming rehabilitation work (Boyer 2015). The author suggests that the premature aging and degradation of the asphalt pavement on RW05-23 and Taxiways A, B, F, and G could have been caused by the absence of milling operations to remove excessively oxidized asphalt during previous overlay projects. He also noted some evidence of check cracking on RW05-23 that also could have accelerated aging. Core samples were obtained on many of the taxiways, and full-depth cracks were noted on RW 05-23 and Taxiways A, B, and F. The author did not recommend a standard mill-and-replace due to the advanced aging of the underlying asphalt layers. Instead, an in-place recycling technique was suggested to reduce the chances of reflective cracking. The following paragraphs will focus on the details of the rehabilitation design in which full-depth reclamation was performed.

Pavement-Transportation Computer Assisted Structural Engineering (PCASE) was used to perform the design for the rehabilitation. The Linear Elastic Design (LED) design method was used, and the controlling aircraft was the P-8 Poseidon with an approximate design traffic level of 1,500 passes. The assumed thickness and modulus value for each layer of the pavement structure can be found in Table 2.

Table 2. Mayport layer elastic design.

Pavement Layer	Thickness (in)	Layer Modulus (psi)
AC Surface	4.0	200,000
In-Place Recycled Layer	8.0	120,000
Subbbase	28.8	75,000
Subgrade	---	22,500

The 8-in. recycled layer thickness is very close to the average FDR layer thickness of 8.5 in. that Cox and Howard (2013) reported from 10 references. A design modulus value of 120,000 psi is on the lower end of the range allowed by PCASE for cement stabilized base courses (100,000 to 200,000 psi) and substantially lower than typical modulus values of 1 to 3 million psi provided in Huang (1993). In addition, Louw (2016) reported FDR modulus values well in excess of 1 million psi from both laboratory resilient modulus testing and from heavy weight deflectometer (HWD) testing on field sections.

While the initial report recommended asphalt emulsion be used, from the files provided by the Designer of Record, it appears that the mix design called for 4.0% of cement by mass to be mixed with the recycled material before being compacted. Optimum moisture content and maximum dry density was determined via ASTM D1557 (2012) and determined to be 9.3% and 117.7 pcf, respectively. A compressive strength value of 190 psi after 7-day curing was the target for actual field production, but this target was not a requirement for acceptance according to the project specifications. The 190-psi requirement is considerably lower than the 7-day compressive strength requirement of 750 psi for stabilized base courses and 250 psi for stabilized subbase courses outlined in *UFC 3-250-11* - “Soil Stabilization for Pavements” (2004). In the highway industry, it is now common to see a range of compressive strengths specified (e.g., 7-day compressive strength must be between 300 and 450 psi). The reasoning for the selection of 190 psi was not discovered.

3.1.4 Findings from 2017 evaluation report

After construction was completed in 2016, an airfield condition survey was conducted in 2017. The 2017 evaluation report indicated those sections that utilized in-place recycling were performing well overall. All PCI values were 92 or above as noted in Figure 3. The keel and wing section of RW 05-23 exhibited mainly low severity weathering with some small areas of low-severity longitudinal and transverse cracking. These distresses were also generally noted by the U.S. Army Engineer Research and Development Center (ERDC) during a site visit in April of 2019. However, there was some evidence that the wing section, which received only a mill and overlay (no in-place recycling) did exhibit more cracking than the keel section, on which FDR was conducted before the overlay was applied. Figures 4 and 5 show the wing and keel sections, respectively, and were taken at approximately the same longitudinal location on the runway. Low severity cracking with somewhat regular spacing was observed on the wing section (Figure 4), while no cracking was observed on the keel section (Figure 5).

Figure 4. Low severity weathering and cracking on RW 05-23 wing section.

Figure 5. Low severity weathering on RW 05-23 keel section.

3.1.5 Overall discussion of NS Mayport project

Overall, the rehabilitation of pavement sections at NS Mayport using FDR is considered successful so far. The pavement sections have exhibited very small amounts of distress and no load-related distresses have been observed. One important design decision made by the design team was the observation that an excessively high cement content for the FDR layer was not required to support the mission traffic. Lower binder contents reduce the potential for shrinkage cracking, particularly when cement is the only binder used. However, as discussed in Chapter 2, many studies from the highway industry recommend using a combination of binders (e.g., cement and emulsion/foamed asphalt) to further reduce the chance of shrinkage crack formation. Multiple binders should have at least been considered for the work at NS Mayport.

3.2 Whiting NAS

In-place recycling was also conducted at Naval Air Station Whiting in 2016. The only specific project information available were evaluation reports before and after recycling was completed and a set of final construction drawings, both of which were reviewed. Figure 6 shows a construction detail from the drawings, which contains a typical cross section. As shown, a 2-in. minimum CIR section is called for, but the exact thickness is not specified, nor is the thickness of the asphalt layer that is to remain after recycling. Table 3 shows the construction history data obtained from the 2017 evaluation report (NAVFAC 2017). The report indicated a combined thickness of the recycled layer and overlay of 10-in. PCI values were also obtained from the evaluation reports. RW5-23 and RW14-32 exhibited PCIs of 49 and 47, respectively during the 2014 inspection. After recycling and overlaying with asphalt, PCI of both runways was reported to be 100 during the 2017 inspection, indicating that recycling operations had performed as intended with no reflected shrinkage cracks reported.

Figure 6. Whitiing NAS shoulder construction detail.

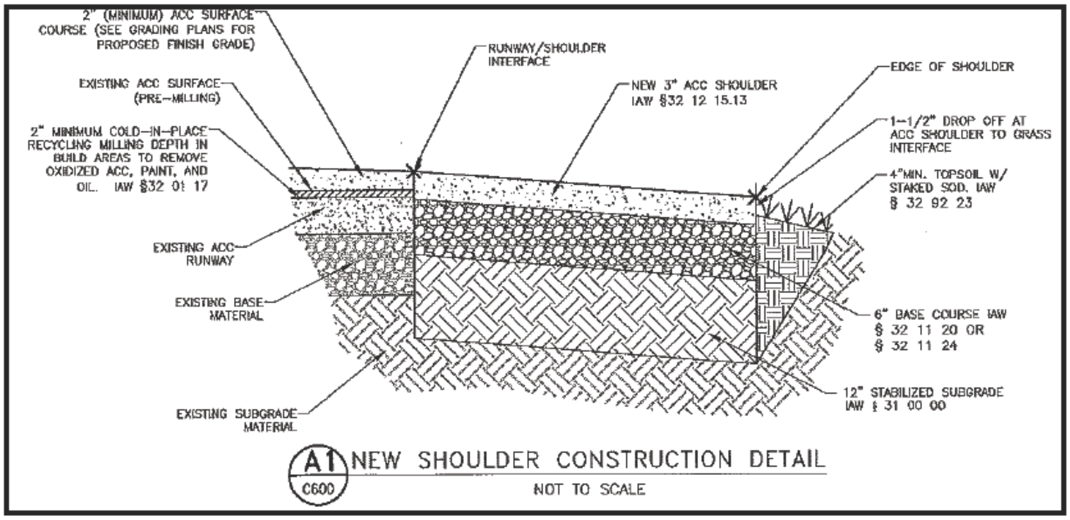


Table 3. Construction history for runways 5-1 and 14-1 on NAS Whiting.

