



DEPARTMENT OF THE AIR FORCE

AIR FORCE CIVIL ENGINEER CENTER

TYNDALL AIR FORCE BASE FLORIDA

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FROM: AFCEC/DD
139 Barnes Drive Suite 1
Tyndall AFB FL 32403-5319

SUBJECT: Engineering Technical Letter (ETL) 14-4: Vertical Landing Zone (VLZ) and Other Airfield Pavement Design and Construction Using High Temperature Concrete

1. Purpose. This ETL provides design and construction guidance for vertical landing zones (VLZ) and other airfield pavement applications requiring concrete that is resilient under frequent applications of surface temperatures in excess of 482 °C (900 °F).

Note: Use of the name or mark of a specific manufacturer, commercial product, commodity, or service in this ETL does not imply endorsement by the Air Force, Navy, Army or Marine Corps.

2. Application: Installations requiring high temperature concrete construction.

2.1. Authority:

- Unified Facilities Criteria (UFC) 3-260-02, *Pavement Design for Airfields*
- Air Force Policy Directive (AFPD) 32-10, *Installations and Facilities*
- AFPD 10-2, *Readiness*

2.2. Effective Date: Immediately

2.3. Intended Users:

- Major command (MAJCOM) engineers
- Base Civil Engineers (BCE)
- U.S. Army Corps of Engineers (USACE) and Naval Facilities Engineering Command (NAVFAC) engineers responsible for Air Force design and construction

2.4. Coordination:

- NAVFAC Engineering and Expeditionary Warfare Center (EXWC)
- MAJCOM pavement engineers
- F35 Joint Program Office (JPO)
- Air Force Flight Standards Agency (AFFSA)

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3. Acronyms:

AC	- Advisory Circular
ACC	- Asphalt Cement Concrete
AFCEC	- Air Force Civil Engineer Center
AFFSA	- Air Force Flight Safety Agency
AFI	- Air Force Instruction
AFPD	- Air Force Policy Directive
AFRL	- Air Force Research Laboratory
ASR	- alkali silica reaction
AWG	- American Wire Gauge
BCE	- Base Civil Engineer
°C	- degrees Celsius
CEMP	- Corps of Engineers Directorate of Military Programs
CF	- coarseness factor
CRC	- continuously reinforced concrete
DODI	- Department of Defense Instruction
ETL	- Engineering Technical Letter
°F	- degrees Fahrenheit
FAA	- Federal Aviation Administration
FOD	- foreign object damage
ft	- foot
HMA	- hot mix asphalt
HTC	- high temperature concrete
ICB	- inorganic composite binder
JPO	- Joint Program Office`
k value	- modulus of subgrade reduction
l	- liter
LED	- light-emitting diode
LHA	- Landing, Helicopter, Assault
LHD	- Landing, Helicopter, Dock
MAJCOM	- major command
m	- meter
MCAS	- Marine Corps Air Station
mm	- millimeter
MPa	- megapascal
NAVAIR	- Naval Air Systems Command
NAVFAC EXWC	- Naval Facilities Engineering Command Engineering and Expeditionary Warfare Center
NFESC	- Naval Facilities Engineering Services Center
NRMCA	- National Ready-Mixed Concrete Association
NTS	- not to scale
oz	- ounce
PCC	- Portland cement concrete
PVC	- polyvinyl chloride

SSD	- saturated surface dry
STOVL	- short takeoff and vertical landing
TDS	- Technical Data Sheet
UFC	- Unified Facilities Criteria
UFGS	- Unified Facilities Guide Specifications
USACE	- United States Army Corps of Engineers
VFR	- visual flight rules
VL	- vertical landing
VL pad	- vertical landing pad using HTC
VLZ	- vertical landing zone comprising the imaginary airspace, VL pad, safety zone, shoulders, and connecting taxiway
WF	- workability factor
WRDA	- Water Resources Development Act

4. References

4.1. Air Force:

- AFPD 10-2, *Readiness*, <http://www.e-publishing.af.mil/>, <http://www.e-publishing.af.mil/>
- AFPD 32-10, *Installations and Facilities*, <http://www.e-publishing.af.mil/>
- Air Force Instruction (AFI) 32-1042, *Standards for Marking Airfields*, <http://www.e-publishing.af.mil/>
- ETL 04-2, *Standard Airfield Pavement Marking Schemes*, <http://www.wbdg.org/>

4.2. Navy:

- TDS NAVFAC EXWC-CI-1403, "Mitigating Concrete Damage Caused by Engine Exhaust Surface Temperature Below 500 °F," December 2013 (supersedes TDS-2058-SHR)

4.3. Joint:

- Unified Facilities Guide Specification (UFGS) 32 13 13.43, *High Temperature Concrete for Airfields*, http://www.wbdg.org/ccb/browse_org.php?o=70
- UFGS 32 13 11, *Concrete Pavement for Airfields and Other Heavy-Duty Pavement*
- UFGS 32 11 23, *Aggregate and/or Graded-Crushed Aggregate Base Course*
- UFGS 32 11 24, *Graded Crushed Aggregate Base Course for [Pervious][Flexible] 11-11 Pavement*
- UFGS 32 11 16, *[Base Course for Rigid] [and Subbase for Flexible] Paving*
- UFGS 32 12 15.13, *Hot-Mix Asphalt for Airfield Paving*
- UFC 3-250-08F, *A Standard Practice for Sealing Joints and Cracks in Rigid and Flexible Pavements*
- UFC 3-260-01, *Airfield and Heliport Planning and Design*
- UFC 3-260-02, *Pavement Design for Airfields*

- UFC 3-270-03, *Concrete Crack and Partial-Depth Spall Repair*
- UFC 3-270-04, *Concrete Repair*
- UFC 3-535-01, *Visual Air Navigation Facilities*

UFCs are available at: http://www.wbdg.org/ccb/browse_cat.php?o=29&c=4.

UFGS are available at: http://www.wbdg.org/ccb/browse_cat.php?c=3

4.4. Federal Aviation Administration:

- FAA Advisory Circular (AC) 150/5345-7, *Specification for L-824 Underground Electrical Cable for Airport Lighting Circuits*
- FAA AC 150/5345-42, *Specification for Airport Light Bases, Transformer Housings, Junction Boxes, and Accessories*
- FAA AC 150/5345-46, *Specifications for Runway and Taxiway Light Fixtures*
- FAA AC 150/5345-47, *Specification for Series to Series Isolation Transformers for Airport Lighting Systems*

FAA ACs are available at:

http://www.airweb.faa.gov/Regulatory_and_Guidance_Library/rgAdvisoryCircular.nsf/MainFrame?OpenFrameSet&CFID=56957&CFTOKEN=71066012&CFID=1409204&CFTOKEN=89169026&CFID=10991906&CFTOKEN=40774853

4.5. American Society for Testing and Materials (ASTM):

- ASTM A722/A722M, *Standard Specification for Uncoated High-Strength Steel Bars for Prestressing Concrete*
- ASTM C330, *Standard Specification for Lightweight Aggregates for Structural Concrete*
- ASTM C131, *Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine*
- ASTM C88, *Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate*
- ASTM C150/C150M, *Standard Specification for Portland Cement*
- ASTM C1580, *Standard Test Method for Water-Soluble Sulfate in Soil*
- ASTM C618, *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete*
- ASTM C136, *Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates*
- ASTM C117, *Standard Test Method for Materials Finer than 75- μ m (No. 200) Sieve in Mineral Aggregates by Washing*
- ASTM C127, *Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate*
- ASTM C260/C260M, *Standard Specification for Air-Entraining Admixtures for Concrete*
- ASTM C494, *Standard Specification for Chemical Admixtures for Concrete*
- ASTM C1017/C1017M, *Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete*

- ASTM C173/C173M, *Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method*
- ASTM C1116/C1116M, *Standard Specification for Fiber-Reinforced Concrete*
- ASTM D5893/D5893M, *Standard Specification for Cold Applied, Single Component, Chemically Curing Silicone Joint Sealant for Portland Cement Concrete Pavements*

ASTM standards are available at : www.astm.org/standard/

4.5. New York State Department of Transportation Materials Bureau:

- NY 703-19 E (2008), "Moisture Content of Lightweight Fine Aggregate," available at: https://www.dot.ny.gov/divisions/engineering/technical-services/materials-bureau-repository/tm_703-19E.pdf

4.6. American Concrete Institute (ACI):

- ACI 201.2R-08: "Guide to Durable Concrete," 2008, available at: <http://www.concrete.org/Store.aspx>

5. Background. Conventional Portland Cement Concrete (PCC) loses free moisture at high rates around 100 °C (212 °F) and starts to lose its chemically combined water at around 121 °C (250 °F). The highest rate of dehydration occurs around 177 °C (350 °F). At temperatures above 177 °C (350 °F), pavement damage increases exponentially. In accordance with this ETL and UFGS 32 13 13.43, *High Temperature Concrete for Airfields*, high-temperature concrete must be used where operations apply temperatures at the surface of the concrete from 482 °C to 926 °C (900 °F to 1700 °F), even for short durations. Operations that apply temperatures at the surface of the concrete from 148 °C to 482 °C (300 °F to 900 °F) for longer durations may use this ETL and UFGS 32 13 11, *Concrete Pavement for Airfields and Other Heavy-Duty Pavement*, modified by using only traprock for the coarse aggregate.

5.1. NAVFAC EXWC Testing. Testing at Naval Facilities Engineering and Expeditionary Warfare Center (NAVFAC EXWC) identified two sets of materials that can survive anticipated temperatures without major degradation.

5.1.1. The first set of materials was developed by NAVFAC EXWC and incorporated Portland cement; fly ash; polypropylene fibers; and coarse and fine aggregate composed either of expanded slate, expanded shale, or specifically-tested and approved traprock sources. Of the expanded aggregates available on the open market, expanded slates and expanded shales are acceptable; expanded clays are too soft and friable for airfield purposes and are not permitted. Mixtures using expanded aggregates (also known as lightweight aggregates) or approved traprock sources are referred to as High Temperature Concrete (HTC), and are suitable for full-depth construction and repairs.

5.1.2. The second set of proprietary materials included Phoscrete™, and Firerok™ with an additive CenterStar, each used in combination with granite aggregate and polypropylene fibers. These materials are suitable for repairing HTC. Performance of these materials in repairs subject to the temperature regimes identified in this ETL has not been evaluated by NAVFAC EXWC (formerly NFESC), but is reported as suitable by the manufacturers.

5.1.3. The HTC surface may require removal (grinding) of damaged HTC to a depth of 3 millimeters (0.125 inches) to 6 millimeters (0.25 inches) after numerous applications of the subject temperature regimes. This damage may take several years to develop, depending upon usage and environment.

