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Final report

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Abstract: This report describes the demonstration of technologies and procedures developed under the Joint Rapid Airfield Construction (JRAC) program at the U.S. Army Engineer Research and Development Center in Vicksburg, MS. The successful demonstration project occurred in Australia in June 2007. The JRAC demonstration project was conducted as an integral part of Exercise Talisman Saber 2007, a U.S. and Australian combined and joint forces military exercise. The project included the construction of a 4,100- by 110-ft (1,250- by 33.5-m) unsurfaced runway and two 45,480-ft^2 (4,225-m^2) aircraft parking aprons with associated connector taxiways, all using JRAC technologies focused on rapid construction with reduced logistics and increased system reliability. This demonstration marked the successful conclusion of the 6-year research and development phase of the JRAC program.

Contents

Figures, Tables, and Photos

Figures

Tables

Preface

This report describes a full-scale field demonstration exercise that included the construction of a C-17 capable runway and two aircraft parking aprons at Bradshaw Field Training Area (BFTA) in Australia's Northern Territory during June 2007. The focus of this field exercise was to demonstrate new materials and technologies developed by the Joint Rapid Airfield Construction (JRAC) program under realistic military contingency construction conditions. Descriptions of the technology used, project design and approval, troop training, and aircraft operations are also included in this report.

The JRAC program was a comprehensive, 6-year, demonstration-based research and development program executed by the U.S. Army Engineer Research and Development Center (ERDC) during the fiscal year 2002 through 2007 time frame. This program was focused on developing new materials and technologies for rapidly constructing or upgrading military contingency airfields, with particular emphasis on expanding existing unsurfaced airfields. The JRAC program was sponsored by Headquarters, U.S. Army Corps of Engineers in Washington, DC.

This publication was prepared by personnel of the ERDC Geotechnical and Structures Laboratory (GSL), Vicksburg, MS. The authors were all principle participants in the planning and execution of the demonstration project, and include the following GSL personnel: Travis A. Mann (Demonstration Project Manager), Dr. Gary L. Anderton (JRAC Program Manager), Dr. Ernest S. Berney IV, Dr. J. Kent Newman, Daniel K. Miller, Quint Mason, Airfields and Pavements Branch (APB), and E. Alex Baylot, Mobility Systems Branch. The authors prepared this publication under the supervision of Don R. Alexander, Chief, APB; Dr. Larry N. Lynch, Chief, Engineering Systems and Materials Division; and Dr. David W. Pittman, Director, GSL.

COL Richard B. Jenkins was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

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Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.45359237	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter
square feet	0.09290304	square meters
square yards	0.8361274	square meters

1 Introduction

The modern U.S. military must be capable of quick and efficient deployments of soldiers and equipment anywhere in the world. Cargo aircraft will play a key role in this effort, both during the initial projection of forces and during sustainment operations. The U.S. military's current power projection policy requires that future force projection capabilities meet or exceed the following deployment objectives: deploy to a distant theater in 10 days, defeat an enemy within 30 days, and be prepared for another fight within another 30 days. Current sealift capabilities provide little assistance in meeting these objectives, which leaves strategic airlift as the primary means of providing mobility for the future force. Unfortunately, in many areas of the world, the airfield infrastructure is denied by the enemy, severely deteriorated, or simply does not exist. Additionally, light/medium engineer units do not have the capability to rapidly upgrade or construct contingency airfields within the required force projection timeline as defined above. Therefore, the rapid construction or expansion of semi-prepared contingency airfields for cargo aircraft is a critical component to the U.S. military meeting future force projection goals.

In light of this shortfall, a new program was initiated by the U.S. Army Engineer Research and Development Center (ERDC) entitled "Joint Rapid Airfield Construction," or JRAC. The primary objectives of the program were to (a) optimize site selection, (b) enhance airfield construction productivity, and (c) incorporate advances in rapid soil stabilization. The JRAC program will serve as the vehicle by which military engineers are provided with new tools and methods that will more expediently allow them to construct and/or upgrade contingency airfields to support future force projection operations. The JRAC program will also drastically reduce the logistical footprint required to build or repair contingency airfields by minimizing material and equipment quantities required for construction.

The JRAC program was a comprehensive 6-year research effort that began in 2002. The program included over 30 individual work units focused on providing engineering solutions to increase the U.S. military's capability to rapidly build or upgrade contingency airfields. The program included two major technology demonstrations where the tools and techniques were used by engineers in a military exercise environment. The first demonstration took place in 2004 at Fort Bragg, NC, and the second event took place in 2007 in a remote region in Australia's Northern Territory. This report describes the technologies and procedures used during the 2007 demonstration.

Although this report describes the use of almost all JRAC technologies in a military exercise environment, it does not necessarily address or explain the comprehensive research performed during the individual projects that led to the development and use of the JRAC technologies. References are provided for the reader throughout the report which detail the unique technologies developed as part of the overall JRAC package.

The report layout begins with the processes and software used in the digital design of the runway, taxiways, and aprons for the demonstration exercise, followed by the training of all JRAC technologies prior to the beginning of the exercise. The report then details the equipment, materials, and procedures used in constructing the runway, taxiways, and aprons including construction of a test section and JRAC quality control/assessment tools used to ensure specifications were met or exceeded. The report then describes the soil stabilization training, materials, and procedures used in constructing the taxiways and aprons as the primary mission of the JRAC exercise followed by a summary of the performance of all the constructed features.

2 Background

Demonstration objective

The objective of the 2007 JRAC demonstration was to validate the complete "package" of technologies developed during the life of the research program in a realistic military contingency construction scenario. During the initial 3 years of research and development, simulated C-130 aircraft loads were used in test section analyses. This was primarily because the C-130 aircraft is considerably lighter and less experimentally intensive when compared to the C-17 aircraft. The JRAC program objectives included developing structural pavement solutions for the C-130 first, and then building on those successes to develop solutions for the C-17 by the end of the program. The scheduled demonstration events were developed in parallel with these objectives and included the 2004 demonstration with a focus on the C-130 aircraft and the 2007 demonstration with a focus on the C-17 aircraft.

In order to validate the JRAC technologies, the demonstration was accomplished using military construction and engineering assets for the entire site assessment, design, and construction processes. The JRAC program is based upon the need for simple, robust systems and tools that require minimal training for successful use within the military. Conducting full-scale demonstrations using military troops and equipment provided extraordinary and critical feedback to the research and development process and helped to further understand the requirements of the end user.

Description of demonstration site

Bradshaw Field Training Area (BFTA) is located near Timber Creek within the Victoria River Region of the Northern Territory, approximately 600 km by road southwest of Darwin, Australia (Figure 1). Situated at the southwestern extremity of Australia's "Top End," the region is subject to the summer monsoon or wet season from October to April, the dry season from May to September, and periods of transition in between. Formally known as Bradshaw Station, the site is named for Captain Joe Bradshaw who moved there in 1894.

Figure 1. Map of Australia showing Darwin and Bradshaw Field Training Area.

BFTA is a pastoral lease of some 8,700 km^2 and is bounded to the north by the Fitzmaurice River and Wombungi Station, to the west by the Joseph Bonaparte Gulf, to the south by the Victoria River and to the east by Coolibah and Innesvale Stations. The property is approximately 150 km east to west and 70 km north to south. It consists of six major physiographic regions: hills and plain to the east (Eastern Hills), a large open plain (Angalarri Plain), a central plateau (Yambarran Plateau), a narrow valley (Koolendong Valley), dissected hills to the west (Western Hills), and a littoral zone which borders the ocean.

The property has been in continuous operation as a cattle station for over 100 years and carried some 13,000 head of cattle at the time of its acquisition by the Australian Department of Defence in 1996. Bradshaw Station was gradually de-stocked under a 3-year lease back agreement; however, feral animals are still present.

Topographical features of the area include the sandstone escarpments of the Pinkerton and Yambarran Ranges, rising approximately 200 to 300 m above the plains of the Victoria River. The principal aboriginal people traditionally associated with the region belong to the Jaminjung language community. Historically, Bradshaw has been widely used as a major foot-path communication link between the Victoria River and the Daly River area north of the Fitzmaurice River. Diverse habitats in the area provide for abundant and unique wildlife.

Geological features also provide shelter and resources for the production of aboriginal art. Rock shelters throughout the escarpment of the Pinkerton Range contain significant galleries of prehistoric and protohistoric art. Numerous archaeological and other sites that are sacred or otherwise significant to aboriginal tradition occur within BFTA.

The town of Timber Creek now has a permanent population of about 300, whereas the population of the Victoria River Region is approximately 3,000. The economy of the region is based on beef cattle and tourism. Areas of conservation significance in the region include Gregory National Park, Keep River National Park, and the Daly River/Port Keats Aboriginal Land Trust.

The Australian Department of Defence purchased the pastoral lease for Bradshaw Station in 1996 and is in the process of developing the property into a field training facility. The facility will permit the military to exercise armored, artillery, engineer, infantry, and aviation elements in a range of combat activities including reconnaissance, maneuver and field live firing from sub-unit to formation level. Further, joint exercises can be undertaken with other Australian forces, combined exercises with foreign forces, along with delivery of aerial ordinance in support of ground exercises.

The Australian Department of Defence is developing the necessary infrastructure and environmental management procedures to ensure the long-term sustainable use of BFTA while also affording ongoing protection to environmentally sensitive areas.

The majority of training is expected to take place during the dry season. The recent addition of the C-17 capable airfield will significantly add to the training value of BFTA by allowing access to the range by transport aircraft.

3 JRAC Design Process

Introduction

The objective of the JRAC design process is to be fast and relevant given the conditions of the project and the intended use of the infrastructure. Some projects may have the luxury of time, allowing the design process to be started early in the planning phases by taking advantage of satellite imagery and elevation data. Other projects require the design to be created at the location of the planned infrastructure using ground truth information with a limited amount of time before construction must begin. In either case, the process involves obtaining the relevant information and producing a product that supports the mission objectives. The design must address both geometric and structural requirements, each of which has a unique impact on the rapid construction process. An additional requirement of the JRAC design process involves the creation of a 3-dimensional (3-D) digital design that can be used by global positioning systems (GPS) which guide grade control systems mounted on the construction equipment.

Software tools overview

A 3-D design is a critical component in any rapid construction project that uses enhanced construction technologies. It incorporates the survey feature data, design specifications, and other design guidance to create a 3-D model of the site. The 3-D design is then shared with the survey and construction equipment and provides cut and fill information specific to locations anywhere on the jobsite.

Currently, the U.S. military uses Terramodel to produce 3-D geometric designs. Terramodel is a very complex land development software tool used by CAD operators, surveyors, and engineers to develop site plans. The application consists of a broad range of functionality including contour generation, road design, volume calculation, 3-D design visualization, and construction drawing development. A user can develop and store templates to improve the speed as well as develop tool pallets to assist with the design steps. The disadvantage of this program is that it requires extensive experience and understanding in order to use the application efficiently. Both JRAC demonstrations included intense training programs for

Terramodel users prior to the start of the exercise to ensure an adequate skill level to complete the task.

The Pavement-Transportation Computer Assisted Structural Engineering (PCASE) application[1], developed at ERDC, offers a broad spectrum of design and evaluation functions to assess transportation systems with a large library of aircraft and vehicle platforms. PCASE capabilities include unsurfaced pavement design and can quickly aid planners and constructors in determining the required pavement thickness for the design aircraft and number of operations required.

Two additional JRAC design tools were developed to perform 3-D geometric designs. The first is an ESRI ArcMAP based tool found in the Rapid Airfield Construction Decision Support Toolset (RACDST) described in Chapter 4, which provides a rapid, coarse assessment of cut/fill requirements for an airfield based on satellite elevation data. The second was designed by XYZ Solutions, Inc. which provides a more accurate cut/fill design tool based on information taken from the RACDST application or from ground-based survey data.

XYZ Solutions created a prototype expedient geometric design tool using their 3-D software, nDView. This software provides suitable functionality to generate an optimized geometric design in minutes versus hours or days, using conventional applications like Terramodel, and can also perform virtual construction estimating, monitor real-time construction progress, and remotely operate equipment. This tool incorporates Air Force Engineering Technical Letter (ETL) 04-7 "Geometric specifications for runway, taxiway, and apron criteria" and showcases an easy and simple design tool pallet and an intuitive 3-D augmented reality environment (Figure 2). The application imports probable airfield location(s), imagery and elevation data from the Site Selection application, which are discussed in Chapter 5. An operator using the tool pallet and imported data selects an airfield feature, places it on the map, orients it on the desired bearing, and automatically generates a design within 5 min. The tool optimizes the design for both transverse and longitudinal directions to minimize cut/fill requirements while giving the user the opportunity to adjust automated design constraints. The output views are intuitive interpretations of the design elevation and areas of cut and fill magnitude as shown in Figure 2.

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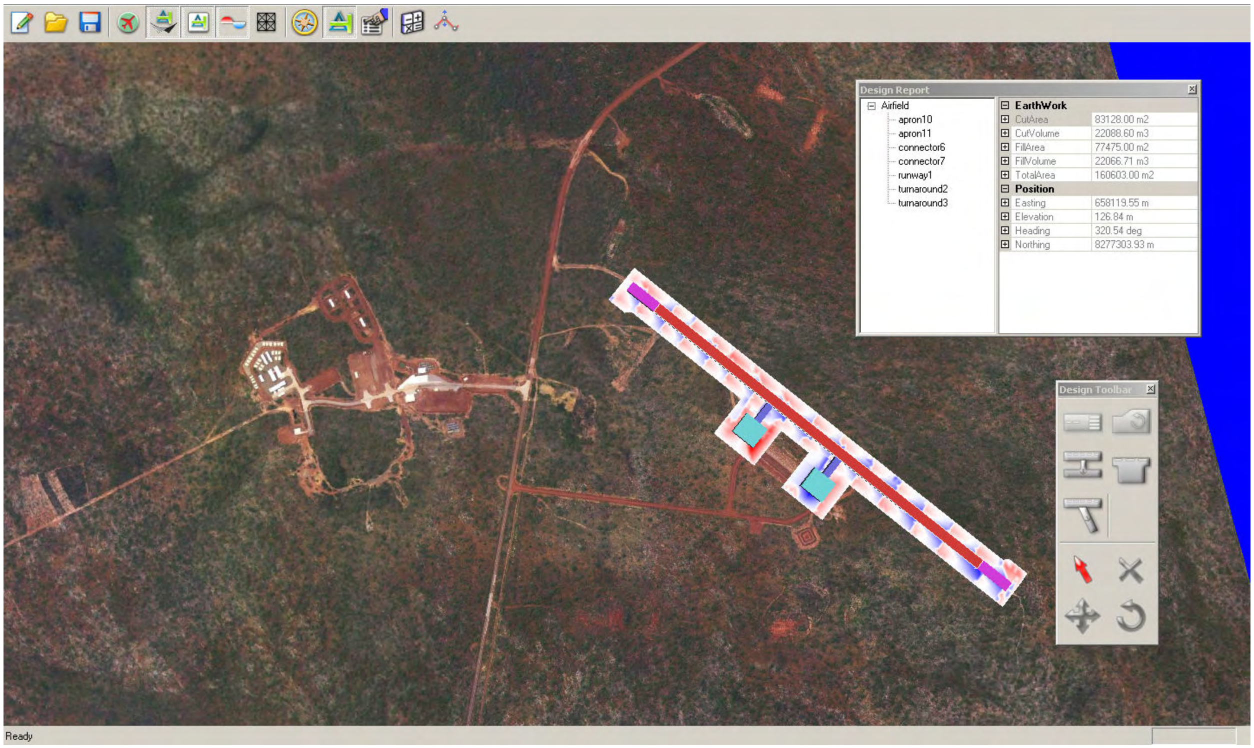
[1] This application is free shareware at the ERDC Airfield and Pavements Branch Web site (https://transportation.wes.army.mil/triservice/apb.aspx).



EarthWork	
CutArea	83128.00 m2
CutVolume	22088.60 m3
FillArea	77475.00 m2
FillVolume	22066.71 m3
TotalArea	160603.00 m2
Position	
Easting	658119.55 m
Elevation	126.84 m
Heading	320.54 deg
Northing	8277303.93 m

Figure 2. Prototype geometric design tool.

It (nDView) also produces a Terramodel point file that can be used for design refinement and can be exported to the GPS grade control systems for use on the construction machines. Even though it was not developed for this prototype, the output file can be prepared for direct export to machine controls.

BFTA airfield design

The 2007 JRAC demonstration involved the construction of an airfield that would become enduring infrastructure for Australia, and it therefore required an extensive design and approval process. ERDC obtained the initial topographic and material information from an extensive, manual on-site survey and created a geometric and structural design consisting of a comprehensive set of construction drawings. This design was used to obtain the necessary project approvals before the commencement of construction during the Talisman Saber exercise and was completed in August 2006. Terramodel was used to create the geometric design over a period of several weeks because it offered the most versatile and proven capability to produce construction drawings. The use of the expedient JRAC design tools was not possible at this time as their development was not yet completed.

In addition to the ERDC airfield design, the JRAC Task Force (discussed in detail in Chapter 7) was required to duplicate the survey and design during the Talisman Saber exercise to demonstrate the JRAC design process. This approach allowed the JRAC team to collect valuable feedback on the other design tools such as the ESRI ArcMAP and nDView based programs, when used in a contingency environment.

Topographic feature surveys

As with any site construction project, the topographic feature survey is a critical task in the construction process. In order to achieve the rapid timeline, real-time kinematics (RTK) GPS survey and grade control equipment (Figure 3) was used. The equipment is described in detail in the following chapter. For this exercise, there were two feature surveys. Each had a specific purpose in preparation for the execution of the airfield construction. The first survey, conducted by ERDC, was to collect the necessary information to complete the airfield design approval process, and the second

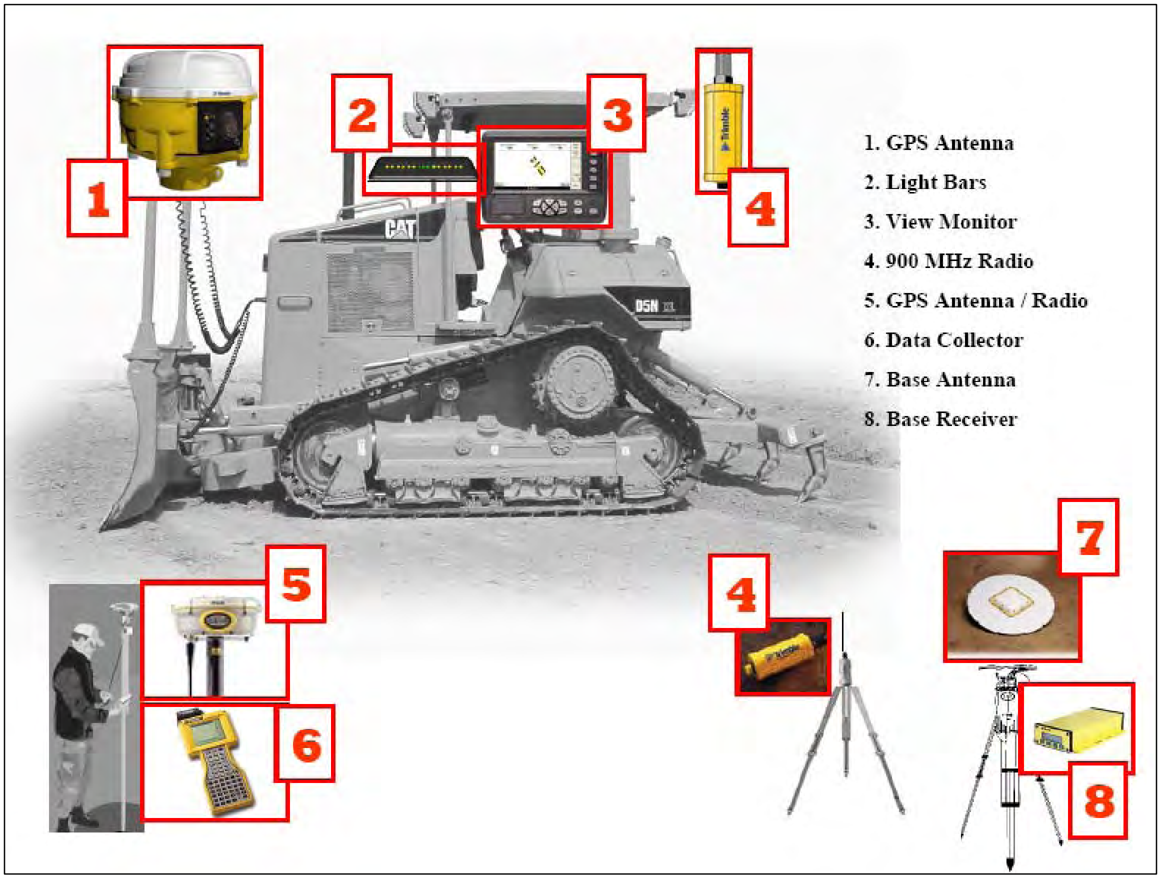


Figure 3. RTK GPS survey and grade control systems.

focused on the JRAC Task Force members collecting data during an expeditionary scenario. The JRAC Task Force survey and design team used Terramodel to perform a runway layout at the exact location of the pre-approved design to ensure proper siting of the airfield.

Geometric design

Geometric specifications

At BFTA, a semi-prepared airfield was needed to support future training operations using C-130 and C-17 aircraft. The governing document, ETL 04-7 (Headquarters, Air Force Civil Engineer Support Agency 2004), outlines the general dimensions to support the design aircraft. The geometric design was developed using the minimum criteria in most cases, with the exception of transverse slopes which were based on local construction knowledge.

The runway length requirement is based on the pressure altitude of the site and the runway condition rating (RCR), which is a measure of the friction characteristics of the surface material. The runway width is dependent on the design aircraft (C-130 or C-17). The slopes (transverse and longitudinal) must conform to various ranges and distance limitations to ensure safe operation of the aircraft. Transverse slopes should also take into account the effects of runoff, while longitudinal slopes should attempt to reduce the amount of effort to construct the runway, and minimize the number of slope changes. The basic runway dimensions are shown in Table 1. Geometric criteria for taxiways and aprons are also described in ETL 04-7; consequently they are not shown in the table.

Table 1. BFTA runway dimensions.

Runway Attribute	Dimensions
Length	1,067 m (3,500 ft)
Overrun	91.5 m (300 ft)
Width	27.5 m (90 ft)
Transverse slope	-1%
Longitudinal slope	Approximately 0.75% to 1.35%

3-D geometric design

The final product of the first design was a 3-D design, shown in Figure 4, and a 56-page, printable construction drawing package. The design included an access road to each apron and a total fill requirement of approximately 40,000 m^3 of material. Preliminary work was accomplished in 2006 to construct the access road, stockpile and screen the material, and install water bores to ensure an adequate supply of water.

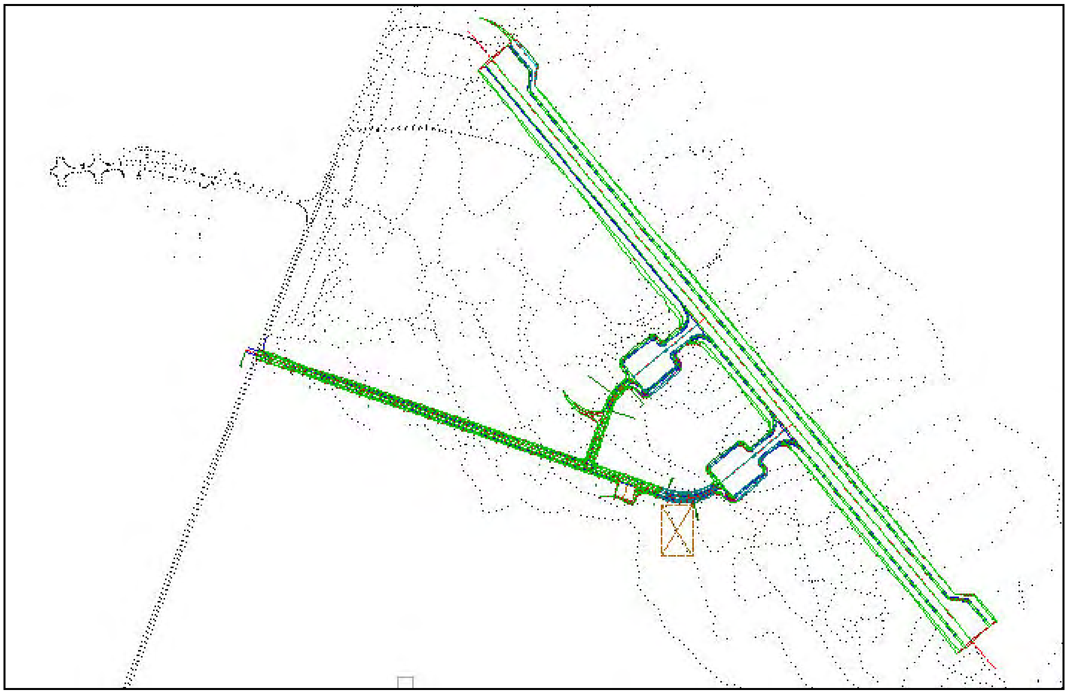


Figure 4. Airfield design with access road.

The second geometric design was executed with several levels of redundancy in order to employ the multiple design tools as previously described. A satellite Internet service was procured as part of the exercise to enable communication between the Site Selection RACDST and the XYZ Expedient Airfield Geometric Design tools. Due to the large file transfer requirements, coupled with the excessive Internet access demand, the Site Selection Data were not transferred to the project site prior to conducting the terrain feature survey and start of the geometric design. Terramodel was used to create and continuously revise the design. Use of the Expedient Airfield Geometric Design tool did occur near the end of the exercise, but it was too late to provide an impact on the mission. A geometrically matching design was created within minutes which generated a fill volume approximately 1,400 m^3 of compacted material more than the actual

Terramodel design, which indicates its usefulness for this type of design and construction.

This design was developed in stages including the runway, turnarounds, taxiways, aprons, and drainage. The first runway design was completed within 2 hours of completion of the survey. This initial design was then loaded into the machine control systems with several hours to spare before construction was scheduled to begin. This staged approach allowed the construction to continue without waiting on the final product. From this time forward, the airfield design was continuously improved to meet the construction supervisor's intent and needs. Revisions addressed changing sides of one turnaround, adding the different lift layers, adjusting elevations when rock was encountered, and incorporating drainage ditches. The final Terramodel design required approximately 20,700 m^3 of compacted material.

Structural design

Soils analysis

It is important to note that soil characterization is critical to the structural design process and significantly impacts the effort required to construct airfields. The soil conditions will affect whether or not an airfield site is selected, as well as the methods and resources needed for construction. Traditional methods require soil samples to be sent to a laboratory for extensive, time-consuming analysis. In order to support rapid engineering buildup, expedient characterization methods yielding acceptable accuracy are needed to determine soil characteristics. This capability must be easily deployable, offer rapid classification of soils, determine the in situ moisture content, and predict moisture/density relationships. The rapid soils analysis kit (RSAK) addresses this need and is fully described in Chapter 4.

For the Talisman Saber exercise, both laboratory and expedient soil assessments were conducted. Soil samples were collected at a nearby borrow site during the site visit on 15 June 2006 (Figure 5). Sixteen containers totaling approximately 455 kg (1,000 lb) of material were collected and shipped to ERDC for laboratory testing. Unsoaked California bearing ratio (CBR), modified and standard Proctor results, and the soil gradation are shown in Figures 6 through 8. Dynamic cone penetrometer tests were also conducted along the proposed runway, taxiway, and apron areas. The results of these tests are discussed in Appendix B and show a minimum of a 10 CBR for natural subgrade.

Figure 5. Example of a borrow pit used to obtain prepositioned material at BFTA site.

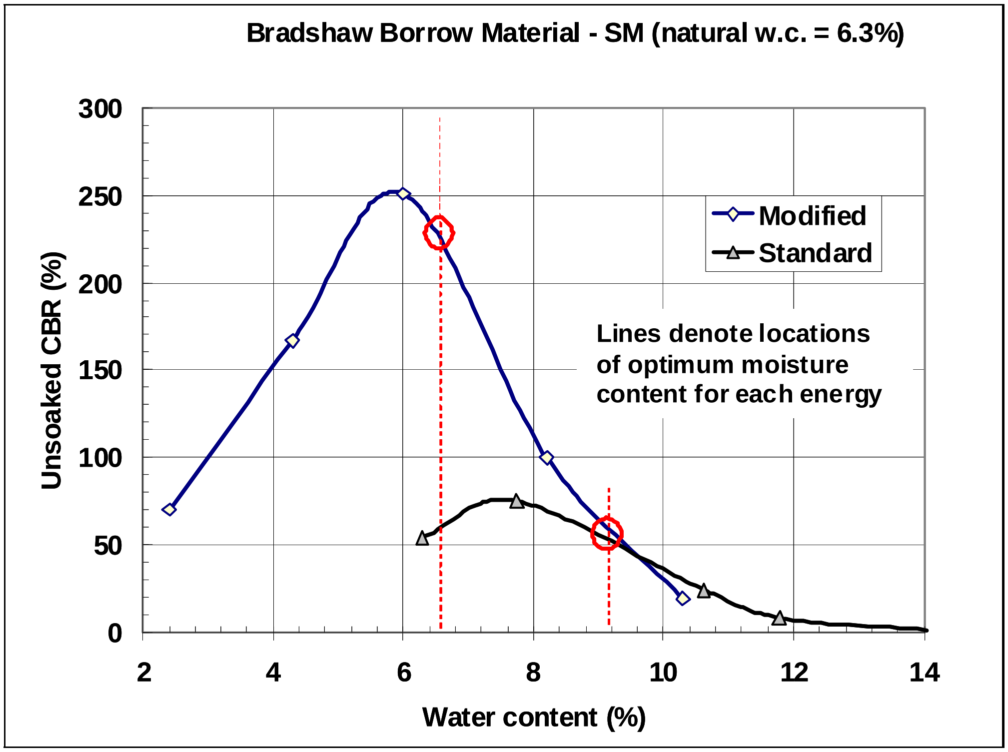


Figure 6. Unsoaked California bearing ratio laboratory results.

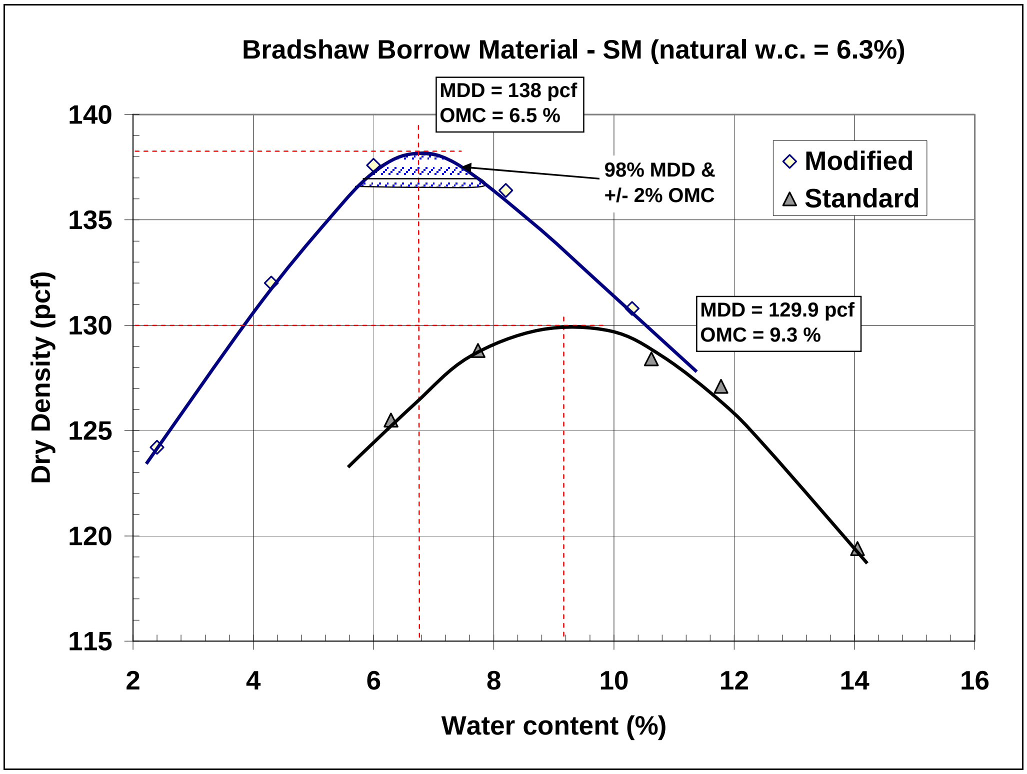
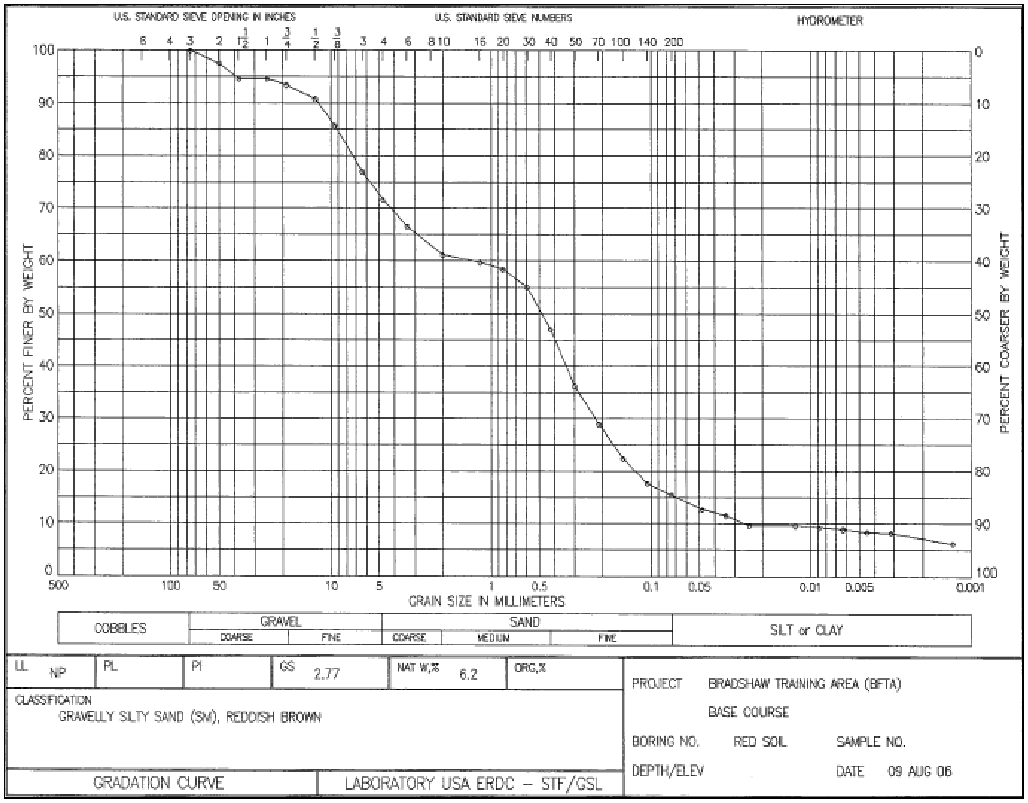


Figure 7. Dry density laboratory results.