Branch ID	Historical Data
RW05-23	2016 – 10.0” in-place recycling and overlay
	2001 – 1.5” AC overlay
	1985 – 2.0” AC overlay
	1967 – 0.5” AC overlay with 0.75” minimum heated scarified and treated
	1953 – 1.5” AC overlay sand AC leveling course bituminous seal coat applied (outer 15’)
	1943 – 6.0” Sand AC, sandy clay stabilized subbase
RW14-32	2016 – 10.0” in-place recycling and overlay
	2001 – 1.5” AC overlay
	1985 – 2.0” AC overlay
	1967 – 1.5” AC overlay with 0.75” minimum heated scarified and treated
	1953 – AC overlay sand AC leveling course bituminous seal coat applied (outer 15’)
	1945 – 1.5” STA 45+00 to 60+00 – Sand AC Overlay; STA 0+00 to 45+00 Bituminous Seal Coat,
	1943 – 6.0” Sand AC, sandy clay stabilized subbase

3.3 Discussion of FAA P-207 specification

The FAA has communicated with the author that FDR has been utilized on several regional airfield projects, but specific project information was unavailable. Previously, a waiver was required for in-place asphalt recycling to be conducted on FAA governed airfields. In 2018, the FAA updated its advisory circular 150/5370-10H entitled “Standard Specifications Construction of Airports” (FAA 2018) to include guidance and general draft specifications for using FDR on airfield pavements. FDR is specifically discussed in Item P-207 of the advisory circular. One major limitation imposed is that P-207 is allowed only for design aircraft with weights under 60,000 lb. However, it may be used as a subbase under stabilized base or with FAA approval for design aircraft over 60,000 lb.

Other notable requirements include proof rolling, a control strip, and a gradation specification, which requires minimum percentages by weight passing the 2-in., No. 4, and No. 200 sieves of 100, 55, and 0 to 15%, respectively. The maximum lift thickness is 12 in. Quality control sampling and testing requirements consist of two gradation samples per day, and field density must reach 95% of the maximum dry density determined via modified proctor (ASTM D1557 2012). Field density is determined by either the sand cone (ASTM D1556 2015) or the nuclear gauge (ASTM D6938 2017).

Overall, the FAA specification seems to indicate that the best candidates for CIR or FDR are those with relatively light design aircraft. However, short-term results from NS Mayport indicate that in-place recycling could be used for larger design aircraft, albeit at a low number of design passes. As in-place recycling use on airfields continues to grow, the FAA could consider increasing the limit for weight of design aircraft. One type of stabilizer that is not mentioned is foamed asphalt, which has been proven to be successful over many years to rehabilitate roads in California, as discussed in Jones et al. (2014a). Only cement and asphalt emulsion binders are mentioned in P-207.

The use of density as a quality control method is preferred by many state agencies for FDR projects and is listed in the FAA P-207 specification. However, work is ongoing by various groups to identify alternative methods of rapidly characterizing in-situ properties of recycled mixtures, primarily to develop new means of acceptance. Work is being conducted through the Transportation Research Board's National Cooperative Highway Research Program (Transportation Research Board 2019). The U.S. military should stay abreast of such developments as new specifications for the use of in-place recycling are brought forward for consideration.

4 Structural Analysis

One of the most challenging design considerations for utilizing in-place recycling for roads or airfields is how to incorporate stabilized layers into existing thickness design methods. As mentioned previously, balancing stiffness, crack resistance, and cost can be achieved by implementing multiple binders during mix design. Another important design consideration is the selection of a maximum lift thickness. Since the recycled layer will likely be compacted in one lift, the bottom part of the lift could experience a reduction in density and, therefore, some reduction stiffness. In order to initially address these design issues, the PCASE tool was utilized in order to determine the stiffness values required for a recycled layer for several example pavement structures for several standard traffic groups.

4.1 Traffic groups considered

Several standard Army helipad, heliport, and airfield designs were obtained from UFC 3-260-02 (2001) and used for analysis. The designs, along with aircraft designation, weight, and pass level can be found in Table 4. Traffic area A was assumed.

Table 4. Airfield designs used for structural analysis.

Group Name	Aircraft	Total Weight (lb)	Passes
Army Class I Helipad	UH-60	16,300	20,000
Army Class I Heliport	UH-60	16,300	50,000
Army Class II Helipad VFR	CH-47	50,000	20,000
Army Class II Helipad IFR	CH-47	50,000	30,000
Army Class II Heliport VFR	CH-47	50,000	50,000
Army class II Heliport IFR	CH-47	50,000	100,000
Army Class III Airfield	C-23	24,600	50,000
	CH-47	50,000	100,000
Army Class IV Airfield (C-130) <5000ft	C-130H	155,000	20,000
Army Class IV Airfield (C-17) <5000ft	C-17A	585,000	20,000
Army Class IV Airfield 5,000-9,000 ft	C-17A	585,000	30,000
Army Class IV Airfield > 9,000 ft	C-17A	585,000	50,000
Army Class V Airfield - Contingency	CH-47	5,000	5,000
Army Class VI Airfield (C-130 LZ)	C-130	155,000	10,000
Army Class VI Airfield (C-17 LZ)	C-17A	585,000	10,000

4.2 Design assumptions

The overall approach for the structural analysis was to assume a set of existing pavement structures and calculate the required stiffness of a stabilized layer that could be constructed using FDR. Remaining base material was considered in the design, but any asphalt layer removal to maintain grade was essentially not considered. A new asphalt layer was assumed for the surface with the thickness being one of the variables. The other variables considered were the subgrade stiffness, thickness of the recycled layer, and traffic level. Figure 7 shows a graphical representation of the existing pavement structure on the left and the new pavement structure used for analysis on the right. To maintain consistency, a 2-in thickness of remaining aggregate base was assumed. The properties assumed for the other pavement layers are listed in Table 5.