5.1.4. Detailed reports of the various materials and testing protocols are contained in TDS NAVFAC EXWC-CI-1403, "Mitigating Concrete Damage Caused by Engine Exhaust Surface Temperature Below 500 °F." Note that only the listed traprock sources have been tested; traprock obtained from other sources must be tested before use. For a current set of testing requirements, limits, and laboratories, e-mail the AFCEC Reachback Center at afcec.rbc@tyndall.af.mil. Potential alternative heat resistant aggregates, such as granite, basalt, or other igneous rocks, may also perform properly, but must be tested before use.

5.2. Air Force Research Laboratory (AFRL) Testing. AFRL in conjunction with NAVFAC EXWC tested a PPG fiberglass product: PPG Mil-Tough® Composite Technology, Inorganic Composite Binder (ICB), Grancrete Inc. provided acceptable performance in heat and load testing. This material is suitable for repairing the HTC.

6. Project Programming.

6.1. NAVFAC EXWC Consulting Services. Programming documents for HTC projects must include provisions to fund and obtain three man-months of consulting services from NAVFAC EXWC, Port Hueneme, Naval Base Ventura County, California, plus travel, per diem, and lodging expenses. Consulting services will address -- but not be limited to -- HTC mix design, development, and optimization; mix plant; stockpiling; and setup and operations; as well as HTC transport, handling, testing, placement, finishing, texturing, curing, and sealing.

6.2. Fund for Alternative Aggregates. When programming, scoping, or designing facilities using HTC, funding and documentation for high-temperature testing of acceptable alternative HTC aggregates must be provided when aggregates from the sources listed in this ETL cannot be economically obtained to meet project requirements.

6.3. Pavement Adjacent to VLZs. When siting and programming a VLZ, the existing apron and taxiway pavement connecting to the VLZ must be considered. Specifically, enough cores and borings must be obtained, examined, or tested to validate the existing pavement structure can sustain the change in type and quantity of traffic. Programmed project scope must include repair, replacement, or upgrade of adjacent existing pavement, if required.

7. Pad Geometry, Location, and Orientation.

7.1. The geometric layout for the VLZ is provided in Attachment 1. Each VLZ includes a VL pad, a safety zone, connecting taxiway, and paved shoulders. The operational dimension of a standard VL pad is 30.5 meters by 30.5 meters (100 feet by 100 feet), which is surrounded by a 15.25-meter (50-foot) paved load-bearing safety zone. The safety zone is surrounded by a paved shoulder 3 meters (10 feet) wide.

7.2. The connecting taxiway must be 22.8 meters (75 feet) wide with paved shoulders 3 meters (10 feet) wide. The connecting taxiway must be long enough so that after an aircraft has landed and is on the VL pad, it does not interfere with aircraft operations on the runway, taxiway or apron to which the VLZ is connected. Refer to UFC 3-260-01, *Airfield and Heliport Planning and Design*, and this section for the appropriate clearances and additional taxiway geometric criteria. When creating pavements to simulate US Navy Landing Helicopter Assault (LHA)/Landing Helicopter Dock (LHD) decks the design must be reviewed and approved by NAVFAC EXWC throughout the design process and prior to the start of construction.

7.3. Select the VLZ or LHA/LHD location taking into account mission requirements, overall facility development, approach-departure surfaces, and local wind conditions. To minimize crosswinds, the strength, direction, and frequency of local winds must be considered when orienting a VLZ or LHA/LHD. Contact HQ USACE (CEMP-ET), the appropriate Air Force MAJCOM pavements engineer, or NAVFAC EXWC for current guidance on siting of landing pads, airfield geometry and airspace requirements.

8. Grading. A uniform slope is required to eliminate irregularities between landing gear during touchdown. The VL pad and safety zone must be graded in the same manner as an apron to provide a warped surface that drains according to the grading requirements of this ETL.

8.1. VL Pad and Safety Zone. Minimum longitudinal and transverse slopes must be 0.5 percent. In no case will any slope of the vertical landing pad exceed 0.5 degrees (0.87 percent). The maximum longitudinal or transverse slope of the safety zone pavement must be 1.0 percent. The design engineer must verify that all areas of VL pads, safety zones, connecting taxiways, and paved and unpaved shoulders effectively drain surface water to eliminate ponding. If VL pad slopes violate these limits, the contractor must grind the surface to meet slope requirements at no additional cost to the government. If the required grinding exceeds ½-inch (12.5 millimeters) deep on any portion of the pad, the contractor must replace the pad at no additional cost to the government.

8.1.1. Raised Elevation. To ensure an elevation that will allow future grinding of the HTC surface, the VL pad and safety zone must be constructed together such that up to 51 millimeters (2 inches) of material may be diamond-ground from the landing pad surface and still maintain the maximum and minimum grades to eliminate ponding (refer to Attachment 1). This higher elevation of the VL pad must be transitioned to the safety zone on all sides, using slopes as indicated in Attachment 1.

8.1.2. Primary Surface Elevation. The primary surface elevation is the highest point on a VL pad. It must be located on the corner of the HTC VL pad that will be closest to the connecting taxiway. The designer will verify that the primary surface of a VL pad does not interfere with the primary surface and other clearances of adjacent runways, aprons, or taxiways.

8.1.3 Shoulder Grades. All paved and unpaved VL pad shoulders must be graded in accordance with UFC 3-260-01, Table 4-4.

8.2. Taxiway Grades. Connecting taxiway surfaces, including paved and unpaved shoulders, must be graded in accordance with UFC 3-260-01, Table 5-1. However, warping is required to connect to the VL pad safety zone.

8.3. Grades within Primary Surface. Exclusive of pavement and shoulders, grades within the primary surface must be at least two percent to a maximum of five percent, prior to drainage channelization; however, the channel bottom may be flat. The balance of the area is to be clear of obstructions and rough-graded to the extent necessary to minimize damage to aircraft in the event of an emergency landing. For VLZs, the grade requirements apply to the entire primary surface.

9. Pavement Thickness Design. Standardization of pavement thicknesses for critical pad elements has simplified VLZ implementation and minimized errors with continuous reinforcement. Per UFC 3-260-02 designers must complete enough cores, borings, test pits, subsurface investigations, and tests to determine the pavement design parameters, including (but not limited to) the design modulus of subgrade reaction.

9.1. Minimum Thickness

9.1.1. Thicknesses for VLZ pavements are designed using PCASE for an F-15C, F/A-18 or similar fighter aircraft. Traffic areas, number of passes, and material types are summarized below in Table 1. The thicknesses shown in Table 1 are the minimum allowable for HTC and PCC. Hot mix asphalt (HMA) thicknesses need to be determined by the designer using paragraph 9.6. The HTC pavement thicknesses for the VL pad thicknesses in Table 1 include the 51 millimeters (2 inches) required for potential future grinding.

9.1.2. Only HTC may be used to construct VL pads. Specific HTC requirements in this ETL must be observed. The safety zone, paved shoulders, and connecting taxiway must be constructed of either HTC or PCC. Selection of HTC or PCC is based upon consideration of the VLZ mission, together with one of the following:

- economics of construction for the site.
- whether the VLZ is used primarily for training or there is a high probability of landings outside the VL pad limits.
- direction of HQ USACE (CEMP-ET), the appropriate Air Force MAJCOM pavements engineer, or NAVFAC EXWC.

Table 1. VL Pavement Traffic and Materials

Surface	Traffic Area Type	Aircraft Passes	Material	Minimum HTC or PCC Thickness Millimeters (Inches)
VL Pad	A	400,000	HTC	300 (12)
Safety Zone Taxiway	A	400,000	HTC	300 (12)
Safety Zone	B	2,500	HTC or PCC	300 (12)
Safety Zone Paved Shoulder	Shoulder	Note 1	HTC or PCC	300 (12)
Connecting Taxiway	A	400,000	PCC, HTC or HMA Note 2	300 (12)
Connecting Taxiway Paved Shoulder	Shoulder	Note 1	PCC, HTC or HMA Note 3	200 (8)

Notes:

1. Thicknesses shown are minimums; design using UFC 3-260-02 and PCASE Shoulder Design single wheel loading, add expected coverages for crash trucks, fuel trucks, snow removal equipment or other similar heavy vehicles.
2. Connecting taxiways may be constructed of either HMA, PCC, or HTC. However, if there is a location on the connecting taxiway where it is anticipated that the aircraft would have to stop, such as a runway hold position marking, then that area must be constructed of PCC or HTC. The minimum thickness provided is for PCC or HTC. Calculate HMA pavement thickness in accordance with UFC 3-260-02.
3. The minimum thickness provided is for PCC or HTC. Calculate HMA pavement thickness in accordance with UFC 3-260-02.

9.2. Modulus of Subgrade Reaction. All HTC and PCC pavement thicknesses are based upon a design modulus of subgrade reaction (k) of 54 kilopascals per millimeter (200 pounds-per-square-inch per inch). For projects with a subgrade meeting or exceeding this requirement, a minimum of 150 millimeters (6 inches) of base course will be provided. For project sites where the subgrade cannot provide this support, the engineer will design a suitable thickness of base course such that the effective k on top of the base is a least 54 kilopascals per millimeter (200 pounds-per-square-inch per inch) and will be a minimum of 150 millimeters (6 inches). For HMA pavements, the engineer will follow the appropriate subgrade testing and design procedures in UFC 3-260-02 and PCASE.

9.3. Base Courses. Engineers will design a base course to meet minimum UFC 3-260-02 requirements. Base courses for VLZs are designed to be granular bases, satisfying criteria of one of the following UFGS:

- UFGS 32 11 23, *Aggregate and/or Graded-Crushed Aggregate Base Course*
- UFGS 32 11 24, *Graded Crushed Aggregate Base Course for Flexible Pavement*

9.3.1. Do not use base course satisfying criteria in UFGS 32 11 16, [*Base Course for Rigid*][*and Subbase for Flexible*] *Paving*, on VLZs. Any base course not satisfying UFGS 32 11 23 or UFGS 32 11 24 must be removed and replaced.

9.3.2. Stabilized bases and subbases may be used for VLZs. Engineers will design and specify those layers in accordance with appropriate UFC guidance; however, the thicknesses of the HTC and PCC described in this ETL must not be reduced. Drainage layers and underdrain systems are not required for VLZs.

9.3.3. If an effective k at the surface of the base course equal to or greater than 54 kilopascals per millimeter (200 pounds-per-square-inch per inch) cannot be attained, or it is more economical to increase the HTC and PCC thicknesses, the contractor may request a waiver from the contracting officer to increase the thickness requirements. The designed or constructed VLZ may not deviate from this ETL without the approval of the contracting officer in consultation with HQ USACE (CEMP-ET), the appropriate Air Force MAJCOM pavements engineer, or NAVFAC EXWC. CRC VL pads may require an increased amount of steel.