LL NP	PL	PI	GS 2.77	NAT W,% 6.2	ORG,%

CLASSIFICATION
GRAVELLY SILTY SAND (SM), REDDISH BROWN

PROJECT BRADSHAW TRAINING AREA (BFTA)
BASE COURSE
BORING NO. RED SOIL
SAMPLE NO.
DEPTH/ELEV
DATE 09 AUG 06

GRADATION CURVE
LABORATORY USA ERDC – STF/GSL

Figure 8. Soil gradation of in situ BRTA material.

The samples were taken from pre-positioned stockpiles that had been exposed to the wet season for 1 year. It was learned that local contractors preferred to pre-position stockpiled material before the rainy season in order to increase its moisture content prior to use. This method did increase the moisture content, which reduced the amount of construction water needed for compaction. In situ samples taken from the airfield yielded moisture contents ranging from 1% to 3% while the moisture content of the pre-positioned stockpiled material was in excess of 6%. In 2006, approximately 40,000 m^3 of screened material was stockpiled to increase the moisture content and reduce the requirement for water during construction.

Unstabilized design (runway)

PCASE (version 2.08) was used to determine the structural thickness requirements for the C-17 aircraft. The evaluation-utilized data from the DCP and soil testing described previously. This process provided the initial design thickness requirements used to determine material quantities and constructive effort. Given an in situ subgrade CBR of 10, and the fill material's projected unsoaked CBR of 50 (for dry operating conditions), a minimum of 250 mm (10 in.) of cover material was required to support an unlimited number of C-17 passes, with proper maintenance. The design chart for the determination of thickness requirements over a given subgrade CBR value for the C-17 aircraft is shown in Figure 9.

Stabilization design (aprons and taxiways)

The soil stabilization design for this project was derived from methods developed specific to a JRAC rapid soil stabilization scenario. The scenario included the elimination of testing requirements and use of lower amounts of soil additives compared to traditional methods. For the BFTA SM screened soil, a fiber-cement combination was chosen to rapidly improve the soil strength. The procedures and materials are further described in Chapter 10.

The suggested dosage rate for the cement ranged from 4% to 5% by dry mass of soil, approximately half the amount suggested in the Army soil stabilization manual, TM 5-822-14 for an SM soil. The fiber selected was a monofilament polypropylene fiber, 19 mm in length with a suggested dosage rate from 0.2% to 0.4% by dry mass of soil. To achieve a short cure time, a Type III high-early strength cement was chosen for the project.

This type of cement was readily available in the NT near BFTA. The depth of stabilization was 150 mm of compacted fill.

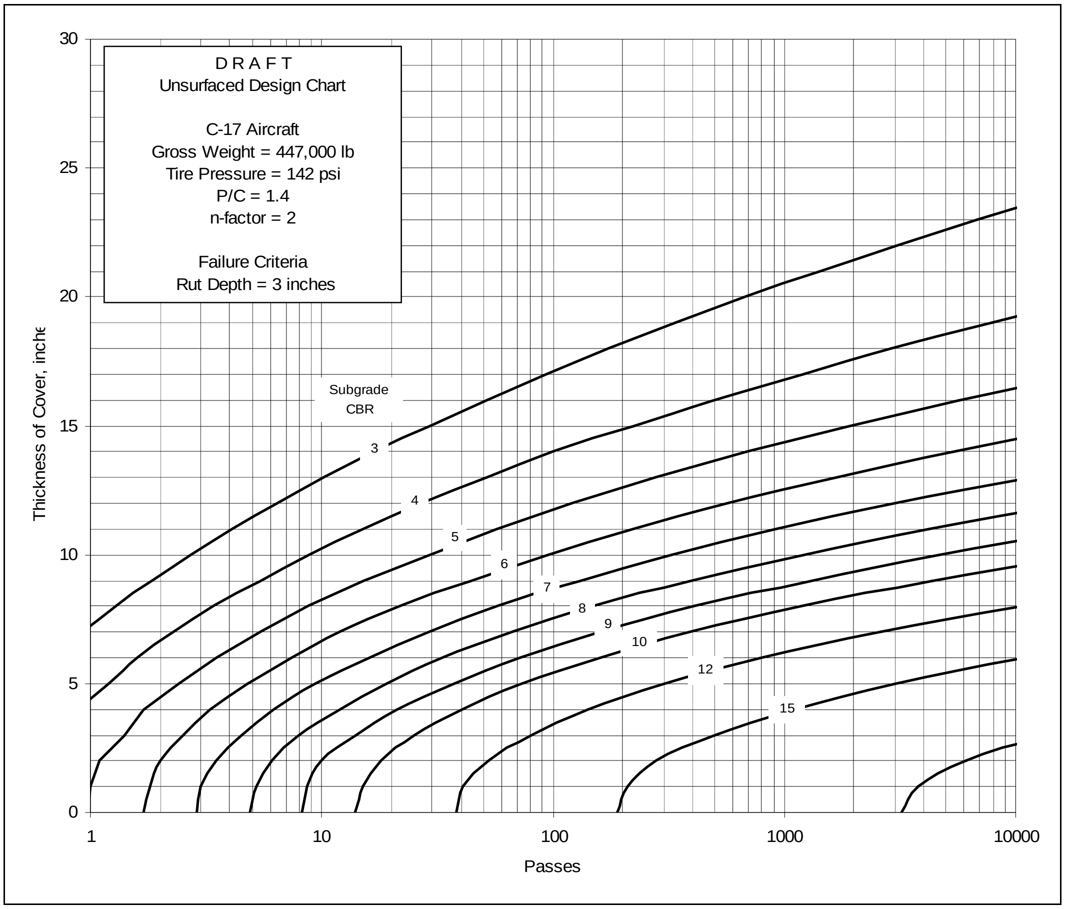


Figure 9. Semi-prepared C-17 airfield design chart.

This soil stabilization design process will allow for aircraft operations after 24 hr of cure time for a subgrade CBR greater than 10 for most climates. If properly maintained, this design method provides the capability to sustain at least 500 operations of a contingency-loaded C-17 aircraft. However, it must be understood that using the low dosage rates of cement suggested for a low-logistics JRAC scenario does not produce a long-term durable structure. This method results in a moisture-susceptible stabilized soil that must be surface sealed to prevent saturation from precipitation. The surface sealing or “cap” is achieved by applying a waterproof, dustproof polymer emulsion. The emulsion must be reapplied as necessary due to traffic wear.

Conclusion and recommendations

By conducting two realistic airfield construction projects, the JRAC program has confirmed the critical need for a user-friendly design system. The ability to quickly and easily generate a 3-D airfield model to be used with GPS grade control construction equipment is critical to meeting rapid earthmoving requirements and reducing the overall timeline. By incorporating structural assessments that address unstabilized and stabilized material requirements, the design can be further optimized thus enabling decision makers to quantitatively assess the risk of a given airfield. For the 2007 demonstration, each design application played a valuable role in developing the airfield design, as explained below.

Terramodel provided the ability to develop a 3-D geometric design model and a set of construction drawings. It is endorsed and taught by the United States Army Engineering School (USAES) at Fort Leonard Wood, MO. However, every USAES-trained engineer soldier encountered over the life of the JRAC program struggled to perform a 3-D airfield design or to develop a construction drawing package without significant outside help from professional trainers provided by the JRAC program. Terramodel is undoubtedly a powerful tool and it provides solutions far beyond the single task of contingency airfield design; however, the program’s level of complexity requires almost daily use and frequent retraining to obtain and sustain efficiency and effectiveness. The U.S. military should investigate and implement ways to increase operator proficiency for this powerful tool as well as continue the development of a simpler, alternative solution for contingency airfield design.

The development of the RACDST tool proved that it was a good macro terrain assessment tool, especially with the advent of a 3-D airfield runway template. However, even though ArcGIS tools are excellent for terrain analysis, stepping down and performing a focused automated land development design model was a daunting task, and it could not outperform programs like Terramodel.

The ERDC-sponsored design tool developed using nDView software from XYZ Solutions provides a simple way to generate designs. The 3-D augmented reality provided the type of visual knowledge needed to make informed engineering decisions about the site. The automated, rule-based design made designing easy and fast with design results that were very comparable to traditional land development applications, in a fraction of the time. This system can improve the situational awareness of a project site far beyond a physical site visit with just a glance. For expedient airfield construction or upgrades, an application will need to be tailored to perform rapid airfield design using current geometric and structural criteria. This capability should be combined with the PCASE software and pursued for advanced development.

In conclusion, project design becomes a critical aspect to the rapid construction process when using enhanced construction technologies. Having collected accurate topographic data, the airfield layout and design can be a quick and easy process that enables planners and executors to make timely and informed decisions about the construction task at hand. These designs can be further processed and immediately passed to the construction equipment, eliminating the need for conventional grade staking.

4 JRAC Site Selection Demonstration

Introduction

One of the components of JRAC was the development of the site selection and assessment tool. The site selection tool referred to here as the Rapid Airfield Construction Decision Support Toolset (RACDST) was developed as a user-friendly tool to be used by HQ combatant/supporting commands; Geo-Spatial Intelligence Office/terrain analysts. The development of this tool was accomplished in such a way that it would be compatible for later introduction into the Department of Defense Commercial/Joint Mapping Toolkit (C/JMTK) Version 9.2. Using the toolset allows for an improved, automated, and standardized process for contingency airfield planning. It effectively assesses and locates plausible airfield sites and effectively reduces the quantity of airfield reconnaissance missions.

JRAC was tasked to build a GIS-based area suitability assessment and airfield lay-down toolset that would be used to quickly identify and prioritize potential airfield locations. There are major benefits in using the RACDST to locate potential sites. First, RACDST allows for the relatively rapid identification and assessment of a large number of airfield sites across a large area of interest (AOI). Second, potential sites can be evaluated based on the amount of cut/fill that is required to prepare the site. This comparison assumes that the lesser the amount of cut/fill, the lesser the amount of construction time. This approach helps to maximize the benefits of the JRAC mission to “deploy anytime, anywhere.”

To evaluate the anticipated benefits of using the tool, RACDST was utilized as part of the Talisman Saber Command Post Exercise (CPX) that was held prior to the field exercise. The USS Blue Ridge of the 7th Fleet, located off the coast of Yokosuka, Japan, acted as the PACOM command post for the CPX. A JRAC liaison officer was stationed onboard to pass the request for site selection of constructing contingency airfields/runways in the BFTA to the appropriate terrain analysts. The U.S. Army PACOM 5th Engineer Detachment (5th EN) out of Fort Shafter, Hawaii, was trained to use the RACDST the week prior to the CPX and was set up to respond to the request for information. Their analysis followed the procedure as given in the following sections.

Description of the RACDST

General overview

The RACDST has four components:

- Area suitability assessment module
- Airfield lay-down and cut/fill module
- Engineer operations
- Data transfer module.

RACDST is designed to work as an extension to ArcGIS. It is launched from a toolbar within ArcMap (Figure 10). Software requirements to run RACDST include ArcGIS 9.2 (service pack 2, ArcView level license or better), with the Spatial Analyst extension, and Microsoft .Net 1.1 Framework. RACDST will also work within the C/JMTK 9.2 environment.

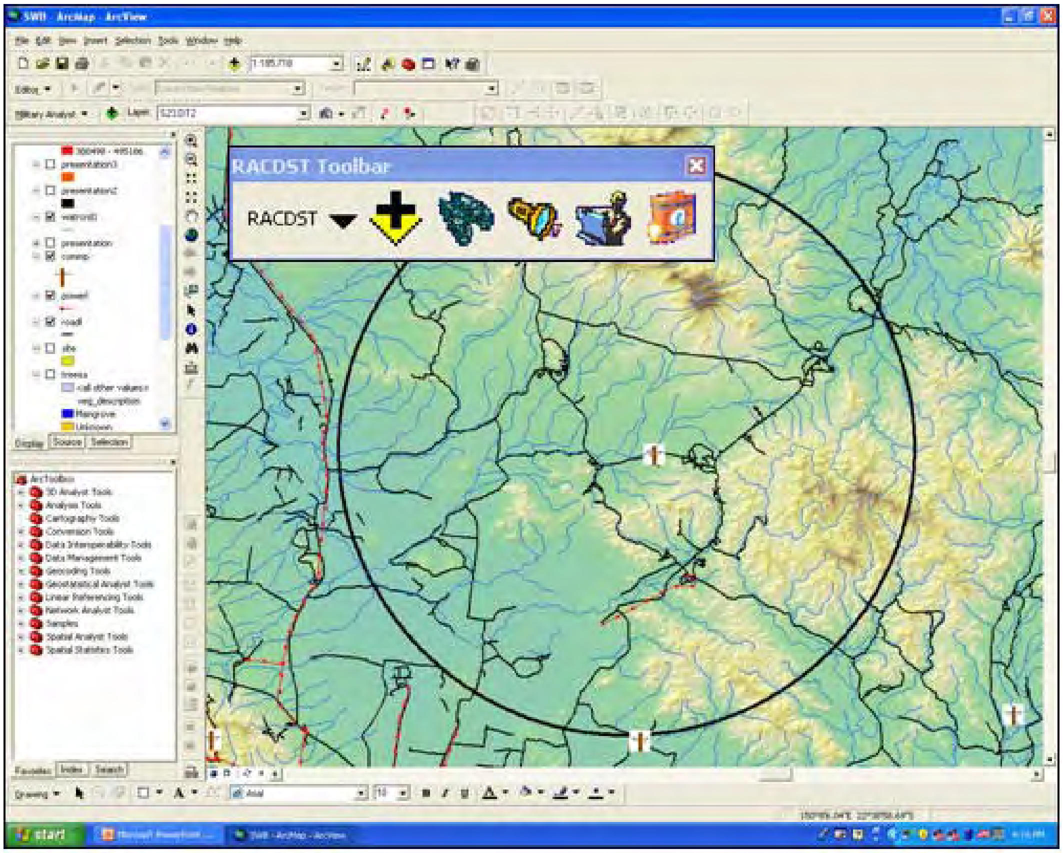


Figure 10. RACDST toolbar.

During the planning process, the area suitability assessment module was designed to assist a user in determining reasonable and feasible areas to construct an airfield given search criteria. The airfield lay-down module evaluates candidate sites by positioning an airfield template within the feasible areas and locating sites that minimize cut/fill requirements.

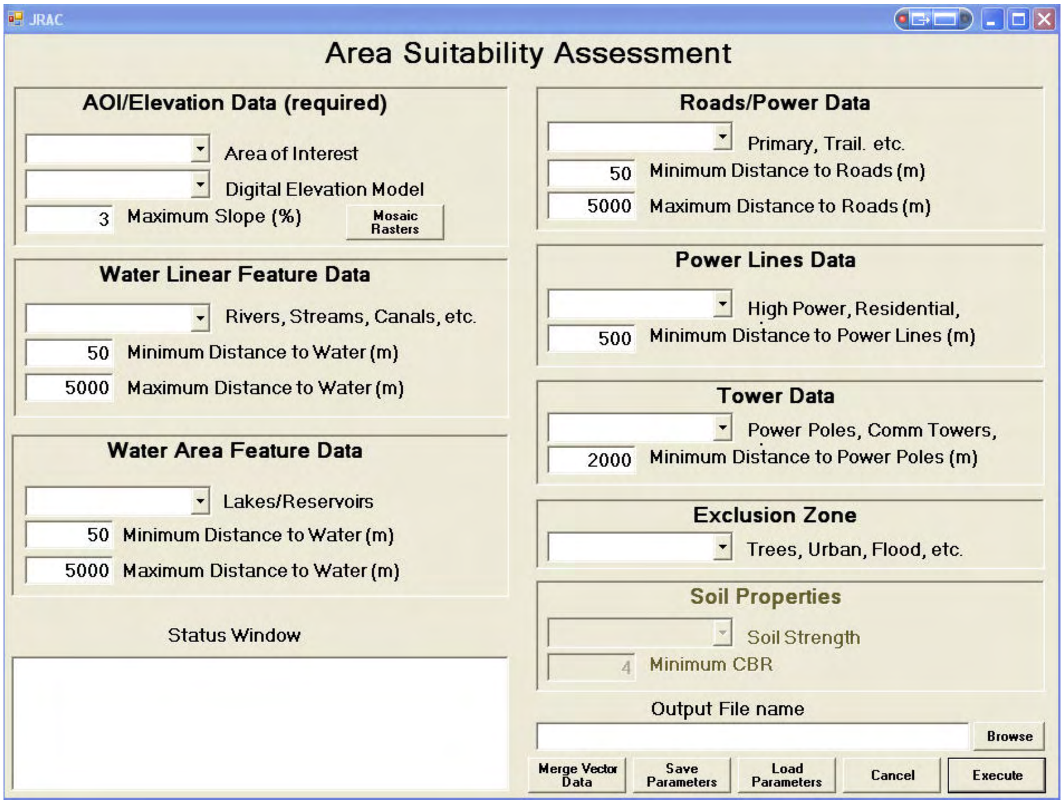
The data transfer module allows the user to “clip” the site(s)’s underlying terrain and imagery data so that a more detailed analysis can be conducted in nDView. Without this feature, the terrain and imagery data would be unwieldy to data transmission and overwhelm the software used for the detailed construction planning. The following sections discuss this procedure.

Area suitability assessment (ASA)

ASA is a critical step of the overall site selection process. The process begins by extracting only the terrain data falling within the AOI. Then, three basic geo-processing divisions of the ASA are used to process elevation data, select suitable areas, and reject areas. During the execution of the elevation data processing, a slope map is generated and only the areas that meet the slope requirements are saved. Figure 11 presents the considered search criteria and default values in the graphic user interface (GUI) form. The soil properties layer was considered in the GUI design, but it was not implemented due to a lack of data in the area of interest.

Figure 12 shows the entire AOI for the BFTA within a red line. The yellow line shows a smaller study AOI. Using JRAC Task Force guidance, the smaller AOI, in yellow, was created to reduce the search effort as it had a smoother landscape and a better ground transportation network.

Next, suitable areas are found using proximity analyses to include those areas that meet the criteria and exclude those that do not. The result of the ASA provides feasible areas to locate an airfield given the user-supplied search criteria. Figure 13 is the result of the ASA for the BFTA study area. The colored area indicates the feasible areas to locate an airfield within the AOI.



Area Suitability Assessment

AOI/Elevation Data (required)

Area of Interest

Digital Elevation Model

3 Maximum Slope (%)

Water Linear Feature Data

Rivers, Streams, Canals, etc.

50 Minimum Distance to Water (m)

5000 Maximum Distance to Water (m)

Water Area Feature Data

Lakes/Reservoirs

50 Minimum Distance to Water (m)

5000 Maximum Distance to Water (m)

Status Window

Roads/Power Data

Primary, Trail. etc.

50 Minimum Distance to Roads (m)

5000 Maximum Distance to Roads (m)

Power Lines Data

High Power, Residential,

500 Minimum Distance to Power Lines (m)

Tower Data

Power Poles, Comm Towers,

2000 Minimum Distance to Power Poles (m)

Exclusion Zone

Trees, Urban, Flood, etc.

Soil Properties

Soil Strength

4 Minimum CBR

Output File name

Figure 11. RACDST ASA GUI.

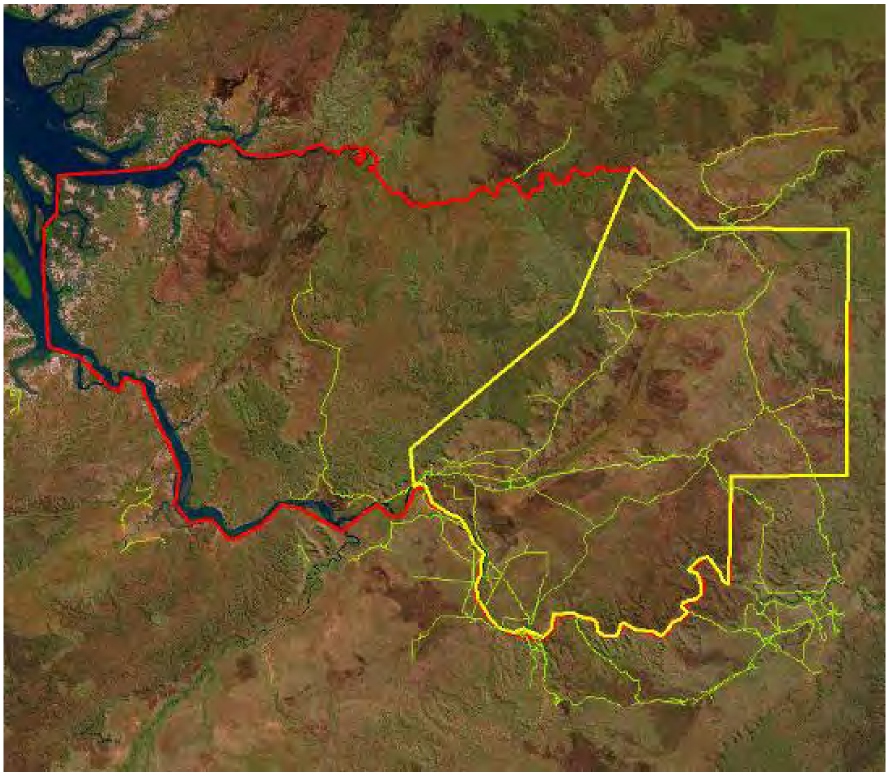


Figure 12. AOI of BFTA.

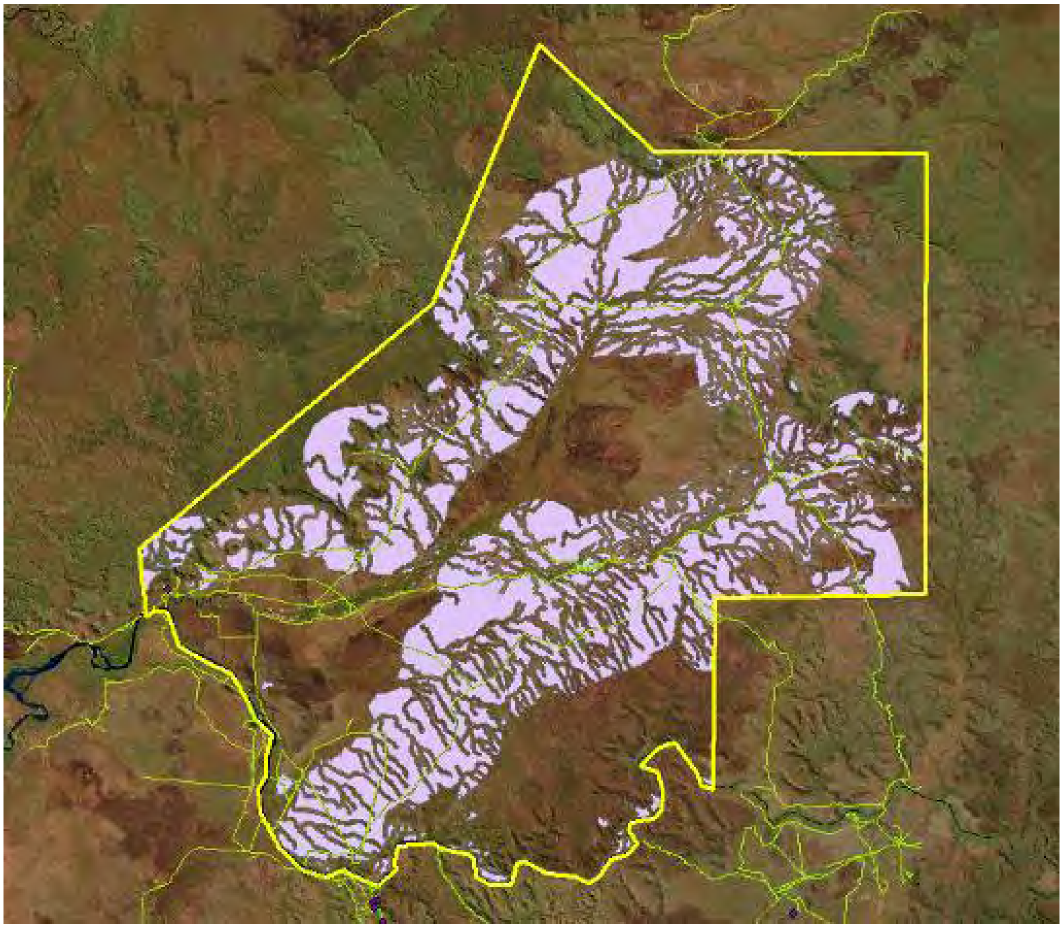


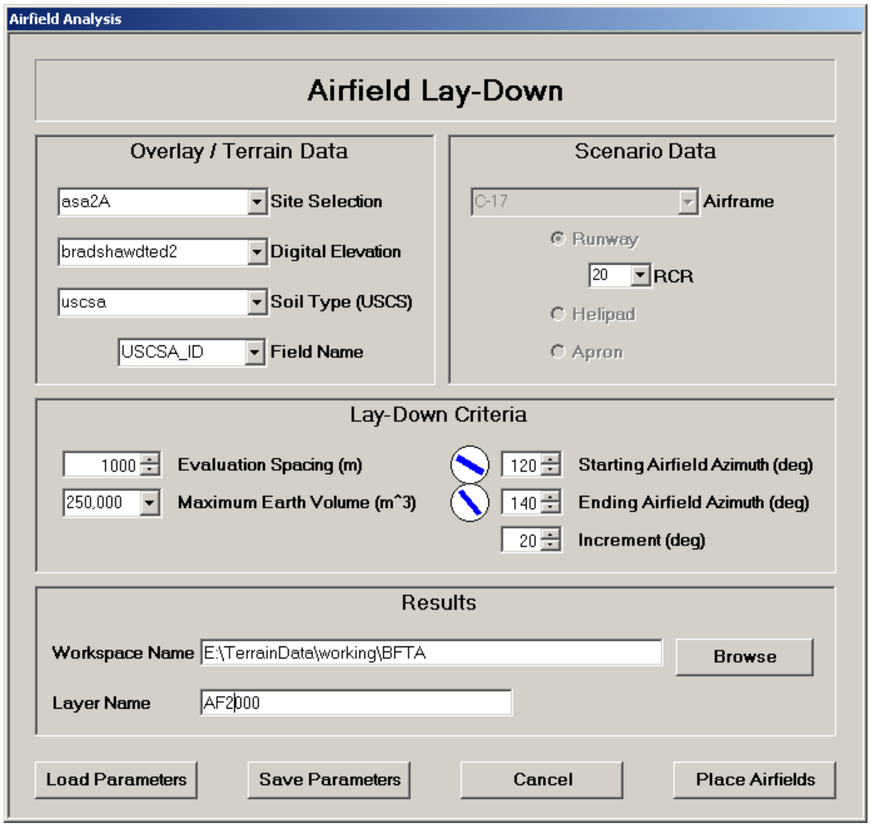
Figure 13. Results of the ASA.

Airfield lay-down and cut/fill module (AFL)

The AFL mathematically introduces a 3-D template of an airfield into the elevation profile. The results of the ASA delineate the areas under consideration. Thus, the solved layer of the ASA and the elevation data are used as inputs to the AFL.

The user dictates the geometry of the template by selecting the airframe (C-17) and the runway criteria rating as documented in ETL-04-7. The length of the runway is further dictated by the elevation above sea-level. The user also specifies the airfield azimuth range (degrees) to be considered and incremental steps to the azimuth to consider. The user can control the fidelity and thus the computation time of the analysis by altering the evaluation spacing and maximum acceptable cut/fill volume.

Figure 14 shows the GUI of the AFL and the default values. The use of the Unified Soil Classification System (USCS) soil layer does not impact the analysis but is later associated with the proposed airfield(s) during the data transfer.



Site Selection: asa2A
Digital Elevation: bradshawdted2
Soil Type (USCS): uscsa
Field Name: USCSA_ID
Airframe: C-17
● Runway
RCR: 20
○ Helipad
○ Apron
Evaluation Spacing (m): 1000
Maximum Earth Volume (m^3): 250,000
Starting Airfield Azimuth (deg): 120
Ending Airfield Azimuth (deg): 140
Increment (deg): 20
Workspace Name: E:\TerrainData\working\BFTA
Layer Name: AF2000

Figure 14. AFL GUI with default and user specified input.

The initial analysis provides an array of proposed airfield sites that can geometrically fit within the ASA results. Then, those remaining airfields are shifted vertically within the elevation data to minimize the difference between the cut volume and the fill volumes. The idea is to minimize the amount of fill to be hauled in from another site. These computed cut/fill volumes are then associated in the database to each proposed airfield. Figure 15 displays all the possible locations of airfields that met the user-specified criteria. Figure 16 shows the proposed sites in the southernmost region of the AOI that required less that 100,000 m^3 of cut/fill (arbitrary amount). The choices of 120-deg and 140-deg azimuths were chosen based on the U.S. Air Force Weather Agency prevailing wind overlays and azimuths of existing airfields in the area. Additionally, the location of the new BFTA airfield is indicated on the same figure.

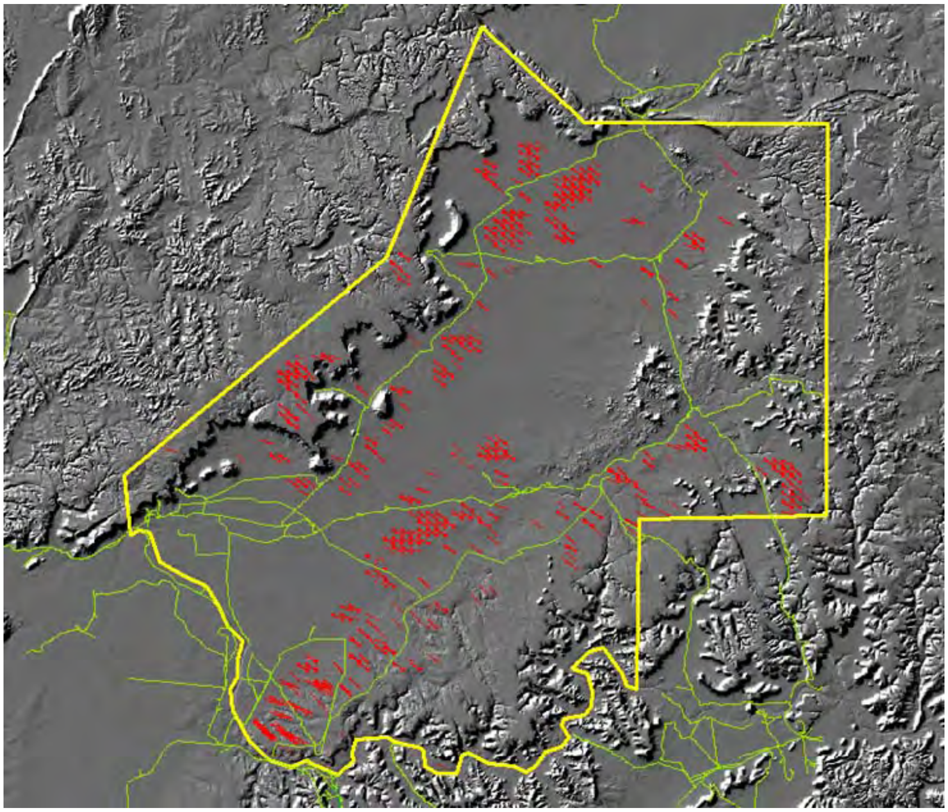


Figure 15. Results of the AFL search.

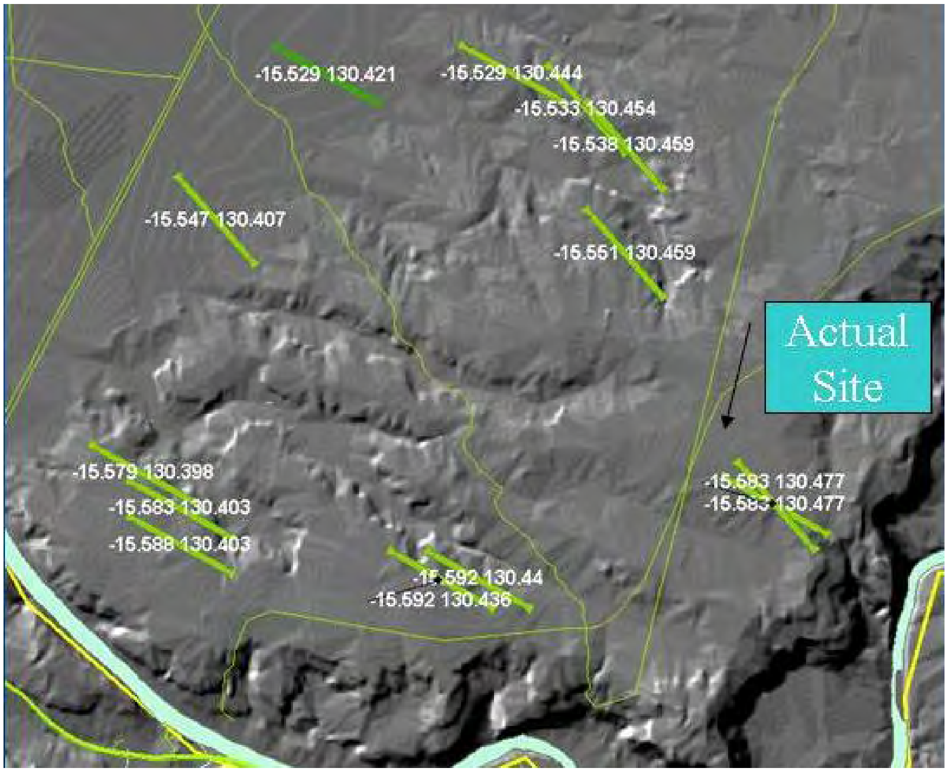


Figure 16. Sites with less than 100,000 m^3 of cut/fill in the southern portion of the BFTA AOI showing latitude and longitude coordinates.