Figure 7. Graphical depiction of basic pavement structure considered.

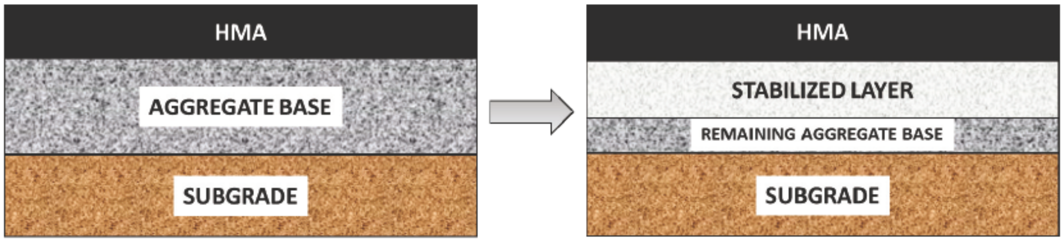


Table 5. Layer property assumptions for pavement structure.

Layer	[a]t (in.)	Elastic Modulus (psi)
HMA	2/3/4/6	350,000
FDR	4/6/8	Calculated
AB	2	60,000
SG	---	5,000/8,000/12,000/15,000

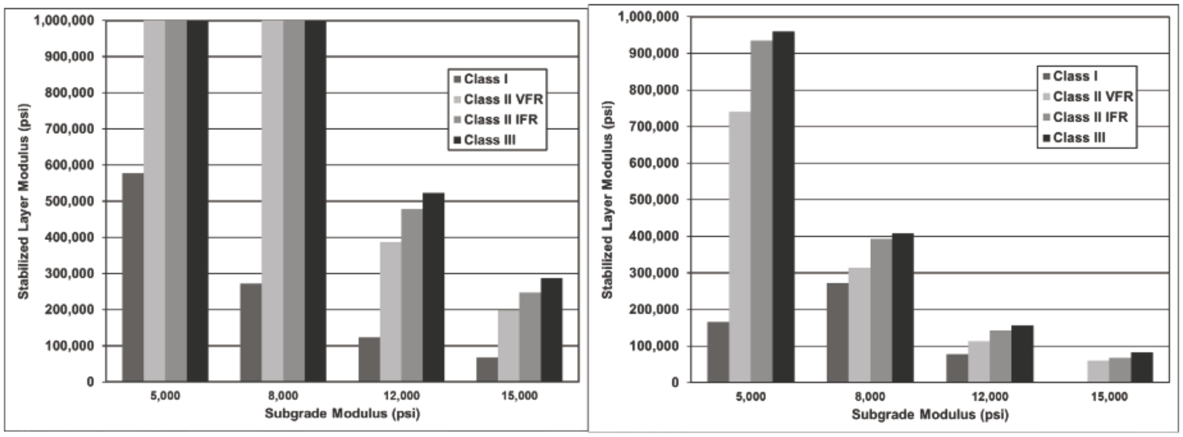
[a]t = thickness

Larger thicknesses of hot mix asphalt (HMA) and FDR layers were considered for Class IV airfields and not the other classes due to higher traffic loads. PCASE allows the user to choose between a California Bearing Ratio (CBR) or layered elastic based thickness design for airfield pavements. For all trial designs, the layered elastic method was chosen to evaluate the stiffnesses required from the recycled layer since the CBR method limits any base layers to a maximum CBR of 100. In-place recycling utilizing even a small cement dosage rate would likely exceed 100 CBR. A minimum value for required modulus was set at 60,000 psi, since even with no stabilizer a reclaimed layer could likely achieve at least that value (61,000 psi is the value recommended by PCASE to use for a crushed stone base). A maximum value for required modulus was set at 1,000,000 psi. Even though many moduli values have been reported well above this limit, a thickness design calling for such a high value is unlikely. Typical moduli values for stabilized layers were discussed further in Section 3.1.3.

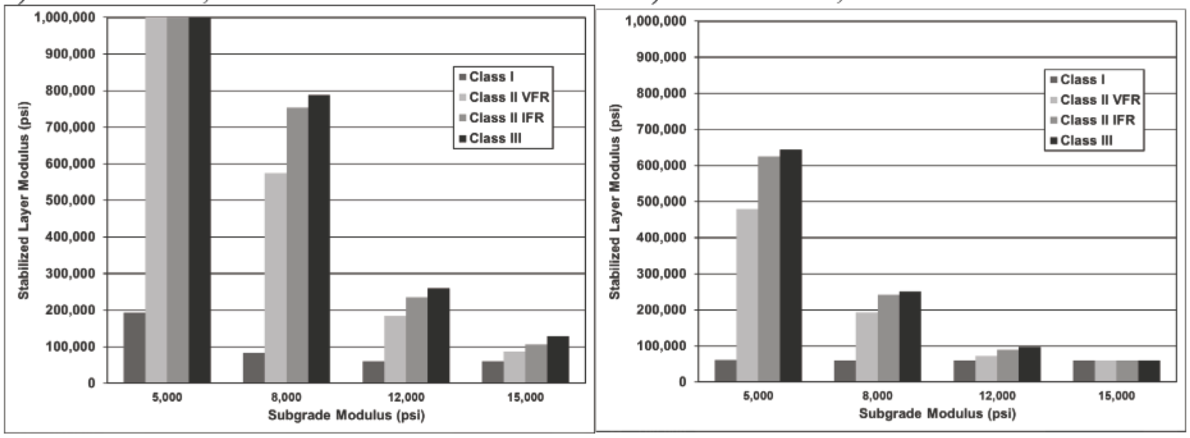
4.3 Results and discussion

In order to develop realistic pavement layer properties, the analysis was essentially divided between lighter traffic and heavier traffic. Class I, II, III, and V airfields were evaluated apart from Class IV and Class VI airfields. Figure 8 plots the modulus value required from the FDR stabilized layer given the assumptions discussed in the previous sections for a range of subgrade moduli values and asphalt thicknesses for Class I, II, and III airfields. Both 4- and 6-in-thick FDR layers were considered. Relatively thin asphalt layers were considered since they correspond with minimum layer thicknesses provided in UFC 3-260-02 (2001). As with traditional pavement design, the stiffness needed from the FDR layer is highly dependent on the stiffness of the existing subgrade. Accordingly, characterization of the existing subgrade is an essential task to complete at the beginning of a project. The required moduli were also somewhat influenced by the depth of stabilization. The most likely implementable pavement structure for all three classes of traffic is using a 3- or 4-in. asphalt layer with an FDR layer depth of 6 in. and minimum subgrade moduli of 8,000 psi. In this case, the required FDR moduli are all less than 250,000 psi.