9.4. Portland Cement Concrete (PCC). Portland cement concrete materials must be designed as conventional airfield concrete using a flexural strength of 4.5 megapascals (650 pounds per square inch), and in accordance with other requirements in UFC 3-260-02. Higher design strengths are not permitted. Use UFGS 32 13 11 for construction of PCC pavements on the airfield.

9.5. High Temperature Concrete (HTC). HTC thickness design must be based on a 4.5 megapascals (650 pounds per square inch) flexural strength. HTC 28-day flexural strength specified for construction must be 3.8 megapascals (550 pounds

per square inch) for lightweight aggregate mixes and 4.5 megapascals (650 pounds per square inch) for traprock aggregate mixes. A higher 28-day flexural strength for HTC is not permitted.

9.6. Hot Mix Asphalt. HMA may be used for the connecting taxiway and the paved shoulders adjacent to the connecting taxiway. HMA must satisfy requirements of UFC 3-260-02 and UFGS 32 12 15, *Hot-Mix Asphalt for Airfields*. HMA may not be used for paved shoulders adjacent to the safety area due to the possible damage from jet engine exhaust.

9.7. VL Pad Continuous Reinforcement. VL pads must be continuously reinforced in both directions to minimize joints. Design is based upon procedures in UFC 3-260-02 for continuously reinforced concrete. However, thickness of the VL pad HTC must not be reduced from that designed for non-reinforced concrete; the steel size and spacing is determined for the VL pad thickness.

9.7.1. Use 25-millimeter (No. 8) steel bars meeting ASTM A722/A722M, *Standard Specification for Uncoated High-Strength Steel Bars for Prestressing Concrete*, Type II, with minimum yield strength of 535 kilonewtons (120,000 pounds-force) to continuously reinforce the VL pad in both directions. Position bars with 300-millimeter (12-inch) centers each way (longitudinal and transverse) for a standard 300-millimeter (12-inch) thick concrete pad. Only threaded rebars and couplers may be used. Three common manufacturers of threaded rebar and couplers are Dywidag, Williams, and Skylinesteel.

9.7.2. Obtaining these threaded rebars may be difficult at some locations; deviations from these requirements must be approved by the contracting officer in consultation with HQ USACE (CEMP-ET), the appropriate Air Force MAJCOM pavements engineer, or NAVFAC EXWC, and must be designed and detailed prior to construction. Use of conventional rebar with lap splices is not permitted, as the steel required for the splice can cause horizontal cracking of the HTC slabs through the plane of the reinforcing steel.

10. HTC Mixture Design. HTC mixtures are unique, composed of 100 percent expanded or approved traprock aggregate, where coarse and fine fractions are from the same manufacturing facility or quarry. Due to increased surface area and angularity, this mixture is less workable. The absorptive nature of the expanded aggregates -- up to 20 percent for some products -- further complicates mixture designs. From the VLZs at Eglin AFB and Duke Field in Florida, MCAS Yuma in Arizona, and MCAS Beaufort in South Carolina, several material handling and mixture procedures have been developed for use with HTC construction. Detailed requirements for construction are contained in UFGS 32 13 13.43.

10.1 Aggregate Sources. HTC must be produced using expanded slate, expanded shale, or traprock from approved traprock sources. Coarse and fine aggregates must be the same material; only gradations may be different. The lightweight and

traprock mixtures use different nominal maximum sizes due to product availability. The nominal maximum aggregate size is defined for this ETL and UFGS 32 13 13.43 as the largest sieve size upon which at least five percent of the coarse fraction (all aggregate retained on the 4.75 millimeters (No.4)) is retained. CONUS expanded aggregate suppliers can be located at their industry web site, <http://www.escsi.org>. Expanded aggregate manufacturers are also located in some OCONUS regions. It is recommended, but not required, that expanded lightweight aggregates that have not been tested be shipped to NAVFAC EXWC for testing prior to use.

10.1.1. Expanded Aggregates. Acceptable expanded slate and shale aggregates that have been tested include Stalite, Solite[®], and Utelite. Expanded slate or shale must be produced in a rotary kiln operated at 1,150 °C (2,100 °F). Expanded clay aggregates are not permitted, as these materials are not durable enough for the airfield pavement environment. The quality of expanded aggregates must satisfy the quality standards of ASTM C330, *Standard Specification for Lightweight Aggregates for Structural Concrete*, together with additional tests specified in paragraph 10.2. Expanded slate and shale are commercially available and can be shipped globally via super sacks, trucks, rail cars, and shipping containers. The nominal maximum size of light weight aggregates will be the largest produced by the manufacturer and equal to or greater than 12.5 millimeters (1/2-inch). As of May 2013, Stalite manufactures a 16.0-millimeter (5/8-inch) nominal maximum size. Utelite manufactures a 12.5-millimeter (1/2-inch) nominal maximum size.

10.1.2. Traprock. The nominal maximum aggregate size of traprock HTC mixes will be 19 millimeters (3/4-inch) or larger. Traprock from Carolina Sunrock was used in the landing pads at Marine Corps Air Station (MCAS) Beaufort, South Carolina. The following CONUS traprock sources have been tested for 926° C (1,700° F) temperatures.

Carolina Sunrock LLC
200 Horizon Drive Ste. 100
Raleigh NC 27615
919-747-6324

Vulcan Materials
Chula Vista Quarry
2041 Heritage Road
Chula Vista, CA 91913
858-530-9472

Pioneer Aggregates
4301 Pioneer Ave
DuPont, WA 98327
253-380-3720

Other traprock aggregates that have been used for heat-resistant concrete applications, but have not yet been tested by NAVFAC EXWC for HTC uses, are:

Chantilly Crushed Stone
Sterling, Virginia
757-494-5200

Luck Stone Corp.
Charlottesville, Virginia
804-784-6300

Traprock may not be sourced elsewhere unless first tested and approved by NAVFAC EXWC. This testing currently is conducted only by NAVFAC EXWC and may be funded only by the sponsoring agency.

10.1.3. Other Traprock Aggregates: Other traprock aggregates able to survive temperatures up to 926 °C (1,700 °F), such as basalt, andesite, or other igneous rocks, may be acceptable but shall be tested and approved by NAVFAC EXWC prior to use or construction.

10.2. Aggregate Quality Tests. Aggregate used in HTC must also be tested and meet the requirements identified in Table 2, as part of general aggregate quality tests. These tests are not part of the lightweight aggregate ASTM C330 testing regime, and must be accomplished in addition to the ASTM C330 tests. Traprock aggregates must meet the deleterious materials testing requirements in UFGS 32 13 13.43 that are similar to normal weight concrete aggregates in UFGS 32 13 11. Expanded aggregates must meet the quality tests in ASTM C330 for lightweight aggregates, as well as additional requirements identified in the specifications. ASTM C330 tests must be completed no more than 60 days prior to delivery of the aggregate to the batch plant. It is not acceptable to rely upon manufacturers' data posted on their web sites; independent testing is required. This testing may be conducted by a manufacturer's independent laboratory, provided the laboratory is certified for the testing.

Table 2. Additional HTC Aggregate Tests

Test	Standard	Requirement
Los Angeles Abrasion	ASTM C131	Less than or equal to 40% loss
Sodium Sulfate Soundness, 5 Cycles	ASTM C88	Less than or equal to 12% loss
Magnesium Sulfate Soundness, 5 Cycles	ASTM C88	Less than or equal to 18% loss

10.2.1. Freeze-Thaw. HTC pavements constructed using approved lightweight aggregates and topically sealed with sodium silicate are freeze-thaw durable. For traprock, normal weight freeze-thaw durability testing is required.

10.2.2. Alkali-Silica Reaction (ASR). ASR testing of light weight aggregates is not required because Stalite and Utelite have shown little ASR reactivity. North Carolina traprock has also not shown ASR reactivity, but the Chula Vista source is mildly reactive and readily mitigated with Class F fly ash. All traprock aggregates, coarse and fine, must be tested for ASR per UFGS 32 13 13.43.

10.2.3. Aggregate Specific Gravity. Expanded aggregates present difficulties when attempting to determine specific gravity and absorption content. It is not acceptable to use results from the manufacturers' web sites, as these may be different from the products arriving at the HTC batch plant site. Numerous mix proportioning trials were conducted during the Eglin AFB studies to develop a suitable method to accurately determine aggregate specific gravity and moisture content. Determine lightweight aggregate specific gravity using the procedure in paragraphs 10.2.3.1 through 10.2.3.4 at least three times for the project: (1) prior to developing the laboratory mixtures; (2) when building stockpiles; (3) and when replenishing stockpiles.

10.2.3.1. Obtain sample and oven dry (not microwave) at 110 °C (230 °F) until constant weight (may take several days).

10.2.3.2. Submerge entire sample in water container for seven (7) days.

10.2.3.3. Determine soaked sample bulk specific gravity.

10.2.3.4. Towel dry to no water sheen, then determine saturated surface-dry (SSD) specific gravity.

10.2.4. Aggregate Free Water

10.2.4.1. It is critical to measure and monitor the amount of free water available in the aggregate stockpiles to ensure consistent mixture properties. The amount of free water available in the aggregate stockpiles must be included in the calculation of the amount of batch water introduced at the mixing plant and for any calculation of the water/cement ratio. The procedure to determine free water on lightweight aggregate and traprock fine aggregate in paragraphs 10.2.4.1.1 through 10.2.4.1.4 (similar to NYDOT 703-19E) must be accomplished a minimum of three times for the project: (1) prior to developing the laboratory mixtures; (2) when building stockpiles; and (3) when replenishing stockpiles. General targets for production are one to three percent free moisture on coarse aggregate and six to ten percent free moisture on fine aggregate.

10.2.4.1.1. Obtain a minimum of two stockpile samples after continuous watering has ensured aggregates have reached 100 percent absorption.

10.2.4.1.2. Determine moisture content of one sample by oven drying (not microwave) at 110 °C (230 °F) until constant weight (may take several days).

10.2.4.1.3. Determine moisture content of second sample, after first towel drying to surface dry condition. Determine the moisture content of the now SSD sample by oven drying (not microwave) at 110 °C (230 °F) until constant weight (may take several days).

10.2.4.1.4. The difference between the two moisture contents is free water on aggregates.

10.2.4.2. Before batching any HTC, determine the stockpile free moisture content. Determine the wet weight and the towel dry SSD weight of the sample, then calculate the stockpile moisture available for batching. Determine stockpile moisture content prior to the first batch of the day and at the frequency in the specification.