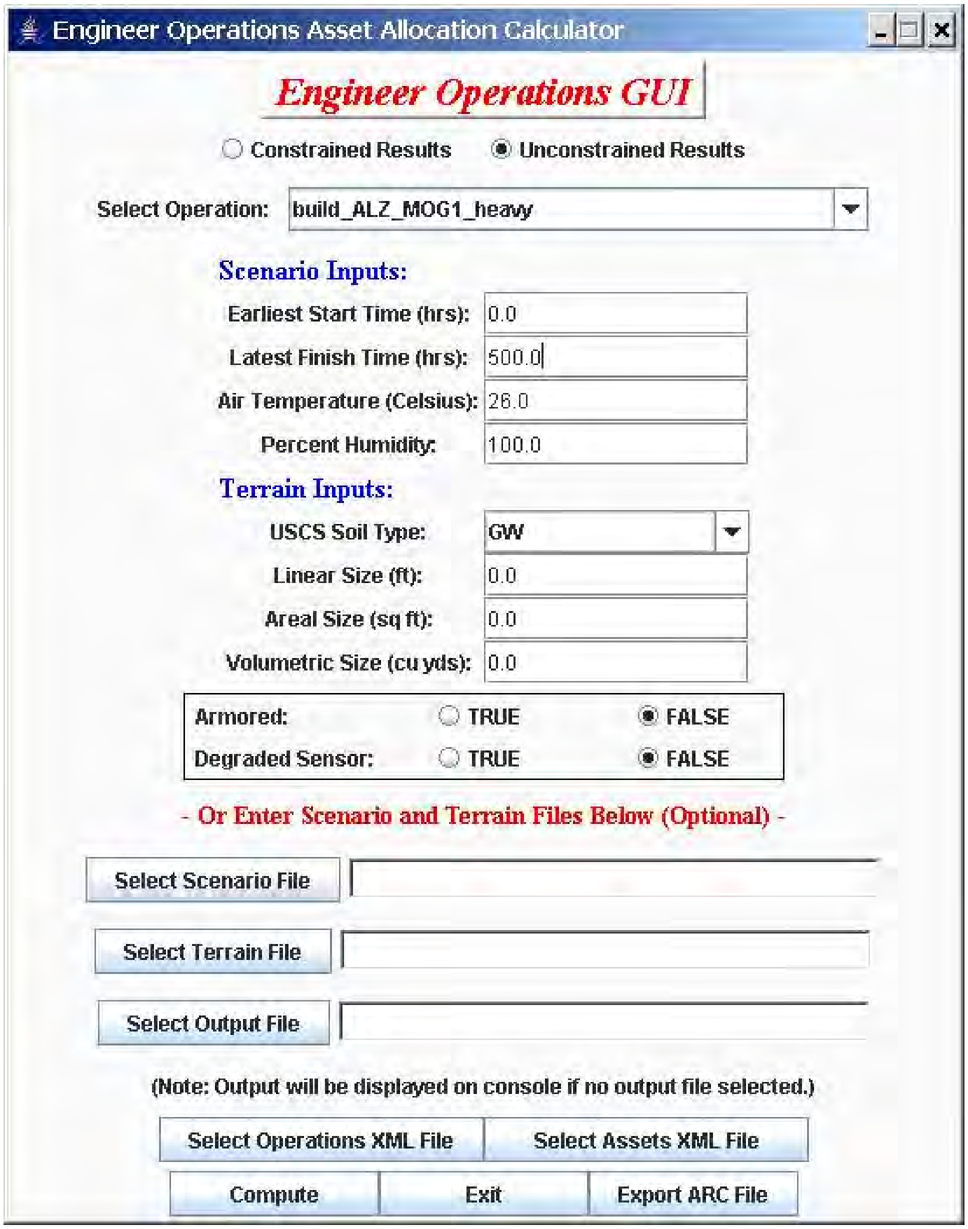
Engineer construction estimate (ENOps)

ENOps is capable of estimating the engineer construction effort given particular dimensions of the feature of interest. As it provides a first-order estimate, predetermined techniques for accomplishing the construction are part of the input data and are not intended to be modified at this phase of its development. However, since the production data are given as rates either by length, area, or volume, ENOps is sensitive to variations in these dimensions.

Figure 17 is the GUI for ENOps. For the JRAC demonstration the user would chose the operation “build_ALZ_MOG1_heavy” to indicate the construction of an air landing zone with a MOG1 (runway only) and heavy aircraft requirement. The scenario inputs dictate the operational environment and the terrain input provides the summary dimensions of the terrain feature of interest. However, since the ALD provided hundreds of plausible sites, upon inspection the terrain analysts reduced the data set to 21 sites. Those sites are listed in Table 2 with the work duration estimated by ENOps. The table is sorted by volume size.

Data transfer module

The data transfer module is simply a step in the process to export the underlying terrain and imagery data associated with each cluster of proposed airfield sites. The sites are clustered in the database (referred to as scenes) in order to minimize the amount of redundant terrain and imagery data made ready for data transfer. The sites database is in the form of an open standards Extensible Markup Language (XML) that allows it to be easily developed and understood. The terrain data are in an ESRI ASCII grided file, and the imagery is in the form of a geoTIFF. The database and files can then be loaded into several commercial off-the-self and government off-the-shelf applications. The application, nDView as shown in Figure 18, was the intended recipient of the data transfer as an initialization point for the detailed design process. The database containing the 21 sites, was transmitted to the construction engineers in Darwin for closer examination either by field reconnaissance and/or as an initialization into nDView.



○ Constrained Results ● Unconstrained Results

Select Operation: build_ALZ_MOG1_heavy

Scenario Inputs:

Earliest Start Time (hrs): 0.0
Latest Finish Time (hrs): 500.0
Air Temperature (Celsius): 26.0
Percent Humidity: 100.0

Terrain Inputs:

USCS Soil Type: GW
Linear Size (ft): 0.0
Areal Size (sq ft): 0.0
Volumetric Size (cu yds): 0.0

Armored: ○ TRUE ● FALSE
Degraded Sensor: ○ TRUE ● FALSE

- Or Enter Scenario and Terrain Files Below (Optional) -

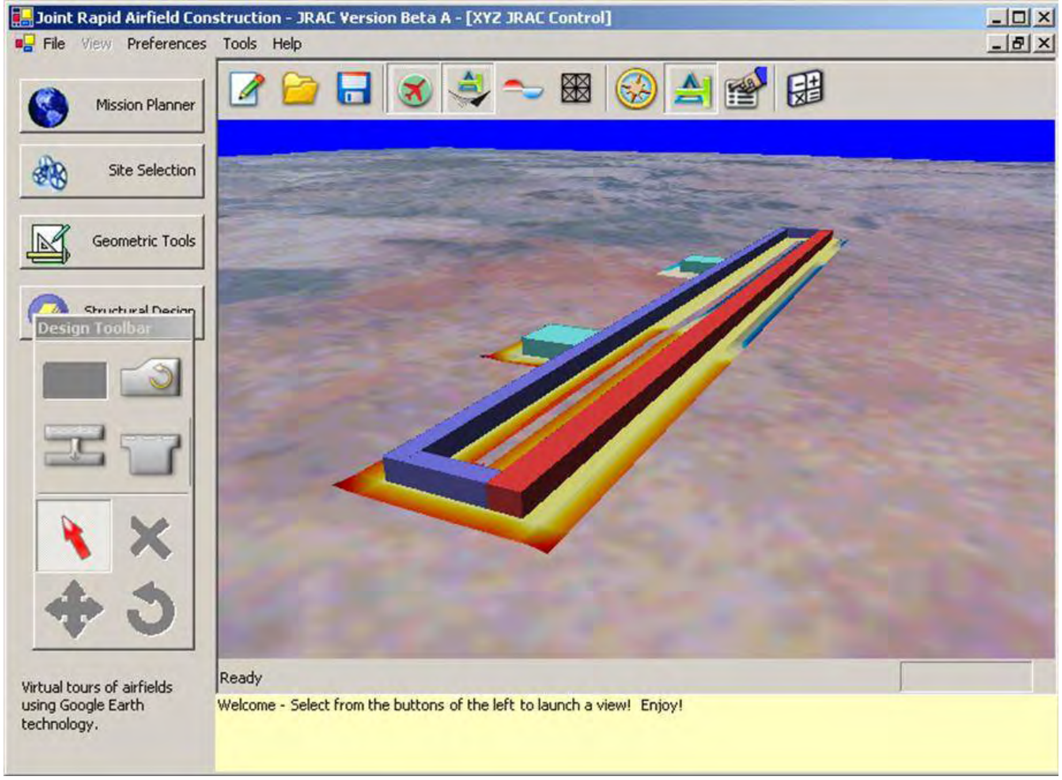
(Note: Output will be displayed on console if no output file selected.)

Figure 17. ENOps GUI showing selection for constructing MOG 1 airfield landing zone.

Table 2. Plausible sites in the BFTA for runways as found in the CPX.

No.	Lat	Long	Azimuth	Volume Size m^3	Soil Type (USCS)	Work Duration hr
1	-15.2910	130.6117	120	10127	SM	230
2	-15.2910	130.6117	140	10127	SM	230
3	-15.3637	130.5564	120	10127	SM	230
4	-15.4001	130.5194	120	14148	SM	230
5	-15.4001	130.5194	140	14388	SM	230
6	-15.4182	130.5195	140	18298	SM	230
7	-14.9651	130.6836	120	21519	SM	230

No.	Lat	Long	Azimuth	Volume Size m³	Soil Type (USCS)	Work Duration hr
8	-15.4182	130.5195	120	22147	SM	230
9	-15.5289	130.4212	120	43986	SM	258
10	-15.5470	130.4073	140	112003	SM	402
11	-15.5827	130.4775	140	120846	SM	421
12	-15.5377	130.4585	140	168038	SM	521
13	-15.5921	130.4356	120	175497	SM	537
14	-15.5512	130.4586	140	189119	SM	566
15	-15.5920	130.4402	120	192358	SM	573
16	-15.5787	130.3982	120	209139	OL	608
17	-15.5287	130.4445	120	214683	SM	620
18	-15.5827	130.4775	120	219038	SM	629
19	-15.5877	130.4029	120	239571	SM	673
20	-15.5832	130.4029	120	244085	SM	682
21	-15.5332	130.4538	140	245585	SM	686
Runway length+clearzones = 1,372 m (4,500 ft) Primary area width = 97.5 m (319.8 ft) Prepared area = 107,104 m² (1,152,268 ft²) USCS soil type assumed uniform for region based on initial site surveys.						



Virtual tours of airfields using Google Earth technology.

Ready

Welcome - Select from the buttons of the left to launch a view! Enjoy!

Figure 18. Example data transfer into nDView.

Summary of site selection in CPX

The CPX (beginning 23 May 2007) request for site selection did not explicitly request for an estimate of construction duration and resources required, but it did require discovery of suitable sites for the runway to be completed no later than 22 June. Therefore, the maximum amount of time available would be 30 days at 24-hr operations (720 hr). However, actual days available would heavily depend on when equipment, material, and personnel would arrive on-site. Nonetheless, the 21 down-selected sites shown in Table 2 were provided to the JRAC Liaison Officer onboard the USS Blue Ridge as part of the product briefing and were later transmitted to the construction team in Darwin.

In Table 2, sites 11 and 18 were the closest to the actual site chosen (715 m, center-point to center-point distance) with Site 11 having the closest azimuth to the actual azimuth (140.5 deg). The offset from the actual site chosen was due to the evaluation spacing of 1,000 m defined in the GUI in Figure 14. This defines the error in distance from which an airfield site may be selected. This error can be minimized by reducing the evaluation spacing but at the cost of increased computational time.

The actual work duration of 14 days with 12 hr/day operations (168 hr) differs for several reasons from the ENOps estimate of 421 hr. These reasons include the following: the sites were not at the same coordinates, the elevation data resolution was 30 m (DTEDII), the construction unit makeup wasn’t exactly the same, and stabilization was not used. If one removes the stabilization and curing components (keeping compaction), Site 11 work duration becomes 298.5 hr.

Furthermore, the difference in volumetric size between Site 11 and the actual site is 131,125 cy. Even on a relatively flat area, cut-fill volumes can vary tremendously and change the construction time drastically, just by changing the azimuth or shifting the location just 715 m. However, for this operation as defined, the constructed area becomes the dominate dimension when the computed cut-fill volume is roughly below 40,000 cy. This explains why some of the sites listed in Table 2 have work durations that exceed 230 hr.

As previously described, these cut-fill volumes were computed using the AFL. A current limitation of the AFL is that it does not take advantage of allowing the runway to follow the slope of the terrain, within specification criteria. The AFL can only lay out the runway horizontally (zero slope). For example, given a runway and clearzone length of 1,370 m and primary width of 97.5 m, the volume difference between a 1% and 0% slope is 91,499 m^3 (118,949 cy).

If one uses the same technique but restricts the cut/fill volume to the actual 27,103 cy and allows for rocky soil, the initial work duration is 261 hr. Furthermore, if one removes the stabilization and curing from this analysis as before, the work duration becomes 138.5 hr; this amounts to a difference of only 29 hr from actual to estimated (assumes no problems, breakdowns, weather, etc.) times. Clearly, had the analysts better known the volume and soil conditions and had a technique been pre-defined in ENOps that did not use stabilization, the estimate would have been much closer to the actual work duration.

The training of personnel to utilize the RACDST (Figure 19) was conducted on-site at the 5th EN facilities at Fort Shafter, Hawaii, from 15 to 18 May 2007. The training and actual site selection analysis held during the CPX the following week was conducted in the same room, on the same equipment, and to the same personnel.

Figure 19. GIS analysts of the 5th EN undergoing a training event using the RACDST.

The following conclusions were reached concerning the JRAC site selection demonstration:

- The ASA component worked well to locate plausible areas for construction.
- The AFL component worked well for laying out a runway with the plausible areas.
- The AFL component did not accurately calculate the cut/fill requirements as it assumes a zero slope to the runway.
- The ENOps component worked well to estimate the total construction time when given accurate cut/fill volumes and a more accurate description of the construction technique. Given those values, the estimate would have been only 29 hr different, or 17% of the actual duration.
- The data transfer component was successful at clipping data from a large AOI and making these data accessible to various applications such as the nDView.

5 JRAC Technologies Demonstrated

Rapid assessment vehicle – engineer (RAVEN)

The RAVEN is a small 4-wheel drive vehicular platform that houses a number of the JRAC technologies. It consists of a Bobcat Toolcat vehicle with several modifications and additions as seen in Figure 20. The vehicle is intended to provide all of the tools and capabilities necessary to conduct a technical engineer assessment as well as to provide the capability for design and quality assurance during contingency airfield construction projects.

Figure 20. RAVEN with automated DCP attachment.

There are two primary workstations on the vehicle, both with a Panasonic Tough Book computer. One is in the cab of the vehicle, and the other is located in the utility box on the back of the vehicle. These workstations are equipped with all of the necessary software to conduct technical engineer operations for survey, design, and soils analysis.

The utility boxes on the rear of the vehicle provide storage for the JRAC RTK GPS equipment and power generation via a diesel generator. The rapid soils analysis kit (RSAK) and the rapid quality assurance kit (RQAK) are also stored in the boxes in the rear of the vehicle and are described later in this chapter. The workstation on the rear of the vehicle also houses the components of the TeleEngineering Communications Equipment – Deployable (TCE-D). This system allows the user to communicate via secure satellite transmissions all of the critical information being obtained. The utility box on the back of the vehicle can also be separated from the vehicle via four electrically operated jacks, which provides simultaneous use of the vehicle and the soils analysis/quality assurance capabilities.

The automated route reconnaissance kit (ARRK) is also installed on the RAVEN. This system provides the capability to conduct tactical engineer reconnaissance and records information such as a GPS trace of the route, still images from the view of the driver, geometry of the route being driven, and location of critical facilities (bridges, intersections, etc.).

The prototype RAVEN offers several implement attachments that can be used on the front of the vehicle. The vehicle accepts standard attachments which also fit the more common skid steer loaders already present in many of the U.S. military equipment fleets. Currently, the RAVEN comes complete with a bucket, extended forks for lifting pallets, and an automated dynamic cone penetrometer (DCP).

Automatic dynamic cone penetrometer

The automated DCP allows a soil strength test to be conducted automatically from inside the cab without human interaction. The test results are displayed and stored on the computer located inside of the vehicle. The DCP attachment consists of a standard DCP inside a device which mechanically lifts and drops a hammer by using the auxiliary hydraulics on the front of the machine. This is advantageous as the DCP components can be easily replaced with standard and readily available parts in the event that damage occurs to the penetrometer. Sensors on the side of the device accurately measure the penetration of the cone after each blow as well as the location of the hammer. This process is automatically controlled by software on the laptop in the cab of vehicle and eliminates the need for any post processing of data as with other methods. The automated device provides an efficient way to conduct DCP tests by reducing the personnel requirement to one soldier, eliminating the physically demanding aspects of the manual method, and providing instantaneous results in a safe environment.

The RAVEN is also equipped with autonomous controls which allow the vehicle to be operated from remote locations via a joystick, radio network, and a series of cameras mounted onboard. The vehicle can also be controlled by the onboard computer and software in a completely autonomous mode, effectively requiring no human interaction. This type of operation will allow the vehicle to conduct such tasks as surveying a large area with detailed coverage, conducting multiple DCP tests in an open and unsecured environment, or sweeping a large runway to eliminate debris with precision and minimum human interaction.

Rapid soils analysis kit

An accurate and expedient means to determine the soil classification is essential to establish design criteria for rapid airfield construction using the in situ soil. Under a contingency design and construction scenario, only a few hours are available to accumulate necessary soils data. Until now, only subjective field analysis techniques (USACE, FM 5-410) satisfied this requirement. These results fail to provide tangible numerical data that can be used to establish the necessary construction criteria for an airfield. To address this need, a small-scale field laboratory following a stepwise procedure, the RASK, was developed for the JRAC program (Berney 2008). The RSAK is the starting point to any on-site contingency design to provide the best estimate possible of initial moisture and density requirements for field construction.

The field kit consists of laboratory quality testing instruments that include a microwave, electric balance, sieve shaker, sieves, grinder, plastic limit tool and necessary bowls, spatulas and scoops to handle the material (Figure 21). These instruments provide a measure of soil moisture, grain size distribution (GSD), and plastic limit (PL). Numerical data generated from these soils tests are input directly into a software program that calculates a soil classification using linear regression to convert PL into plasticity index, PI. Using the soil classification, PI and GSD, the software program uses linear regression routines based on an extensive database of soil properties to estimate optimum moisture content (OMC) and maximum dry density (MDD). Built-in higher order regression equations allow the user to visualize complete curves for Proctor density, as-built CBR and soaked CBR for the constructed condition of the soil of interest. The Proctor curve and probable CBR strength data are necessary to establish design criteria for rapid airfield construction.

Figure 21. Rapid soils analysis kit field equipment.

Moisture contents taken from in situ soil samples establish baseline moisture requirements. DCP data points taken at random locations within the area of interest provide baseline CBR strength data. Initial CBR strength data can determine the structural conditions at the site of interest and whether conditions need modification or are satisfactory. If improvement is necessary at the site given insufficient in situ CBR, conducting the rapid soils analysis will allow the soldier to estimate the potential CBR increase occurring from soil compaction. The complete Proctor curve tells the soldier the water and mechanical effort requirements to bring the in situ soil to a satisfactory CBR strength condition and the compaction tolerance allowed during construction. All of this information can be established within the first few hours of arriving at a site and provides the soldier a level of construction information far superior to that previously available, which was no construction data.

Packaging

The RSAK is delivered to the field in one of two ways. In its initial conception, the RSAK was packaged in defined locations on a utility box designed to fit on the back of the RAVEN (Figures 22 and 23). This provided a portable platform along with other key components of site investigation critical to the JRAC mission success such as a DCP and GPS coordinate identification. The RAVEN is equipped with a diesel generator and built-in 110 V power strips to power the various tools in the RSAK.

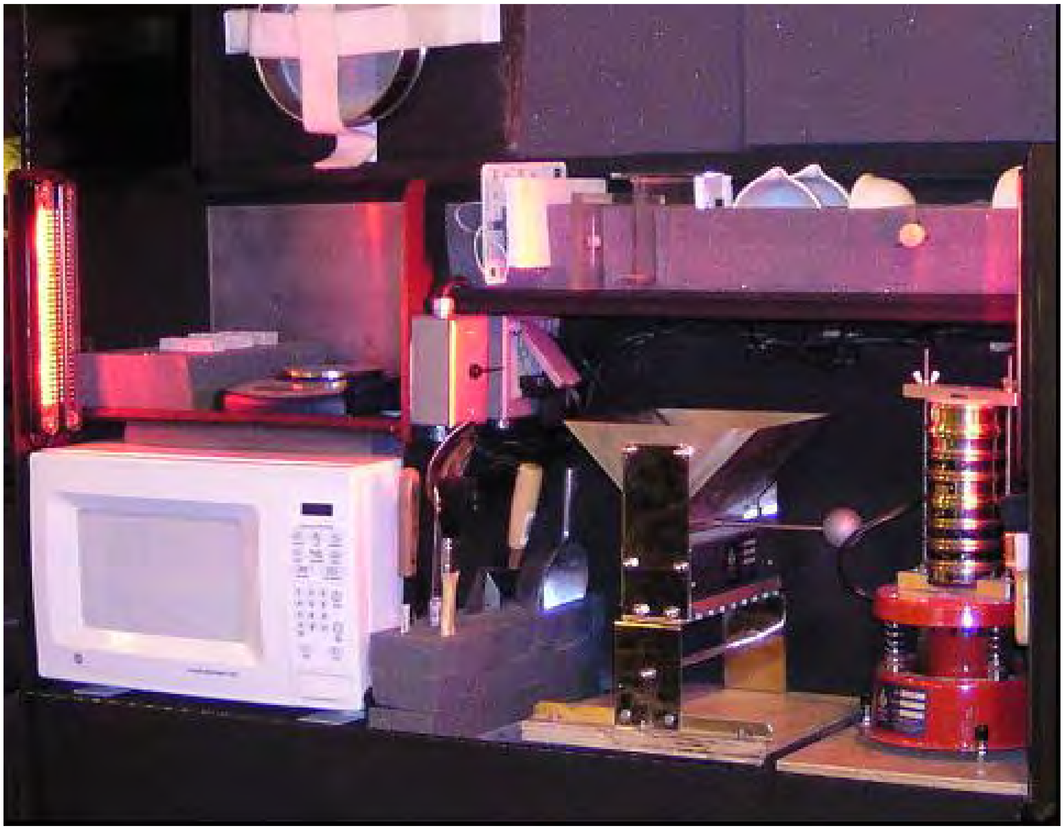


Figure 22. RSAK mounted on the RAVEN prior to 2004 JRAC demonstration.

The kit is also available as a stand-alone kit repackaged in a pair of Pelican cases that enabled the kit to be portable in any vehicle (Figure 24). Each case weighs approximately 34 kg (75 lb). The only component critical to the portable kit's success not included in the Pelican cases is the availability of a power source to run the microwave, sieve shaker, and coffee grinder.

Software

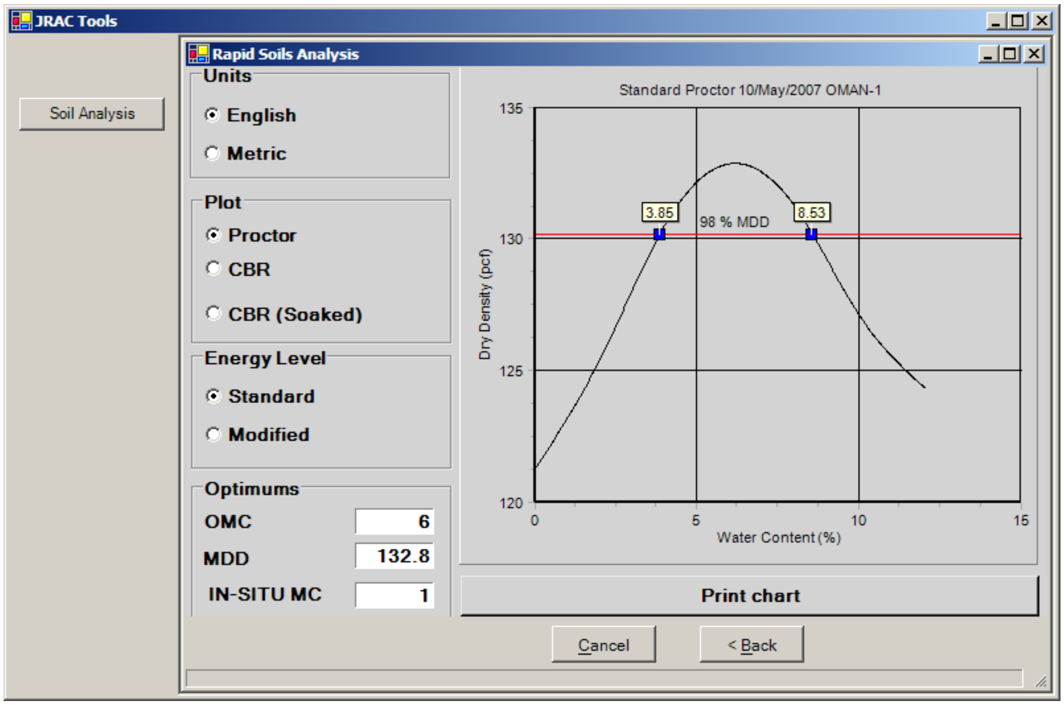
To provide a tool for rapid soil classification, a coupling between the regression model and the field instrumentation suite is required. A software package was developed which prompts the user to input field measurements in a systematic format. After completing data inputs over a sequence of screens, a USCS soil classification is returned. The user can then generate the desired construction plots, the Proctor moisture content-density, and CBR-moisture for one of four combinations: modified or standard Proctor energy and soaked or unsoaked CBR.

Figure 23. RSAK remounted on RAVEN in use during 2007 JRAC demonstration.

Figure 24. RSAK packaged in two large Pelican cases (2-man carry).

After classifying the soil, the program uses the sieve percentages and PL data to compute the OMC and MDD and then couples that information with the USCS to define a complete Proctor curve. A similar procedure occurs for the CBR value, taking into account the estimated OMC and MDD in addition to the real data collected in the field.

The program displays the computed construction curves in a simple GUI run by a series of radio buttons allowing the user to toggle between Proctor, CBR, and soaked CBR curves at standard or modified energy (Figure 25). The soil plot routine calculates and displays the MDD and the OMC for a desired energy level, standard or modified. Further, the program calculates and displays the desired Proctor curve (standard or modified) and associated CBR plot (soaked or unsoaked). The program further calculates a line at 98% MDD to show the allowable range of moisture content wet and dry of optimum to achieve the specified density or strength requirements. The program also displays the in situ moisture content of the field site.



Units
● English
○ Metric

Plot
● Proctor
○ CBR
○ CBR (Soaked)

Energy Level
● Standard
○ Modified

Optimums
OMC 6
MDD 132.8
IN-SITU MC 1

Figure 25. Screenshot of construction design curves from RSAK.

Rapid quality assurance kit (RQAK)

Military engineering projects across the world are often plagued with quality problems which significantly add to the overall timeline and affect the expected outcome of the constructed facility. This is primarily due to a lack of rapid, easy-to-use procedures as well as the forced timelines that are so common with contingency construction. With the introduction of the C-17 aircraft, which is almost three times the weight of the C-130 and has higher tire pressures, there was an urgent need to provide solutions that would guarantee quality in semi-prepared pavement construction.

As part of the JRAC program, ERDC researchers developed a set of procedures that would address the unique challenges of quality assurance encountered during contingency airfield construction (Freeman et al. 2008). Relative to private construction and Department of Defense civil construction projects, quality assurance for JRAC operations is unique in that the owner and the contractor are the same entity, that is, the U.S. military.

The JRAC quality assurance program includes the necessary precautions for ensuring adequate compaction and it includes rapid, low-logistics materials testing for remote or contingency environments. The products include a RQAK packaged in two field cases as well as guidance for test procedures, testing frequencies, data reduction, and construction decisions (Figures 26 and 27). The physical components of the kit are considered an augmentation of the RSAK described earlier and can be used in a stand-alone environment from the cases (power supply is required) or stored in the compartments onboard the RAVEN (Figure 28). The primary components of the RQAK are as follows[1]:

1. ***Moisture content determination test***. The standard microwave test procedure (ASTM D 4643) is used for measuring the moisture content of soil. This test is used when determining the dry density of soil as well as controlling moisture content during construction. This test is also an integral part of the RSAK and, therefore, takes advantage of the physical equipment and software capabilities of the RSAK.
2. ***Steel shot density test***. A volume replacement method was developed for measuring the in-place density of soils. This test method is a hybrid between the sand cone method (ASTM D 1556) and a simpler sand replacement test (ASTM D 4914). The steel shot density test, which involves 3/16-in. stainless steel balls, is fast, easy, and sufficiently accurate. The equipment required to perform this test is included in the RQAK.
3. ***Dynamic cone penetrometer (DCP)***. The DCP (ASTM D 6951) is used for estimating the strength of soil. An automated version of the DCP was developed under the JRAC program and is mounted on the front implement of the RAVEN (Figure 20). The DCP device is automatically controlled via the software program included in the onboard laptop and instantaneously displays a plot showing CBR vs. depth. The files

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[1] A more comprehensive and detailed list of the RQAK components and procedures can be found in Freeman et al. (2007).

Figure 26. Rapid quality assurance kit (RQAK) field equipment (Box 1).

Figure 27. Rapid quality assurance kit (RQAK) field equipment (Box 2).

Figure 28. RQAK mounted on the rear of the RAVEN.

containing the test data with GPS location are also stored on the laptop for later analysis or reference. The manual version of the DCP is a standard piece of equipment in most military engineering units and can be used in the absence of the automated version. Standard procedures for reducing DCP data and converting these data quickly to CBR are included in the RQAK.

4. ***Clegg hammer***. The Clegg hammer (ASTM D 5874) is used for estimating the strength of cement-stabilized layers (with or without fibers). Two equations are used for converting Clegg impact value (CIV) to unconfined compressive strength (UCS) in units of pounds per square inch:

$$\log(UCS) = 0.081 + 1.309 \cdot \log(CIV)$$

$$UCS = 12.51 \cdot (CIV) - 285.9$$

The first equation is conservative and the second equation provides estimates of likely values. Together, they provide a range of probable unconfined compressive strengths. These equations are limited to CIVs that are greater than or equal to 32, which corresponds to a UCS value of approximately 100 psi for both equations (the difference between UCS estimates increases with increasing CIV). Due to its simplicity and speed, the Clegg hammer is also recommended as a backup tool for estimating the strength of soil. The recommended equation for converting CIV to CBR (%) is:

$$CBR = 0.05 \cdot CIV^2 + 0.53 \cdot CIV$$

This equation is limited to CIVs less than or equal to 40, which corresponds to a CBR of approximately 100%. The Clegg hammer is included in the RQAK as shown in Figure 28 and is explained by Freeman et al. (2008).

5. ***Guidance on test strip construction.*** The JRAC compaction procedures used are highly dependent on the results of a compaction test section. The test section serves several purposes, among which include identifying the optimum number of compactor coverages and obtaining target material properties. This process involves the Clegg hammer as the primary tool and the steel shot density test as the secondary tool. Guidance for how to properly construct a test strip is included as part of the RQAK.
6. ***Guidance on JRAC testing frequencies.*** For convenience and simplicity, the lot size for JRAC operations is flexible and is defined as being as close to 500 yd^2 as possible and preferably between 400 and 600 yd^2. Smaller lots are allowed to prevent a lot from including more than one day's placement. Testing includes moisture content, density, smoothness, and Clegg hammer.
   a. Four moisture contents are required for each lot to ensure that the compaction is accomplished near OMC. The average moisture content must be from -1% to +2% of the target OMC and no single measured moisture content can be outside of the range -2% to +3% of the target OMC.
   b. Due to the Clegg hammer test's simplicity and speed, 20 tests are required for each lot. The Clegg hammer is the primary device for ensuring quality and consistent construction in a JRAC operation. Warning and action limits are established for both the mean value and the lower tail of the distribution of Clegg hammer results. The warning and action limits are based on results of the compaction test section. The mean comparison ensures adequate central tendency for a lot. The lower tail comparison ensures that that there are no exceptionally weak areas within the lot.

c. Density tests are time consuming, so a stepwise approach is recommended where as few as two tests may be required for each lot. Warning and action limits are established for both the mean value and any single test, based on results of the compaction test section.
d. Smoothness testing is conducted with a 12-ft straightedge wherever smoothness appears to be questionable. Deviations from the straightedge in excess of 3/8 in. shall be corrected by removing material and replacing with new material, or by reworking and recompacting existing material.

Soil stabilization equipment and materials

Some existing soils and aggregates may not be appropriate for use in all contingency airfield construction projects, or they may have unfavorable characteristics such as moisture susceptibility, low strength, or durability. Soil stabilization is used to improve the engineering properties of unfavorable soils. JRAC soil stabilization efforts have focused on reducing the amounts of conventional soil stabilizers to ease logistical requirements while attempting to improve performance. JRAC efforts utilized fibers with other stabilizing agents (such as portland cement) to improve the stabilized soil performance and reduce cracking, which, for airfield applications, minimizes foreign object damage (FOD) problems.

The fibers used are 19-mm (3/4-in.) monofilament fibers with fast-setting (Type III) cement. The monofilament fibers and cement can be efficiently mixed with a single pass of the pulvermixer to a depth of 150 mm, which is important for maximum construction speed in contingency environments. As the soil begins to move under loading, the fibers are brought into tension, adding strength to the soil. The fibers also help prevent cracking of the soil under loading and shrinkage during curing and drying. The same types of fibers are often added to concrete to help minimize shrinkage cracking and enhance flexural strength.

The fiber cement stabilized soil using the JRAC methods of low dosages of cement do not result in a durable soil. The stabilized soil is susceptible to loss of strength due to excess moisture and must be protected from precipitation. This is accomplished by a surface seal or cap of polymer emulsion applied to the structure. Polymer emulsion forms a tough, waterproof film over the soil surface that also provides a dustproof wearing surface. This film, however requires reapplication as needed due to wear.

Reclaimer/stabilizer machine

In order to achieve proper stabilization of soils and aggregates, thorough mixing of the stabilization agents and the soil is critical. The equipment used to conduct the mixing plays a critical role in the stabilization process. Currently, the U.S. Army units responsible for airfield construction do not have equipment to provide this mixing capability.

The research conducted by the JRAC program on mixing equipment was divided into two parts: the selection of the type of mixer required and a comprehensive study of the mixing capabilities of the machine with different stabilizing agents (fibers, liquid polymer, and portland cement), to include the evaluation of the quality of the in situ mixing and spray distribution of the stabilizing agents.

The first task in this effort was to select a self-propelled reclaimer/stabilizer machine, equipped with a suitable rotor that could be used for asphalt reclamation and soil stabilization. The JRAC program requirements mandated that the geometry and weight of the machine be compatible with C-130 aircraft to allow for intratheater transportability. Investigations of the equipment market revealed that the CMI/Terex RS-325B Roto-Mixer (hereafter referred to as the pulvermixer; Figure 29) was the only machine that would meet the size and weight

Figure 29. CMI/Terex RS-325B Roto-Mixer (pulvermixer).

restrictions and still have the performance characteristics to achieve the rapid stabilization objectives. After a successful trial period, ERDC purchased the machine in order to conduct further evaluation and to use it in the JRAC demonstrations. Test trials also demonstrated that carbide teeth (versus paddles) are sufficient for mixing a wide variety of soils and also allow for the pulverization of asphalt or rocky soils. The characteristics of the machine are listed in Table 3.

Table 3. CMI/Terex RS-325B (pulvermixer) characteristics.