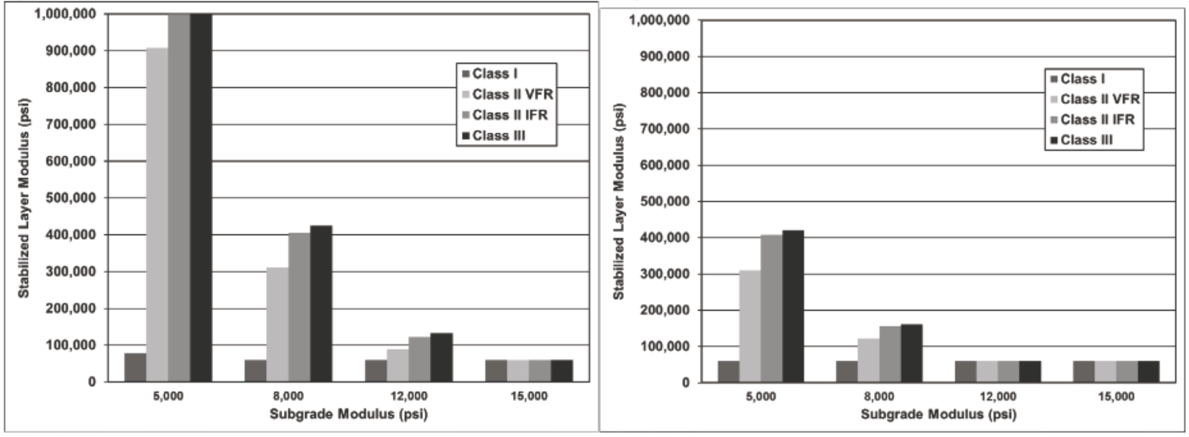
Figure 8. Required FDR layer moduli values for Class I, II, and III Army airfields.



a) HMA = 2 in., FDR = 4 in. b) HMA = 2 in., FDR = 6 in.



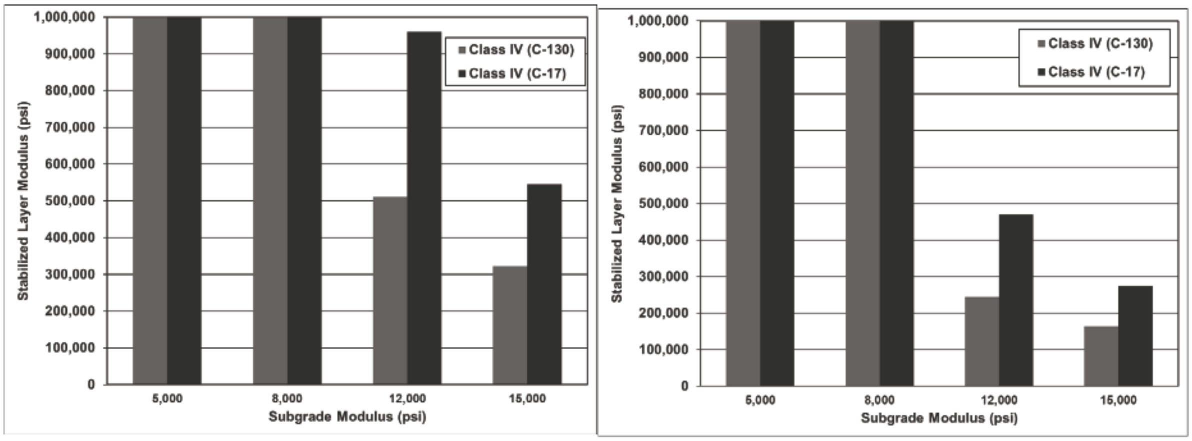
c) HMA = 3 in., FDR = 4 in. d) HMA = 3 in., FDR = 6 in.



e) HMA = 4 in., FDR = 4 in. f) HMA = 4 in., FDR = 6 in.

The results for the same analysis conducted for Class IV airfields are shown in Figure 9. As shown for both C-130 and C-17 traffic, a relatively stiff (at least 12,000 psi modulus) existing subgrade is essential at the FDR thicknesses investigated, since lower subgrade stiffnesses required moduli values near 1 million psi. Moving from a 6-in. FDR layer to an 8-in. layer also reduces the required stiffness considerably. As discussed in Section 3.1, a major design consideration for implementing in-place recycling on airfields is the selection of a design recycled layer thickness. The layer must be properly compacted to ensure homogenous density throughout. It appears when large cargo aircraft are considered; stabilized layer thicknesses above 8 in. could be required in many cases.

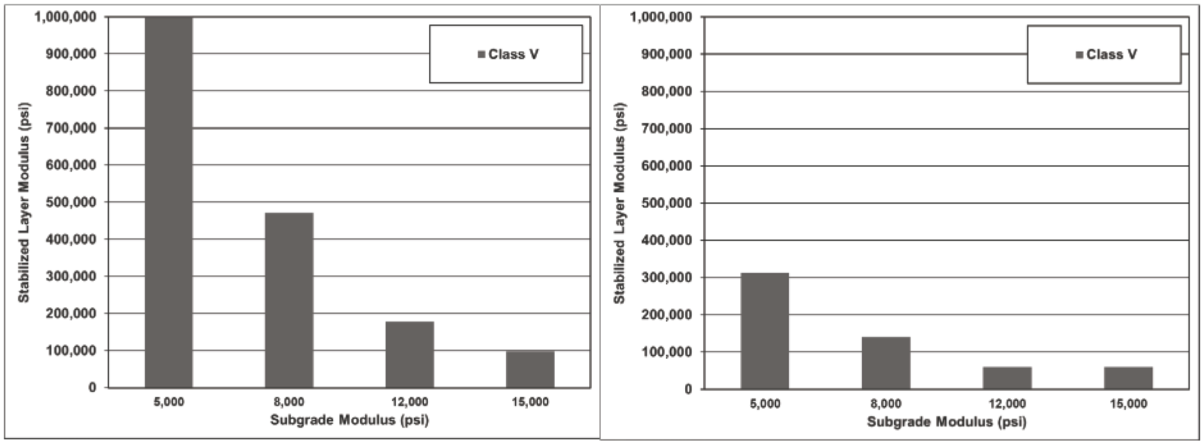
Figure 9. Required FDR layer moduli values for class IV Army airfields.