10.2.4.3. As expanded aggregates can have absorption as high as 20 percent, the aggregate stockpiles for construction must be continuously watered, 24 hours a day, for a minimum of seven days prior to batching. If this watering regime is not followed, the aggregates will absorb the mixing water from the batch and the HTC will rapidly become unworkable. Water used for wetting or soaking the stockpiles must meet requirements for batching HTC in accordance with UFGS 32 13 13.43. Numerous trials have demonstrated the need to follow the prescribed watering method. In addition, when paving with traprock manufactured sands, the same watering regime is critical due to the high surface area of the fine aggregate.

10.2.4.4. From November 2011 through January 2012, during batching operations at MCAS Yuma using Utelite aggregates, a revised watering protocol was developed for lightweight aggregates. Use the following watering protocol for lightweight aggregates in an arid climate.

- Water the piles 24 hours a day for 7 days.
- Shut off watering 24 hours prior to paving and allow free water to drain down.
- Mix piles thoroughly with an end loader to provide uniform moisture content throughout.
- Cover piles with polyethylene sheeting and anchor.
- For day of batching, remove polyethylene sheeting, remix the piles and determine moisture content.
- Target lightweight aggregate free moisture contents (moisture above SSD) are one to three percent for coarse aggregates and six to ten percent for fine aggregates. These are for the Utelite expanded shale

aggregates. These moisture contents enable consistent batch water and material flow in the plant bins and weigh hopper.

- After batching, resume constant watering.

10.2.4.4.1. It may be possible to reduce the number of days of water to less than seven; however, the initial piles must first be continuously watered for seven days and the free water content determined. The number of watering days may be reduced until sufficient free moisture (above SSD) is in the pile to enable consistent stockpile moisture content.

10.2.4.4.2. If after seven days of watering, the free moisture content is not consistent or within the target limits, adjust the rate and distribution of water to reach the required target limits.

10.2.4.4.3. Regardless of moisture content, the minimum number of days of continuous watering for lightweight aggregate is four days (96 hours) after the initial seven-day soaking.

10.3. HTC Materials.

10.3.1. Cementitious. HTC requires only conventional ASTM C150/C150M, *Standard Specification for Portland Cement*, Type I, Type II, or Type V Portland cement. There is no requirement for high-temperature refractory-type cements. When working OCONUS where ASTM C150/C150M testing is not routine, select local cements that have test properties similar to ASTM C150. Type V cement with sulfate resistance may be required if the aggregate used for the base course, subgrade, or ground water have soluble sulfates. High concentrations of water soluble sulfates are common in desert regions. This determination is made by testing the aggregates and subgrade following the procedures of ASTM C1580, *Standard Test Method for Water-Soluble Sulfate in Soil*, and classifying according to ACI 201.2R-08, *Guide to Durable Concrete*. It is a more useful test result if the concentration is provided as milligrams per liter, rather than a percent of soluble sulfates.

10.3.1. Fly Ash and Other Pozzolans. ASTM C618, *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete*, Class F fly ash is the only pozzolan permitted for use in HTC. Class C ultra-fine fly ash, silica fume, or ground granulated blast furnace slag are not permitted, as these are detrimental to HTC performance. The specification provides the current requirements of Class F fly ash and the dosages. The typical proportion is in the range of 15 to 35 percent of the total cementitious material, based upon the chemistry of the fly ash. In non-US territories only, where Class F fly ash is not available and where ASR mitigation is not necessary, it is acceptable to not incorporate fly ash into the mixture. In those regions, deletion of the fly ash requirement must first be approved by HQ USACE (CEMP-ET), the appropriate Air Force MAJCOM pavements engineer, or NAVFAC EXWC.

10.4. Mixture Proportions. Mixture proportioning for HTC is similar to PCC. However, additional requirements and modifications are necessary due to the functional aspects of HTC.

10.4.1. Maximum Sand Content. The combined gradation of all the aggregates, coarse and fine, must have a maximum of 10 percent passing the 0.150-millimeter (No. 100) sieve. This is to minimize the fine surface paste that increases cementitious and water demand, and increases the potential for surface spalling. It is imperative this requirement is achieved. Many of the expanded aggregate manufacturers provide numerous gradations for fine aggregates. Use coarser gradations to avoid creating excessive paste, shrinkage and spall potential.

10.4.2. Cementitious Content. For expanded aggregate with 19-millimeter (3/4-inch) maximum aggregate size, a minimum total cementitious material content of 448 kilograms per cubic meter (752 pounds per cubic yard) is required. The traprock mixes require a minimum total cementitious material content of 307 kilograms per cubic meter (517 pounds per cubic yard).

10.4.3. Combined Gradations.

10.4.3.1. Optimized Process. HTC follows the same aggregate gradation process as normal airfield PCC. Optimizing concrete aggregate gradations is the process of blending of aggregates to improve workability, minimize cement paste, while remaining constructible for the haul and environmental conditions. The optimized process requires gradations of the various aggregate sizes and mathematical combination. Combinations are plotted on the workability and coarseness factor chart, the percent retained chart, and the 0.45 power curve chart. Several states offer these charts as free, on-line software, and commercial packages are available.

10.4.3.2. Stages of Batch Development. It is not possible to optimize a mixture from a laboratory study only. Rather, initial gradations must be evaluated using the methods presented in this ETL; then laboratory batches must be prepared, followed by trial batches at the plant site, and ultimately the test sections with the paving equipment.

10.4.3.2.1. Each stage enables the contractor to adjust the proportions based upon the observed response to placing, consolidation, and finishing. Specifications permit only a maximum of 3 millimeters (1/8-inch) of paste on the surface.

10.4.3.2.2. During production paving, the contractor is required to check the mathematical blend of aggregates daily. This enables adjusting batch weights to ensure the paving mixture meets the same combined gradation as the approved test section.

10.4.3.3. Standard Gradations. Determine particle distributions in accordance with ASTM C136, *Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates*, and ASTM C117, *Standard Test Method for Materials Finer than 75- μ m (No. 200) Sieve in Mineral Aggregates by Washing*. Include sieve sizes shown in Table 3. Determine the specific gravity and saturated surface dry conditions of the aggregates in accordance with ASTM C127, *Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate*. Also determine the specific gravity of all of the cementitious materials, as appropriate.

Table 3. Standard Sieves Required for Gradations

Metric (millimeters)	US Standard
50.0	2 inch
37.5	1½ inch
25.0	1 inch
19.5	¾ inch
12.5	½ inch
9.5	⅜ inch
4.75	No. 4
2.36	No. 8
1.18	No. 16
0.600	No. 30
0.300	No. 50
0.150	No. 100
0.075	No. 200

10.4.3.3.1. Evaluate the entire combination of coarse and fine aggregates for coarseness (CF) and workability (WF). Adjust WF upwards only by 2.5 percentage points for each 42.6 kilograms (94 pounds) of cementitious material per cubic yard greater than 335 kilograms per cubic meter (564 pounds per cubic yard).

Coarseness Factor (CF) = (Cumulative percent retained on the 3/8-inch sieve)(100)/(cumulative percent retained on the No. 8 sieve)

Workability Factor (WF) is defined as the percent passing the No. 8 sieve based on the combined gradation by weight.

10.4.3.3.2. Plot WF and CF on the graph provided at Figure 1. This graph uses a rectangular scale. The Y-axis is labeled WF, with units from 20 (bottom) to 45 (top); the X-axis is labeled CF, with units from 30 (left

side) to 80 (right side). Plot a parallelogram with corners at these coordinates (Figure 1 provides an example):

CF-75, WF-28
 CF-75, WF-40 (43) (see Note)
 CF-45, WF-32.5
 CF-45, WF-44.5 (47.5) (see Note)

Note: The upper WF box limit for lightweight aggregate is 3 points higher than for conventional PCC and HTC made with traprock.

If the point determined by the intersection of the computed CF and WF does not fall inside this parallelogram, change the grading of each size of aggregate used and the proportions selected as necessary.

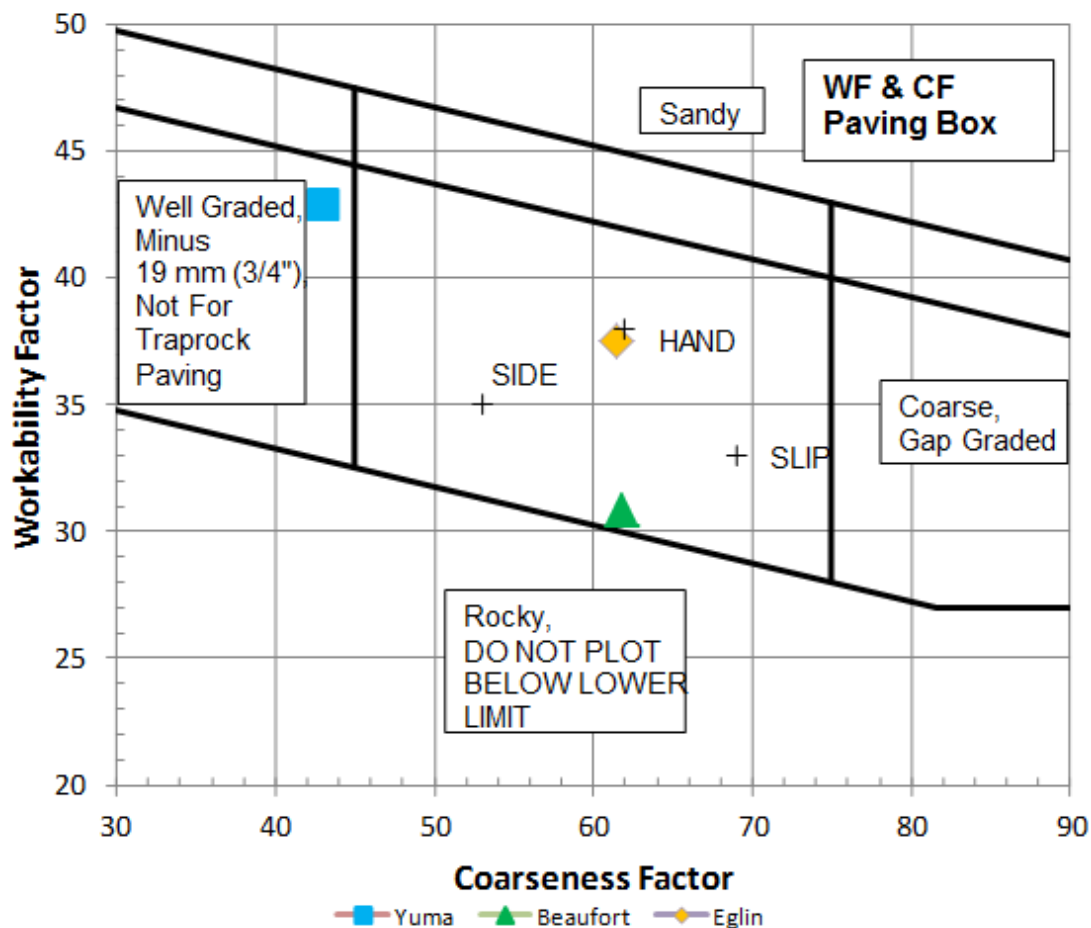


Figure 1. Workability and Coarseness Factor Chart

10.4.3.3.3. Note the upper limit line for lightweight HTC is set three points higher than for HTC with traprock and conventional airfield PCC. This is to improve the opportunity for development of enough paste to finish the

HTC surface. An initial starting point determined from expanded slate is a CF 60 and a WF 40. If necessary, adjust proportions so the WF increases to develop enough mortar for a tight, smooth pavement surface when using a vibrating truss screed. For HTC made with traprock, use the PCC WF limits, since traprock concrete is also a normal weight PCC.