Machine Specifications	
Engine	340 HP Cummins QSC8.3L Diesel
Dimensions	
Height	297 cm (9 ft 9 in.)
Length	716 cm (23 ft 11 in.)
Width	224 cm (8 ft 1 in.)
Weight	15,438 kg (35,600 lb)
Ground Clearance	488 cm (16 in.)
Drivetrain	4×4 with traction control Four-wheel steering High and low travel speed
Fuel Capacity	511 L (135 gal)
Acceptable Substitute Fuels	No. 1 and No. 2 diesel No. 1K kerosene Jet A and Jet A1 JP 5 and JP 8
Cutter	Heavy duty 198 cm (6 ft 3 in.) reclamation pulvermixer cutter with doweled tool holders Rotary-hydraulic drive-drum type 2 Speeds (Low-reclamation and stabilization) (High-mixing) 488 cm (16 in.) maximum mixing depth
Cutter Teeth	96 Carbide tipped (replaceable)
Liquid Proportioning System	
Pump	Gorman-Rupp centrifugal pump - 200 gpm (minimum 2-in. inlet hose)
Spray Bar	10 spray nozzles (20 gpm each) mounted on cutter housing
Optional Equipment	
Ground Speed Gauge	Measures ground speed in feet per minute or meters per minute
Flow Meter Gauge	Measures liquid flow in gallons per minute or liters per minute
Automated Liquid Proportioning	
Manual Mode	Operator controls pump output with manual knob
Auto Mode	According to ground speed operator enters desired gallons per square yard and pump output is controlled
Liquid Supply Truck	
Truck	2-ton Ford flat bed
Tank	1,025-gal agricultural tank with 2-in. outlet

The pulvermixer was used extensively during the JRAC program to assist in test section construction for stabilization research, and it was used by the military as an integral part of both JRAC demonstrations. A comprehensive set of tests was also carried out to determine the mixing characteristics of the machine with the various stabilizing agents used in the JRAC stabilization process.

The capabilities of the machine include 4-wheel drive with traction control, 4-wheel steering with 4 steering modes, high speed travel, excellent visibility, and a wide variety of cutter options. The main feature is a rotary hydraulic drive-drum capable of operating at two speeds (Figure 30). The cutting rotor is composed of 96 carbide tipped teeth and offers a maximum cutting/mixing depth of 40 cm (16 in.).

Figure 30. Carbide teeth of the CMI/Terex RS-325B Roto-Mixer (pulvermixer).

The ERDC also purchased the liquid proportioning system from the manufacturer. This automated system includes 10 spray nozzles located in the cutter housing, each with a capacity of spraying liquid at a rate of between 150 and 760 L/min (40 and 200 gal/min). The system includes a metering device and control box (Figure 31) which the operator can easily use to the control the rate of application. This feature proved to be very useful when the stabilization process involved the use of liquid polymer; also the feature is very accurate when modification of moisture content in the soil is required.

Figure 31. Control box for the liquid proportioning system.

Airfield matting

One of the primary goals of the stabilization effort in the JRAC program was to identify suitable matting products that could be used to rapidly expand aircraft parking capacity. These matting products must be strong enough to support the aircraft loads (C-130 or C-17) over low-strength soils and must also be logistically attractive compared to current methods (e.g., AM2 mat). Several rounds of testing and evaluation on commercially available matting were conducted in order to identify solutions for the C-130 and C-17 aircraft (Anderton and Gartrell 2005; Gartrell 2007). The ACE Mat was chosen as having the best characteristics of portability, function, and construction. Although not used on any of the airfield surfaces during the 2007 demonstration, a sample installation of ACE Mat was installed on the helipad to demonstrate the easy-handling characteristics and effectiveness of the product.

The primary application for this mat is parking and taxi aprons for contingency airfields, extensions or temporary additions to existing airfields, temporary helipads, and equipment storage pads. ACE matting is a lightweight matting system composed of square fiberglass-reinforced panels. The mat was originally developed for expedient road construction over soft soils (CBR range of 1 to 10). However, the mat has also been demonstrated to be durable enough for C-130 and C-17 aircraft loads for medium-strength (>CBR 10%) soils and as FOD covers for high-strength soils. It is not recommended for use as a landing or take-off surface for fixed-wing aircraft. The mats are constructed such that any interior mat in a system can be easily released, removed, and replaced. The mats can be secured along the outer edges using any of a number of anchoring systems including deep rebar stakes, duck-bill cable anchors, large railroad spikes, or u-shaped picket stakes.

ACE Matting Systems consist of square mat units measuring 2.03 m (80 in.) long and wide with a thickness of approximately 8.9 mm (0.35 in.), and each mat weighs approximately 52 kg (115 lb). A single mat provides 3.34 m^2 (36 ft^2) of usable surface area (Figure 32) and the mats have an indefinite storage life. They can be easily moved and placed by two average-sized men. Once in place, the mats are connected using manufacturer-supplied bushing-style pins that are tightened down with a standard wrench and Allen-head socket (power drills may be used to expedite the process). The site preparation required before placing the mats is minimal, typically accomplished by light grading and compaction to ensure the surface is flat. The area under the mats must be free of foreign objects and debris and should be compacted prior to placement of the mats. Additional mats and pins can be stored on-site and used to replace any mats or pins damaged during operations.

Figure 32. Placement of ACE matting.

6 JRAC Earthmoving and Monitoring System

Introduction

Regardless of which supervisory level is responsible for monitoring construction progress, each is confronted with the need to interpret a great deal of data in order to gain an acceptable understanding of the status of the project and to make informed decisions. In the case of constructing or upgrading an Aerial Port of Debarkation (APOD) for early entry operations, multiple echelons of the command structure will have an increased interest in the construction progress since it impacts the APOD's capability and throughput. Construction must be fast, producing a structurally sufficient facility that will support the mission requirements. The traditional means of monitoring construction progress are very subjective and are validated at the end of construction by an airfield inspection team prior to landing an aircraft. In many ways, the traditional methods rely on accurate manual reporting, which only comes with experience.

The JRAC program focused significant effort on solving this problem by taking advantage of emerging technology in the earthmoving and construction industry. Early efforts involved evaluating GPS construction systems for use by the U.S. military (Tingle and Mann 2001) and building relationships with industry partners to ensure they considered the needs of the military during product development. JRAC's primary industry partner in enhanced construction, Caterpillar Trimble Control Technologies (CTCT), provided an unprecedented capability during the 2007 demonstration through advancements in machine control technology, and by combining the capabilities of several systems from the mining and earthmoving industries to satisfy the requirements of the JRAC program and ultimately, the U.S. military.

Equipment description

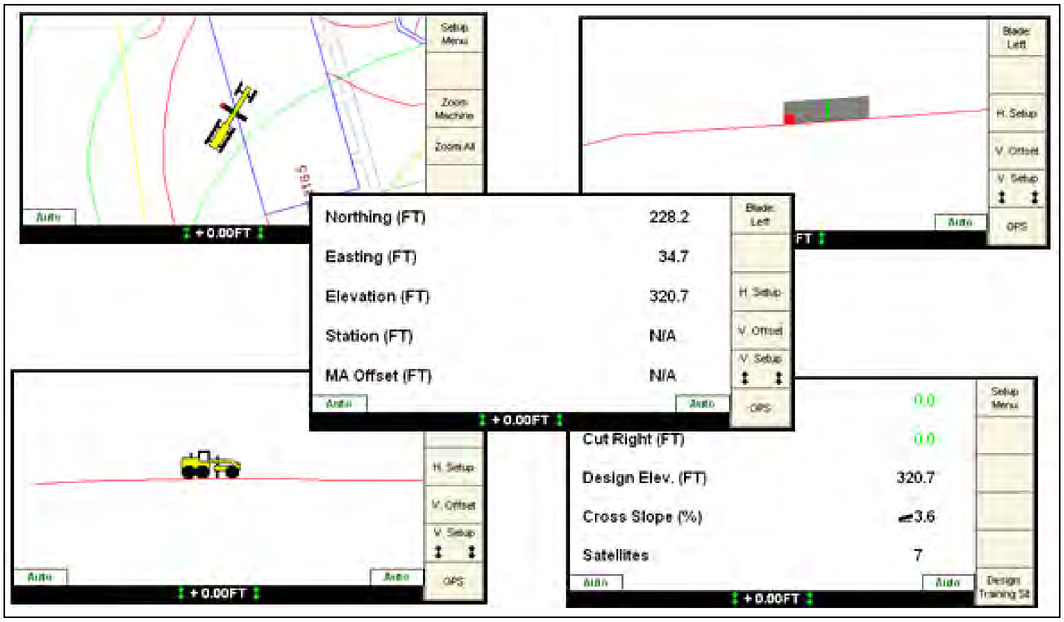
The 2007 JRAC demonstration included the use of 22 machine control systems and represents the first time that such a large number of systems have been used on a single project. The grade control systems came from two of the industry leaders in machine control technology: Trimble Navigation, Ltd. and Caterpillar Inc. Trimble's GCS 900 and Caterpillar's Accugrade products are essentially comprised of the same components;

however, the Trimble product is installed on after-market machines whereas the Caterpillar product comes installed on the machine from the factory. These grade control systems provide RTK GPS automated blade control capabilities to most construction machines available on the market. Currently, the system uses an industrial grade 900 MHz two-way radio to communicate between the office computer, base station, and the machines. The only significant feature not provided by these systems was an ability for operators to see the location of other machines on the display mounted in the cab.

The instrumented construction equipment included 6 dozers, 6 graders, 5 scrapers, and 5 compactors with the basic grade control system components illustrated in Figure 3. The dozers and graders had dual GPS receiver systems with one mounted on each corner of the blade, while scrapers and compactors had single GPS receiver systems to monitor the elevation of the cutting edge of the bowl and bottom of drum, respectively.

The operator display located in the cab of the machine displayed the machine’s location relative to the design and continuously provided the equipment operators with a visual display that shows the physical difference between the current elevation and the finished design elevation for the specific location of that piece of equipment. Several of the screen views available to the operator are shown in Figure 33. By providing machine locations relative to the project site for each piece of equipment, operators are constantly aware of project boundaries and earthwork geometry without having to rely on grade stakes. This method of construction can greatly reduce the risk of construction errors, thereby increasing the overall efficiency of the earthmoving operations.

The grade control systems used during the JRAC 2007 demonstration increased the speed of construction, improved operator efficiency, and eliminated the need for the labor intensive task of construction grade staking. The systems enabled multiple construction machines, varying by type and make, to work efficiently within 40 mm (1.5 in.) of accuracy and without surveyors constantly placing construction grade stakes. Operators, experienced to inexperienced, provided positive feedback on the improvement of their individual level of workmanship when operating different construction equipment.



Northing (FT) 228.2
Easting (FT) 34.7
Elevation (FT) 320.7
Station (FT) N/A
MA Offset (FT) N/A

0.0
Cut Right (FT) 0.0
Design Elev. (FT) 320.7
Cross Slope (%) 3.6
Satellites 7

Figure 33. Display views available to the operator.

Construction monitoring

A requirement of the JRAC construction system is the ability to monitor the progress of the earthwork in near real-time in order to improve the situational awareness of the project supervisors. This project used a prototype version of Trimble's Site Vision Office (SVO), which included a production monitoring capability. SVO's major capabilities include the following:

- 3-D design import
- 3-D model checking
- Limited geometric design capabilities
- Wireless design upload to construction machines
- Monitoring of radio links and design files being used
- Consolidated equipment tracking
- Cut/fill map showing earthwork progress.

A screenshot of SVO near the completion of the runway construction is shown in Figure 34. The left side of the screen lists the designs that are currently being used. The center portion displays color-coded rendering of the cut/fill requirements and position of equipment relevant to the extents of the view. The right side of the screen view lists the equipment pool, the radio link status, and the active design being used by each machine.

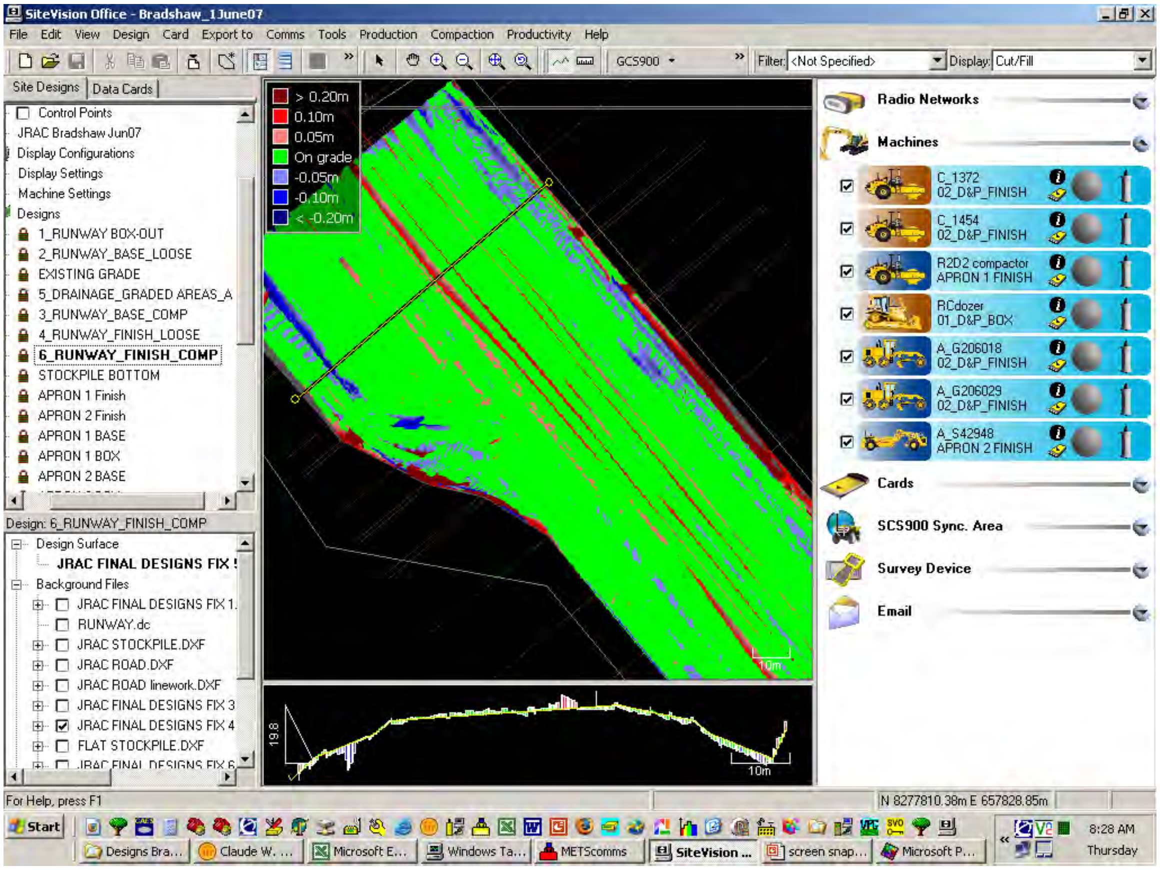


Figure 34. Site Vision Office's as-constructed elevation map.

The prototype version of SVO included a production server that processed machine elevation and position data to provide a latent cut/fill map to show the status of the project. The cut/fill map rendering had various and significant update latencies; however, machine locations were represented near real-time. These latencies were a result of radio and software limitations of the prototype version and are not expected to be an issue in the commercially releasable version of the system.

Overall, the SVO application, including the production server and cut/fill mapping, performed very well. The application was utilized extensively throughout the project to update design files and monitor cut/fill progress. The production monitoring feature provided a very useful way for supervisors to develop an instantaneous visual status of the project without physically inspecting the entire site. Because supervisors could easily see the location of all 22 machines instantaneously, they actively integrated the application into their management process. Supervisors used the information to help adjust work effort and synchronize follow-on tasks. On multiple occasions, instructions were radioed to ground supervisors based on data displayed on the office computer. The only complaints stemmed from the confusion associated with the latent reporting of data. The supervisors collectively described the tool as very beneficial; however, they also requested that it be real-time and portable so that they could have it with them as they walked around on the site.

Caterpillar's intelligent compaction and remote control D8T

Caterpillar, Inc. participated in the demonstration by providing two emerging capabilities that are sure to greatly impact the construction industry. Five CS 563 rollers were instrumented with the newly-released intelligent compaction system, and a D8T bulldozer was instrumented with remote control features. The rollers and D8T dozer provided the capability of real-time performance monitoring by displaying the machine information in the nDView application, as illustrated in Figure 35. Both systems were successfully demonstrated and provided a glimpse of the future of the construction industry.

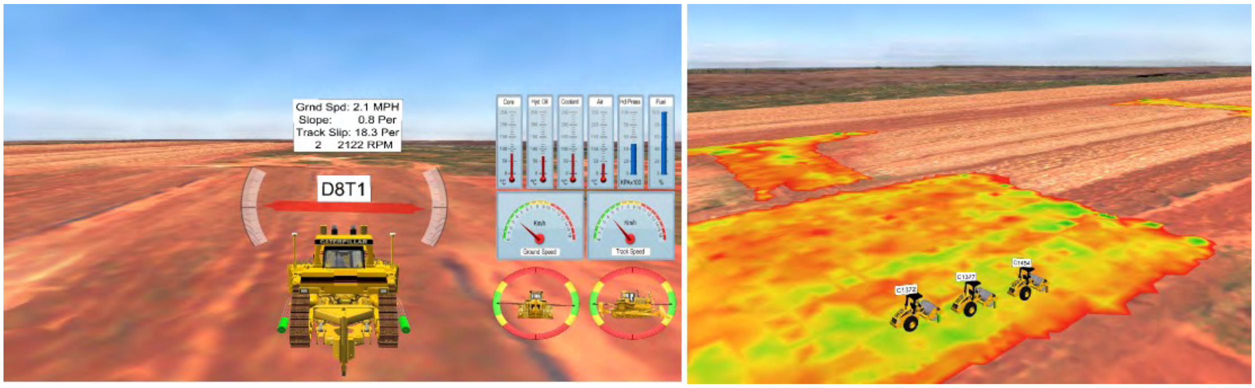


Figure 35. 3-D, real-time augmented reality view of the jobsite.

Intelligent compaction

The intelligent compaction system uses accelerometers mounted on the drum of a vibratory roller to measure response in soil behavior during compaction operations (Newman and White 2007). The intelligent compaction system is integrated with the Accugrade GPS system and provides all the functionality of the grade control systems mentioned previously, plus additional information such as gear engaged, ground speed, number of passes, compaction value, drum amplitude, frequency, and the energy return from the ground surface.

The intelligent compaction system provides two methods to assist in the compaction management process. First, it keeps track of the number of passes that the machine makes over any one spot, and displays this information for the operator in the cab of the machine. The desired number of passes can be programmed into the display and a color-coded map shows the progress and helps the operator ensure adequate and efficient coverage. Secondly, the system provides a compaction meter value (CMV) from the onboard measurements, and displays this information in a color-coded map as well. Although efforts to correlate this value with density have been problematic, the information can be very useful in the quality control/ assurance process by identifying weak areas and also preventing overcompaction by identifying areas of high energy return.

Remote control D8T

The remote control dozer was developed as a line of sight (LOS) platform to improve operator safety when working in areas of life threatening conditions for the mining industry. For this demonstration, the remote controlled D8T was used only to assist with tree clearing operations to introduce the soldier to the technology. There are numerous military applications for this type of technology, which essentially eliminates the dangers of exposure to human operators that are physically located on the machine.

The remote control harness, shown in Figure 36, provides all of the controls for an operator to drive the machine, just as if they were in the cab. The D8T is an electro-hydraulic machine, allowing onboard machine data to be easily extracted for remote viewing, including tractor roll and pitch percentages, gear, RPM, ground speed, track speed, track slip, core temperature, hydraulic oil temperature, coolant temperature, ambient air temperature, and hydraulic pressure.

Operators were most comfortable operating to the side and near the front of the machine in order to see the conditions as the blade loaded. The stand-off distance was varied from near the front of the blade to approximately 100 m away. As the distance increased, the LOS visual and audible parameters used to control the machine changed. Up close, control was mostly contingent on the blade loading conditions and slip. At greater

Figure 36. Caterpillar's dozer remote control harness.

distance, the more informative blade conditions were less obvious and the operator had to use his perception of the blade with tractor tilt and pitch to determine his response actions. Later in the exercise, an operator used the machine by observing a computer, augmented by LOS observations.

Jobsite communications

The 22 grade control systems transmitted data through the GPS base station access point radio to a project computer, which was co-located with the site office tent on the airfield (triangle 1 in Figure 37). Once the information was on the project computer, SVO processed and consolidated all of the machine information and presented it for viewing. SVO was then used by the supervisors and surveyors to help manage the construction process. The processed data were also directionally transmitted to the base camp tactical operation center (triangle 2 in Figure 37), using AFAR Ethernet bridge radios, and then routed through the commercial satellite network to a designated server in the United States.

The AFAR radio provided a valuable asset to the jobsite communication network. Its ability to transfer a large volume of data over significant distances became a critical enabler between the headquarters and the jobsite supervisor's operating center. Although the radios were only separated

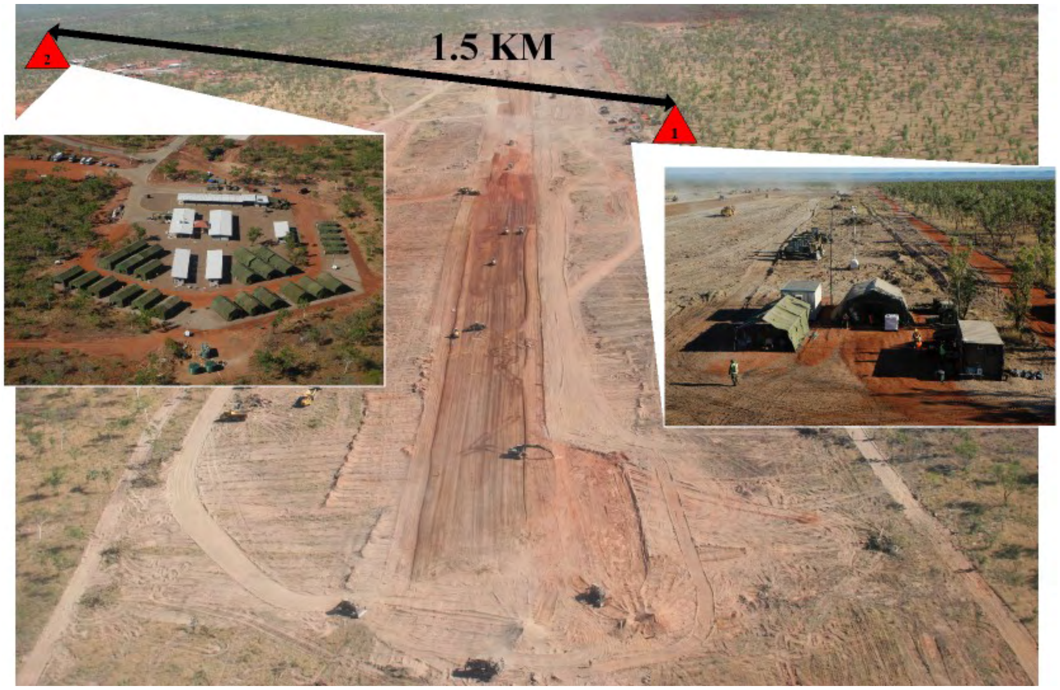


Figure 37. Communication access points.

by 1.5 km during this exercise, they were capable of operating at LOS distances of up to 80 km. These radios were easy to install and experienced no malfunctions during the operation. At the time of the exercise, the radio was being evaluated for military certification. If required, this radio could be a valuable asset to link sites within an area of operation, which would minimize the number of satellite systems at each site.

The intent of the commercially leased satellite broadband system was to stream real-time data from the jobsite to rear locations for remote monitoring, and to demonstrate the connected jobsite. In order to accommodate the data requirements and support control and performance monitoring of the jobsite, the system should have a 512 kbps upload speed at a 2:1 contention ratio. Although the system was properly sized, the service only provided a 10:1 contention ratio, which limited the data throughput for most of the exercise. By adding a satellite communication link, machine control or performance monitoring could be observed remotely from anywhere in the world. The system support requirements are shown in Figure 38.

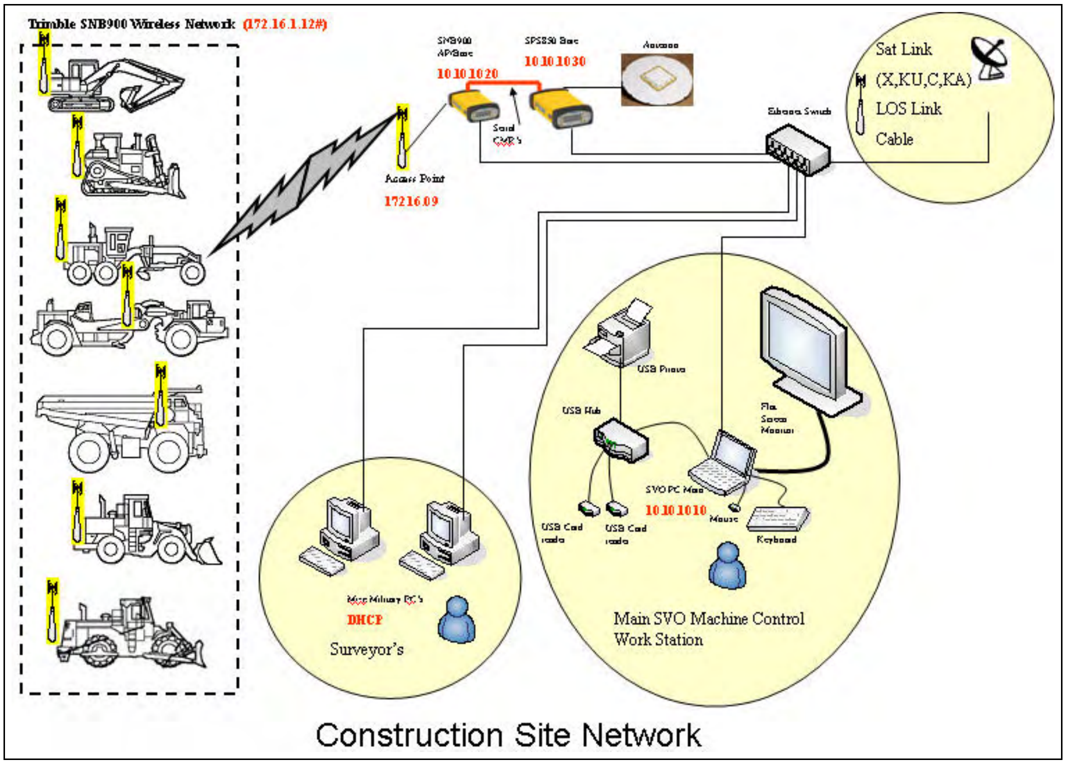


Figure 38. Jobsite communication configuration.

The construction site's wireless network incorporated Trimble's GCS 900 grade control and Caterpillar's real-time control and performance systems together, without creating performance issues. The system successfully integrated 22 construction machines working simultaneously to provide automated blade control and position reporting. The most significant problem occurred with data backlogging on the individual machines. When backlogging of data started, the machines would lose their data link and subsequently their GPS accuracy, while the base station was being overloaded with data. Once gridlock occurred, neither GPS correction nor supervisory monitoring was possible from the site office. The Cat/Trimble support team determined that the base station firmware had programming glitches, and this problem was reported and quickly corrected by the product development team. Once updated, the entire grade control network worked flawlessly for the remainder of the project. The only other notable problem occurred as one particular satellite entered into the constellation of satellites over the jobsite causing a temporary GPS reception failure. This was eventually diagnosed by identifying the time of occurrence related to the satellite group. The supervisors planned for the next occurrence and continued work with little hindrance to the overall operation. All in all, the RTK GPS grade control radio system met its design intent to provide GPS correction, ruggedness, and surface data reporting.

Conclusion

The integration of enhanced construction systems, such as those used in this demonstration, provides a distinct advantage to any airfield construction project by dramatically increasing the project efficiency and by reducing the timeline and the resource requirements. The systems used in this project clearly demonstrated an improvement in operator efficiency, enhanced situational awareness at multiple levels, and the ability to conduct remote and autonomous operation of construction machines.

All of the systems performed well throughout the duration of the project. Supervisors and operators adequately grasped the basic technical aspects of the survey and grade control systems, indicating that the training was sufficient. As user involvement and understanding increased over the life of the project, the ability to troubleshoot the various problems inherent to these technologies dramatically increased and further improved efficiency. Although there were some problems associated with data transmission using the 900 MHz radios, the problems were quickly resolved once they were identified. Due to the military's wireless encryption requirements, it is recommended that future RTK GPS systems (survey and grade control) incorporate IP (Internet protocol), Ethernet ready radios. An Ethernet ready radio will enable plug and play connectivity, allowing the industry RTK GPS system to be augmented with a military approved Ethernet radio.

This exercise also identified issues such as a lack of computer/network skills within units typically responsible for horizontal construction tasks. The introduction of GPS and wireless technologies to the jobsite will require additional skill sets in engineering units of the future. Much of the setup and troubleshooting tasks during this project were performed by the industry support team augmented by members of the survey/design team. Although grade control systems eliminate the need for manual grade staking, which reduces the survey support requirement, they by no means eliminate the need for surveyors. Military surveyors and technical engineers of the future must become proficient in these GPS and wireless technologies to ensure system reliability.

The ability to remotely monitor a construction site is an exciting concept that was highlighted during this exercise. This capability had a positive effect on the operators and supervisors alike. It allows for an improved response and decision time due to enhanced knowledge of the site's conditions through the viewing of informative real-time performance data. Incorporating a satellite communication link to the Internet allows critical construction information to be pictorially represented to higher echelons, which will improve operational knowledge and support.

7 JRAC Task Force

ERDC offered a proposal to the Concept Development Conference for Exercise Talisman Saber in January 2006 to include JRAC as an integral part of the exercise scenario. The proposal was accepted and resulted in the Executive Agent (EA) for the exercise (Commander, Pacific Fleet, COMPACFLT) authorizing the formation of a combined joint task force to execute the mission.

The JRAC Task Force was created with 219 personnel from both the U.S. and Australian militaries representing six different services. TF 660.5 or “JRAC” was the only major activity in exercise Talisman Saber located in the Northern Territory of Australia, while the other TS07 forces were located primarily on the east coast of Australia. The composition of the JRAC Task Force is listed in Table 4.

Table 4. Composition of the JRAC Task Force.

Organization	Number of Personnel
Australian Army	93
Royal Australian Air Force	17
U.S. Army	38
U.S. Navy	31
U.S. Air Force	7
U.S. Marines	33

In addition to these forces, there were also approximately 12 ERDC personnel and 12 support personnel from various industry partners who provided technical support and training throughout the project.

The JRAC Task Force consisted of personnel with various trades and specialties to accomplish the mission. The breakdown is listed in Table 5.

During the execution of the project at BFTA, the JRAC Task Force was accommodated at the Task Force Maintenance Area (TFMA) located approximately 1 km from the airfield construction site. The newly constructed TFMA consists of a 250-man Scale A camp, a 250-man satellite camp, and numerous parking and storage areas (Figures 39 and 40).

Table 5. Trades and specialties of the JRAC Task Force.

Trade or Specialty	Number of Personnel
Heavy Equipment Operator	67
Supervisors	12
Drivers	29
Maintenance Personnel	26
Cooks	9
Medics	15
Plumbers, Carpenters, Electricians	6
Survey/Soils Technicians	11
Headquarters Staff and Supply	10
Communicators	30

Figure 39. JRAC Task Force maintenance area.

This exercise was the first time the TFMA had been occupied by a sizable force and proved to be an excellent staging ground for the construction of the airfield and supporting facilities.

Figure 40. Living quarters for the JRAC Task Force.

The JRAC Task Force used construction equipment from both countries as well as leased commercial equipment. Although significant shipping delays prevented the U.S. equipment from being effective, the JRAC Task Force was able to maximize the use of on-hand equipment and meet the timelines set forth in the planning stages. The equipment used to construct the airfield is listed in Table 6.

Table 6. Equipment used by the JRAC Task Force.

Equipment Type	Quantity
Medium Bulldozer (John Deere 850J)	6
Heavy Bulldozer (Komatsu D155)	5
Medium Scrapers (Komatsu)	6
Heavy Scrapers (Caterpillar 563)	5
Motor Graders (John Deere 672D)	10
Rollers	10
Water Trucks	6
Dump Trucks	6
Excavators	2
Loaders	2
RAVEN	1
Reclaimer/Stabilizers (Terex RS 325/350)	2

8 JRAC Training

In order for the JRAC demonstration to be successful, a comprehensive training program was developed so that all the technologies and procedures could be properly employed by the military personnel during the construction. Technology that involves new procedures and equipment can be very intimidating for soldiers who have years of construction experience using traditional methods, making it critical to invest significant effort into the training and integration of the JRAC products into the construction process.

Although the majority of JRAC training took place just prior to the start of the exercise, several training events were scheduled and conducted at different locations around the world to train equipment operators on the grade control systems discussed in Chapter 6. This was done to provide equipment operators with the maximum time possible on the machines so that they would be comfortable with the operation of the grade control systems when they arrived at the project site.

Pre-deployment training (U.S. Forces)

Training on GPS grade control systems and the GPS survey equipment was provided to members of the JRAC Task Force in Hawaii in March 2007 (Figure 41). Training was conducted by professional trainers from Trimble and CTCT, and focused on three distinct groups: construction supervisors, surveyors, and equipment operators. The training schedule was developed such that surveyors were trained on the GPS survey equipment the week before the operator training so they could assist in developing digital designs required by the machines during operator training. This approach proved to be very effective and allowed the surveyors to gain additional experience troubleshooting the system during the operator training week.

Another important benefit of the training was the opportunity for the responsible unit (84th Engineer Battalion) to learn about the hardware and conduct detailed inventories of the 10 grade control systems prior to shipment overseas. This proved critical in ensuring the safe and accurate arrival of all components and ultimately led to the effective use of these

Figure 41. Operators getting “stick time” at Schofield Barracks, Hawaii.

systems during the exercise. Although effective at exposing JRAC Task Force members to the grade control systems, the training was impacted by a lack of participation from the supervisors and some operators. This was primarily due to the concurrent task of equipment cleaning in preparation for the rigorous inspection process required by the Australian Quarantine and Inspection Service (AQIS) prior to its arrival in Australia.

Pre-deployment training (Australian Forces)

Training was also conducted for the Australian JRAC Task Force members in Brisbane in April 2007 (Figure 42) with a similar training schedule to that which occurred in Hawaii. Every attempt was made to maximize participation; however, many of the Task Force members could not attend due to operational requirements. Training in Brisbane was somewhat limited due to the small training site; however, it was effective at introducing the participants to the grade control systems which had been installed on Australian equipment.

Pre-demonstration training (Combined Forces)

The JRAC Task Force arrived in Darwin, Australia, two weeks prior to the start of the exercise in order to accomplish several administrative tasks as well as to conduct training on equipment and JRAC technologies.

Figure 42. Australian soldiers discuss the use of grade control systems.