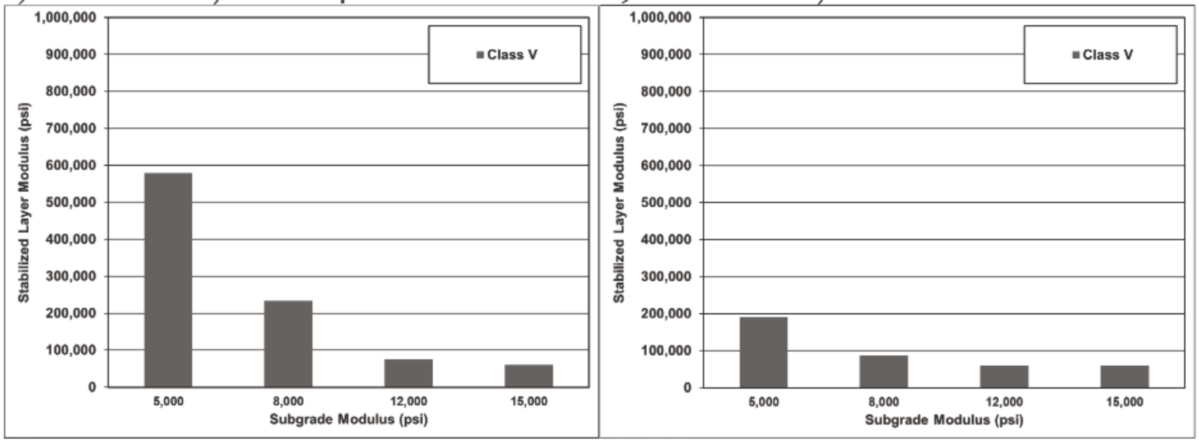
a) HMA=4 in. (C130), 6 in. (C17), FDR=6 in. b) HMA=4 in. (C130), 6 in. (C17), FDR=8 in.

Figure 10 and Figure 11 plot the results for Class V and Class VI airfields, respectively. Class V results were similar to those discussed previously for Class I, II, and III airfields since the traffic levels are similar. Class VI airfields results are similar to Class IV results for the same reason.

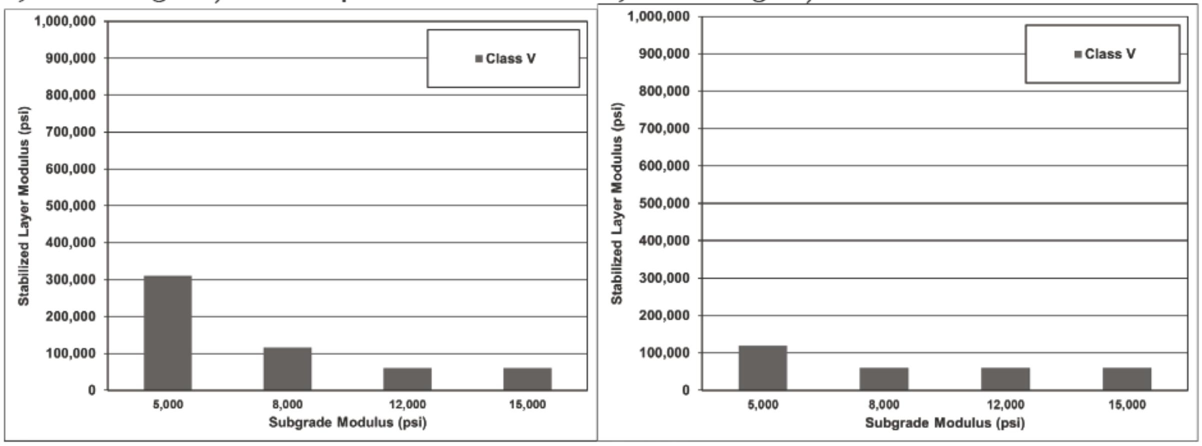
Figure 10. Required FDR layer moduli values for class V Army airfields.



a) HMA = 2 in., FDR = 4 in. b) HMA = 2 in., FDR = 6 in.

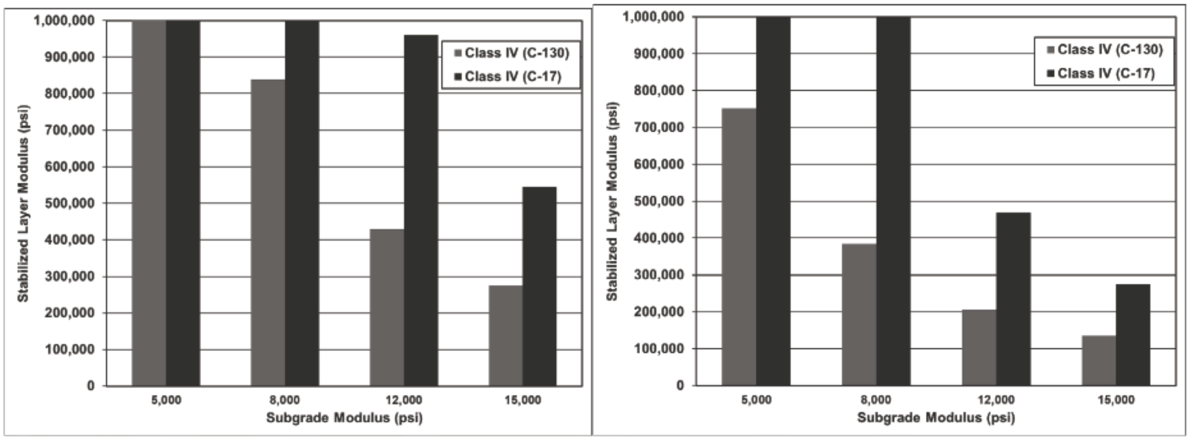


c) HMA = 3 in., FDR = 4 in. d) HMA = 3 in, FDR = 6 in.



e) HMA = 4 in., FDR = 4 in. f) HMA = 4 in., FDR = 6 in.

Figure 11. Required FDR layer moduli values for class VI Army airfields.



a) HMA=4 in. (C130), 6 in. (C17), FDR=6 in. b) HMA=4 in. (C130), 6 in. (C17), FDR=8 in.

Many of the cases evaluated called for large design stiffness values for recycled layers. Research groups have reported results that approach these higher values, particularly when cement is the sole binder used. See section 3.1.3 for further discussion. Although these higher stiffness values have been reported, they are rarely called for in design. At NS Mayport, a modulus value of 120,000 psi was used for the FDR thickness design. The designers used 4% as the design cement content and, although modulus values were not reported, they likely far exceeded 120,000 psi when considering similar cement dosages such as those provide by Cox and Howard (2015).