10.4.3.3.4. Although there are numerous lightweight concretes made with expanded aggregates for use in high-rise building construction, those mixes normally use natural sand. HTC uses 100 percent expanded coarse and fine aggregates, which reduce the mixture workability. From the Eglin AFB and Duke Field pads, the typical HTC mix produced only minimal paste. The challenge is to create enough paste to have a tight surface free of voids, but not allow the aggregate to segregate.

10.4.3.4. Percent Retained Chart. The percent retained chart in Figure 2 is an adaptation of a chart prepared by the American Concrete Institute for architectural concrete. For airfield paving mixtures, the chart enables evaluation of gaps in the gradation in cases where the mixture will be prone to surface voids behind the paver and where the mixture will be overly sensitive to water content.

10.4.3.4.1. Interpretation of the chart relies on three aspects of the mixture design:

Criterion 1: The highest peak (the maximum percent retained) must be on the 9.5-millimeter (3/8-inch) sieve or larger to ensure adequate coarse aggregate in the mixture. In addition, at least 60 percent of the total mass must be retained on the 4.75-millimeter (No. 4) sieve. A common error is to set the highest peak on the 4.75-millimeter (No. 4) sieve so the mix will be easier to finish, but the pavement surface will be pasty and spall, which is not acceptable for airfield concrete.

Criterion 2: There must be at least four points' difference between the two highest peaks. If peaks are equal or near-equal, the mixture will demonstrate any of the following properties:

- Surface voids immediately behind the paver that cannot be closed, even with excessive hand work.
- Excess sensitivity to water content, where normal batching tolerances result in a mixture being too stiff or too fluid on a load-to-load basis and no batch plant settings were modified.

Criterion 3: There must not be any more than one low point between any two peaks. If there are two low points, the mixture is gap-graded; if there are three or more low points, the mixture is severely gap-graded and will not function as an airfield concrete mixture. This

criterion is useful in determining alternative aggregates needed to optimize the mixture.

10.4.3.4.2. A traditional approach for architectural concrete involves targeting the plot to remain within the limits of 8 to 18 percent retained. This is not applicable to airfield concrete and must not be used. Similarly, another concept requires grading the aggregates ideally to make a gradual distribution curve known as a haystack. This approach must not be used for airfield concrete, either; it usually results in violation of the 0.45 power curve chart.

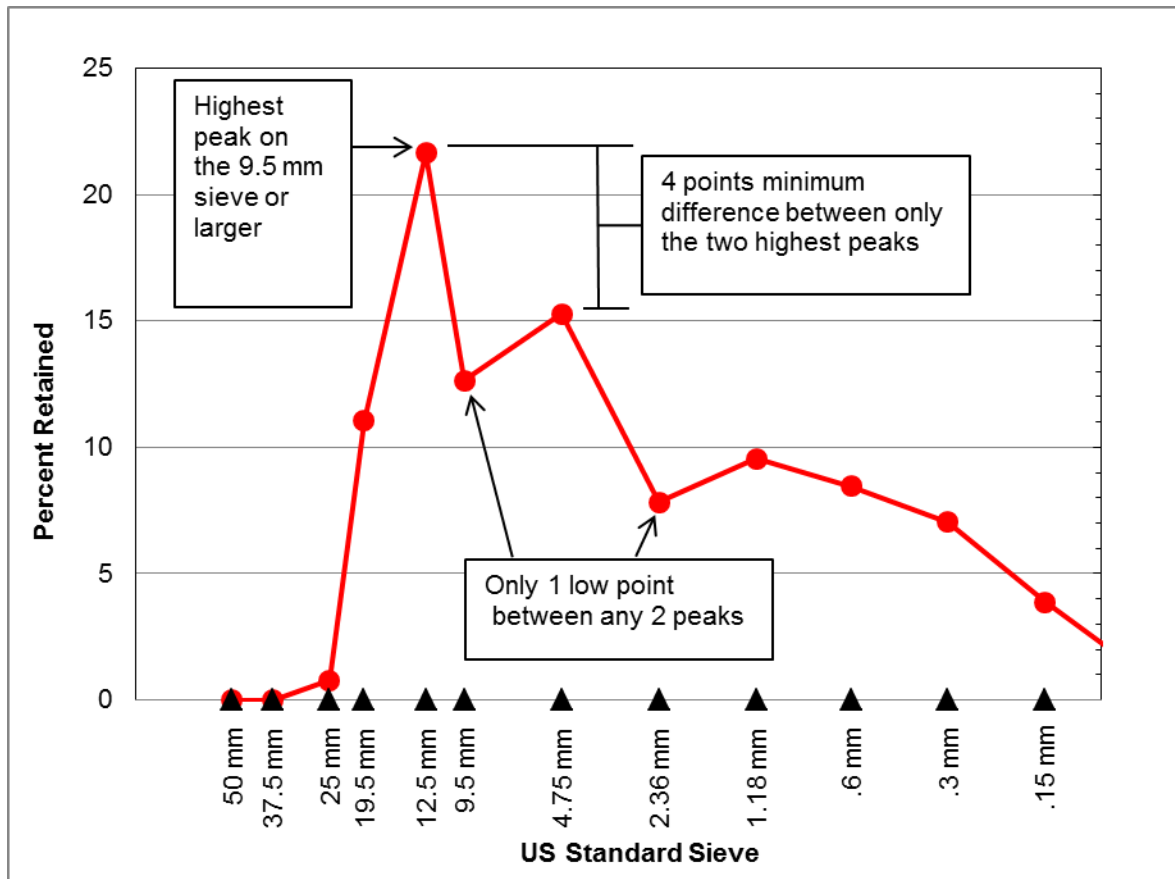


Figure 2. Percent Retained Chart

10.4.3.5. 0.45 Power Curve Chart. The 0.45 power curve chart (Figure 3) is similar to that used for asphalt paving mixtures; it's "built" by raising the sieve opening size to the 0.45 power. This chart can be used to evaluate whether a mixture is harsh, prone to spalling of the joints at an early age, or too dense. The theory is that a line drawn from the origin through the maximum particle size provides the particle distributions of theoretical maximum density. The theoretical maximum density assumes that every void in a given volume is filled with aggregate. It is not desirable for the concrete aggregate gradation to trace

the maximum density line, as there will be no voids available for cement, water, and air.

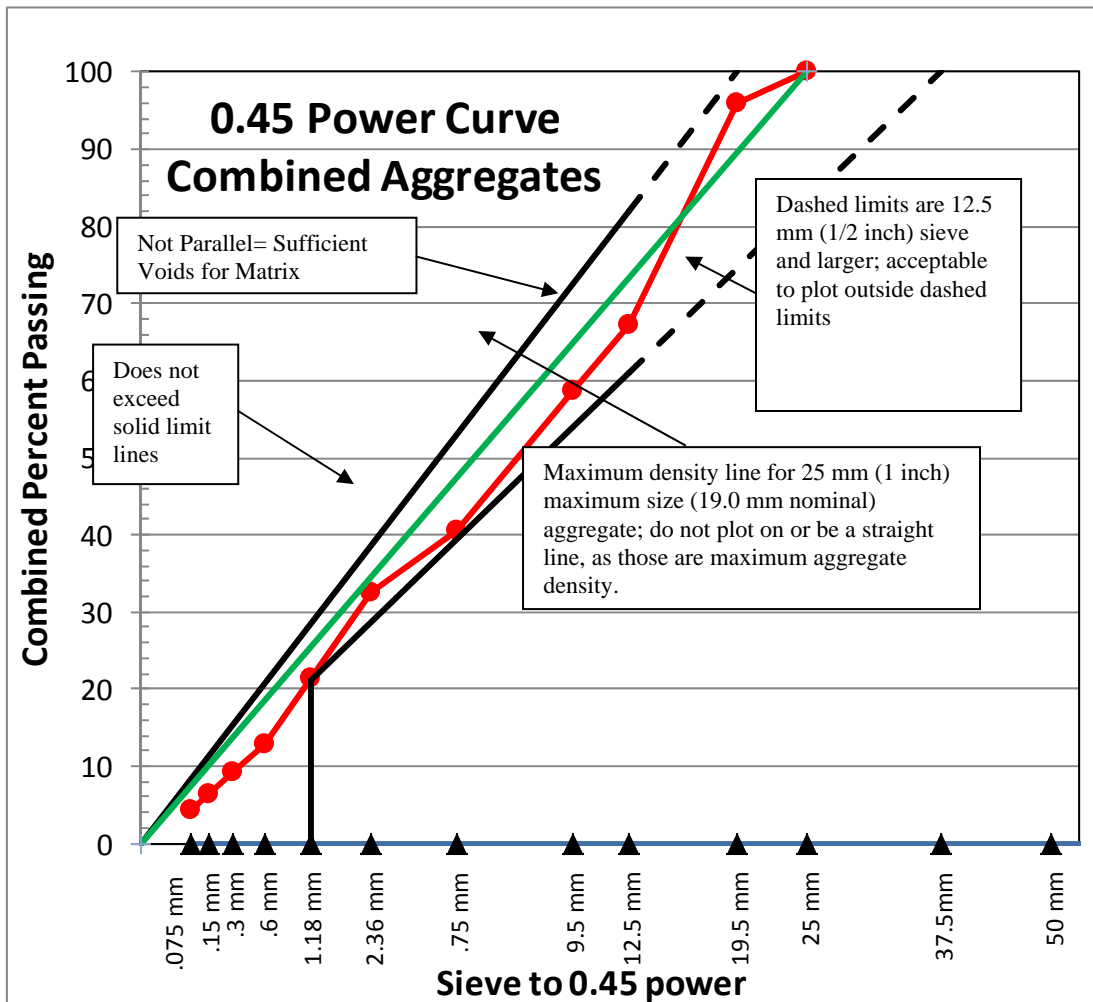


Figure 3. 0.45 Power Curve

10.4.3.5.1. For airfield concrete mixture designs, it is common to question if the maximum aggregate size or the nominal maximum size should be used for the maximum density line. That is evaluated for each particular gradation; it is best to use the maximum aggregate size. However, if the gradation is finer and it appears the nominal maximum size should be used, that is acceptable provided the theoretical maximum density line plots through the nominal maximum size aggregate. If it does not, then use the maximum aggregate size. Only rarely is the nominal maximum size used for the 0.45 power curve theoretical maximum density.