During the first week, the JRAC Task Force conducted such tasks as the integration of personnel and equipment, establishment of the communications systems and procedures, and briefing members of the Task Force on safety and environmental concerns at BFTA. The second week was focused on training the Task Force to use the various JRAC technologies and provided them an opportunity to conduct a short duration, full scale Mission Rehearsal Exercise (MRX). This rehearsal of construction tasks was an excellent opportunity for the Task Force to prepare for the upcoming mission and accomplish significant work on the much-needed Driver’s Training Area just outside Robertson Barracks, near Darwin in Australia’s Northern Territory.

The JRAC research team began the training in the classroom by introducing all members of the Task Force to the various aspects of the JRAC program. The Task Force members were then broken into the three subgroups once again (supervisors, soil technicians/surveyors, and equipment operators) for the intense technical training which continued for the next 6 days (Figure 43).

Figure 43. U.S. Marine gets some last minute instruction from a CTCT trainer.

The 6 field days included 3 days of rotating station training where the Task Force members received supervised hands-on training and 3 days of the MRX where the JRAC trainers were in more of an observer role. Although successful, the training was severely impacted by the limited number of machines available (10) and large number of equipment operators (80). This was due in large part to the late arrival of the U.S. Army equipment, which was delayed during the overseas shipping process. In order to compensate for the late arrival of the U.S. equipment, additional grade control systems were leased and installed on Australian equipment; however, the installation was not complete when the training started, resulting in additional problems from the lack of personnel and resources to assist with the installation.

The MRX consisted of the construction of 600 m of aggregate surfaced road constructed in three layers (Figure 44). Tasks included excavation and subgrade preparation, placement of the subbase and surface layers, and material processing to ensure proper moisture content. The MRX portion of the training was very successful and gave the Task Force the opportunity to get familiar with the JRAC technologies and procedures at an operational tempo similar to what they would experience during the exercise. It also provided them a chance to work through many of the leadership and construction management issues prior to the start of the exercise.

Figure 44. Compaction operations on the final lift during the MRX.

9 Construction of the Runway

The following chapter outlines the general procedures implemented in the construction of the primary runway at BFTA. Work began on the 1,250 × 27.5 m primary runway on 2 June with clearing and grubbing. Work on the final wearing surface was completed on 17 June, a total of 16 days construction time. During these 16 days, a test strip was conducted to train the soldiers on the proper use of JRAC equipment and to define the construction variables required for each soil used in the runway construction. Subgrade, subbase, base, and wearing surface layers were each prepared, watered, and compacted to a near optimum moisture condition and to certain minimum dry densities as defined by the RSAK. On-site quality control using the RQAK ensured no deficiencies were present on the airfield and that final layer strengths were sufficient to support C-17 aircraft traffic.

Site preparation

Prior to construction, the runway at BFTA was overgrown with trees extending about 3 to 5 m in height and covered with native grasses from 1 to 2 m in height. This required a period of clearing and grubbing prior to preparation of the runway subgrade beginning on 2 June and ending on 4 June (Figure 45). Boxing out of the runway subgrade provided removal of any remaining organics in the upper few centimeters of the native ground surface.

Materials

The runway was constructed in four layers, including a subgrade, subbase, base, and wearing surface. Figure 46 shows a typical cross section of the runway.

The subbase was used only when material was overexcavated beyond the level of the natural subgrade; and in all instances, the subbase layer was less than 125 mm in thickness. The base course consisted of both a red base material (also used for the wearing surface) and a white base material, both included in the overall screened stockpile.

Figure 45. Clearing and grubbing of primary runway.

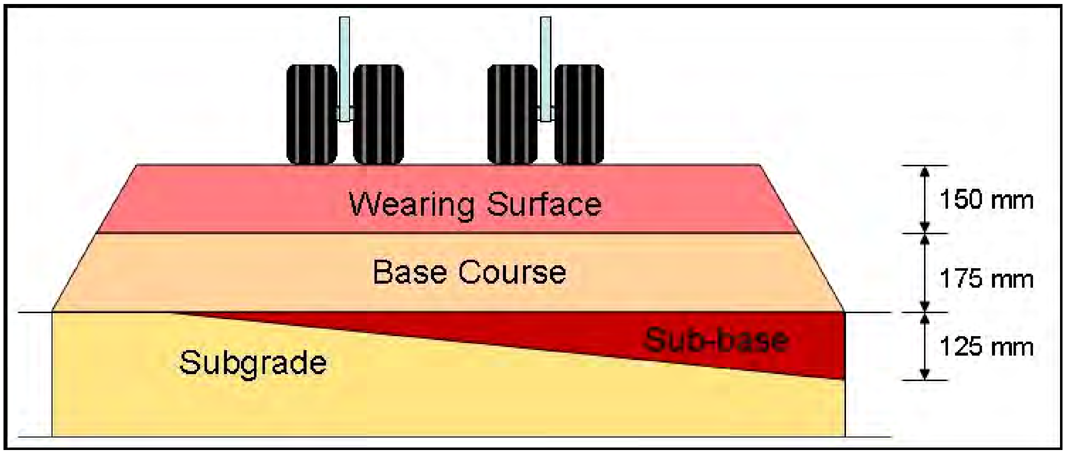


Figure 46. Cross section of runway showing principal material layers.

During the first day of field operations (2 June), the soils team collected a series of soil samples from across the construction site to establish the moisture-density criteria for construction of the test section and runway using the RSAK (Figure 47). Several samples were taken over a 3-day period from 3 locations: screened white base and red wearing surface soil taken from the stockpile located near the runway (Figure 48), a quarry of unscreened wearing surface material located approximately 2 km from the runway, and the natural subgrade at the centerline of the runway. At least two classification tests were performed for each soil using the RSAK.

Figure 47. U.S. Army soldier performing a soils analysis on the RAVEN using the RSAK.

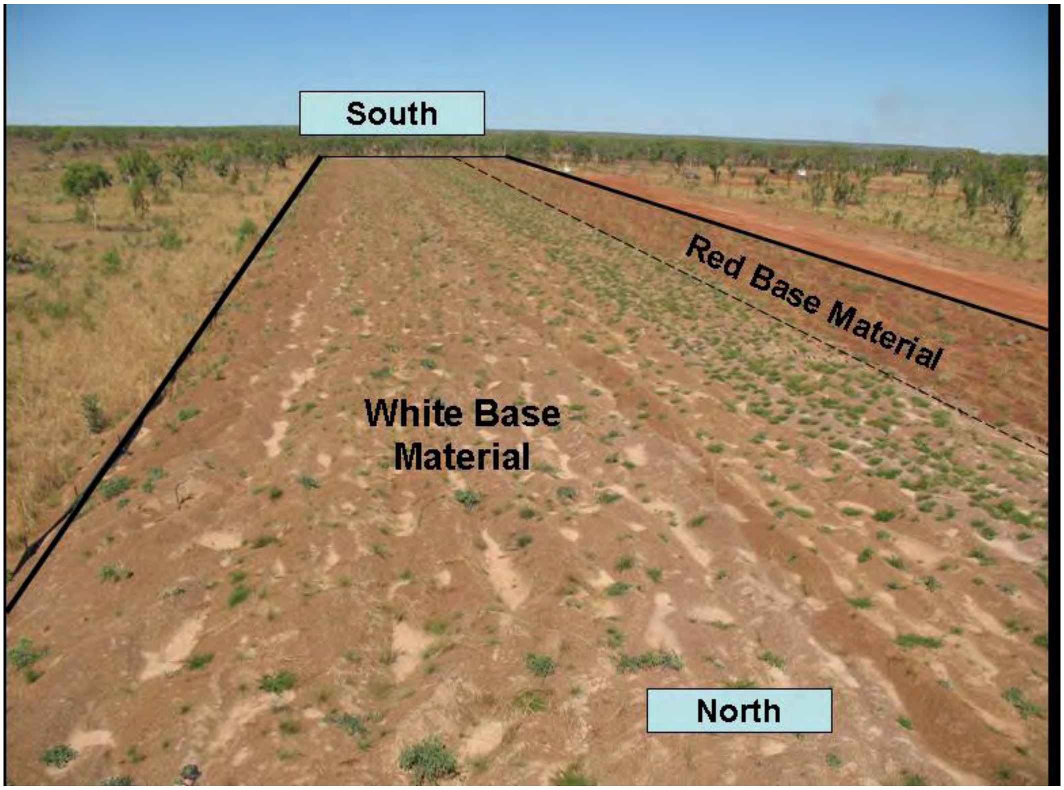


Figure 48. BFTA runway stockpile prior to clearing and grubbing.

To ensure a conservative design, the highest predicted MOD was selected for each soil along with an average OMC. Table 7 summarizes the material properties as determined from the RSAK. Appendix C displays the detailed moisture-density curves. The grain size distributions are shown in Figure 49.

Table 7. Summary of construction properties for Bradshaw area soils.

Layer	USCS Class	Gravel[a] %	Sand[b] %	Fines[c] %	MDD[d] pcf	MDD kg/m³	OMC %
Subbase	SP	18.4	79.2	2.4	134.8	2159	6.4
Subgrade	SP-SM	17.8	76.0	6.1	121.4	1945	7.3
White Base	SP	37.9	59.1	3.0	129.7	2078	4.2
Wearing/Base	SP	22.4	74.2	3.4	129.5	2074	5.3

[a] Gravel = Soil with a particle diameter greater than 4.75 mm.
[b] Sand = Soil with a particle diameter between 4.75 mm and 0.075 mm.
[c] Fines = Soil with a particle diameter less than 0.075 mm.
[d] MDD = Maximum dry density for modified Proctor energy level.

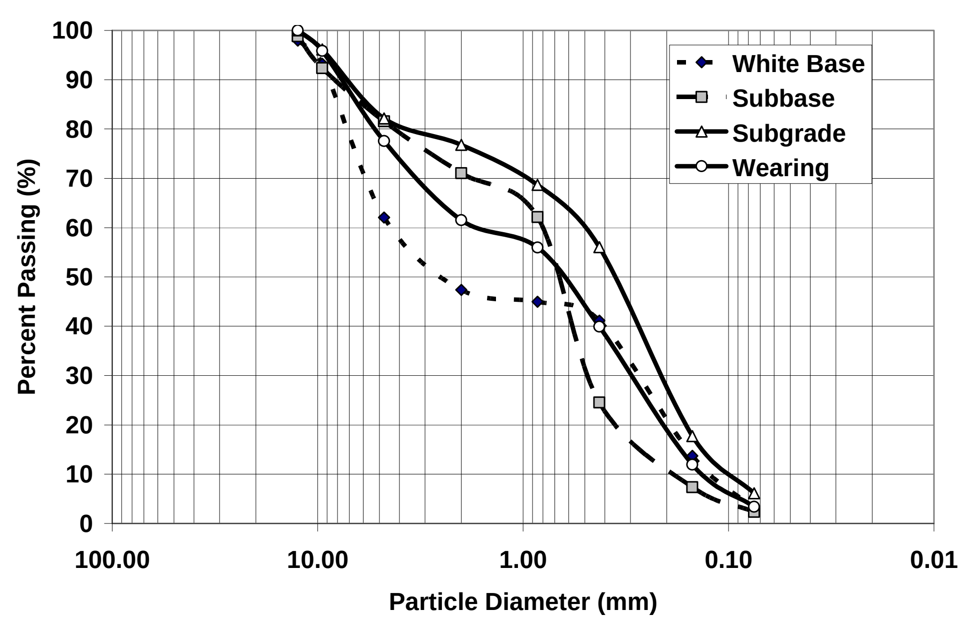


Figure 49. Grain size distributions for the JRAC design soils.

A noticeable difference occurred between the MDDs of the stockpile and quarried material. The larger aggregate present in the quarried material (soil that had not been screened for base and wearing course use and referred to as subbase in Figure 49) resulted in the highest required MDD of any of the available soils. In general, an average OMC of 5% was selected for the base and wearing soils for simplicity of field quality control.

Test section construction

To establish a proper construction procedure for the runway and to validate the construction criteria returned from the rapid soils analysis, a test strip was constructed as per guidance given in Freeman et al. (2008). The test strip was located at the end of the northwest turnaround within the boundaries of the designed runway as shown in Figure 50. This was done to simulate as much as possible the actual conditions during runway construction. After completion, the test section was removed in order to rebuild the lot as a single unit.

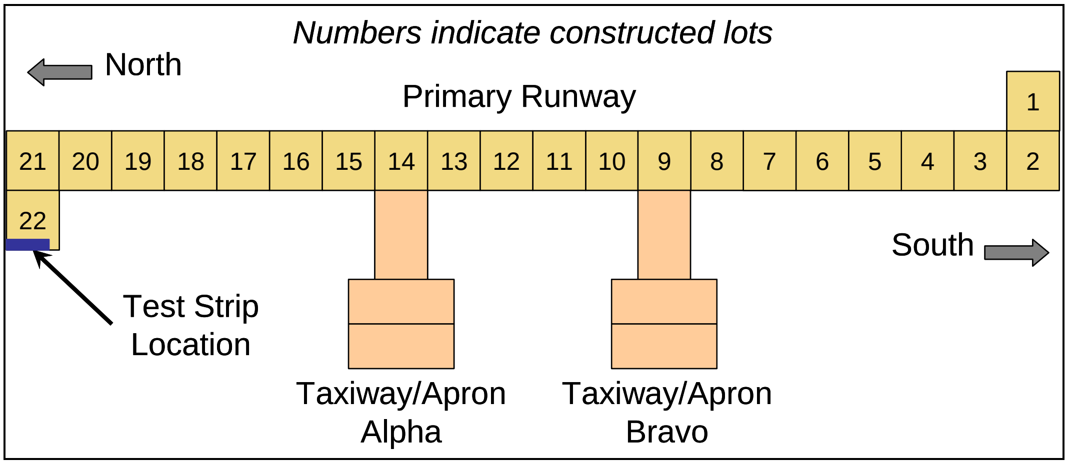


Figure 50. Test strip location and runway lot layout.

For the purpose of construction monitoring and quality control, the runway was divided into 22 lots for each constructed lift. The primary runway, including overruns, was 1,250 m in length and was evenly divided into twenty 1,718.8-m^2 (18,500-ft^2) lots (62.5 m length by 27.5 m width) shown in Figure 50. Each turnaround was assigned as a separate lot. The taxiways and aprons were divided into 10 individual lots.

The test strip was constructed over a 3-day period (5 to 7 June) but was not indicative of the pace at which full-scale construction occurred. Much of the time was spent learning the proper application technique for the water to ensure a uniform distribution across the test section. Efficiency was limited by the availability of a single roller, grader, and water truck as well as erratic delivery of fill material when a free scraper was available rather than on demand. Further, careful monitoring of final lift density and training on the use of proper QC techniques slowed the process. The intent of the test strip was to identify the techniques and proper use of JRAC technology to minimize inefficiencies during runway construction. A detailed timeline of the test strip construction is described in Table 8.

Table 8. Timeline of test section construction.

Date	Time	Activity
5 June	0830-1130	Boxing out of subgrade
5 June	1200-1400	Tilling, wetting, and rolling of subgrade
5 June	1400-1500	Placement and grading of 200 mm of subbase fill
5 June	1500-1800	Compaction of subbase to a depth of 150 mm with testing
6 June	0630-1200	Additional 50 mm (compacted) of subbase brought in, underlying layer tilled, soil blended, wetted and compacted
6 June	1200-1300	Subbase lift tested for density
6 June	1400-1800	White base material brought in, subbase tilled, soil wetted and compacted
7 June	0630-0800	White base layer tested for density
7 June	0800-0900	Base layer tested for CCV value
7 June	0900-1200	Wearing layer material brought in, base tilled, soil wetted and compacted
7 June	1200-1430	Wearing surface tested for density, DCP values taken on cross section, and CCV values measured
7 June	1500	Test strip complete

Dimensions

The test strip was approximately 30 m in length by 8 m wide at the subgrade layer with a gradual narrowing of the test strip by a few centimeters with each successive lift (Figure 51). This provided an adequate running length for the compactor to achieve a constant speed and at least four roller widths wide to allow the compactor to exercise coverage techniques.

Lift thicknesses

The subgrade was boxed out to a depth of approximately 200 mm below grade for placement of the subbase material and to remove loose surface fines (Figure 52). The excessive box out was done to allow placement of a quarried subbase soil to evaluate its performance when used as fill for overexcavation on various runway sections. All materials were compacted to 98% of the MDDs shown in Table 7. Two lifts of subbase material

Figure 51. Layer construction of test strip.

Figure 52. Illustration of test strip subgrade box out.

were needed to fill the box out, an initial lift (200 mm loose and 150 mm compacted) and a second lift (67 mm loose and 50 mm compacted). The white base course lift was brought in at 200 mm loose, which compacted to 175 mm owing to its more granular nature. The wearing surface was brought in 200 mm loose and compacted similarly to the subbase to 150 mm. This procedure resulted in a 525 mm (20.6 in.) total thickness test strip upon completion, indicative of final runway dimensions.

Properties of constructed layers

Subgrade

The in situ subgrade was the poorest quality material on the jobsite, with an SP-SM soil classification containing very little moisture in its in situ condition. The construction criteria called for the prepared subgrade to meet a minimum 90% of MDD and 10 CBR. During test strip construction, it was found that tilling 150 mm deep, wetting and recompacting the subgrade did not produce a layer significantly denser or stronger than the in situ material in terms of CBR strength as determined by the DCP. Therefore, it was decided to only lightly scarify the surface, moisten the soil, and recompact to protect the loose tilled surface from fines loss and to solidify the upper few centimeters of subgrade.

Subbase

The subbase was of similar origin as the natural select fill material used for the base and wearing surface. The base and wearing surface soils were screened over a 12.5-mm-diameter sieve from material obtained from the same quarry as the subbase. The subbase material was not screened, allowing it to contain a coarser fraction of material, increasing its MDD as noted in Table 7. The subbase compacted very well and provided an excellent foundation material to compliment the natural rocky subgrade. Since no layer of subbase exceeded 125 mm in depth, it was assumed as part of the subgrade layer. Therefore, it only had to meet the 90% MDD and 10 CBR criterion of the subgrade versus the 98% MDD criteria set forth for the base and wearing structural layers.

White base select fill

The natural, white base material was more deficient in fines content as opposed to the red select fill and contained greater gravel content as noted in Table 7 and Figure 49. This material appeared very similar to the subgrade soil in origin. The white select fill had a similar maximum dry density but much lower OMC than the other soils due to its coarse nature, making moisture control during compaction of this soil difficult. In order to achieve the proper dry density (98% of the MDD), the white base was compacted one afternoon and allowed to cure overnight. Density and moisture retests in the morning met the 98% MDD and ±2% OMC criteria. This material constituted only a small portion of the overall select fill stockpile and was ultimately blended into the red select fill material. As such, its properties were of concern only during the test section construction.

Red wearing surface select fill

The red select fill was a natural soil, carefully screened over a 12.5-mm-diameter screen prior to the commencement of the project to minimize the impact of any large aggregate as FOD potential for C-17 operations. This material was indicative of the red soils typically seen in the area and originated from the same quarry as the subbase soil. A full 40,000 m^3 of material was stockpiled along the edge of the runway and had been left exposed to the environment throughout the rainy season. This allowed moisture to be collected within the stockpiled material and reduced the need for additional water on the jobsite, a procedure common in this area of Australia. A negative effect of this approach was the leeching of fines in the upper 1 m of stockpiled soil from both rainwater and wind effects reducing the desirability of the soil from its unquarried state.

The red select fill had a maximum dry density slightly lower than the sub-base due to its finer gradation. The compaction criteria for this material were 98% MDD and ±2% OMC. This was the predominant soil used in all base and wearing surface construction throughout the project. Most of the time and effort in the testing and monitoring went towards establishing proper construction procedures for this layer.

Quality control testing

In an experience unique to military construction, the JRAC process places the ability to provide Quality Control (QC) into the hands of the soldiers executing the construction. This gives the military direct ownership of the final runway quality. This is a critical task in a contingency construction scenario when time limitations require identification of any construction defects as soon as they occur. The tools to achieve this task are described in detail in Chapter 5 and their effectiveness discussed throughout this chapter.

A Project Management Team (PMT) supplied by the Australian military provided Quality Assurance (QA) on the project due to the condition that the runway would serve as a long-term structure and not merely a short-term facility. The results of their validation testing were for Australian headquarters-level sign-off on the completed project but had no bearing on the as-built construction of the runway for the JRAC Task Force.

Moisture content determination

Moisture content was determined using the RSAK microwave drying oven. The sandy soils present could be dried in 5 min or less, resulting in rapid turnaround times for the field engineers. Water content varied somewhat between the tests for the test section, ranging between 4.2% and 8.7%. The test strip indicated that the OMC tended to be around 4% to 6% for all of the various soils tested and the specifications called for ±2% of OMC. Therefore, an average value of 5% for OMC would allow for a range of between 3% and 7% water content for all fill soils used on the project site to simplify the compaction criteria.

Clegg hammer

A 4.5-kg Clegg hammer is included as part of the RQAK kit for the purpose of determining the strength of a stabilized soil and quality control of compaction (Freeman et al. 2008). However, its potential use as a quality control tool during runway construction was evaluated during the test section construction. During construction of each of the three fill lifts, subbase, base, and wearing surface, the Clegg hammer was operated ten times after every two compactor coverages as outlined by the RQAK guidelines (Figure 53). An average of 10 CIVs was calculated. Figure 54 shows the progression of average CIV with number of coverages. During construction, the dry density reached a maximum between six and eight coverages of the compactor. This same trend was observed in the average CIVs where a dramatic change in slope occurred following six roller coverages. This suggests that soil nearing the required dry density could be identified based on average CIV.

Figure 55 compares average CIV with measured dry density from the steel shot replacement method included in the RQAK. This figure shows that when an average CIV exceeded a value of 27, in all cases the soil would have a compacted dry density exceeding the target value. These CIVs occurred at a minimum of six coverages at slow speed (3 km/h) or eight

Figure 53. Operation of the Clegg hammer.

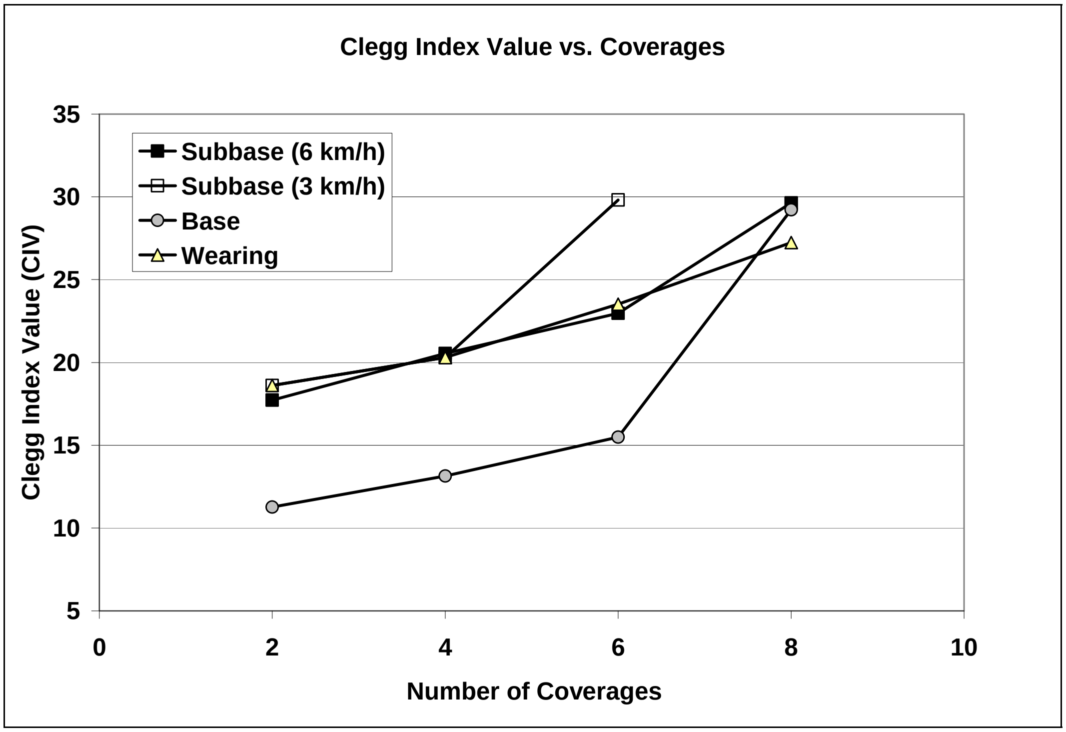


Figure 54. Clegg index value versus number of roller coverages on test section.

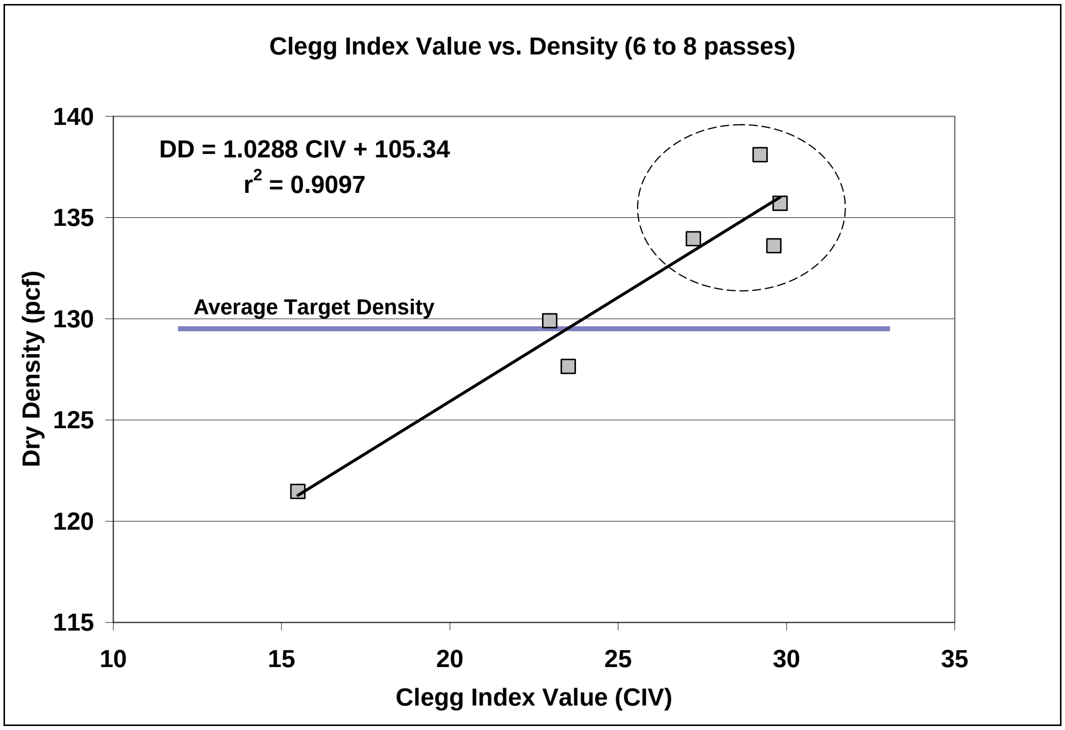


Figure 55. Clegg index value versus compacted dry density for all soils.

coverages at a faster speed (6 km/h) (Figure 54). Thus, the CIV could indeed be used to check constructed lots to determine if design density had been achieved or whether soft spots existed in a given lot. This tool drastically reduced testing efforts by minimizing the number of steel shot density tests required to check density by determining whether a lot was ready for testing using the CIV. Further, soft areas on a constructed lot could be outlined by the CIV, reducing the volume of material that would have to be recompacted to meet density.

Steel shot and nuclear density gauge

The steel shot density test was the primary tool used to provide quality control for measuring dry density of the compacted layers. This tool helped ensure the success of construction for each lot as the JRAC soils team could measure both dry density and moisture content, assess whether rolling or watering operations should continue, and determine when to move equipment from the current lot. The ability for the soldiers to monitor their own construction was so successful that no lot failed nuclear gauge validation testing that was previously validated by the steel shot.

On the test strip, the steel shot test was used at the end of compaction for the subgrade and then at pass coverage levels six and eight for the subbase, base, and wearing layers to determine when the 98% MDD criterion was met. The greatest benefit of this exercise was to allow the soldiers to determine the most efficient manner in which to conduct multiple tests given varying numbers of available technicians (one to three). The ideal arrangement for testing was found to be three-person teams where two individuals each simultaneously dug a hole while a third person collected soil samples from each hole, dried them in the microwave, recorded the data, and calculated the results. In this configuration, two steel shot tests could be completed in about 15 min. Two person teams also proved efficient in that it took about 7 min to dig a hole and then about 10 min to dry out a sample and record the density data. Therefore, in about 35 min, a two-person team could complete two tests to validate a single lot. A one-person effort required about 50 min to conduct two steel shots, since digging and microwave testing must be performed sequentially (15 min to dig the hole, weigh the material, pour the shot, determine the volume of shot, reclaim the shot, and fill the hole and another 10 min to sample the soil, conduct the water content, enter the data, and perform the calculations).

For the entire test strip and runway construction, steel shot test holes were dug between 100 and 150 mm deep with the average being 125 mm. Considering the quantity of steel shot supplied on the RAVEN (approximately 27 kg), this allowed about seven to eight tests to be performed in the field prior to having to rinse and dry the steel shot.

To compare the effectiveness of the steel shot to conventional field density methods, a Humboldt nuclear density gauge was used by the PMT QA team to measure in situ moisture content and dry density alongside the steel shot tests as shown in Figure 56. The calibration of the nuclear gauge was checked with periodic sand cone tests. The nuclear gauge moisture content value was calibrated based on microwave moisture contents run by the JRAC soils team. In most cases, the steel shot and nuclear gauge agreed very closely both in percentage of MDD and in moisture content with the nuclear density gauge being within 1% of the compaction percentage and within 0.1% to 0.4% of the measured moisture content. It helped that the nuclear gauge was calibrated to the steel shot, but the results of the steel shot densities remained consistent with differing operators.

Figure 56. Steel shot replacement and nuclear gauge testing on the test strip.

Therefore, for a large operation, the steel shot test is a viable test alternative to the nuclear gauge, being reproducible and less time consuming than a sand cone test due to the ability to reuse the steel shot. It should be noted that the nuclear density gauge was not part of the JRAC exercise and no data from this device was used in the quality control and construction practices of the JRAC Task Force.

Primary runway construction

Timeline

Construction operations on the runway occurred according to the timeline given in Table 9. Construction was conducted in linear staging as one designated lift was required to be completed and approved prior to starting the next lift. Table 9 also includes the construction activities involving the aprons and taxiways which are further detailed in Chapter 10.

Table 9. Primary runway construction timeline.

Date (2007)	Time	Activity
5 June	0630	Boxing out of subgrade begins
5-8 June		Subgrade box out continues
5-9 June		Subbase placement occurs
9 June	0900	Begin placement of 150-mm base course layer
12 June	1500	Base course layer completed
12 June	1530	Begin placement of 150-mm wearing surface layer
17 June	1600	Completion of wearing surface layer; primary runway surface completed
17 June		Boxing out of subgrade for taxiways Alpha and Bravo begins
18-23 June		Rain event – no construction
23 June	0700-2300	Boxing out of subgrade for aprons Alpha and Bravo
24 June	0800-1730	Placement of 150-mm base course layer for both taxiways and aprons
24-26 June		Rain event – no construction
26 June	1400-2200	Placement of 150-mm wearing surface layer for both taxiways and aprons

Subgrade and subbase construction

Boxing out of the subgrade began just shortly before construction of the test strip on 5 June at 0630 (Figure 57). Boxing out continued until 8 June, when cutting operations ceased and only placement of subbase material was occurring. The subgrade and subbase preparation occurred nearly simultaneously as subbase was being placed and compacted as soon as any overexcavation occurred during boxing out (Figure 58). The subbase placement was completed on the morning of 9 June.

Over much of the airfield, the subgrade was interlaced with several boulders of sandstone and occasionally harder quartzite rock. Boulders were between 0.1 m and 1 m along their largest axis. This required the use of heavy bulldozers to box out the entire runway (Figure 59). Boulders were pushed off to the edges of the runway and later loaded into dump trucks and hauled off-site (Figure 60). The majority of boulders were located between the center and southern end of the primary runway. For a majority of this area, the quarried subbase material was brought in and compacted to bring the overexcavated subgrade up to the original design surface for base construction.

Figure 57. Boxing out of the subgrade.

Figure 58. Subgrade and subbase preparation (7 June).

Figure 59. Komatsu D155 dozer clearing boulders in the subgrade layer.

Figure 60. Handling of on-site boulders.

The area of the subgrade equaled that of the completed runway surface. The depth of subgrade was assumed to continue indefinitely for providing support for the overlying structural layers. For purposes of predicting the allowable number of aircraft passes, the strength values listed in the following sections are assumed continuous with depth. The constructed subbase did not exceed a depth greater than 150 mm.

Subgrade preparation where subbase was not required was a simple process, as determined from the test section, since the in situ conditions of the soil already met or exceeded the 90% MDD and 10 CBR criteria. The recommended surface preparation was to scarify approximately 50 mm in depth, apply one to two passes of a water truck to moisten the soil, and recompact with a steel-wheeled roller. This tightened the surface to prevent loss of fines and provided adequate near surface CBR strength. In areas where subbase was placed, it was constructed in one lift, wetted to the optimum moisture content (5% ±2%), and then compacted with a steel-wheeled roller. The surface was then leveled until final grade was achieved.

Base and wearing layer construction

Initially, a white sandy material was to be the principal material for the base course. After further inspection of the stockpile, only a minimal amount of this material was present in the stockpile. The remaining material was similar to that of the wearing surface. Therefore, the compaction criteria used on the base lift from the test sections were replaced with the criteria developed for the wearing surface, owing to the similar materials. This simplified construction on the runway as all materials placed in both the base and wearing surface were treated equally for quality control and construction technique.

Construction of the base course began on 9 June at 0900 on the center of the runway at lots 10 and 12 identified on the runway in Figure 61 (after completion of base course construction). Construction progressed from lot 10 southward and from lot 12 northward, with lot 11 constructed as soon as lots 10 and 12 were completed. This improved construction efficiency with two teams working in opposing directions so that no interference between equipment occurred. Rather than have all of the equipment on-site equally divided amongst the two teams, the construction supervisors for each team worked together to maximize equipment usage.

For example, when one team was placing material and not compacting, the other team would use all of the available compactors to finish a given lot.

Figure 61. Completed base course and beginning of wearing surface construction on 12 June.

The chosen construction technique was to complete the base lift and ensure that all lots passed prior to placement of any fill on the next lift. The base lift was completed at 1500 on 12 June, followed immediately by placement of the wearing surface at 1530. The wearing surface was placed similarly to the base with operations beginning in the center lots 10 and 12 of the runway with construction emanating southward and northward from the center (Figure 61). Construction on the wearing layer and completion of the primary runway occurred at 1600 on 17 June, approximately 13 days after initial runway box out began, and only 9 days from commencement of base course construction.

While the base course was placed directly on top of the in situ subgrade, the wearing surface was blended in with the base course. After the base course lift was completed, graders scarified the upper 50 mm of the compacted surface prior to placement of the loose wearing soil (Figure 62).