This concept creates a dilemma for airfield designers who wish to take advantage of the additional stiffness a reclaimed asphalt layer can provide. A determination must be made by the designer to select the maximum stiffness values he or she is willing to assign based on experience and any laboratory sample data available. Typically, binder content mix designs are based upon unconfined compression strength (UCS) testing for cementitious binders, while Marshall Stability (MS) and indirect tensile strength (ITS) tests are used for mixtures that contain foamed asphalt or emulsion. These tests are relatively easy to perform, and specimen fabrication is mostly straightforward. Since modulus testing is more involved, it is typically correlated from UCS or ITS for use in the structural design.

Although modulus testing is more difficult than UCS, MS, or ITS, more and more laboratories are gaining experience with how to perform this test (typically per ASTM C469 2014). A new method enables quick and easy fabrication of specimens that can be used both in the laboratory and from samples obtained during construction. The plastic mold (PM) device uses plastic concrete molds to compact specimens that are appropriately sized for elastic modulus testing (3-in. by 6-in. or 4-in. by 8-in.) using a standard proctor hammer. The number of blows counts needed to produce specimens of the proper density are established in the laboratory to conduct the mix design. During construction, a sizeable number of specimens can be compacted quickly in order to ensure the in-place modulus is similar to the one used for design. More information regarding the use of the PM Device can be found in AASHTO standard of practice PP-92-18 (American Association of State Highway Transportation Officials [AASHTO] 2018) and in Sullivan et al. (2015), Howard et al. (2016), Sullivan and Howard (2017), and Sullivan et al. (2020). In future development of Department of Defense (DoD) criteria for mixture design and quality assurance/quality control (QA/QC), the use of the PM device is recommended for consideration.

5 Conclusions and Recommendations

5.1 Conclusions

- In-place recycling of aged asphalt pavements has been conducted successfully in the highway industry over the past several years. In-place recycling can produce considerable cost and logistical savings over typical reconstruction.
- The best candidates for in-place recycling are those pavement sections that exhibit distress in base layers or at the bottom of the asphalt layer.
- Use of multiple binders (e.g. portland cement and asphalt emulsion or foamed asphalt) appears to be a preferred method of producing a recycled layer with adequate strength properties while also exhibiting good crack resistance.
- The most important design considerations are pulverization depth, design moisture content, type of stabilizer(s), mix design procedures, and construction procedures.
- The U.S. Navy has successfully used in-place recycling at both NAS Whiting and NS Mayport.
- Design information was unavailable for NAS Whiting, but condition survey reports indicate the sections that utilized FDR as a rehabilitation method are performing well.
- A site visit was conducted and all available design information for FDR conducted at NS Mayport was thoroughly reviewed with the following conclusions:

  - While the exact mix design procedure used was somewhat unclear, the FDR layer appears to be performing well with very little reflective surface cracking exhibited, especially when compared to sections where traditional mill and overlay methods were used.
  - The dosage rate of binder (portland cement) used was 4% by weight, which appears to have been enough to sufficiently support the required traffic, but not excessive such that reflected shrinkage cracking developed due to excessive stiffness in the stabilized layer.
  - The design modulus of 120,000 psi is on the low end of values discovered in literature obtained from field and laboratory testing, but reasonable with limited data available. Actual in-place modulus of the FDR layers at NS Mayport is unknown, but estimation via HWD or core sampling and testing is recommended.

- A structural analysis was performed using PCASE with the following conclusions:
    - The stiffness value required by the recycled layer is very dependent on the subgrade stiffness, as expected.
    - Army airfield classes with lighter traffic (Class I, II, III, and V) would likely be able to utilize in-place recycling with relatively low required stiffness values.
    - Army airfield classes with higher traffic levels (Class IV and VI) would likely require adequate in-situ subgrade stiffness values (at least 12,000 psi) and recycled layer thicknesses of at least 8 in. Weaker subgrades or thinner layer thicknesses would require stiffness values for the recycled layer that are well above typical design values, but fairly similar to values discovered in literature obtained from field and laboratory testing.

5.2 Recommendations

- The DoD pavement community should continue to pursue in-place recycling as a rehabilitation technique for airfield pavements in order to take advantage of the potential cost and logistical savings.
- An instrumented, full-scale test section is needed in order to:
    - Evaluate the maximum thickness of recycled layers that should be allowed.
    - Confirm values for stresses and strains in the recycled layers estimated from LED calculations.
    - Determine a range of stabilizer(s) contents that balance both strength and crack resistance, which produce a pavement structure that is capable of supporting aircraft traffic.
- Further evaluation is needed to develop more accurate stiffness design values for recycled layers. Laboratory and field testing have indicated these values to be much higher than the typical design values used.
- The PM device should be considered in the future development of guidance for in-place recycling mixture design and quality control.
- Guidance for use of in-place recycling on airfields should be incorporated into UFC 3-260-02 in the future.

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Appendix A: Structural Analysis Raw Data

Table A1. Required recycled layer modulii for 2 in HMA layer.

Traffic Group	HMA Thickness (in)	Subgrade Modulus (psi)	Recycled Layer Thickness (in)	Required recycled layer modulus	
				psi	GpA
Army Class I Helipads	2	5,000	4	414,000	2.854
			6	118,000	0.814
		8,000	4	204,000	1.407
			6	63,000	0.434
		12,000	4	102,000	0.703
			6	60,000	0.414
		15,000	4	60,000	0.414
			6	60,000	0.414
Army Class I Heliports	2	5,000	4	577,000	3.978
			6	166,000	1.145
		8,000	4	272,000	1.875
			6	77,000	0.531
		12,000	4	124,000	0.855
			6	60,000	0.414
		15,000	4	68,000	0.469
			6	60,000	0.414
Army Class II Helipad VFR	2	5,000	4	1,000,000+	6.895
			6	536,000	3.696
		8,000	4	805,000	5.550
			6	230,000	1.586
		12,000	4	287,000	1.979
			6	82,000	0.565
		15,000	4	147,000	1.014
			6	60,000	0.414
Army Class II Helipad IFR	2	5,000	4	1,000,000+	6.895
			6	620,000	4.275
		8,000	4	929,000	6.405
			6	265,000	1.827
		12,000	4	328,000	2.261
			6	95,000	0.655
		15,000	4	169,000	1.165
			6	60,000	0.414
Army Class II Heliport VFR	2	5,000	4	1,000,000+	6.895
			6	741,000	5.109
		8,000	4	1,000,000+	6.895
			6	315,000	2.172
		12,000	4	387,000	2.668
			6	113,000	0.779
		15,000	4	199,000	1.372
			6	60,000	0.414