10.4.3.5.2. Using the 0.45 power curve requires limits for guidance. The lower limit is the maximum density line for the next larger standard sieve size. The upper limit is the maximum density line for the next smaller

standard sieve size. The best performing mixtures occur when the plot remains between the upper and lower limits. Note that there are segments where the limits are shown as dashed lines (larger than the 12.5-millimeter (1/2-inch) sieve). In these areas, it is permissible for the true plot to exceed the limits, as it is on the coarse fraction and does not contribute to spalling. Similarly, the lower limit is vertical at the 1.18-millimeter (No. 16 sieve), indicating the lower limit no longer applies for the subsequent smaller sieves. This is because the particles are coarser and minimize spall potential.

10.4.3.5.3. The most critical area of Figure 3 exceeds the solid upper limit. Exceeding the upper limit results in a mixture that is too fine and contains excessive mortar (sand, cementitious materials, and water). This typically occurs when only coarse aggregate and natural sand are used, or when the coarse aggregates are so large that additional intermediate aggregates are required to balance the blend. Gradations exceeding the upper limit, especially in the range between the 2.36-millimeter and 0.300-millimeter (No. 8 to the No. 50) sieves, have been observed to develop joint sliver spalls after joint sealing and prior to the first aircraft operation. It is mandatory that the combined gradation never exceed the solid portion of the upper limit. It is acceptable if the gradation plots on the solid upper line; however, exercise caution that normal variations may plot above the line.

10.4.3.6. Optimized Gradation Execution

10.4.3.6.1. As the mix designer analyzes the proportions, it is common that for traprock, three aggregates are necessary: a coarse, an intermediate, and a fine. Light weight mixes normally only require a coarse and fine aggregate, as the gradations are typically finer. However, for the MCAS Yuma project, the concrete supplier arranged for Utelite to manufacture the optimized blend for the project.

10.4.3.6.2. Adherence to daily determination of the aggregate gradations, calculating the mathematical blend, and adjusting daily batch proportions, is required to maintain acceptable airfield concrete. Checking the daily gradations is also how contractors have discovered the supplier sent the wrong materials, producing a mixture that was substantially different than before, and creating an unworkable mixture.

10.4.3.6.3. Some aggregate combinations may not satisfy all criteria. In this case, if the workability and coarseness factors plot correctly, the 0.45 power curve criteria are achieved, criteria 1 and 2 of the percent retained chart are achieved, and the mixture is demonstrated it can be placed, consolidated and finished to meet specification requirements, then the third percent retained chart criterion may be relaxed from specification

requirements provided there are no more than two low points between any two peaks.

10.4.4. Water Cement Ratios. Maximum allowable water-cementitious material ratio is 0.45. A ratio of 0.40 provided good workability at Eglin AFB. For traprock at MCAS Beaufort, a ratio of 0.45 was necessary.

10.4.5. Chemical Admixtures. HTC requires a variety of chemical admixtures. These include the normal air entraining admixture meeting ASTM C260/C260M, *Standard Specification for Air-Entraining Admixtures for Concrete*, and normal retarding or water-reducing admixtures meeting ASTM C494, *Standard Specification for Chemical Admixtures for Concrete*, Types A, B, or D. They improve the workability of the mixtures due to the angular coarse and fine aggregates. Contractors are cautioned that concretes with high range admixtures can progress into initial set rapidly or develop early age cracking, especially when used in pavements with large surface areas exposed to the elements. Water-reducing admixtures meeting ASTM C494 Types F and G are permitted only when ASTM C494 Types A, B, or D are used to the maximum recommended dosage and then Types F or G are as-needed supplements. This approach worked well at MCAS Yuma and MCAS Beaufort. ASTM C494 Type S and ASTM C1017/C1017M, *Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete*, flowable admixtures are not permitted.

10.4.6. Entrained Air. Concrete must be air-entrained with a total air content of 6 percent, plus or minus 1.5 percentage points, at the point of placement. Determine air content for expanded aggregates using the rolling air meter in accordance with ASTM C173/C173M, *Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method*. Vinsol resin-based admixtures create a more uniform distribution of entrained air and are preferred.

10.4.7. Slump. The slump of the concrete at the point of placement must be 75 millimeters (3 inches,) plus or minus 25 millimeters (1 inch). The HTC VL pads at Eglin AFB, placed by hand methods and finished with a vibrating truss screed, used a target slump of 75 millimeters (3 inches). This was considered optimal for consolidating, finishing, and maintaining cross-slope. At MCAS Beaufort with traprock, a target slump of 64 millimeters (2.5 inches) was optimal.

10.4.8. Fibers: Fibers must be multifilament polypropylene meeting ASTM C1116/C1116M, *Standard Specification for Fiber-Reinforced Concrete*. These fibers must be between 9.5 and 19 millimeters (3/8 and 3/4 inches) long, and have a maximum diameter of either 0.40 millimeters (0.0157 inches) or a maximum average weight of 10 denier. The concrete mix must contain 1.78 kilograms per cubic meter (3 pounds per cubic yard). The fibers are required in the concrete mixture to prevent spalling. This quantity of fiber is typically triple that of conventional fiber-reinforced concrete. Therefore, it is necessary to extend the mixing times with central plant mixers to ensure the fiber bags have

disintegrated and the fibers have dispersed. Time of mixing can be determined at the test sections; however, the minimum mixing time is 65 seconds. Procedures in ACI 544.3R-08 may help with fiber dispersal.

10.5. Example Mix Designs: For reference, the following mix designs were used at Eglin AFB and MCAS Beaufort. These are for reference only, and each contractor must develop its own mixture design.

10.5.1. Light-weight Example

10.5.1.1. Table 4 contains the final mixture proportions used for the HTC pads at Eglin AFB with Stalite expanded slate and the typical mix properties in Table 5. Note that these proportions are only a reference for future projects, and on-site trial batches are required to optimize materials to the batching, placing, and local climate.

10.5.1.2. Table 6 summarizes the beam and cylinder strengths achieved for the Eglin AFB VL pads. The pads were placed between 20 December 2010 and 8 January 2011. The data indicates the 28 day flexural strength of 3.8 megapascals (550 pounds per square inch) was achieved. Figure 4 shows various correlations between the beam and cylinder strengths. Beam/cylinder correlations are for research purposes and are not to be used for acceptance. Accept HTC for strength based upon the third-point flexural beam testing in the specification.

Table 4. Stalite Mixture Proportions at Eglin AFB

Material	Quantity per Cubic Meter (Cubic Yard)
Type I/II Portland Cement	335 kilograms (564 pounds)
Class F Fly Ash	112 kilograms (188 pounds)
Water	174 kilograms (294 pounds)
3/4-inch Lightweight Aggregate	459 kilograms (773 pounds)
3/8-inch Lightweight Aggregate	188 kilograms (317 pounds)
Fine Lightweight Aggregate	388 kilograms (654 pounds)
Air Entraining Agent	0.16 l (4.14 ounces)
Medium Range Water Reducer	1.75 l (45.12 ounces)
Polypropylene Fibers	1.78 kilograms (3 pounds)

Table 5. Stalite Mixture Results at Eglin AFB

Mixture Property	Result
W/C Ratio	0.39
WF	37.5
CF	61.4
Slump	75 millimeters (3 inches)

Table 6. Summary of Beam and Cylinder Strengths, Eglin AFB

	Beam Strength, MPa (psi)		Cylinder Strength, MPa (psi)	
	7 Day	28 Day	7 Day	28 Day
Average	3.33 (483)	4.16 (604)	18.0 (2610)	31.0 (4500)
Standard Deviation	0.36 (52)	0.31 (46)	4.1 (590)	4.8 (700)

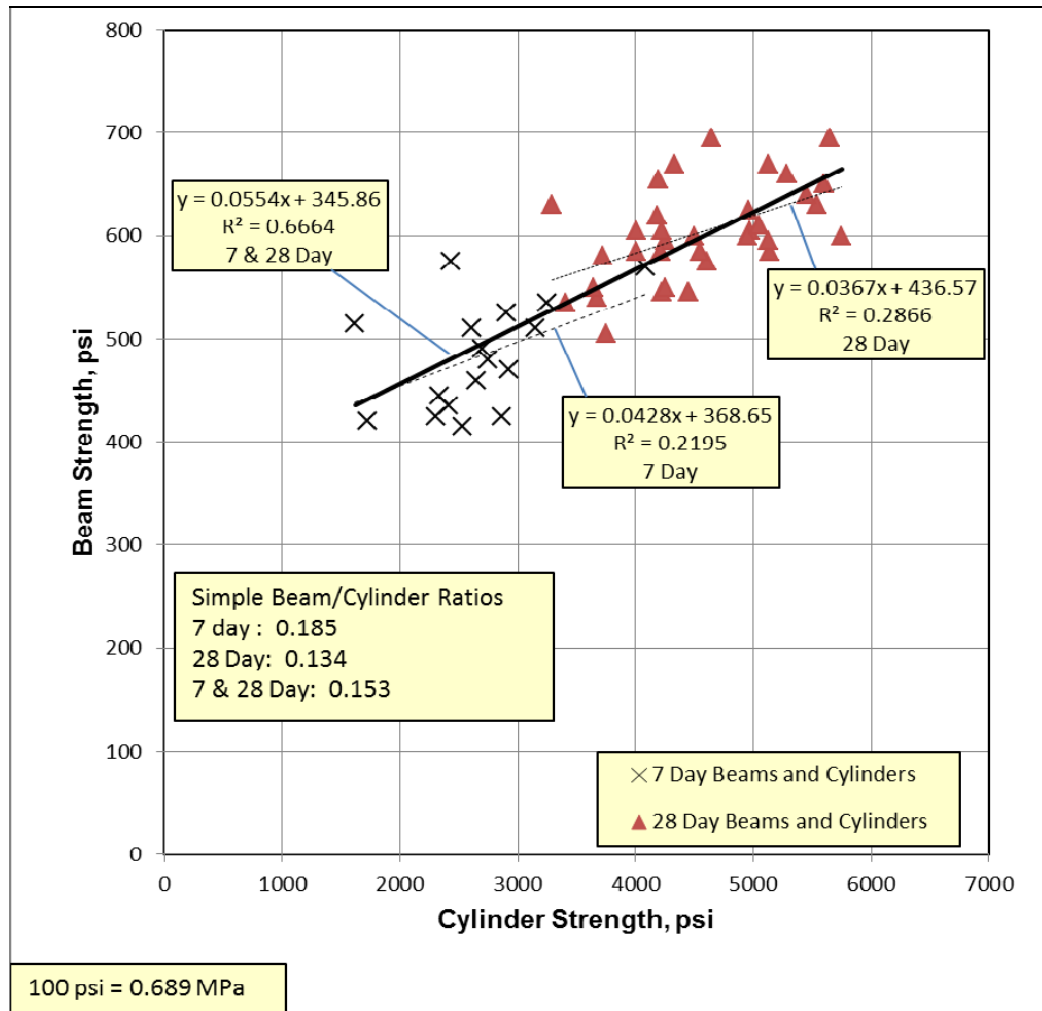


Figure 4. Beam/Cylinder Correlations, Eglin AFB with Stalite

10.5.2. Traprock Example

10.5.2.1. Table 7 contains the final mixture proportions used for the HTC pads at MCAS Beaufort with Carolina Sunrock, LLC, traprock and the typical mix properties in Table 8. Note that these proportions are only a reference for future projects, and on-site trial batches are necessary to optimize the materials to the batching, placing, and local climate.