Figure 62. Scarifying base layer prior to placement of wearing surface.

Graders would then blend the loose wearing soil with the tilled base course soil, along with any water applied. Padfoot rollers would then knead the loose wearing and base material together creating a stronger bond between the lifts.

Equipment usage

There were five smooth drum rollers and three padfoot drum rollers in use on the runway. They were operated at a nominal speed of 4 km/hr, near the optimal speed from the test section evaluation. The padfoot rollers were used to blend lifts together by kneading loose soil dumped from the scrapers into the previously compacted and smoothed surface. Most of the soil was wetted after placement, and the padfoot rolling assisted the graders in blending the material to expedite moisture migration throughout the soil prior to final compaction with the steel-drum rollers. The rollers were commonly used in series providing a wide area of coverage across a given lot as shown in Figure 63.

Ten motor graders were available on-site, although their use was divided between blending, grading, and leveling of select fill and clearing of debris on the shoulders and perimeter of the runway. The graders were outfitted

Figure 63. Compactor train during base course construction.

with GPS grade control systems, as described earlier, and provided the operators with the ability to obtain accurate loose fill depths across the runway prior to roller compaction to ensure a level compacted surface.

Two types of scrapers were available on the jobsite; Australian Komatsu with only front-wheel drive, which had to be pushed through the stockpile by a dozer, and CAT 563s with all-wheel drive, which could self-power themselves through the stockpile. A majority of the scrapers were kept busy with transfer of material from the stockpile to the runway. On several occasions, the scrapers exceeded the construction rate of the graders and compactors, in which case they were either redirected to removing loose box out material on the runway edges, or more commonly, sat idling until a new lot was ready to be constructed (Figure 64).

Figure 64. Water distribution on wearing surface while the grader blends in the water. CAT scrapers (yellow) and Komatsu scrapers (green) in background.

Water trucks were necessary to provide moisture to the otherwise dry soil to achieve the optimum moisture content. They were also used extensively to provide dust control along dirt haul roads around the perimeter of the airfield. The water supply was a pumping station located approximately 8 km from the airfield, which drew water from the Victoria River. This haul distance required that trucks be efficient in their water usage with each pass. Construction of the test strip provided some guidance as to water volume and truck speed to ensure adequate watering of the select fill material. A horizontal spray bar on the rear of the water trucks provided a wide area spray that evenly covered a 2-m strip of placed fill (Figure 64).

Quality control and quality assurance testing

Quality control on the runway construction was conducted by the JRAC Task Force soils team. Several tools were made available to the soils team to assist in this measure: the steel shot density test, the microwave drying oven, the Clegg hammer, and the DCP. These four tools enabled the soils team to monitor the quality of the construction in order to ensure that the PMT QA team would sign-off on the construction.

MDD and OMC were determined from the RSAK and were the basis for both the JRAC Task Force and the PMT QA team for validation of the lot construction. The PMT QA team relied principally on the nuclear density gauge and calibrated the moisture content reading to moisture contents determined in the microwave oven. The PMT QA team did not conduct independent moisture-density curves on the select fill material and, therefore, relied upon the estimated moisture-density response returned from the RSAK.

Subgrade strength and density evaluation

The subgrade required two criteria to be met under the guidelines set forth in the design specifications:

1. A CBR value greater than 10, as determined from the DCP.
2. Dry density must exceed 90% of the modified energy, MDD (ASTM 2006; method 1557).

The MDD as determined from the test section was 1,945 kg/m^3 (121.3 pcf) of which only 90% of this value was required to validate the layer. A select number of lots were tested for density (>90% MDD) with no condition for moisture, and checked for a sufficient (>10) CBR value at depth for continuation of the base layer construction. Figure 65 shows that for the selected lots tested, the average dry density exceeded the 90% MDD criterion for the prepared subgrade surface (without subbase), as determined by both the steel shot replacement (Figure 66) and nuclear density gauge techniques.

The CBR was estimated using both the manual DCP and the automatic DCP mounted on the RAVEN. For each DCP test conducted on the subgrade, refusal occurred within 150 mm or less depth from the scarified surface, suggesting that a shallow rocky layer existed along the entire runway. This refusal indicated a CBR value of 100 which ensured a minimum 10 CBR present in the upper 150 mm of the subgrade.

Subbase, base, and wearing surface

For each constructed lot on the runway, on both the base and wearing layers, two steel shot density tests were performed (Figure 67). If both the 98% of MDD and ±2% of OMC criteria were met, then the lot was passed and work progressed. If one or both of the tests failed, then the surface of the lift was reworked, wetted if necessary, and recompacted with more passes of the smooth drum roller. At this point, two more density tests were taken and, in nearly every case, the lot then passed.

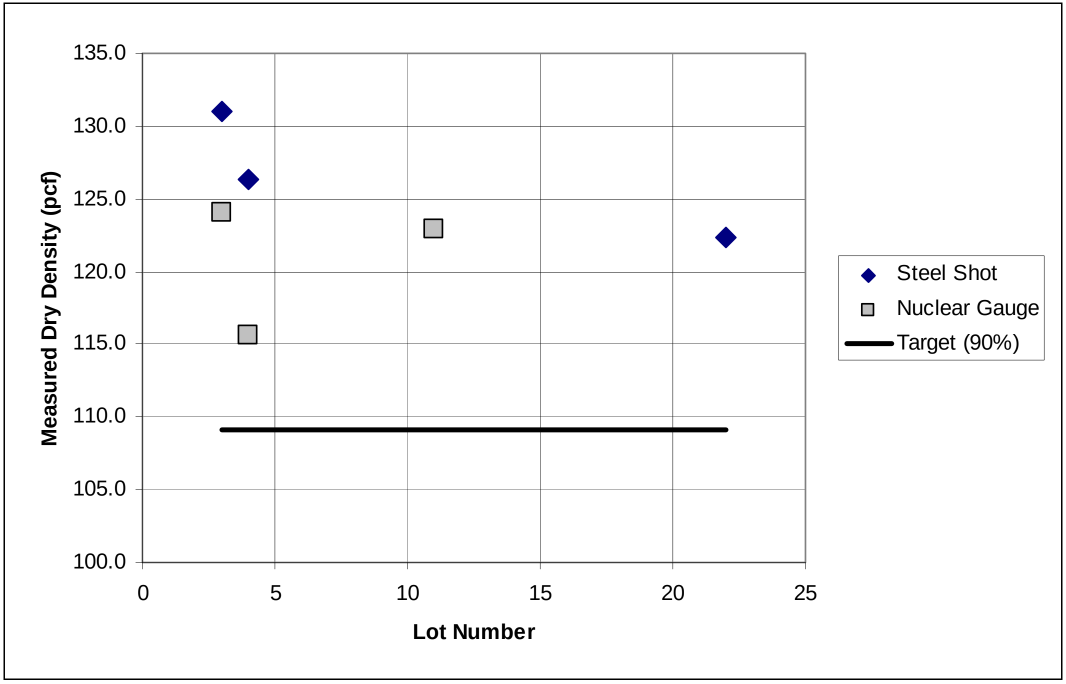


Figure 65. Density measurements on subgrade.

Figure 66. Soldier performing steel shot density test on improved subgrade soil.

Figure 67. Steel shot density and Clegg hammer quality control on runway.

Throughout the construction, the Clegg hammer was used to determine when a particular lot was approaching its 98% MDD minimum. After six to eight passes of the roller, the Clegg hammer was run to minimize the number of steel shot density tests required to validate a lot. The Clegg hammer was used primarily in the early phases of construction (the base layer) to develop a best construction practices routine. A CIV value of 25 or greater, as shown in Figure 54, was used to quickly assess the overall compaction state of each lot prior to steel shot density testing. As well, the JRAC Task Force could investigate small areas of a lot for low density, outline the extent of the poor performing material without a density test, and require that only a certain portion of the lot be repaired versus recompacting the entire lot. This saved a lot of time by reducing the number of density tests conducted and made construction more efficient, focusing the QC on only those areas that needed repair. As a result, very few lots failed their first steel shot density checks.

Figures 68 through 70 compare the average steel shot density values conducted on each lot versus the nuclear density gauge value from the PMT QA team against the target 90% or 98% density level. In nearly every case, the average density passed on the first two field tests. When one or more steel shot tests failed, then reworking of the soil and retesting of the lot ensued. If the two new tests on the reworked lot passed, the lot was passed; and in all instances after reworking the lot passed.

In Figures 68 through 70, the data points represent the average of all steel shot tests taken on a given lot whether low (failed) or high (passing). When a data point shown lies below the target line, the failed values recorded for that lot were so low that the overall average of density for the lot (including the two passing values after reworking) is skewed to the low side. The PMT QA team sign-off was based upon the nuclear density values on random lots, and as shown in the figures, all of the lots passed.

After completion of the wearing surface and sign-off by the PMT QA team, a rubber tire roller was used to help smooth any surface deficiencies remaining from the final layer compaction. Deficiencies arose such as spalling, dusting, and pop-outs because of uneven moisture distribution at the surface due to either poor mixing or over-rolling of the surface.

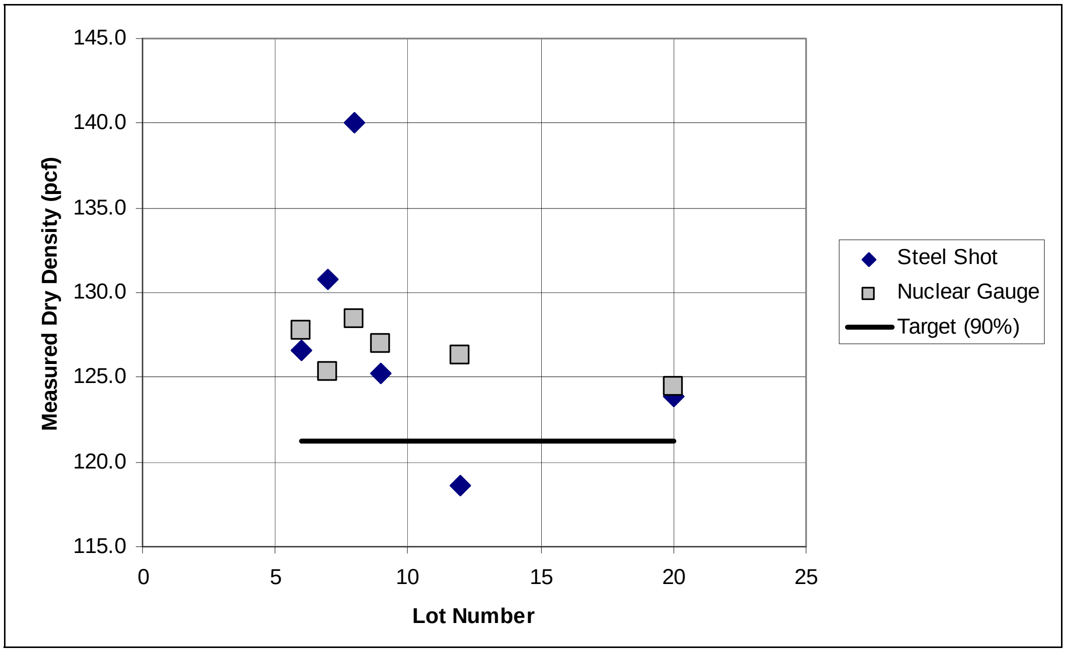


Figure 68. Subbase density measurements on runway.

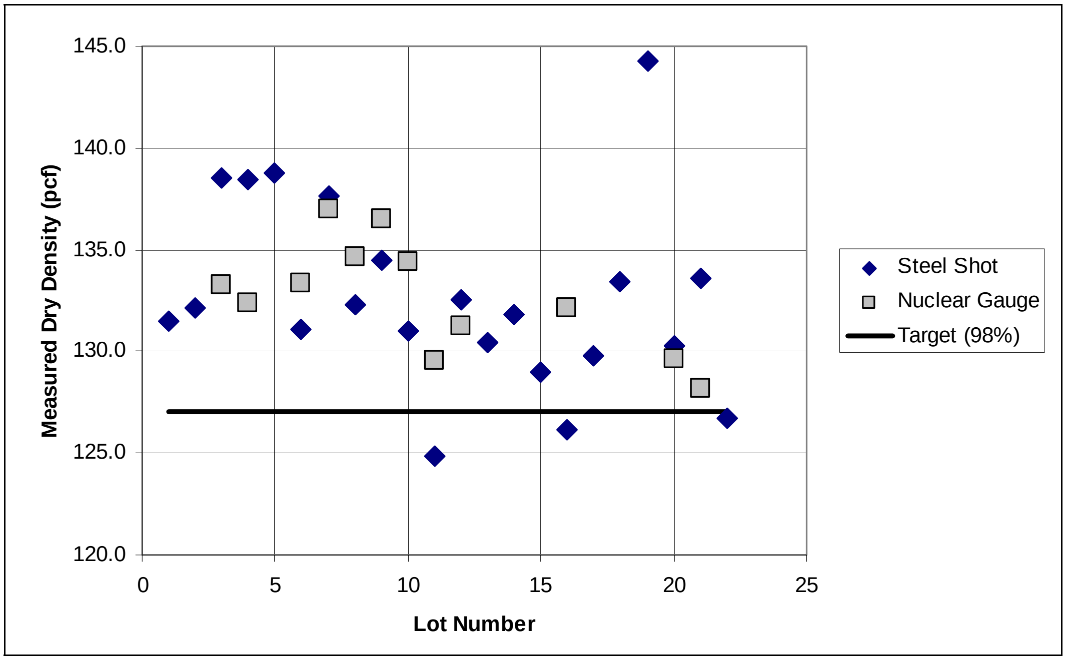


Figure 69. Base course density measurements on runway.

To correct these problems and create a visually appealing wearing surface, water was sprayed over the runway surface immediately followed by trafficking with a rubber tire roller to evenly distribute surface moisture. This in-turn smoothed out bumps and tightened the surface to decrease potential FOD.

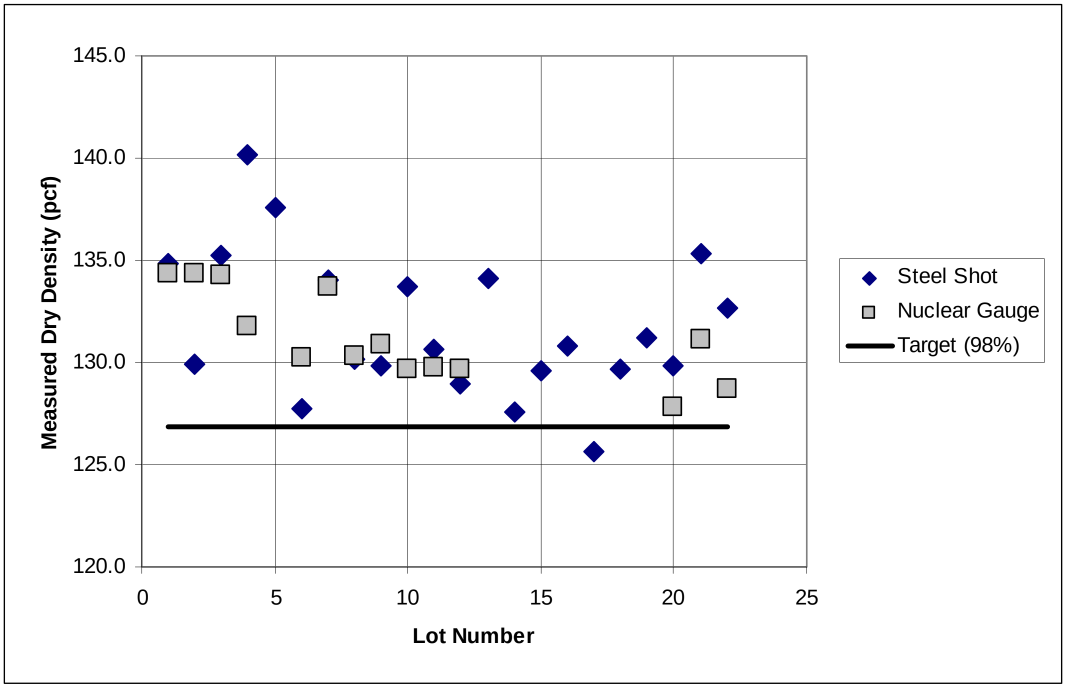


Figure 70. Wearing surface density measurements on runway.

CBR strength evaluation

After primary runway completion and PMT QA team sign-off of the wearing surface, a series of DCP tests were conducted to ensure an adequate CBR value throughout the depth of the runway cross section along the length of the centerline. This was a JRAC Task Force QC exercise to ensure that the runway had met or exceeded the CBR requirement for C-17 operations that would later be validated by DCP tests conducted by the Air Force prior to any aircraft landing (Figure 71). Multiple tests were conducted, and the estimated CBR values from all DCP tests met or exceeded the criteria in the design documentation. These DCP tests are discussed more fully in Chapter 10 and Appendix B.

Summary of runway construction

The following is a list of the relevant improvements in the construction process accomplished through the introduction of JRAC technology.

- A 1,250 × 27.5 m × 0.3 m runway capable of landing a C-17 aircraft consisting of four distinct constructed lifts: subgrade, subbase, base, and wearing surface were cleared, boxed out, compacted, and certified for landing in only 16 days from on-site arrival (2 to 17 June).

Figure 71. U.S. Air Force conducting DCP tests on runway prior to C-130 arrival.

- The 16-day JRAC construction time is at least 50% faster than conventional construction techniques which involve grade staking and non-GPS enhanced earth-moving equipment. Conventional construction was estimated to take at least 30 days or longer to complete a similar set of tasks.
- The conventional construction estimate does not account for delays due to design changes during construction. Manual drawing and time consuming restaking of the jobsite would have led to an even longer construction process. The JRAC process allowed real-time design changes to be made during construction using Terramodel and then immediately uploaded to the construction equipment and monitored with Site Vision Office™ software, requiring no downtime in the construction process.
- The RSAK provided the only tool capable of providing soil design data for use in the quality assessment of the compaction. Currently, in a typical horizontal construction project, the military has no options for determining the soil construction data making this a leap ahead in contingency design technology and allowing the project to begin so rapidly. The RSAK delineated between on-site materials, providing specific design guidance for each of the four material lifts.
- The RQAK provided an expedient, non-nuclear alternative to moisture-density monitoring that empowered the military construction team to

validate their construction product. JRAC Task Force quality control with the RQAK resulted in “no failed lots” by an outside evaluation team when final moisture-density and CBR strength data were obtained. This in-turn expedited continuation of construction on subsequent lifts and aircraft landing.

- Use of GPS-enhanced earthmoving equipment provided uniform lifts of loose soil that in turn provided for level final compaction at near final grades when rolling was completed. Only slight final trimming was required by the grader.
- Site Vision Office allowed centralized construction monitoring that improved efficiency of equipment usage and captured errors in construction early in the process. Color-coding of completed runway sections based on number of roller passes simplified assessment of the current progress.
- Within a very short timeframe, soldiers were self-sufficient in using JRAC technology and could adapt the equipment and processes readily to the task of expeditiously constructing a C-17 capable semi-prepared runway.

10 Construction of the Taxiways and Aprons

Apron and taxiway construction (pre-stabilization)

The construction of two 61- by 68-m aprons and adjoining 71- by 20-m taxiways occurred in two stages: the first being the initial placement and compaction of the select fill materials and the second being stabilization of the uppermost wearing surface with cement and fibers. The material used to construct the aprons and taxiways was from the same quarried and stockpile soil described in Table 7, nonplastic lateritic poorly graded sand (SP). Specifically, only the wearing/base soil was used, as all of the white base material had been used up before this stage of the project began.

Subgrade preparation

Construction of the aprons and taxiways was intermittent and cumbersome due to the influence of two primary rain events during the project (Table 9). As the primary runway was being completed on 17 June, taxiways Alpha (north) and Bravo (south) were boxed out to prepare the subgrade to grade and to ready the areas for select fill material (Figure 72). Neither apron was boxed out at this time. An extended rain event then ensued, delaying further construction until 23 June at 0700 when boxing out of the subgrade for the two aprons began and continued until 2300 (Figure 73). The extended rain event caused the boxed out taxiways to fill with water. The SP soil drained quickly and was ready for fill material within 1 day of saturation.

Moisture content tests were run on the subgrade prior to rolling, similar to the construction procedure for the primary runway. The rain event caused the in situ moisture content to increase from an average of 2.7% to 7.5%. As Table 7 shows, this is very near the OMC for the subgrade, allowing roller compaction to occur without placement of water, thus expediting the process. CBR strengths of the subgrade still satisfied the minimum 10 CBR requirement.

Base and wearing construction

Construction of the base course using select fill for both taxiways and aprons began at 0800 on 24 June and was completed by 1730 on the same day. The long rain event had added considerable moisture to the

Figure 72. Box out of Taxiway Alpha prior to first rain event (18 June).

Figure 73. Box out of Taxiway and Apron Bravo after first rain event (23 June).

available stockpile material, increasing its moisture content to an average of 7.3%. This required some grading and retilling of the soil in order to dry it out to meet the ±2% OMC requirement (5.3%), but overall, construction was expedited due to the absence of the need for water trucks.

A second rain event occurred immediately following the construction of the base lift, prohibiting further construction until 1400 on 26 June. This second rain event caused water to pond on Taxiway Bravo, weakening the compacted soil to the point that some material had to be excavated and replaced prior to placement of the wearing surface. Taxiway Alpha had a drain cut along its length that tied into the primary runway drain to the north (Figure 74). This drained the majority of the excess water, allowing the base layer to retain its strength. Construction of the final wearing surface was completed that same day at 2200, with stabilization beginning 2 hours later at 2400, 27 June (Figure 75). The moisture content of the wearing surface was even higher than the base layer after the second rain event, being 7.6% on average. However, the wearing surface was to be tilled with cement, which has a higher moisture demand than the non-cemented OMC, so the additional water proved to be an advantage in expediting the stabilization phase of construction, as again, no water trucks were required.

Figure 74. Drain from Taxiway Alpha to edge drain on primary runway.

Strength and density evaluation

Figure 76 shows the results of the expediency enacted to finish the construction on the taxiways and aprons prior to the aircraft landing on 28 June. The wearing surface dry density averages are almost all above the target value, although not as large as during the primary runway construction. The base layer densities, however, are frequently below the

Figure 75. Compaction of base surface on Apron Alpha (24 June).

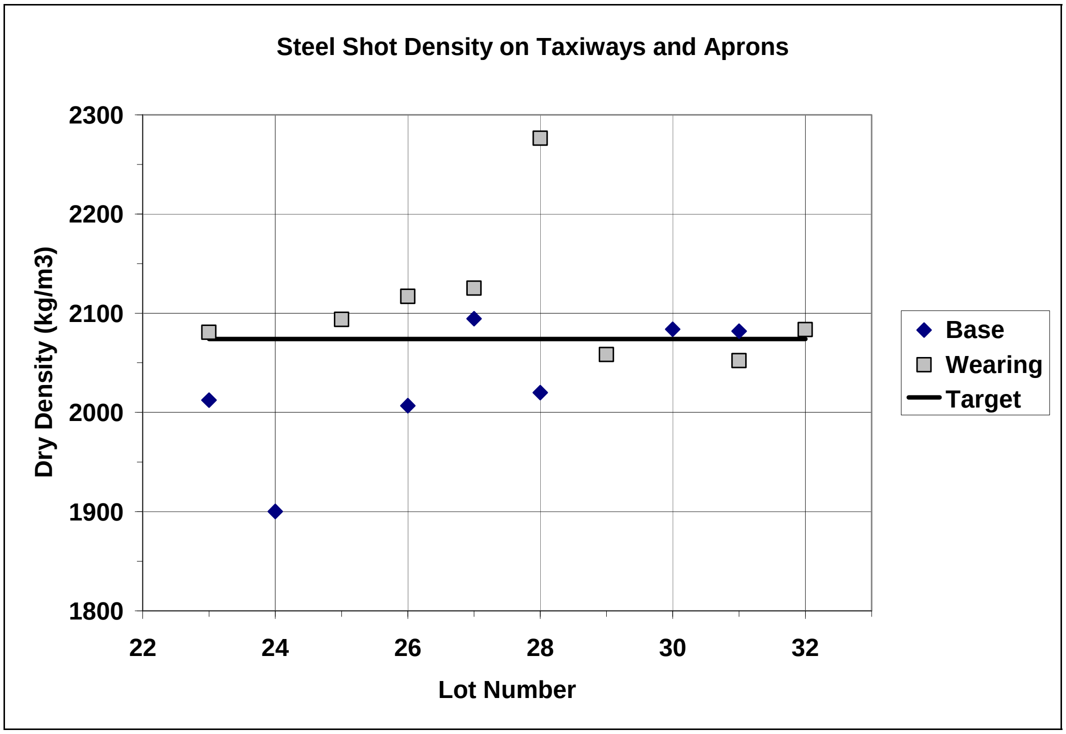


Figure 76. Steel shot dry density averages for taxiway and apron layers.

acceptable target density, and in most cases no reworking of the layer was done. Because these areas were being constructed to be the foundation material to a cement-fiber stabilized surface, their ultimate CBR strength only needed to achieve a 10 CBR assuming that the surface layer would be a minimum 50 CBR after stabilization. This matched the design criteria imposed on the primary runway, a 50 CBR soil over a 10 CBR subgrade. The base course for these structures became like the subgrade to the runway. Earlier it was found that a 50 CBR was achieved on the base course of the primary runway at the target density, so it was assumed that a minimum 10 CBR would be possible in the base layer at the densities recorded. The decision to not rework was made given the contingency nature of the construction and the tight deadline to finish the taxiway and apron prior to aircraft arrival.

Upon completion of the two taxiways and aprons to final grade, DCP testing was conducted by the JRAC Task Force team prior to stabilization. In the apron and taxiway areas, an indicated range of CBR values from 30 to 75 with an average of 45 was found within the two compacted layers, which was more than sufficient as a foundation for the stabilized layer. Note that density values below the acceptable limit (Figure 76) were allowed here as the soil was to be stabilized and recompacted. Only the final elevation and smoothness criteria on the unstabilized taxiways and aprons needed to be met prior to stabilization.

Overview of stabilization

The stabilization portion of the project included a helipad (50 by 50 m), two taxiways (71 by 20 m each), and two parking aprons (61 by 68 m each). The layout of the taxiways and parking aprons are shown in Figure 77. Taxiways and parking aprons were stabilized using a combination of high-early strength portland cement and polypropylene fibers. The amount of cement was 4%, approximately half the amount that would typically be used according to conventional mix design procedures outlined in U.S. Army field manual TM 5-822-14 (1994). The low amount of cement used was possible by incorporating fibers into the mix. The fibers help form a composite with the soil and the cement. The low cement dosage also reduces the durability of the soil-cement to moisture. The loss of durability is offset by using a polymer surface treatment that waterproofs the surface, preventing water from saturating the soil cement. The polymer cap also serves as a wearing surface and provides dust control. It should be reapplied as traffic and weather conditions dictate.

Although most JRAC training occurred in Darwin, Australia prior to the start of construction, stabilization training was delayed until a few days prior to the start of actual stabilization of the taxiways and aprons at BFTA. This was primarily due to a lack of resources during the Darwin training phase. The pulvermixer (Terex RS 325) had not arrived in Australia and the materials used during stabilization (fibers, cement,

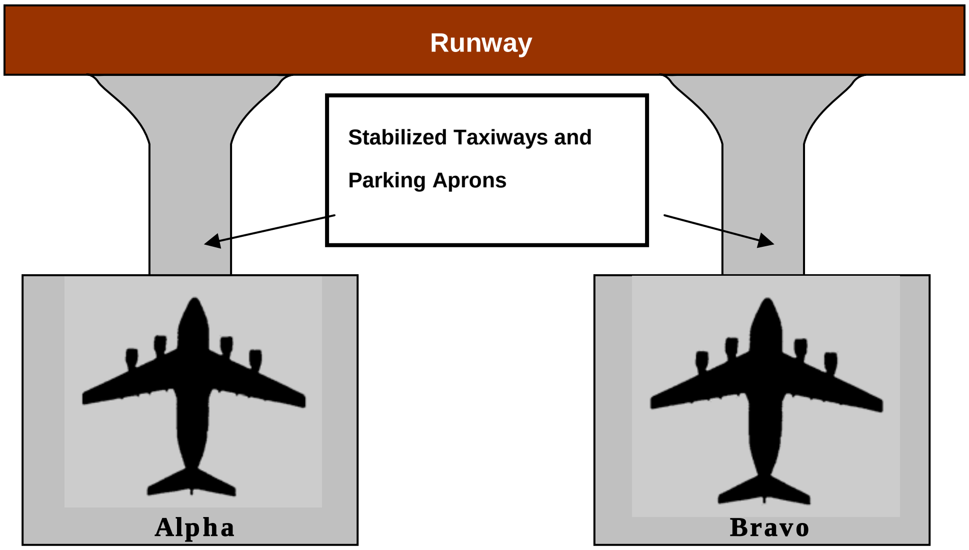


Figure 77. Stabilized taxiways and parking aprons.

and polymer) were pre-staged at locations close to BFTA and not available during the Darwin training. For these reasons, it was determined that the stabilization training would occur at BFTA where adequate resources would allow for proper training and preparation.

The stabilization training started on 18 June and took place on the existing helipad located on the south side of the new access road very close to the site of the aprons. Immediately prior to the commencement of training, a portion of the helipad was dedicated to construction of a test section for determining key construction techniques and criteria. These included verification of fiber dosage rates, optimization of pulvermixer ground speed, roller-integrated compaction monitoring, and strength gain versus time plots for in situ DCP and CIV tests. Although not part of the JRAC testing process, a lightweight deflectometer (LWD) was available and was employed as an additional tool to verify Clegg hammer results and to gain additional insight into the physical properties of the stabilized layer. Based on the results of the test sections, construction guidelines and target acceptance values were established. These construction guidelines and acceptance criteria were implemented during construction of a helipad at the airfield project site, which also served as training and refinement of practice for the more critical taxiway and apron structures presented in the next section.

Helipad test area

A test area was planned and prepared prior to stabilization of the helipad to evaluate pertinent variables and construction techniques. Table 10 summarizes the test section variables of cement content, fiber content, and the Terex RS-325 pulvermixer ground speed. This allowed evaluation of mixing efficiency with low or high fiber content and low or high soil stabilizer ground speed. The cement dosage rates combined with different fiber dosages provided for the establishment of minimum values for CMV, CIV, and LWD immediately after compaction and during curing. CMV technology uses accelerometers installed on the drum of a vibratory roller to measure roller drum accelerations in response to soil behavior during compaction operations and was installed on several of the Caterpillar 563 compactors used on this project. Each of the test sections was comprised of one Terex RS-325/350 cutter width (lane width of 6 ft or 1.83 m) approximately 25 m in length by 150 mm in mixing depth. Prior to placement of the cement and fibers, the stabilization layer was placed, compacted, and trimmed to design grade elevation using motor graders outfitted with the GCS 900 system previously described. By compacting and trimming to design elevation prior to stabilization, it was determined that little or no trimming would be required after final compaction. Minimizing post-compaction trimming is necessary due to the difficulty of grading fiber-stabilized soils. Note that a test section with no stabilizers was not necessary as the runway was constructed without stabilizers so the pertinent construction variables were already known at the time of the test section construction.

Table 10. Summary of test section variables.

Test Section	Type III Cement Content (%)[a]	Polypropylene Monofilament Fiber Content (%)[a]	Mixing Speed with Terex RS 325 (meters per minute/feet per minute)
1[b]	4	0.4	9.1/30
2		0.2	
3		0	
4		0.4	13.7/45
5		0.2	
6	0	0.4	

[a] Based on dry weight of soil at modified Proctor density.

[b] Selected for implementation for helicopter pad construction.

In situ test area measurements

Results of LWD and CIV after compaction are presented in Figure 78. The LWD measurements provide a measure of the dynamic modulus and indicate that sections with the slower 9.1 m/min (30 ft/min) mixing rate result in increased strength at short cure times. This is an assumed result of improved cement and fiber distribution. DCP results at 100 mm depth are shown in Table 11 and also indicate significant strengthening after 24 hr of curing in all stabilized test items.

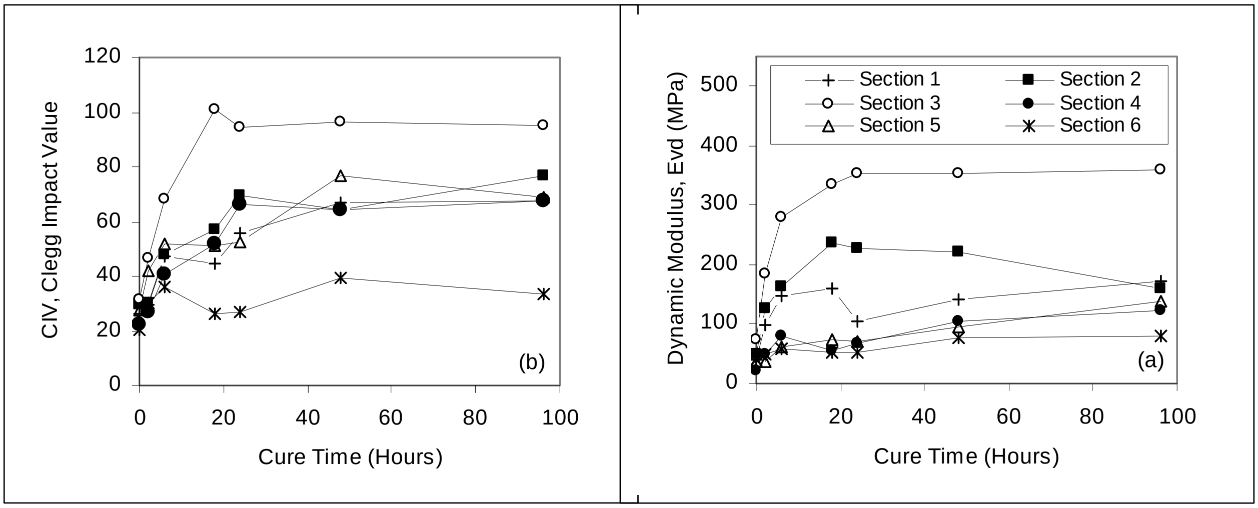


Figure 78. CIV and LWD versus time results for all test sections.

Table 11. Summary of DCP results in test area.