Traffic Group	HMA Thickness (in)	Subgrade Modulus (psi)	Recycled Layer Thickness (in)	Required recycled layer modulus	
				psi	GpA
Army Class II Heliport IFR	2	5,000	4	1,000,000+	6.895
			6	935,000	6.447
		8,000	4	1,000,000+	6.895
			6	393,000	2.710
		12,000	4	478,000	3.296
			6	143,000	0.986
		15,000	4	247,000	1.703
			6	68,000	0.469
Army Class III Airport	2	5,000	4	1,000,000+	6.895
			6	960,000	6.619
		8,000	4	1,000,000+	6.895
			6	408,000	2.813
		12,000	4	523,000	3.606
			6	157,000	1.082
		15,000	4	287,000	1.979
			6	83,000	0.572
Army Class IV < 5000ft C-130	2	5,000	4	1,000,000+	—
			6	1,000,000+	—
		8,000	4	1,000,000+	—
			6	1,000,000+	—
		12,000	4	1,000,000+	—
			6	1,000,000+	—
		15,000	4	1,000,000+	—
			6	1,000,000+	—
Army Class IV < 5000ft C-17	2	5,000	4	1,000,000+	—
			6	1,000,000+	—
		8,000	4	1,000,000+	—
			6	1,000,000+	—
		12,000	4	1,000,000+	—
			6	1,000,000+	—
		15,000	4	1,000,000+	—
			6	1,000,000+	—
Army Class V	2	5,000	4	1,000,000+	6.895
			6	313,000	2.158
		8,000	4	472,000	3.254
			6	141,000	0.972
		12,000	4	178,000	1.227
			6	60,000	0.414
		15,000	4	98,000	0.676
			6	60,000	0.414

Traffic Group	HMA Thickness (in)	Subgrade Modulus (psi)	Recycled Layer Thickness (in)	Required recycled layer modulus	
				psi	GpA
Army Class VI C-130	2	5,000	4	1,000,000	6.895
			6	1,000,000	6.895
		8,000	4	1,000,000	6.895
			6	1,000,000	6.895
		12,000	4	1,000,000	6.895
			6	911,000	6.281
		15,000	4	1,000,000	6.895
			6	643,000	4.433
Army Class VI-C-17	2	5,000	4	1,000,000	6.895
			6	1,000,000	6.895
		8,000	4	1,000,000	6.895
			6	1,000,000	6.895
		12,000	4	1,000,000	6.895
			6	1,000,000	6.895
		15,000	4	1,000,000	6.895
			6	1,000,000	6.895

Table A2. Required recycled layer modulii for 3 in HMA layer.

Traffic Group	HMA Thickness (in)	Subgrade Modulus (psi)	Recycled Layer Thickness (in)	Required recycled layer modulus	
				psi	GpA
Army Class I Helipads	3	5,000	4	193,000	1.331
			6	61,000	0.421
		8,000	4	84,000	0.579
			6	60,000	0.414
		12,000	4	60,000	0.414
			6	60,000	0.414
		15,000	4	60,000	0.414
			6	60,000	0.414
Army Class I Heliports	3	5,000	4	284,000	1.958
			6	92,000	0.634
		8,000	4	117,000	0.807
			6	60,000	0.414
		12,000	4	60,000	0.414
			6	60,000	0.414
		15,000	4	60,000	0.414
			6	60,000	0.414
Army Class II Helipad VFR	3	5,000	4	1,000,000+	6.895
			6	335,000	2.310
		8,000	4	402,000	2.772
			6	139,000	0.958
		12,000	4	135,000	0.931
			6	60,000	0.414
		15,000	4	60,000	0.414
			6	60,000	0.414
Army Class II Helipad IFR	3	5,000	4	1,000,000+	6.895
			6	394,000	2.717
		8,000	4	472,000	3.254
			6	161,000	1.110
		12,000	4	152,000	1.048
			6	60,000	0.414
		15,000	4	68,000	0.469
			6	60,000	0.414
Army Class II Heliport VFR	3	5,000	4	1,000,000+	6.895
			6	479,000	3.303
		8,000	4	575,000	3.964
			6	193,000	1.331
		12,000	4	184,000	1.269
			6	72,000	0.496
		15,000	4	87,000	0.600
			6	60,000	0.414

Traffic Group	HMA Thickness (in)	Subgrade Modulus (psi)	Recycled Layer Thickness (in)	Required recycled layer modulus	
				psi	GpA
Army Class II Heliport IFR	3	5,000	4	1,000,000+	6.895
			6	625,000	4.309
		8,000	4	753,000	5.192
			6	242,000	1.669
		12,000	4	235,000	1.620
			6	90,000	0.621
		15,000	4	106,000	0.731
			6	60,000	0.414
Army Class III Airport	3	5,000	4	1,000,000+	6.895
			6	644,000	4.440
		8,000	4	788,000	5.433
			6	251,000	1.731
		12,000	4	260,000	1.793
			6	97,000	0.669
		15,000	4	129,000	0.889
			6	60,000	0.414
Army Class IV < 5000ft C-130	3	5,000	4	1,000,000+	---
			6	1,000,000+	---
		8,000	4	1,000,000+	---
			6	1,000,000+	---
		12,000	4	1,000,000+	---
			6	1,000,000+	---
		15,000	4	1,000,000+	---
			6	1,000,000+	---
Army Class IV < 5000ft C-17	3	5,000	4	1,000,000+	---
			6	1,000,000+	---
		8,000	4	1,000,000+	---
			6	1,000,000+	---
		12,000	4	1,000,000+	---
			6	1,000,000+	---
		15,000	4	1,000,000+	---
			6	1,000,000+	---
Army Class V	3	5,000	4	580,000	3.999
			6	191,000	1.317
		8,000	4	234,000	0.1613
			6	86,000	0.593
		12,000	4	75,000	0.517
			6	60,000	0.414
		15,000	4	60,000	0.414
			6	60,000	0.414

Traffic Group	HMA Thickness (in)	Subgrade Modulus (psi)	Recycled Layer Thickness (in)	Required recycled layer modulus	
				psi	GpA
Army Class VI C-130	3	5,000	4	1,000,000+	6.895
			6	1,000,000+	6.895
		8,000	4	1,000,000+	6.895
			6	1,000,000+	6.895
		12,000	4	1,000,000+	6.895
			6	621,000	4.282
		15,000	4	1,000,000+	6.895
			6	419,000	2.889
Army Class VI-C-17	3	5,000	4	1,000,000+	6.895
			6	1,000,000+	6.895
		8,000	4	1,000,000+	6.895
			6	1,000,000+	6.895
		12,000	4	1,000,000+	6.895
			6	1,000,000+	6.895
		15,000	4	1,000,000+	6.895
			6	1,000,000+	6.895

Table A3. Required recycled layer modulii for 4 in & 6 in HMA layer.