Table 7. Traprock Mixture Proportions at MCAS Beaufort

Material	Quantity per Cubic Meter (Cubic Yard)
Type I/II Portland Cement	230 kilograms (388 pounds)
Class F Fly Ash	77 kilograms (129 pounds)
Water	139 kilograms (235 pounds)
No. 57 Traprock	890 kilograms (1500 pounds)
No. 78 Traprock	430 kilograms (725 pounds)
Fine Traprock Aggregate	745 kilograms (1255 pounds)
Air Entraining Agent (Daravair 10)	0.0058 liters/45 kilograms (0.2 ounces/hundredweight)
Normal Range Water Reducer (WRDA-79)	0.18 liters/45 kilograms (6.0 ounces/hundredweight)
High Range Water Reducer (ADVA-140(M))	0.38 liters/45 kilograms (13.0 ounces/hundredweight)
Polypropylene Fibers	1.78 kilograms (3 pounds)

Table 8. Traprock Mixture Results at MCAS Beaufort

Mixture Property	Result
W/C Ratio	0.45
WF	30.3
CF	61.3
Slump	64 millimeters (2.5 inches)

10.5.2.2. Table 9 summarizes the beam strengths achieved for the MCAS Beaufort test section lanes. The lanes were placed 13 December 2012 and 10 January 2013. The data indicates the 28 day flexural strength of 3.8 megapascals (550 pounds per square inch) was achieved. Note that when Beaufort was designed, the specification required only 3.8 megapascals (550 pounds per square inch) strength in the field. The results of Beaufort and similar traprock projects since indicate that higher traprock strengths are

achievable. Accept HTC for strength based upon the third-point flexural beam testing in the specification.

Table 9. Traprock Strength Summary, MCAS Beaufort

	Beam Strength, MPa (psi)	
	7 Day	28 Day
Average	4.0 (580)	4.2 (610)
Standard Deviation	0.27 (40)	0.25 (37)

11. VLZ Construction Details and Methods. Construction of VLZs should be achievable with basic concrete tools and labor, though consideration of sequencing is required to optimize the construction schedule. Several lessons learned from the Eglin AFB, Duke Field, MCAS Yuma, and MCAS Beaufort pads are discussed in this section.

11.1. Batching HTC. HTC is best batched using central mix plants. The plant may be on- or off-site. On-site plants normally haul the HTC in dump trucks; off-site plants normally transport in ready-mix trucks. These two methods have been used successfully with HTC. Dry batching and mixing with ready-mix trucks was successful at MCAS Yuma, but required substantial coordination and a dedicated plant for the project.

11.1.1. Mix Control. Using ready-mix trucks for airfield concrete presents additional production variability issues. Primarily, each truck will have a varying amount of blade wear or debris buildup that may interfere with mixing efficiency, even though the truck may pass inspection. Ready-mix plants are not normally on the airfield installation, and must transit through traffic. Routine traffic and security checkpoint inspection times will vary throughout the day, causing a variation in the delivery times, resulting in variability of the mixture arriving on site. This variability in delivery times results in a variation in mix properties, temperatures, and air content. This can be overcome by having additional quality control personnel at the batch plant and the paving site, capable of testing and adding admixtures to the mixture as necessary. If ready-mix trucks are used for transport, observe the following:

- Remove any automatic reduction of batch water in the computer so that target batch water is charged into the drum and the actual amount of water in each batch is known, recorded, and reported.
- Make water adjustments only at the plant. Though many ready-mix operations require the driver to adjust the slump, HTC mixtures are unique and may not be adjusted by a driver. Furthermore, experience with HTC has demonstrated it is not possible to add enough water and mix it suitably to improve the mixture workability.

- Use only trucks with clean drums and fins. Every truck will have different mixing characteristics due to the cleanliness of the drum and condition of the fins. Even if all trucks pass National Ready-Mixed Concrete Association (NRMCA) or a state inspection, it is still important to use clean drums with fins in good condition.

11.1.1.1. The Eglin AFB VL pad HTC used a central-mix drum plant and the HTC was hauled to the site in ready-mix trucks.

11.1.1.2. At Duke Field, the contractor used an on-site batch plant (Figure 5). Concrete was hauled to the VL pads in ten-wheel dump trucks. The contractor also built special stockpile bins for the lightweight aggregate (Figure 6). These prevented cross-contamination of the individual aggregates and with other conventional PCC aggregates on the site. Note the sprinklers mounted above the piles, which enabled continuous watering over the seven days prior to placing.



Figure 5. Duke Field On-Site Batch Plant (Horizontal Shaft Type)



Figure 6. Stockpile Bins and Watering System

11.1.1.3. At MCAS Beaufort, the contractor also used an on-site horizontal shaft batch plant. The HTC mixture used traprock aggregates. It was determined from the test batches that a minimum 65 seconds mix time was required to achieve a workable mix. Therefore, all HTC mixes must be mixed for a minimum of 65 seconds.

11.1.2. Uniformity Testing. The batch plant for conventional PCC for airfield paving is subject to a mixer uniformity test. The test validates that the mixer is capable of producing a uniform mix throughout the drum. Mixture uniformity is primarily affected by aggregate size, charging sequence, and mixing time. Many modern batch plants are designed to mix in about 60 seconds. However, the uniformity test may require 75 seconds or more. It is not known how applicable the conventional PCC uniformity requirements are to HTC. Therefore, as most VLZ projects will likely have some conventional PCC, mixers (including truck mixers) must be subjected to the conventional PCC uniformity test. If the mixer passes, then the same requirements are applied to the HTC. However, HTC contains triple the amount of fibers per cubic yard as common fiber reinforced concrete, so a minimum of 65 seconds mixing time is required, but additional mixing time may be required to ensure proper dispersal.

11.2. Placement of Continuous Reinforcement

11.2.1. UFC 3-260-02, Chapter 15, states that for pavements thicker than 279 millimeters (11 inches), the continuous longitudinal reinforcement is placed above mid-depth and with a minimum of 75 millimeters (3 inches) of cover. As the VL pads are reinforced in both directions equally, there is no definitive longitudinal direction. The minimum reinforcement cover after the full 2-inch sacrificial layer is ground off over time will be 63 millimeters (2.5 inches) for the VL pads. To meet these criteria, the center of the lower 25-millimeter (No. 8) rebar is set at 150 millimeters (6 inches); which when adding the two bar diameters of 50 millimeters (2 inches), allows 114 millimeters (4.5 inches) cover before any grinding.

11.2.2. Keeping the center of the lower bar at 150 millimeters (6 inches) above grade requires 140-millimeter (5.5-inch) chairs, which are readily available. Provide substantial chair support for the reinforcement layer to prevent sagging during HTC placement. The required method using threaded rebar is:

- (1) Place a coupler adjacent to the form on the inside of the lane to be placed. Insert a nominal 300-millimeter (12-inch) length of threaded rebar through the form to support the rebar mat.
- (2) Place enough chairs or continuous fabricated zigzag supports throughout so that the reinforcement mat is supported by a chair or side-form on a maximum 1200-millimeter (4-foot) grid.

11.2.3. Figure 7 shows the placing of the continuous reinforcement, and Figure 8 shows the completed mat. Note the support chair spacing in Figure 8 proved to be inadequate to support the concrete and workers during placement. Although the 25-millimeter (No. 8) bars at 300-millimeter (12-inch) centers are very stiff, the weight of the placement caused the steel to sag.



Figure 7. Placing Continuous Reinforcement



Figure 8. Completed Bar Mat (Support Spacing Inadequate)

11.3. HTC Concrete Placement

11.3.1. Placement of the HTC requires substantial planning and coordination. To determine whether the safety zone concrete will be placed before or after the VL pad, the strength gain of the PCC and the HTC must be considered. The HTC with light weight aggregate is very slow at strength gain, even with the high cementitious materials content, and concrete trucks cannot be allowed on the HTC until it meets its 28-day strength of 3.8 megapascals (550 pounds per square inch). HTC also has substantial wet curing requirements to take into account. The specification states that the HTC VL pad must be placed using a minimum of three pours in the sequencing shown in Figure 9. This enables placement of the steel and couplers. No deviations from this pouring sequence are permitted.



Figure 9. Mandatory HTC Placing Sequence

11.3.2. The placing sequence is governed by placement of the threaded rebar. Each threaded rebar needs to be continuous across the construction joints. If the steel sideforms are not drilled and the couplers do not protrude through the form, then the coupler will sag slightly. This will prevent proper threading and alignment of rebar in adjacent lanes. Therefore, couplers must be placed using one of the following two methods:

- The steel sideforms may be drilled to allow the rebar extend enough to allow posterior connection with a coupler. The center lane rebar length will need to exceed the lane width.
- The steel sideforms may be drilled to allow the coupler itself to be centered on the construction joint.

11.3.3. The contractor will use a telescoping conveyor truck to place the HTC, as shown in Figure 10. This works well to deposit the concrete where it was needed and to direct it through the rebar (Figure 11). Adequate maneuvering space is necessary to allow haul trucks to minimize time for alignment. Use of a conventional belt placer to feed the telescoping conveyer enables use of dump trucks for hauling and accelerates placement. The telescoping trucks are not as common as pumps; therefore availability may be a concern in some regions.