Test Section	CBR at 100 mm at 2 hr	CBR at 100 mm at 24 hr
1	50	100
2	60	100
3	90	Refusal
4	50	Refusal
5	35	90
6	30	30

Helipad construction

The total area of the constructed helipad was 50 by 50 m. Building on the experience of the test sections, a target CMV value of 30 was established for the helipad construction. This CMV value was chosen as it coincided with between 6 and 8 roller passes. The mix design of Test Section 1 (see Table 10) was selected for the construction. Construction methods were to replicate the test section (cement/fiber distribution, mixing at 9.1 m/min with 8 roller passes). A few changes were observed during construction that deviated from test strip construction, though. These changes were suggested after a review of the test section construction. Differences included (1) additional passes of the water truck, (2) rolling with no vibration and inconsistent number of passes, (3) use of motor grader on north quarter of pad to spread material, and (4) use of motor grader to rip the surface prior to placing the cement and fibers. Additional moisture conditioning was applied as necessary to maintain optimum water contents due to drying from wind and warm temperatures. The minimum number of passes was set at eight on the test section construction (i.e., 16 coverages). Poor compaction operation (no vibration) and a lack of adequate monitoring resulted in low CMVs and an inadequate number of passes. This led to low CMVs for a large portion of the pad. An excessive number of roller tracks remained in the surface after curing, indicating that further compaction should have been performed. As further verification of poor compaction, in situ measurements of LWD and CIV are summarized in Table 12. Results indicate that the average values are lower for the helicopter pad for the selected cure times (18 hr for LWD and 24 hr for CIV), and they are more variable based on comparison of the range of values compared to the test section. A photograph of the construction is shown in Figure 79.

Table 12. Comparison of in situ measurements for Test Section 1 and helicopter pad.

In situ Measurements	Test Section 1		Helicopter Pad	
	Average	Range	Average	Range
LWD	160	90 to 216	149	54 to 246
CIV	56	33 to 61	50	15 to 120+

Figure 79. Stabilization training and construction of helipad.

Parking apron and taxiway construction

Parking apron and taxiway stabilization layout began at approximately 0900 on 26 June 2007, and stabilization began at approximately 0030 on 27 June 2007. The size of each taxiway was 71 by 20 m (244 by 80 ft) and the size of each apron was 61 by 68 m (200 by 225 ft).

Preparation for stabilization began by marking the corners of the parking aprons, intersection points of the apron and taxiway, and the curved fillet into the runway. The layout involved marking the corner of the aprons, delineation of stabilization machine lanes, and marking of ropes that were used to determine points for cement and fiber bag placement along stabilization machine lanes. Considerable attention to detail is required to place and spread materials properly to insure an even distribution over the surface prior to mixing. Trial and error showed that a convenient way of placing bagged materials was to fashion a series of ropes/lines with different colored tape markers (for mixing lanes, cement and fiber bags). This allows the lines to be moved from lane to lane and provides an easy spot reference for bag placement.

To begin the line layout, a reference line was placed at the rear of Apron Bravo from corner to corner that extended about 7 m past each side of the apron. The reference line was temporarily staked. A second reference line was placed parallel to the first, at the front of the apron, in similar fashion. The lane marking lines were then staked out perpendicular to the reference lines and approximately 3 m outside the apron sides. This defines the mixer lanes and allows enough room between the apron side and the lane line for the cutter head to be dropped outside the apron edge. This is important because the pulvermixer cutter head, when raised or lowered, leaves deep gouges that need to be graded when the stabilization is complete. Lane markers were numbered to insure that the reference and cement/fiber lines are placed at the proper marker.

A cement line and a fiber line were prepared by placing colored tape at intervals along the line that corresponded to the necessary spacing for material placement, 0.84 m for 20 kg cement sacks and 5.73 m for 13.6 kg fiber bags. The spacing was determined by stabilization depth, fiber/cement dosage rates, density of compacted soil, mixing lane width, and size of the area to be stabilized. For this project, an Excel spreadsheet was designed specifically for this purpose that calculates a number of useful parameters needed. The cement line is usually laid out first, beginning at the first lane marker inside the apron. The first two rows of cement can then be placed by dropping cement sacks at each marker. It is best to stagger the sacks within the lane to aid in achieving an even spread of cement. The sacks are then opened and spread evenly over the two lanes using rakes (Figure 80). The cement line can then be picked up and moved two lane markers over and the process repeated. The fiber line is then placed where the cement line was. The fibers are best spread by either tossing clumps of fibers onto the cement surface or rubbing the fibers between the hands and letting them drift onto the surface. The former is better in windy conditions but the latter results in a more even distribution.

It is recommended that material placement not outpace the mixing operation, in case of equipment failure or inclement weather. It is also best to achieve a continuous operation where material placement, mixing, and compaction keep pace with one another. Experience has shown that compaction is usually the slow step in the stabilization process so the material placement and mixing must be slowed to keep pace with compaction.

Figure 80. Placement of stabilizer materials on Apron Alpha.

Prior to mixing, the first reference line was moved approximately 1/3 m outside of the apron edge. This allowed the reference line to be just outside the leading wheel edge of the mixer so the operator could easily follow the reference line at a glance. The mixing was delayed until the second lane of material was placed so no interference between mixing and material placement occurred. After the mixer completed the second lane, the compactors began on the first lane. It is recommended that the reference line be moved and reestablished to keep up with the mixing operation after about four or five lanes. This will keep the mixing lanes from becoming skewed and/or curved as the mixing progresses.

In Figure 81, a schematic of the mixing lanes is shown for the apron, taxiway, and fillets. The arrows show the direction of pulvermixer travel. Due to the excessive rainfall, it was not necessary to inject water during mixing of soil, cement, and fibers. This allowed the pulvermixer to operate independently without a nurse truck for water. For this project, it was best to keep the mixer traveling in the same direction. This eliminated the need for a turnaround at the end of each apron and allowed the mixer operators to always line up on the mixing lane from the same side, minimizing overlap with the previous lane. For mixing at taxiway/runway intersection,

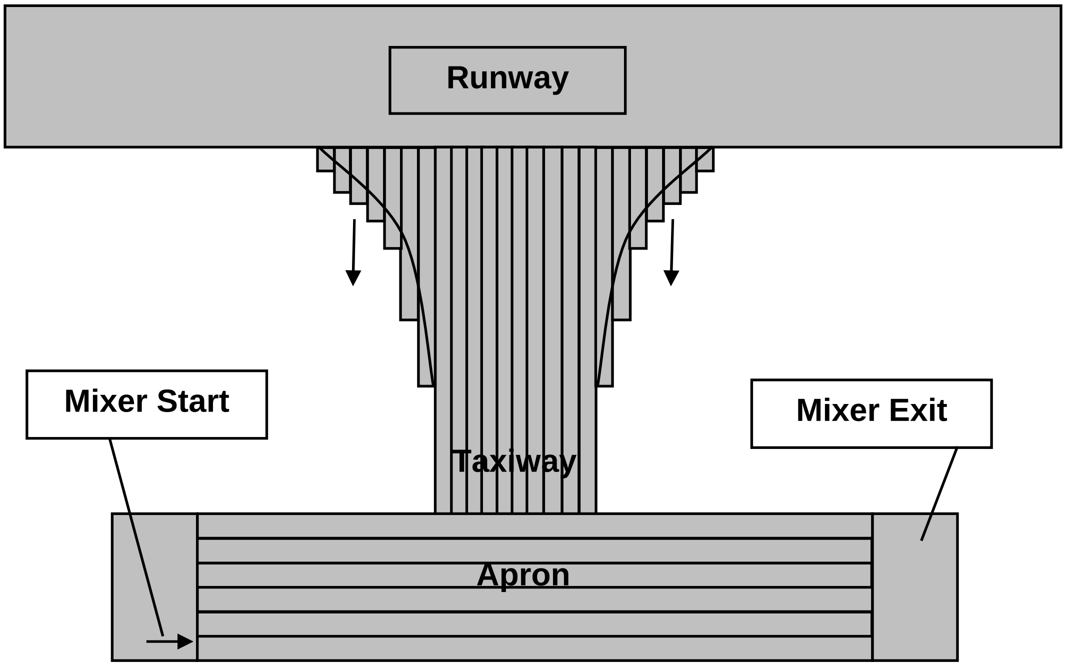


Figure 81. Layout of mixing lanes, mixing directions, and the mixer lanes used to create the curved fillets. (Drawing is not to scale.)

the mixer backed up just over the runway shoulder line and lowered the cutter head to minimize damage and operation on the runway surface. Graders later repaired the runway, taxiway, and apron edges where the pulvermixer cutter head was raised and lowered.

The stabilization of Apron Bravo continued uninterrupted (Figure 82) for approximately 12 hr but had to be halted due to repairs being made in the adjacent taxiway. Approximately 3/4 of the apron was complete at this time. Stabilization resumed approximately 4 hr later on the taxiway. The original strategy was to stop the apron construction short of the taxiway intersection which would allow the equipment to operate on the unstabilized portion of the apron while constructing the taxiway. The final piece of the apron would then be stabilized and would help prevent an unwieldy joint from forming due to the rapid curing of the high-early strength cement. Unfortunately, due to the delay in repairing a section of the taxiway, the first portion of the apron that was stabilized had set sufficiently. This caused some difficulty in compacting freshly stabilized soil adjacent to the older apron surface and to providing a tight bond of the older stabilized material to the new.

Figure 82. Terex 350RS mixing soil with fiber and cement on Apron Bravo, 27 June 2007.

Construction of the taxiway proceeded with some difficulty due to the short lanes that were necessary to generate the curved fillets. The problem was not in the mixing, it was in grading and compaction. During helipad construction, before mixing and compaction, the surface smoothness of the loose lift was found to dictate the smoothness of the final compacted surface. It was also discovered that it was difficult to grade the mixed fiber/cement. The mix tended to ball in front of the blade, causing scarring and streaking that could not be compacted smooth. Attempts to smooth the curved fillets by grading were difficult and took longer than expected. The lesson learned for the construction of the fillets is the axiom of "the surface you start with is the surface you end with." The attempts to grade the mixed material smooth before compaction probably caused more problems than it fixed. In retrospect, it would have been better to have mixed the fillet area first, started compaction to visually assess what the final smoothness would be, and graded as little as possible before completing compaction.

The taxiway was completed at approximately 2300 on 27 June and the final part of the apron was completed in the early morning of 28 June. The polymer emulsion surface cap was diluted 2:1 with water and applied to the apron/taxiway surface at a rate of 1.2 L/m^2 (Figure 83).

Figure 83. Application of polymer emulsion surface cap on helipad using a HUMVEE sprayer.

Stabilization of Apron Bravo and Taxiway Bravo were started first as construction of the unstabilized portions of Apron/Taxiway Alpha was ongoing. Due to intermittent fuel problems with the pulvermixer, the backup RS350 (newer version of RS325) machine provided by Terex was used for construction of Apron/Taxiway Bravo. The Bravo area was completed at approximately 0500 on 27 June 2007. Prior to completion of Bravo, layout of stabilizer materials on Alpha began at approximately 2000 on 27 June. Due to time constraints and the scheduled arrival of the first C-17 on 28 June, both the RS325 and the RS 350 were employed to construct Alpha. Stabilization of Alpha began in earnest at approximately 0000, 28 June 2007 and was completed at 1400, 28 June 2007. Figure 84 shows an overall view of Taxiway and Apron Bravo with a C-17 parked on the surface. Figure 85 shows a close-up of the main gear of the first C-17 parked on Apron Bravo just after operation on Taxiway Bravo.

Final material inventory used on helipad, taxiways, and parking aprons are shown in Table 13. A tabulation of the timeline for stabilization of the taxiways and parking aprons is presented in Table 14.

Figure 84. C-17 operating on Apron Alpha less than 24 hr after completion of the stabilization.

Figure 85. Close-up of C-17 main gear on Apron Bravo.

Table 13. Material inventory used in construction of the helipad, parking aprons, and taxiways.

Feature	Cement, kg	Fiber, kg	Polymer, L
Helipad, 50 by 50 m	40,585	3,250	2,040
Parking Apron Alpha, 61 by 68.5 m	54,400	5,440	3,120*
Parking Apron Bravo, 61 by 68.5 m	54,400	5,440	1,660
Taxiway Alpha, 71 by 20 m	20,800	2,110	625
Taxiway Alpha, 71 by 20 m	20,800	2,110	1,250[a]
Total	**190,985**	**18,350**	**8,695**
[a] Two applications.			

Table 14. Timeline for stabilization of taxiways and parking aprons.

Date	Time	Activity
26 June	2200	Corners of Apron/Taxiway Bravo marked and staked
27 June	0000	Completed layout of reference and lane marker lines
27 June	0100	Soil, fiber, and cement mixing begins on Apron Bravo
27 June	0130	Compaction begins on Apron Bravo
27 June	1000	Excavation of soft area on Taxiway Bravo begins
27 June	1400	Stabilization operations on Apron Bravo halted awaiting completion of Taxiway Bravo repairs
27 June	1700	Stabilization operations on Taxiway Bravo begin
27 June	2200	Stabilization operations on Taxiway Bravo completed
26 June	2200	Corners of Apron/Taxiway Alpha marked and staked
27 June	2300	Completed layout of reference and lane marker lines on Apron/Taxiway Alpha
27 June	2300	Stabilization operations on Taxiway Bravo completed
27 June	2330	Stabilization operations on Taxiway Alpha begin
28 June	0000	Stabilization operations resume on Apron Bravo
28 June	0200	Stabilization operations on Taxiway Bravo completed
28 June	0230	Stabilization operations on Apron Bravo completed
28 June	0300	Stabilization operations on Taxiway Alpha completed
28 June	0330	Stabilization operations on Apron Alpha begin
28 June	0600	Polymer surface treatment on Taxiway/Apron Bravo began
28 June	0600	Polymer surface treatment on Taxiway/Apron Bravo completed
28 June	1400	Stabilization operations on Apron Alpha completed
28 June	0600	Polymer surface treatment on Taxiway/Apron Alpha begin
28 June	0600	Polymer surface treatment on Taxiway/Apron Alpha completed

Summary

Apron/taxiway construction

- Two 1.4-acre taxiways/aprons consisting of prepared subgrade, base course and wearing surface were constructed in 40 hr using GPS-enabled construction equipment.
- Rain events caused delays in apron/taxiway construction, stretching the overall timeline out over a period of 9 days.
- Delays in construction due to rain still enabled the overall project to be completed in 26 days (2 to 28 June), a time savings of several weeks over conventional construction estimates.

Stabilization

- Stabilization with fibers and fast-setting cement produced highly functional taxiways and parking aprons that should require little maintenance relative to unstabilized soil. The construction time for both taxiway/apron structures was approximately 40 hr. C-17 aircraft operated on these surfaces less than 8 hr after final construction.
- Stabilization needs to be an integral part of the design phase in order to maximize soil strength and smoothness of surface. Special attention should be given to the operating lanes and direction of the pulvermixer during the design such that an operating area at the same grade as the taxiway/apron is established. This area should be approximately 5 m outside the perimeters of the taxiways and aprons to allow for movement of the pulvermixer and raising/lowering of the cutter. The shoulder areas needed for drainage outside of the stabilization perimeter should be scheduled for construction stabilization.
- Placement of fibers and cement by hand requires care to achieve an even distribution of materials within pulvermixer lanes. Ultimately, this affects mixing and even distribution of the stabilizers within the soil. This is particularly difficult in windy conditions, e.g., those experienced on 27 June 2007.
- Quality control tools for the apron and taxiways were moisture contents and CIV. All moisture contents were within the specified range (6.3%-9.3%) and all CIVs were above the required minimum of 20 within 30 min of completing compaction.

11 Airfield Certification, Operations, and Opening Day

Airfield certification

The certification process for the airfield was a complex undertaking due to multiple types of aircraft (C-130 and C-17) landing at the facility at various stages of completion. Additional resources were also required such as on-site Air Traffic Control (ATC) and crash fire rescue teams. The process also spanned the criteria of two militaries and involved all service components. In addition, the acquisition of the C-17 was a very recent development for the Australians, and this project was the first time that the RAAF performed semi-prepared landing operations on Australian soil. All of these factors combined to create an excellent opportunity for the U.S. and Australia to work together in a true coalition environment to solve problems and build relationships that were more significant than just the construction of a runway.

Upon completion of the airfield, it was proudly named Nackeroo Field after the famous North Australian Observation Unit (NAUO), nicknamed the “Nackeroos,” which patrolled the Northern Territory (NT) during World War II. Based in Katherine, NT (about 250 km east of Timber Creek) and led by a former anthropologist familiar with the area, Maj. William Stanner, the Nackeroos gained a reputation for their toughness and dedication to service. Initially struggling in this harsh territory, the Nackeroos formed strong alliances and gained respect from the aboriginal inhabitants that helped them navigate the area and survive. The cooperation and mutual respect continues today as evidenced by the cooperation that is Bradshaw Field Training Area.

C-130 operations

Certification of the airfield was always at the forefront of the planning process and required quick navigation through several approval processes to ensure safe landings immediately after construction was completed. Initially, the runway was certified for C-130 landings by the RAAF engineers prior to completion of the parking aprons. The first landing at Nackeroo Field took place on the morning of 23 June 2007 by a RAAF C-130 aircraft (Figure 86).

Figure 86. The RAAF C-130 just after landing.

C-17 operations

The certification of the airfield for C-17 operations was performed by the 320th Special Tactics Squadron with assistance from their RAAF counterparts. The process involved verifying the design geometry and pavement strength using field measuring techniques to ensure compliance with the current U.S. and Australian standards (Figure 87). Optical survey instruments were used to measure airfield geometry as well as approach-departure clearance surfaces. DCP tests were conducted to measure the strength of the various pavement layers and the results are discussed in Appendix B. Initially, there was concern that the heavy rainfall received prior to the scheduled operations would lower the RCR to a value of 4 resulting in much longer requirements for runway length. However, the surface of the airfield dried quickly after the rainfall, allowing aircraft operations to proceed safely.

The first C-17 operation occurred on 28 June by a U.S. aircraft (Figure 88) and was quickly followed by a second aircraft bearing the Australian flag. The flight operations on 28 June were essentially a rehearsal for the VIP/Airfield Opening Day scheduled for 29 June. Multiple landings on 28 June allowed the pilots, crews, and ground teams to gain familiarity with landings at Nackeroo Field prior to the airfield opening event on 29 June.

Figure 87. The assessment team measuring runway strength and geometry.

Figure 88. The first C-17 touches down on the new JRAC airfield.

Activities on 29 June started with the landing of an Australian C-130 transporting VIP's from Darwin to participate in the JRAC VIP/Airfield Opening Day. Following the landing of the C-130, two C-17s arrived and parked on the newly constructed parking aprons. With the C-130 on the runway and the two C-17s parked on the aprons, the new airfield displayed its MOG 3 capability. All aircraft departed the airfield without noticeable damage to the taxiways and aprons. Figure 89 shows the last C-17 departing the airfield.

Figure 89. C-17 Departing the runway.

Airfield opening day

At the conclusion of the 2007 JRAC technology demonstration and the completion of the construction of the runway and aprons on 29 June, a Visitor's Day Program was held to allow guests to visit the project site, view the technology firsthand, and visit with members of the JRAC Task Force. The event consisted of two groups of visitors: Group A arrived the day before and were transported to BFTA by bus from Darwin, and Group B arrived and departed on 29 June via an Australian C-130 from Darwin. A large event tent was erected to provide a venue for the day's activities and the visitors were presented with numerous briefings and demonstrations explaining the technology and the intricacies of how the project was completed. This was also an opportunity for the JRAC Task

Force to gather at the completed airfield project site to celebrate their unprecedented accomplishments (Figure 90). After the formal presentations were complete, the visitors witnessed first hand the multiple operations of the C-17 aircraft on the newly constructed runway.

Figure 90. JRAC Task Force posing with a C-17.

12 Conclusions and Summary

Conclusions

The Joint Rapid Airfield Construction (JRAC) 2007 technology demonstration project was, by all accounts, a resounding success. After over 6 years of extensive research and development efforts, JRAC technologies were put into the hands of the JRAC Task Force in a realistic contingency setting, and the Task Force used these technologies to build a C-17 capable semi-prepared runway in less than 16 days and two C-17 capable parking aprons and taxiways in a mere 40 hr. These accomplishments met two of the JRAC program's most important metrics:

1. Reduce construction time by at least 50% (JRAC runway took sixteen 12-hr days versus projected 30 to 45 days by conventional methods.).
2. Add MOG2 (or ramp space for two aircraft) to an existing airfield in 48 hr. (JRAC accomplished this task in less than ideal conditions in an amazing 40 hr!)

A number of more specific conclusions on particular JRAC technologies that were demonstrated are worth noting here:

1. The ability to quickly and easily generate a 3-D airfield design to be used with GPS grade control construction equipment is critical to meeting rapid earthmoving requirements and reducing the overall timeline.
2. The Rapid Airfield Construction Decision Support Toolset (RACDST) used during the Talisman Saber Command Post Exercise (CPX) worked well in locating plausible project sites, laying out the runway orientation, and sharing site selection outputs with other software applications.
3. The Rapid Assessment Vehicle – Engineer (RAVEN) proved that housing virtually all JRAC site assessment and engineering tools on a single mobile platform was a viable concept.
4. The rapid soils analysis kit (RSAK) proved to be one of the most valuable and accepted JRAC technologies by serving as a critical component of rapid assessment and construction quality control.
5. The rapid quality assurance kit (RQAK) was used for the first time during this demonstration project, and it proved itself as a valuable and functional

set of tools for measuring soil density and soil strength in an expedient manner on the project site.

6. The Terex pulvermixer used during the soil stabilization process provided the required mixing capabilities with limited operator training, and it has been certified as C-130 transportable.
7. The enhanced construction systems used in this project clearly demonstrated an improvement in operator efficiency, enhanced situational awareness at multiple levels, and the ability to conduct remote and autonomous operation of construction machines.
8. The Site Vision Office software system allowed for centralized construction monitoring that improved efficiency of equipment usage and helped identify construction errors as soon as they occurred.
9. Soil stabilization of the parking aprons and taxiways produced smooth and stable surfaces that effectively carried slow-rolling and static C-17 loads less than 24 hr after completion.

Summary

The 2007 JRAC demonstration project was successful on three important levels:

1. It provided valuable engineering and construction training to over 200 military personnel representing all service branches in both the U.S. and Australian militaries.
2. It produced a valuable piece of enduring infrastructure (a C-17 capable MOG3 airfield) for the Australian military at an important new training area in Australia's Northern Territory known as the Bradshaw Field Training Area.
3. It proved the viability of the individual JRAC technologies demonstrated and the collective JRAC approach to rapid construction of contingency airfields in austere environments.

It is projected that many of the technologies demonstrated by this project will soon become a part of the U.S. military's capabilities. The need for these technologies has been emphasized in recent military operations involving rapid force projection requirements. It is now up to those agencies responsible for new military systems integration and acquisition to recognize the value of the JRAC approach and to get these technologies into the hands of the engineering and construction forces they are intended to serve.

References

Anderton, G. L., and C. A. Gartrell. 2005. *Rapid maximum-on-ground (MOG) enhancement technologies*. ERDC/GSL TR-05-2. U.S. Army Engineer Research and Development Center.

ASTM. 2006. *Annual book of ASTM standards*. West Conshohocken, PA: American Society of Testing and Materials.

Berney IV, E. S., and R. W. Wahl. 2008. *A rapid soils analysis kit*. ERDC/GSL TR-08-3. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Caterpillar. 2002. *Caterpillar performance handbook*. Peoria, IL: Caterpillar Inc.

Department of the Army (DA). 1994. Planning and design of roads, airfields, and heliports in the theater of operations – Road design. FM 5-430-00-1. Washington, DC.

Department of the Army (DA). 1994b. Planning and design of roads, airfields, and heliports in the theater of operations – Airfield and heliport design. FM 5-430-00-2. Washington, DC.

Department of the Army (DA). 1994. Soil stabilization for pavements. FM 5-822-14. Washington, DC.

Department of the Army (DA). 1997. Military soils engineering. FM 5-410. Washington, DC.

Department of the Army (DA). 2000. Earthmoving operations. FM 5-434. Washington, DC.

Freeman, R. B., T. A. Mann, L. M. Webb, C. A. Gartrell, and V. M. Moore. 2008. *Quality assurance for rapid airfield construction*. ERDC/GSL TR-08-7. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Gartrell, C. A. 2007. *Full scale instrumented testing and analysis of matting systems for airfield parking ramps and taxiways*. ERDC/GSL TR-07-33. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Headquarters, Air Force Civil Engineering Support Agency. 1997. *Criteria and guidance for C-17 contingency and training operations on semi-prepared airfields*. Engineering Technical Letter (ETL) 97-9. Tyndall AFB, FL.

Headquarters, Air Force Civil Engineering Support Agency. 2004. *C-130 and C-17 landing zone (LZ) dimensional, marking, and lighting criteria*. Engineering Technical Letter (ETL) 04-7. Tyndall AFB, FL.

Mann, T. A., R. B. Freeman, and G. L. Anderton. 2006. *Grout impregnation of pre-placed recycled concrete pavement (RCP) for rapid repair of deteriorated portland cement concrete airfield pavements*. ERDC/GSL TR-07-09. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Newman, J. K., and D. J. White. 2007. Rapid assessment of cement/fiber stabilized soil using roller-integrated compaction monitoring. *Transportation Research Board* (in press).

Tingle, J. S., and T. A. Mann. 2001. *Expedient airfield construction using the computer-aided earthmoving system*. ERDC/GSL TR-01-20. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Unified Facilities Criteria (UFC). 2001. *Pavement design for airfields*. UFC 3-260-02. Washington, DC.

Webster, S. L., R. H. Grau, and T. P. Williams. 1992. *Description and application of dual mass dynamic cone penetrometer*. Instruction Report GL-92-3. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Appendix A: Stabilization Construction Criteria

The construction criteria used for the stabilization project are presented below. These criteria, guidelines, and procedures were developed on-site following the test area and helipad construction. Additional comments, notes, and experiences have been added where necessary and are given in italics.

1. The operational tempo should be adjusted such that a continuous operation of material placement, mixing, and compaction is achieved. *This is to prevent the mixing operation from getting too far ahead of the compactors. Compaction is almost always the slow step in this process. Thus, the mixing operation should be slowed to the point that the compactors are just able to keep up.*
2. Each feature (taxiway or apron) shall be completed as a continuous operation from start to finish without interruption. *This is to prevent a hard joint where the cement has already begun to set before the next lane is begun. In some cases, this is not avoidable. For example, during Bravo stabilization, portions of the taxiway had to be excavated and the material replaced due to a wet subbase that shoved during compaction. This delayed stabilization of the taxiway such that the apron construction had to be halted for a few hours, when the older lane was mated with the newer lane, the cement had began to set and caused considerable problems achieving compaction at the joint.*
3. Lot size shall be 500 m^2. Each lot shall be divided into four equal sublots.
4. The grade shall be prepared with proper elevation and density on the unstabilized soil before stabilization can commence. *In short, for stabilization with a reclaimer/stabilize, the surface smoothness at the start will be what results after stabilization.*
5. Moisture contents shall be between 6.3% to 9.3% with OMC = 7.3%. No moisture contents shall be outside the range of 5.3% to 10.3%. Four moisture contents per lot should be measured both before and after adjusting soil moisture. Note that changes may be required to these criteria if soil property changes occur during construction. *This uses a rule of thumb for cement stabilization. Increase the moisture content by 1% for less than 5% cement dosage. The OMC for the stockpile soil for the apron/taxiway construction was 6.3%. As cement stabilization needs extra*

water to cure, the lower limit was set at 1% below OMC and the upper limit set at +2% of OMC. Excluding stabilization, the moisture content limits on this project were ±2%.

6. Fiber bag spacing within each 1.83-m- (6-ft-) wide lane shall be at 5.75-m (19-ft) intervals. Cement bag spacing within each lane shall be 0.85-m (2.75-ft) intervals. Fiber bag weights were 13.6 kg (30 lb) and cement bag weights were 20 kg (44 lb). Fiber dosage rate was 0.4% and cement dosage was 4% by weight of soil.
    a. For Apron Alpha, this was a total of no more than 34 pallets of cement (2,720 bags) and 17 pallets (408 bags) of fiber for an area of 61 by 68.5 m (200 by 225 ft).
    b. For Taxiway Alpha, this was a total of no more than 13 pallets of cement (1,040 bags) and 6.5 pallets (155 bags) of fiber for an area of 71 by 20 m (230 by 65 ft) including the runway fillets.
    c. For Apron Bravo, this was a total of no more than 34 pallets of cement (2,720 bags) and 17 pallets (408 bags) of fiber for an area of 61 by 68.5 m (200 by 225 ft).
    d. For Taxiway Bravo, this was a total of no more than 13 pallets of cement (1,040 bags) and 6.5 pallets (155 bags) of fiber for an area of 71 by 20 m (230 by 65 ft) including the runway fillets.
    e. A uniform distribution of cement and fiber must be spread across each lane. This is a subjective criterion, but it must be obtained to the satisfaction of the Quality Control Team. The cement is best spread by gentle raking to avoid dust. The fiber is best spread by dropping by hand as evenly as possible back and forth across each lane.

    The actual amounts of material placed on the aprons and taxiways were very close to the projected amounts.
7. The material placement shall be no more than three lanes ahead of the mixing. *In case of interruption due to weather, this helps prevent spoilage of materials.*
8. Pulvermixer speed must be no more than 9.1 m/min (30 ft/min) with a mixing depth of 150 mm (6 in.). Mixing depth settings should be verified for each feature (taxiway or apron) prior to mixing by the QCT.
9. Mixing shall start approximately 2 m (7 ft) before one side of a feature and end approximately 2 m (7 ft) past the opposite side. This will minimize smoothness problems within the stabilized area due to cutter head pickup and dropdown. Based on the experience at this project, these criteria should be amended to 5 m or the length of the machine. All mixing will be conducted in the starting direction and shall not occur in opposite directions. This is for the ease of the Terex operators. It is much easier for the

operator to maintain a proper line and overlap with the adjacent lane when always moving in the same direction. This does not increase the overall time of stabilization since the slow step is compaction.

10. After mixing and before compaction, any uneven areas shall be smoothed (by hand, if necessary) to the same grade as the as-mixed soil to within plus or minus 20-mm (0.75-in.) difference over a 3.66-m (12-ft) span. It is not necessary to smooth the longitudinal marks made by the pulvermixer cutter housing.
11. Under no circumstances should compaction be started more than 30 min after mixing. For fast-setting cements (and especially during warm weather and sunny days), this is absolutely necessary.
12. Compaction consists of a minimum of eight roller passes (forward and reverse = 1 pass, low amplitude vibration forward pass only, 3 km/hr) and a target Compaction Meter Value of 30. Roller passes shall be checked periodically by the QCT by viewing the in-cab display or communication with the Site Office. Additional static rolling may be needed to smooth roller marks on the surface. As always, the importance of proper compaction cannot be overemphasized, as was learned from the experience with the helipad. Poor compaction will seriously degrade performance.
13. CIV measurements shall be obtained within 30 min after compaction is complete. An average of 5 CIVs per sublot shall have values no less than 25. If any CIV falls below 20, the QCT shall assess the conditions of the materials placement, materials distribution and compaction process to determine if changes are warranted. The Clegg hammer proved its worth as a valuable field tool for assessing proper compaction.
14. Grading of the surface should be avoided unless absolutely necessary. Grading of fiber stabilized surfaces causes tearing of the soil/cement/fiber material. If grading is needed to smooth an area, it should be apparent after the first few roller passes and be conducted at that time. Graders should not operate on as-mixed soil unless enough compaction has been achieved to prevent tire ruts. If grading is necessary, it should be performed before final compaction is complete.
15. If grading is necessary before compaction is complete, compaction should resume on the surface according to Item 12 until the final compaction criteria are met. Note that additional smooth drum static rolling may be necessary following grading to reestablish smoothness.
16. No traffic is allowed on the stabilized surface for 24 hr after compaction, excluding polymer capping, quality control test vehicles, and required certification vehicles.

Appendix B: DCP Test Data

DCP tests were conducted during an initial site survey in June 2006 to determine the design CBR value for the subgrade. The results of these tests are summarized in Table B1.

Table B1. In situ airfield DCP summary.

	CBR Based on DCP			
Station	**6" (152mm)**	**12" (305mm)**	**18" (457mm)**	**24" (610mm)**
STA 0 RW CL	20	Refusal at 230mm	Refusal at 230mm	Refusal at 230mm
STA 0 - 45'E of RW CL	12	Refusal at 305mm	Refusal at 305mm	Refusal at 305mm
STA 0 - 45'W of RW CL	8	8	Refusal 490mm	Refusal 490mm
STA 1000 RW CL	12	18	25	Refusal at 590 mm
STA 2000 RW CL	28	38	38	6
STA 2000 - 45'E of RW CL	5.5	26	46	Refusal at 520mm
STA 2000 - 45"W of RW CL	18	19	Refusal at 330mm	Refusal at 330mm
STA 3000 RW CL	Refusal at 150mm	Refusal at 150mm	Refusal at 150mm	Refusal at 150mm
STA 4000 RW CL	12	48	48	Refusal at 515mm
STA 4000 - 45'E of RW CL	36	Refusal at 270mm	Refusal at 270mm	Refusal at 270mm
STA 4000 - 45'W of RW CL	36	Refusal at 260mm	Refusal at 260mm	Refusal at 260mm
Taxiway 1 - 105' W of RW edge	18	40	100	Refusal at 495mm
Apron 1 Center	100	Refusal at 215mm	Refusal at 215mm	Refusal at 215mm
Taxiway 2 - 140'W of RW CL	3.8	8	31	50
Apron 2 Center	6.5	16	Refusal at 420mm	Refusal at 420mm

Multiple DCP tests were also conducted prior to C-17 aircraft landings in order to certify the airfield and verify the strength of the various layers. The tests were conducted by the 320th Special Tactics Squadron as described in Chapter 11. In total, 55 DCP tests were conducted and the test locations are shown in Figure B1. All DCP tests met or exceeded the requirements for multiple aircraft landings on 28 and 29 June 2007. Representative tests of the runway conducted after construction are shown in Figures B2 through B8.