Traffic Group	HMA Thickness (in)	Subgrade Modulus (psi)	Recycled Layer Thickness (in)	Required recycled layer modulus	
				psi	GpA
Army Class I Helipads	4	5,000	4	78,000	0.538
			6	60,000	0.414
		8,000	4	60,000	0.414
			6	60,000	0.414
		12,000	4	60,000	0.414
			6	60,000	0.414
		15,000	4	60,000	0.414
			6	60,000	0.414
Army Class I Heliports	4	5,000	4	131,000	0.903
			6	60,000	0.414
		8,000	4	60,000	0.414
			6	60,000	0.414
		12,000	4	60,000	0.414
			6	60,000	0.414
		15,000	4	60,000	0.414
			6	60,000	0.414
Army Class II Helipad VFR	4	5,000	4	594,000	4.095
			6	215,000	1.482
		8,000	4	217,000	1.496
			6	86,000	0.593
		12,000	4	60,000	0.414
			6	60,000	0.414
		15,000	4	60,000	0.414
			6	60,000	0.414
Army Class II Helipad IFR	4	5,000	4	718,000	4.950
			6	253,000	1.744
		8,000	4	255,000	1.758
			6	101,000	0.696
		12,000	4	70,000	0.483
			6	60,000	0.414
		15,000	4	60,000	0.414
			6	60,000	0.414
Army Class II Heliport VFR	4	5,000	4	908,000	6.260
			6	310,000	2.137
		8,000	4	311,000	2.144
			6	121,000	0.834
		12,000	4	90,000	0.621
			6	60,000	0.414
		15,000	4	60,000	0.414
			6	60,000	0.414

Traffic Group	HMA Thickness (in)	Subgrade Modulus (psi)	Recycled Layer Thickness (in)	Required recycled layer modulus	
				psi	GpA
Army Class II Heliport IFR	4	5,000	4	1,000,000+	6.895
			6	408,000	2.813
		8,000	4	406,000	2.799
			6	156,000	1.076
		12,000	4	122,000	0.841
			6	60,000	0.414
		15,000	4	60,000	0.414
			6	60,000	0.414
Army Class III Airport	4	5,000	4	1,000,000+	6.895
			6	420,000	2.896
		8,000	4	425,000	2.930
			6	161,000	1.110
		12,000	4	133,000	0.917
			6	60,000	0.414
		15,000	4	60,000	0.414
			6	60,000	0.414
Army Class IV < 5000ft C-130	4	5,000	6	1,000,000+	6.895
			8	1,000,000+	6.895
		8,000	6	1,000,000+	6.895
			8	1,000,000+	6.895
		12,000	6	511,000	3.523
			8	244,000	1.682
		15,000	6	323,000	2.227
			8	163,000	1.124
Army Class IV < 5000ft C-17	6	5,000	6	1,000,000+	6.895
			8	1,000,000+	6.895
		8,000	6	1,000,000+	6.895
			8	1,000,000+	6.895
		12,000	6	960,000	6.619
			8	470,000	3.241
		15,000	6	545,000	3.758
			8	275,000	1.896
Army Class V	4	5,000	4	310,000	6.895
			6	119,000	0.820
		8,000	4	116,000	5.226
			6	60,000	0.414
		12,000	4	60,000	6.895
			6	60,000	0.414
		15,000	4	60,000	0.414
			6	60,000	0.414

Traffic Group	HMA Thickness (in)	Subgrade Modulus (psi)	Recycled Layer Thickness (in)	Required recycled layer modulus	
				psi	GpA
Army Class VI C-130	4	5,000	6	1,000,000+	
			8	752,000	
		8,000	6	839,000	
			8	385,000	
		12,000	6	430,000	
			8	207,000	
		15,000	6	275,000	
			8	135,000	
Army Class VI-C-17	6	5,000	6	1,000,000+	
			8	1,000,000+	
		8,000	6	1,000,000+	
			8	1,000,000+	
		12,000	6	960,000	
			8	470,000	
		15,000	6	545,000	
			8	275,000	

Acronyms and Abbreviations

Term	Definition
AASHTO	American Association of State Highway Transportation Officials
AC	Asphalt Concrete
APA	Asphalt Pavement Analyzer
ASTM	American Society for Testing and Materials
CBR	California Bearing Ratio
CIR	Cold In-place Recycling
DOD	Department of Defense
DOT	Department of Transportation
EASL	Equivalent Single Axle Load
ERDC	Engineer Research and Development Center
FAA	Federal Aviation Administration
FDR	Full-Depth Reclamation
HMA	Hot Mix Asphalt
IDT	Indirect Tensile
ITS	Indirect Tensile Strength
LED	Linear Elastic Design
MS	Marshall Stability
NAS	Naval Air Station
NS	Naval Station
OMC	Optimum Moisture Content
PCASE	Pavement-Transportation Computer Assisted Structural Engineering
PCI	Pavement Condition Index
PM	Plastic Mold
QA/QC	Quality Assurance/Quality Control
SGC	Superpave Gyratory Compactor
UCS	Unconfined Compression Strength
UFC	Unified Facilities Criteria

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
cubic yards	0.7645549	cubic meters
degrees (angle)	0.01745329	radians
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
inches	0.0254	meters
miles (US statute)	1,609.347	meters
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals
tons (force)	8,896.443	newtons
tons (force) per square foot	95.76052	kilopascals

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14. ABSTRACT

Over the last few decades, in-place recycling of asphalt pavements has seen increased use by the highway industry, primarily to take advantage of potential cost and logistical savings compared to conventional reconstruction. More recently, the U.S. Navy and Federal Aviation Administration have allowed recycling to be used on airfields with lighter traffic. This report contains a discussion of in-place recycling design considerations obtained from a literature review of its use in the highway industry. Observations developed from a review of airfield pavement projects that have utilized recycling is also included. A structural analysis was performed using the Pavement-Transportation Computer Assisted Structural Engineering (PCASE) tool to determine typical stiffness values that recycled layers must achieve to support various types of military aircraft traffic for different pavement structures. Overall, in-place recycling is recommended for consideration as a rehabilitation technique for military airfield pavements, and further investigation is recommended before it is implemented it into design guidance.

15. SUBJECT TERMS

In-place recycling
Full-depth reclamation
Pavements, Asphalt – Recycling
Cold in-place recycling
Airfield Pavement rehabilitation
P-CASE
Asphalt pavements
Structural design
Pavements – Evaluation
Runways (Aeronautics)
Structural engineering – Computer programs

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