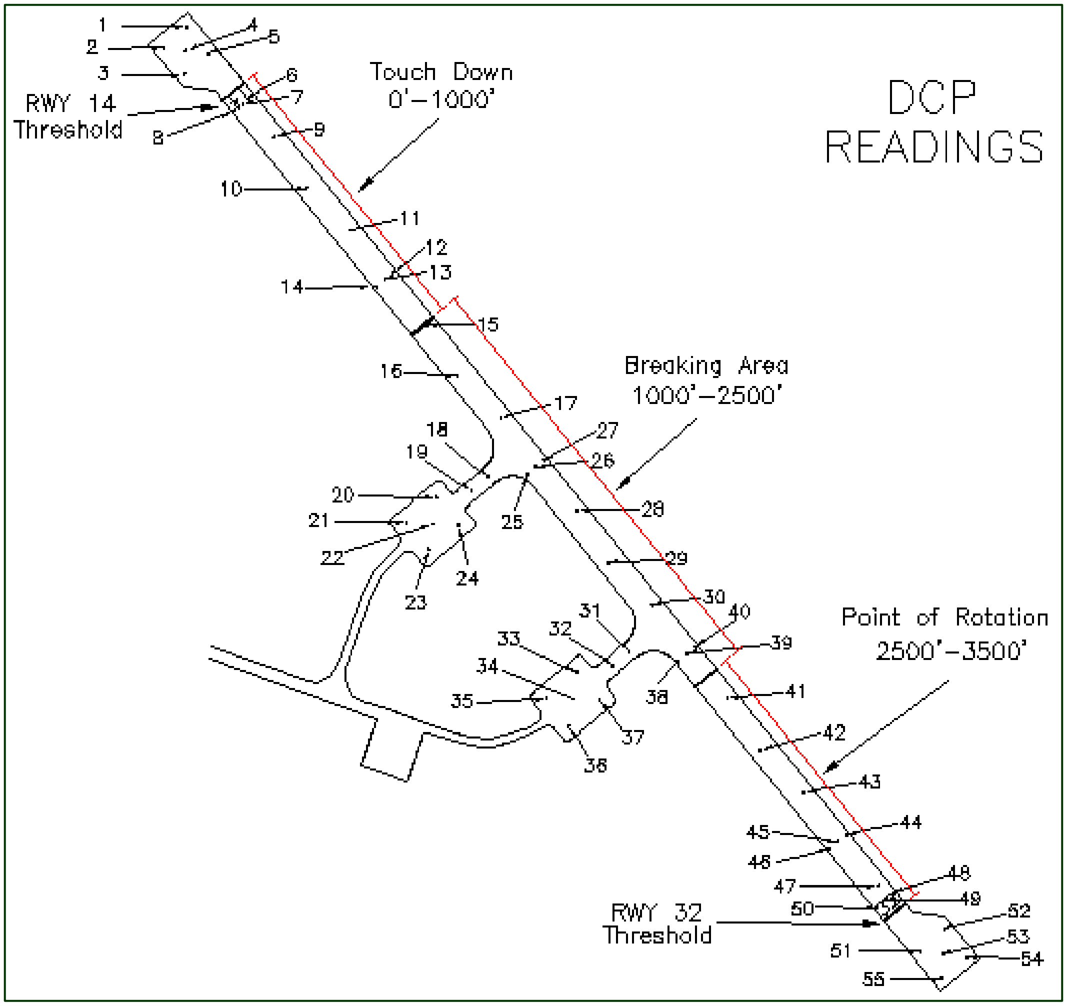


Figure B1. Layout of DCP readings.

CONTINGENCY DCP TEST DATA

File Name: Nackeroo DCP's

Project: *Nackeroo LZ, Bradshaw Training Area* Date: 23-Jun-07
Location: RWY 14 Over Run Reading 55' North of Center DCP #1
Surface Thickness: ____________ Soil Type(s): All Others
Base Course Thickness: _________

Hammer
○ 10.1 lbs.
● 17.6 lbs.
○ Both hammers used

Soil Type
○ CH
○ CL
● All other soils

No. of Blows	Accumulative Penetration (mm)	Type of Hammer
0	0	1
2	30	1
3	60	1
3	90	1
3	120	1
3	150	1
2	175	1
3	200	1
2	225	1
2	250	1
2	275	1
3	300	1
3	330	1
3	360	1
3	385	1
4	415	1
6	435	1
9	460	1
10	485	1
10	510	1
9	535	1
9	560	1
6	585	1
5	610	1
5	635	1
5	660	1
5	685	1
4	710	1
6	735	1
7	760	1
10	785	1
17	810	1
18	835	1
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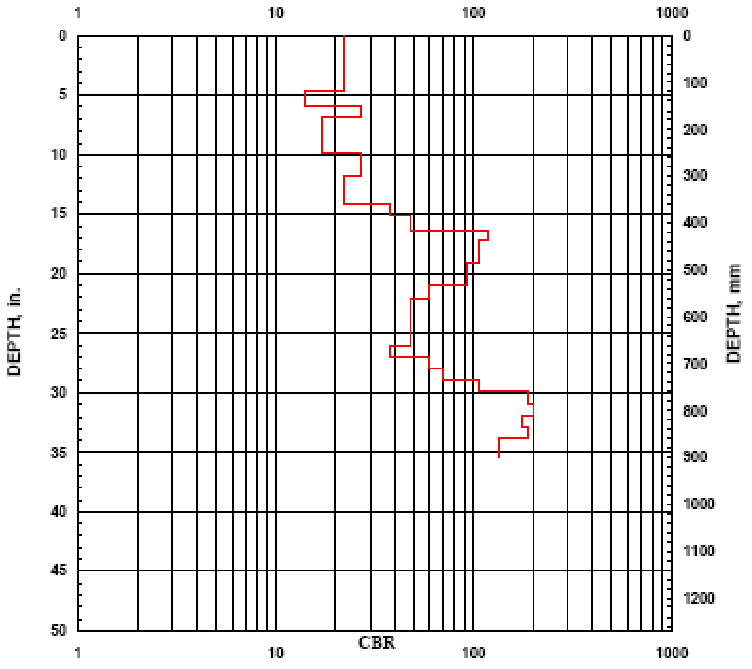
		1



Layer	Depth	CBR	Cover	K	Eff K	AGL	Passes
AC/PCC							
Base Course	16	21					
Subbase	22	70					
Subbase	35	100					
Subgrade	NA						

a. For unidentifialbe impenetrable material, assign CBR 80
b. For flex pavement, adjust layer thicknesses if AC and base course > min design thickness.
c. Adjust flex and rigid AGLs if evaluating for Type C Traffic or if PC≤ 40 (poor)
d. For rigid pavement, reduce AGL by 25% if no load transfer.

Figure B2. DCP test 1.

CONTINGENCY DCP TEST DATA

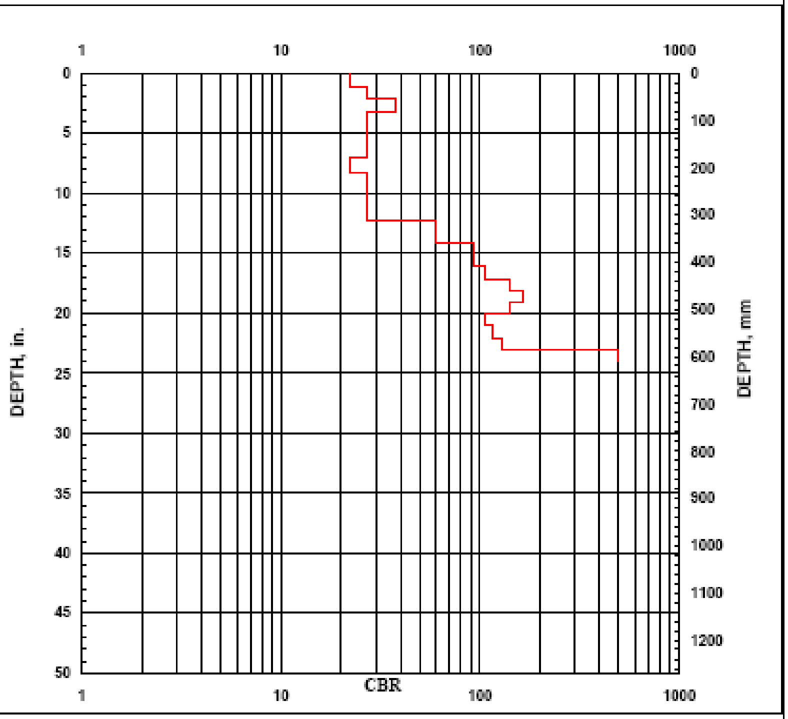
File Name: Nackeroo DCP's

Project: *Nackeroo LZ, Bradshaw Training Area* Date: 23-Jun-07
Location: RWY 14 Over Run Reading 55' South of Center DCP #3
Surface Thickness: ____________ Soil Type(s): All Others
Base Course Thickness: _________

Hammer
○ 10.1 lbs.
● 17.6 lbs.
○ Both hammers used

Soil Type
○ CH
○ CL
● All other soils

No. of Blows	Accumulative Penetration (mm)	Type of Hammer
0	0	1
3	30	1
3	55	1
4	80	1
3	105	1
3	130	1
3	155	1
3	180	1
3	210	1
3	235	1
3	260	1
3	285	1
3	310	1
6	335	1
6	360	1
9	385	1
9	410	1
10	435	1
13	460	1
15	485	1
13	510	1
10	535	1
11	560	1
12	585	1
40	610	1



Layer	Depth	CBR	Cover	K	Eff K	AGL	Passes
AC/PCC							
Base Course	12	30					
Subbase							
Subbase							
Subgrade	NA	80					

a. For unidentifialbe impenetrable material, assign CBR 80
b. For flex pavement, adjust layer thicknesses if AC and base course > min design thickness.
c. Adjust flex and rigid AGLs if evaluating for Type C Traffic or if PC≤ 40 (poor)
d. For rigid pavement, reduce AGL by 25% if no load transfer.

Figure B3. DCP test 3.

CONTINGENCY DCP TEST DATA

File Name: Nackeroo DCP's

Project: *Nackeroo LZ, Bradshaw Training Area* Date: 23-Jun-07
Location: RWY 14 00' Right Reading 40' from Centerline DCP #8
Surface Thickness: ____________ Soil Type(s): All Others
Base Course Thickness: __________

Hammer
○ 10.1 lbs.
● 17.6 lbs.
○ Both hammers used

Soil Type
○ CH
○ CL
● All other soils

No. of Blows	Accumulative Penetration (mm)	Type of Hammer
0	0	1
3	30	1
6	55	1
6	80	1
5	105	1
4	130	1
4	155	1
4	180	1
7	205	1
5	230	1
6	255	1
7	280	1
7	305	1
5	330	1
4	360	1
3	385	1
4	420	1
3	445	1
3	470	1
3	495	1
3	520	1
2	545	1
3	570	1
4	595	1
3	620	1
3	645	1
3	670	1
5	695	1
5	720	1
5	745	1
4	770	1
3	795	1
3	820	1
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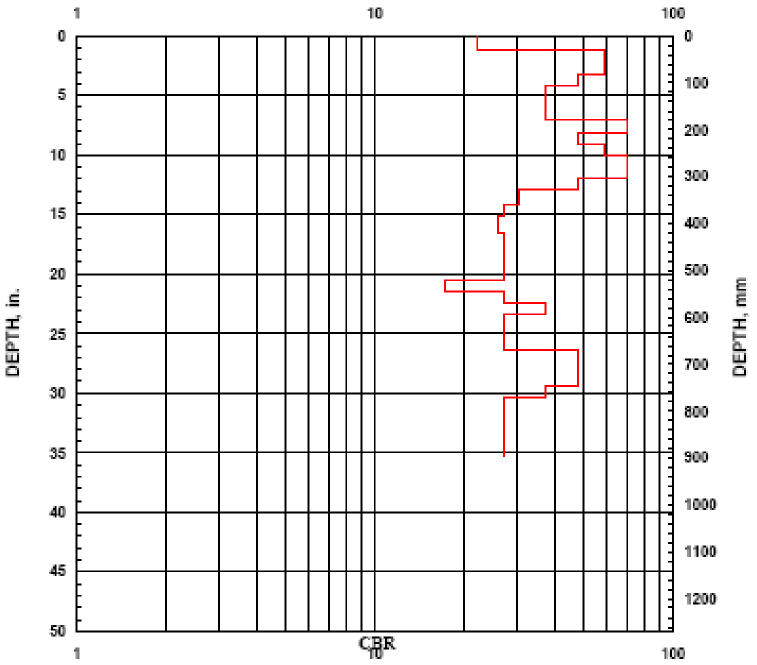
		1
		1



Layer	Depth	CBR	Cover	K	Eff K	AGL	Passes
AC/PCC							
Base Course	10	40					
Subbase	26	34					
Subbase							
Subgrade	NA	36					

a. For unidentifialbe impenetrable material, assign CBR 80
b. For flex pavement, adjust layer thicknesses if AC and base course > min design thickness.
c. Adjust flex and rigid AGLs if evaluating for Type C Traffic or if PC≤ 40 (poor)
d. For rigid pavement, reduce AGL by 25% if no load transfer.

Figure B4. DCP test 8.

CONTINGENCY DCP TEST DATA

File Name: Nackeroo DCP's

Project: *Nackeroo LZ, Bradshaw Training Area* Date: 23-Jun-07

Location: RWY 14 800' Left Reading 40' from Centerline DCP #12

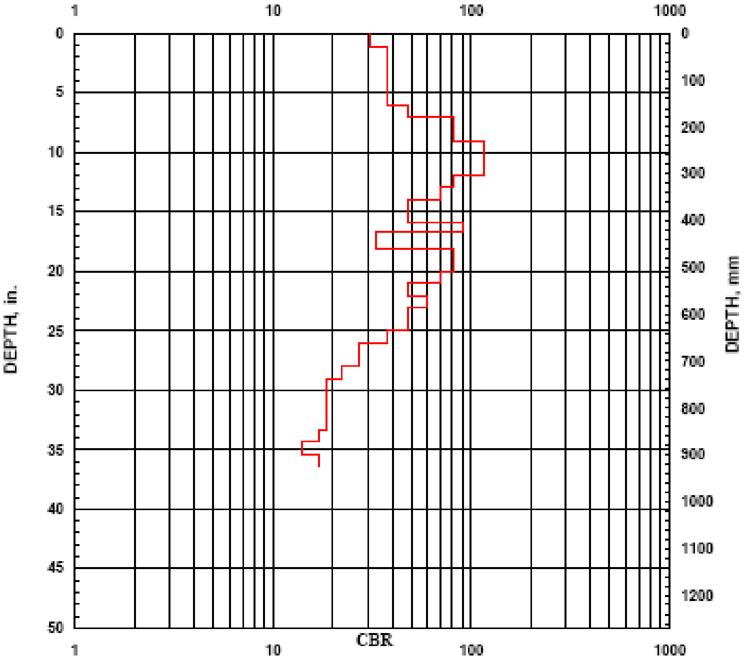
Surface Thickness: ____________ Soil Type(s): All Others

Base Course Thickness: _________

Hammer
○ 10.1 lbs.
● 17.6 lbs.
○ Both hammers used

Soil Type
○ CH
○ CL
● All other soils

No. of Blows	Accumulative Penetration (mm)	Type of Hammer
0	0	1
4	30	1
4	55	1
4	80	1
4	105	1
4	130	1
4	155	1
5	180	1
8	205	1
8	230	1
11	255	1
11	280	1
11	305	1
8	330	1
7	355	1
5	380	1
5	405	1
7	425	1
5	460	1
8	485	1
8	510	1
7	535	1
5	560	1
6	585	1
5	610	1
5	635	1
4	660	1
3	685	1
3	710	1
3	740	1
3	775	1
3	810	1
3	845	1
2	870	1
2	900	1
2	925	1
	905	1
		1
		1
		1
		1
		1
		1



Layer	Depth	CBR	Cover	K	Eff K	AGL	Passes
AC/PCC							
Base Course	7	38					
Subbase	14	90					
Subbase	25	60					
Subgrade	NA	20					

a. For unidentifialbe impenetrable material, assign CBR 80
b. For flex pavement, adjust layer thicknesses if AC and base course > min design thickness.
c. Adjust flex and rigid AGLs if evaluating for Type C Traffic or if PC≤ 40 (poor)
d. For rigid pavement, reduce AGL by 25% if no load transfer.

Figure B5. DCP test 12.

CONTINGENCY DCP TEST DATA

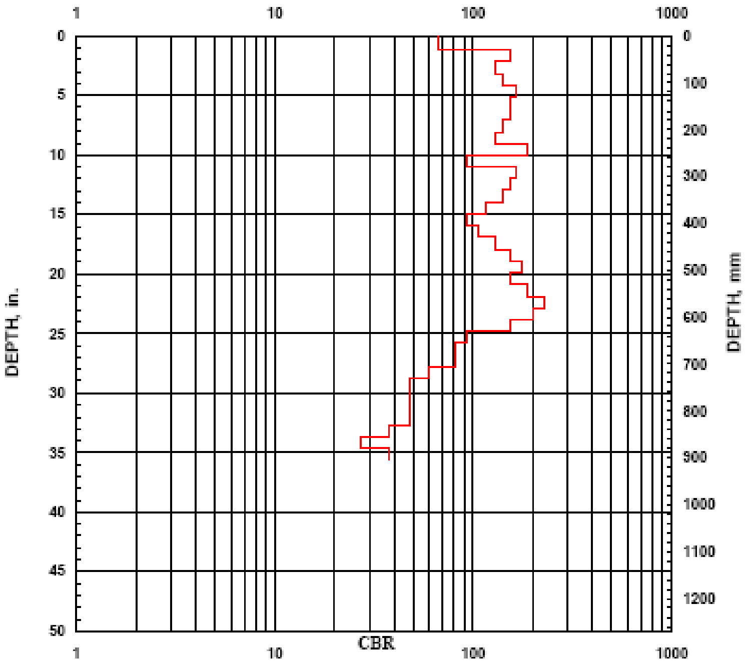
File Name: Nackeroo DCP's

Project: *Nackeroo LZ, Bradshaw Training Area* Date: 23-Jun-07
Location: RWY 14 1800' Left Reading 12.5' from Centerline DCP #28
Surface Thickness: ____________ Soil Type(s): All Others
Base Course Thickness: _________

Hammer
○ 10.1 lbs.
● 17.6 lbs.
○ Both hammers used

Soil Type
○ CH
○ CL
● All other soils

No. of Blows	Accumulative Penetration (mm)	Type of Hammer
0	0	1
8	30	1
14	55	1
12	80	1
13	105	1
15	130	1
14	155	1
14	180	1
13	205	1
12	230	1
17	255	1
9	280	1
15	305	1
14	330	1
13	355	1
11	380	1
9	405	1
10	430	1
12	455	1
14	480	1
16	505	1
14	530	1
17	555	1
20	580	1
18	605	1
14	630	1
9	655	1
8	680	1
8	705	1
6	730	1
5	755	1
5	780	1
5	805	1
5	830	1
4	855	1
3	880	1
4	905	1
		1
		1
		1
		1
		1
		1



Layer	Depth	CBR	Cover	K	Eff K	AGL	Passes
AC/PCC							
Base Course	27	100					
Subbase							
Subbase							
Subgrade	NA	45					

a. For unidentifialbe impenetrable material, assign CBR 80
b. For flex pavement, adjust layer thicknesses if AC and base course > min design thickness.
c. Adjust flex and rigid AGLs if evaluating for Type C Traffic or if PC≤ 40 (poor)
d. For rigid pavement, reduce AGL by 25% if no load transfer.

Figure B6. DCP test 28.

CONTINGENCY DCP TEST DATA

File Name: Nackeroo DCP's

Project: *Nackeroo LZ, Bradshaw Training Area* Date: 23-Jun-07
Location: RWY 14 3000' Left Reading 12.5' from Centerline DCP #43
Surface Thickness: ___________
Soil Type(s): All Others
Base Course Thickness: _________

Hammer
○ 10.1 lbs.
● 17.6 lbs.
○ Both hammers used

Soil Type
○ CH
○ CL
● All other soils

No. of Blows	Accumulative Penetration (mm)	Type of Hammer
0	0	1
3	30	1
3	60	1
4	90	1
4	115	1
4	140	1
4	170	1
4	195	1
4	220	1
6	255	1
6	280	1
6	305	1
8	330	1
8	355	1
7	380	1
7	405	1
8	430	1
9	455	1
7	480	1
15	505	1
24	530	1
50	555	1
		1
		1
		1
		1
		1
		1
		1
		1
		1
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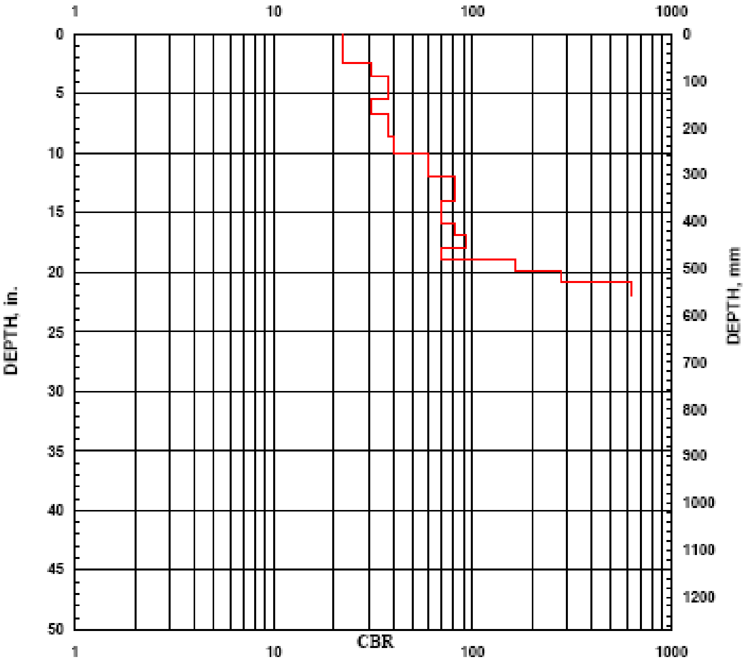
		1
		1
		1



Layer	Depth	CBR	Cover	K	Eff K	AGL	Passes
AC/PCC							
Base Course	6	30					
Subbase	12	45					
Subbase	22	80					
Subgrade	NA						

a. For unidentifialbe impenetrable material, assign CBR 80
b. For flex pavement, adjust layer thicknesses if AC and base course > min design thickness.
c. Adjust flex and rigid AGLs if evaluating for Type C Traffic or if PC≤ 40 (poor)
d. For rigid pavement, reduce AGL by 25% if no load transfer.

Figure B7. DCP test 43.

CONTINGENCY DCP TEST DATA

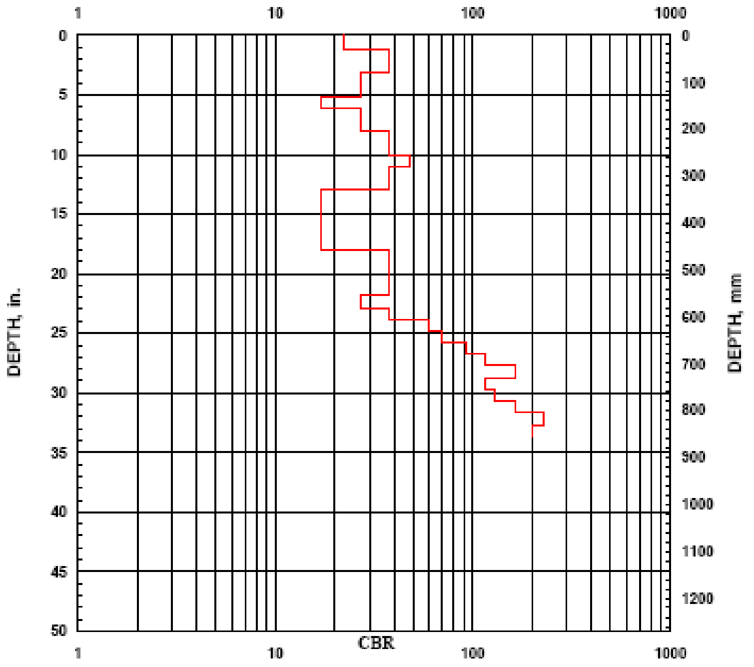
File Name: Nackeroo DCP's

Project: *Nackeroo LZ, Bradshaw Training Area* Date: 23-Jun-07
Location: RWY 32 Over Run Reading 55' North of Center DCP #52
Surface Thickness: ___________ Soil Type(s): All Others
Base Course Thickness: _________

Hammer
○ 10.1 lbs.
● 17.6 lbs.
○ Both hammers used

Soil Type
○ CH
○ CL
● All other soils

No. of Blows	Accumulative Penetration (mm)	Type of Hammer
0	0	1
3	30	1
4	55	1
4	80	1
3	105	1
3	130	1
2	155	1
3	180	1
3	205	1
4	230	1
4	255	1
5	280	1
4	305	1
4	330	1
2	355	1
2	380	1
2	405	1
2	430	1
2	455	1
4	480	1
4	505	1
4	530	1
4	555	1
3	580	1
4	605	1
6	630	1
7	655	1
9	680	1
11	705	1
15	730	1
11	755	1
12	780	1
15	805	1
20	830	1
18	855	1
		1
		1
		1
		1
		1
		1
		1
		1



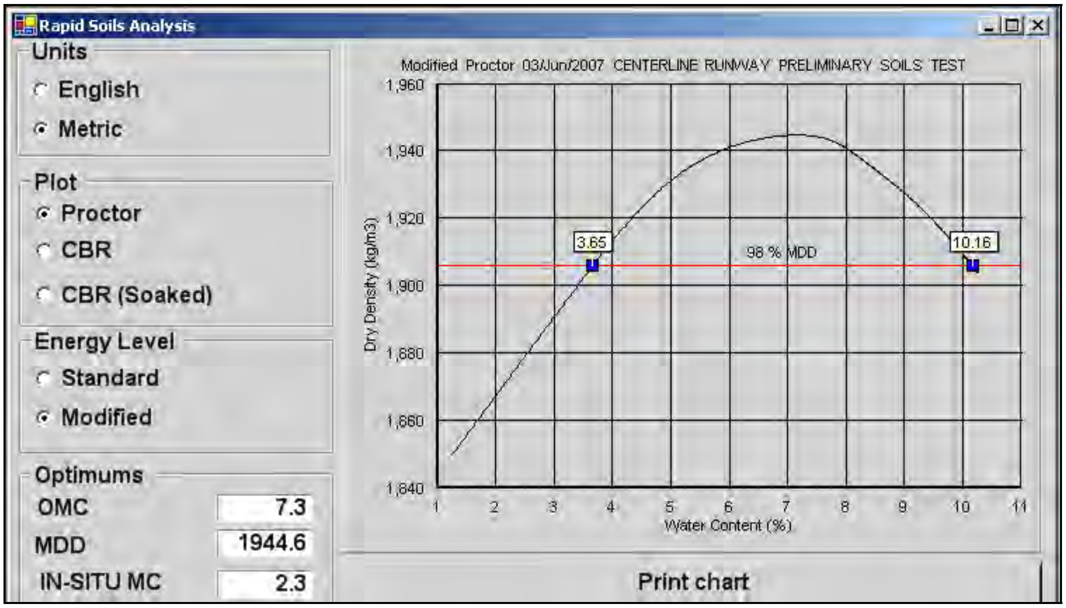
Layer	Depth	CBR	Cover	K	Eff K	AGL	Passes
AC/PCC							
Base Course	6	29					
Subbase	13	39					
Subbase	24	23					
Subgrade	NA	75					

a. For unidentifialbe impenetrable material, assign CBR 80
b. For flex pavement, adjust layer thicknesses if AC and base course > min design thickness.
c. Adjust flex and rigid AGLs if evaluating for Type C Traffic or if PC≤ 40 (poor)
d. For rigid pavement, reduce AGL by 25% if no load transfer.

Figure B8. DCP test 52.

Appendix C: RSAK Moisture-Density Curves

The following are the modified Proctor energy, moisture-density curves as determined by the JRAC Task Force soils team using the RSAK. Curves were generated for each of the four unique soils on-site: in situ subgrade (Figure C1), red quarried subbase (Figure C2), white base course (Figure C3) and red wearing surface/base course material (Figure C4). Each curve was used as the basis for construction design, quality control, and quality assurance during the project. A summary of their data is given in Table 7.


Rapid Soils Analysis

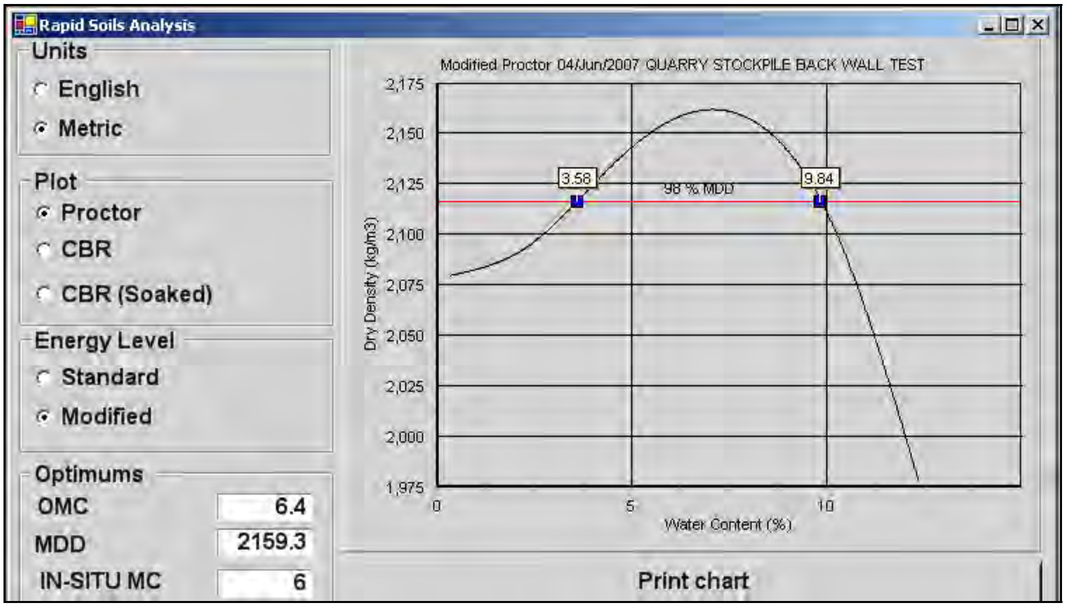
Units
○ English
● Metric

Plot
● Proctor
○ CBR
○ CBR (Soaked)

Energy Level
○ Standard
● Modified

Optimums
OMC 7.3
MDD 1944.6
IN-SITU MC 2.3

Figure C1. In situ subgrade moisture-density curve.



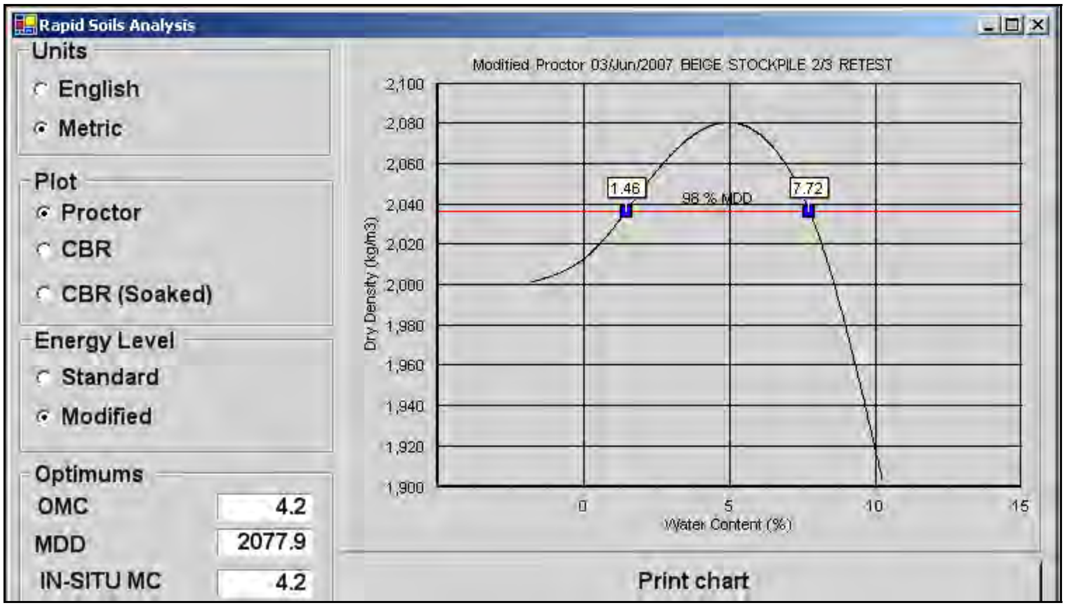
Units
○ English
● Metric

Plot
● Proctor
○ CBR
○ CBR (Soaked)

Energy Level
○ Standard
● Modified

Optimums
OMC 6.4
MDD 2159.3
IN-SITU MC 6

Figure C2. Red quarried subbase moisture-density curve.



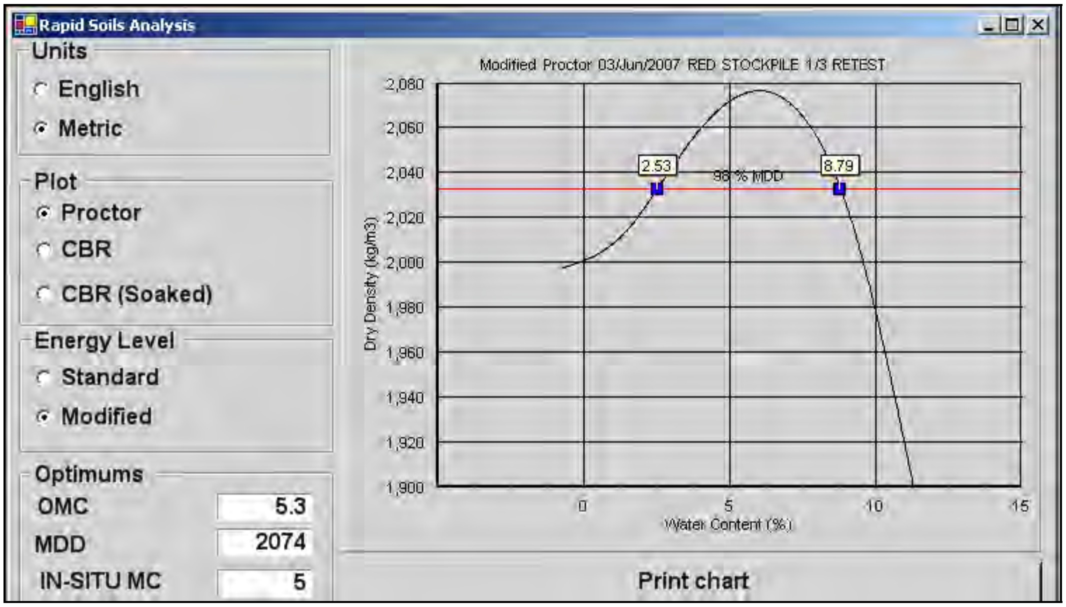
Units
○ English
● Metric

Plot
● Proctor
○ CBR
○ CBR (Soaked)

Energy Level
○ Standard
● Modified

Optimums
OMC 4.2
MDD 2077.9
IN-SITU MC 4.2

Figure C3. White base course moisture-density curve.



Rapid Soils Analysis

Units

○ English

● Metric

Plot

● Proctor

○ CBR

○ CBR (Soaked)

Energy Level

○ Standard

● Modified

Optimums

OMC 5.3

MDD 2074

IN-SITU MC 5

Figure C4. Red wearing surface/base course moisture-density curve.

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14. ABSTRACT

This report describes the demonstration of technologies and procedures developed under the Joint Rapid Airfield Construction (JRAC) program at the U.S. Army Engineer Research and Development Center in Vicksburg, MS. The successful demonstration project occurred in Australia in June 2007. The JRAC demonstration project was conducted as an integral part of Exercise Talisman Saber 2007, a U.S. and Australian combined and joint forces military exercise. The project included the construction of a 4,100 by 110 ft (1,250- by 33.5-m) unsurfaced runway and two 45,480-ft^2 (4,225-m^2) aircraft parking aprons with associated connector taxiways, all using JRAC technologies focused on rapid construction with reduced logistics and increased system reliability. This demonstration marked the successful conclusion of the 6-year research and development phase of the JRAC program.

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Stabilization

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