During one placement at Eglin AFB, the telescoping truck experienced mechanical failures, and the pour had to be completed by direct discharge from the ready mix truck.



Figure 10. Telescoping Conveyor



Figure 11. Conveyor Discharge

11.3.4. Direct discharge from the ready-mix truck can be an acceptable method, as shown in Figure 12. The key element is being able to reach across a 6.1-meter (20-foot) lane with the discharge chutes to minimize moving the mixture by hand tools. The current HTC specification allows this method, provided the HTC is deposited within 900 millimeters (3 feet) of its final position.



Figure 12. Direct Discharge from Ready-Mix Truck

11.3.5. An attempt was made with a concrete pump, and the mixture was unworkable at the discharge, even with additional super plasticizer dosages. Part of the issue is the resistance of the mixture to pumping, which forces more water into the expanded aggregate pores, thereby further reducing the workability. Although pumping is common for the high-rise building industry of expanded aggregate concrete, use of the expanded fine aggregate in HTC adds to the complexity of the construction. Therefore, pumping of HTC is not permitted.

11.3.6. At Duke Field, placement for the test sections was completed using a conventional concrete belt placer, shown in Figure 13. Construction personnel indicated the telescoping conveyor used at Eglin AFB provided more control over the point of placement, as the belt placer required more hand-shoveling to distribute the concrete. Belt placers are not allowed except to feed the telescoping conveyor.



Figure 13. Conventional Belt Placer - Not Allowed

11.4. Finishing

11.4.1. At Eglin AFB, a vibrating truss screed was used for finishing. At Duke Field, attempts were made at the test section to use a triple-tube roller screed to level any piles from the belt placer. This proved to be cumbersome, so better placement controls were quickly implemented and the roller screed was removed. Roller screeds are not allowed in the specification. Finishing was completed with a vibrating screed, as shown in Figure 14.



Figure 14. Vibrating Truss Screed

11.4.2. The contractor attempted to slipform a lane of HTC at the plant. A Gomaco two-track slipform paver was used (Figure 15). The challenge with any slipform paving mixture is to attain solid, dense corners behind the paver. If the corners require handwork to close any voids, then the potential for spalling increases. Workers were unable to achieve the necessary corner finishing behind the paver (Figure 16). Slipform paving will not be used with HTC VL pads.



Figure 15. Gomaco Two Track Slipform Paver



Figure 16. Rough Edge and Side Face of Slipform HTC

11.4.3. Final finishing of HTC requires experimentation during the initial test batch slabs and test sections to determine the best combination of tools after the vibrating truss. Normally, the first tool is a 3.7-meter- (12-foot-) long magnesium bump cutter or channel float. Only one or two passes (one pass is across and back on a lane) are normally required to achieve an acceptable surface. The

magnesium tools are able to generate sufficient paste to fill in any voids from the vibrating truss. Exercise care to not allow the tools to contact the granular base and become contaminated with non-high temperature aggregate, as shown in Figure 17. Figure 18 shows the final finishing steps and Figure 19 shows the final surface prior to brooming.



Figure 17. Burlene Mat for Tools



Figure 18. Final Finishing with Channel Float and Hand Tools



Figure 19. Final HTC Surface Prior to Brooming

11.5. Broom Texture

11.5.1. Applied temperatures and velocities degrade the HTC surface by erosion, and in particular, by water vaporization within the top few millimeters. From testing of poorly finished disks at NAVFAC EXWC that contained surface voids, the surface deterioration began at the surface voids. An example of unacceptable surface voids is shown in Figure 20. The smoother and tighter the surface, the better the VL pad will perform. From this performance perspective, a smooth-troweled surface appears desirable. However, experience has shown that personnel will eventually be on a VL pad for aircraft maintenance or servicing. Slipping on oils or wet surfaces may cause injuries that can impact the mission. Therefore, typical airfield texturing is required for HTC.



Figure 20. Unacceptable Surface Voids

11.5.2. Burlap drags are too inefficient and variable for the placement methods of a typical VLZ. Brooming is, therefore, the required texturing method. The desired final broomed texture has 1.6-to-3.2 millimeter (1/16-to-1/8 inch) ridges. This is considered a fine surface texture. Achieving this texture requires consideration of the broom type and time to broom. Broom bristles are available in a variety of natural and synthetic fibers; use of bristles with soft to medium stiffness is recommended.

11.5.3. The elapsed time to begin brooming is crucial to obtaining the proper texture and not opening the surface. As HTC is made with lightweight fine aggregate, these small particles can be dislodged easily by the broom. Although the particles may be removed after the concrete has hardened, the particles will often drag on the broom or may roll to the surface. Some particles may also be trapped in the bristles, requiring rinsing after each broom pass. The result is an HTC surface containing surface scarifications, as shown in Figure 21, that promote degradation from the aircraft exhaust. These surface scars are not desirable for VLZs. Optimum timing for brooming will be determined during placement of the test sections.



Figure 21. Unacceptable Broomed Surface

11.5.4. At Duke Field, the HTC required three hours of set time before the concrete could be broomed without rolling the fine aggregate to the surface (Figure 22). The air temperatures were 23 °C (74 °F) at the time of placement and 32 °C (90 °F) at the time of brooming. It is imperative to not rush the brooming.



Figure 22. Unbroomed and Acceptable Broomed Surfaces

11.6. Shrinkage

11.6.2. Eglin AFB HTC Placements

11.6.2.1. The two VL pads were placed between 20 December 2010 and 7 January 2011. Air temperatures on the placement dates are shown in Table 10.

Table 10. Eglin AFB HTC Pour Temperatures

Date	Test Temperatures During Placement	
	Air °C (°F)	HTC °C (°F)
20 Dec 10	- - -	- - -
21 Dec 10	9.4, 11.7 (49, 53)	16.1, 19.4 (61, 67)
29 Dec 10	13.3 (56)	16.1 (61)
03 Jan 11	5.6, 7.8 (42, 46)	16.7, 17.8 (62, 64)
04 Jan 11	18.3 (65)	20.6 (69)
06 Jan 11	10.0, 16.7, 11.1, 12.8, 15.6 (50, 62, 52, 55, 60)	20.0, 22.8, 19.4, 21.7, 20.6 (68, 73, 67, 71, 69)
07 Jan 11	12.8, 17 (855, 64)	17.2, 21.7 (63, 71)
08 Jan 11	7.8, 8.9 (46, 48)	16.7, 17.8 (62, 64)

11.6.2.2. Temperatures for the first 90 days ranged from -6 to 28 °C (21 to 83 °F). The continuously reinforced lanes were expected to crack every 0.91 meters to 1.5 meters (three to five feet), as is common for continuously reinforced pavement. However, even after 90 days and several below-freezing periods, there were no cracks in the HTC. The VL pad shrank 6 millimeters (¼-inch) on all four sides, for a total of 12.5 millimeters (½-inch) total shrinkage for the 30.5-meter (100-foot) length, as shown in Figure 23. This equates to 0.042% shrinkage. Lack of transverse cracking is not detrimental for the VL pad function. Shrinkage at the slab ends can be accommodated with wider joint seal reservoirs.



Figure 23. HTC Shrinkage at Isolation Joint

11.7. VLZ Joint Layouts. Attachment 1 shows the general joint layout for VLZs, including PCC and HTC areas. The joint layouts for the VL pad, safety zone, and safety zone PCC shoulder are matched to their respective thicknesses, and are not to be changed without first contacting HQ USACE (CEMP-ET), the appropriate Air Force MAJCOM pavements engineer, or NAVFAC EXWC for guidance. The connecting taxiway joint layouts should follow the PCC safety zone layout to avoid requiring the paving contractor to alter the equipment or methods, but may be adapted to meet local conditions.

11.7.1. VL Joint Types. The PCC safety zone, paved shoulders and connecting taxiways use joint types developed from UFC 3-260-02 and are as shown in Attachment 1. Joint details and load transfer arrangements provided in Attachment 1 will be followed; connections to existing paved areas will be developed by the designer following UFC 3-260-02 procedures.

11.7.1.1. The HTC CRC joints are specifically detailed and designed for VL pad performance and must not be modified. Attachment 1 shows the required joint arrangement and details.

11.7.1.2. The VL pad HTC is continuously reinforced in both directions. This is to minimize joints in the paving lanes and to minimize the amount the cracks may open in the paving lanes. The CRC HTC longitudinal construction joints between the paving lanes require the continuous reinforcement across the joint to keep the joint tight.

11.8. HTC Curing. Wet-cure HTC in accordance with UFGS 32 13 13.43. Research studies by NAVFAC EXWC determined that wet curing is the best method for HTC. This results from the absorptive nature of the expanded aggregates and the desire to optimize cement hydration for performance under high temperatures. Tests indicate continuous water curing for 14 days is required.

11.8.1. Wet curing is easy to accomplish at potential Short Take-Off/Vertical Landing (STOVL) sites. Sprinklers attached to a water main for continuous operation would be ideal; however, this is rarely an option. Early attempts at Eglin AFB involved spraying from a water truck, but the benefits were reduced whenever the truck had to be refilled or the driver was not diligent. An attempt to use a gravity-fed soaker hose attached to a water truck met with the same difficulties.

11.8.2. Based on experience at MCAS Yuma and Beaufort, use burlap bonded to polyethylene similar to Burlene® (burlap side down) to cover HTC during wet curing. Continuous 24-hour monitoring is required to ensure Burlene® is maintained in a wet condition. At MCAS Yuma and MCAS Beaufort, auxiliary water tanks with gasoline pumps were used, as shown in Figures 24 and 25. The pumps fed a manifold with hose connections for each pour. Sprinkler hoses were stretched over the HTC and covered with the Burlene®. This method was highly effective for providing wet cure with a minimum of water loss to overflow and evaporation.

11.8.3. The specification recognizes that at some point before the 14 days of wet curing is complete, the adjacent HTC lane needs to be placed. Wet curing can be interrupted for a 12-hour period after the completion of 48 hours of curing, and then reinstated for the duration of the curing period plus the interruption time for placement.



Figure 24. Auxiliary Water Tanks and Manifold, MCAS Beaufort



Figure 25. Water Distribution, MCAS Beaufort

11.9. VLZ Joint Sealants. VL pads are constructed using continuously reinforced concrete (CRC) to minimize joints which will remain unsealed. Expansion around the perimeter of the VL pad and the safety area joints must be sealed. Joint sealant material thermal load testing was conducted by NAVFAC EXWC; findings are summarized in paragraphs 11.9.1 through 11.9.3.2. The result is that self-leveling silicone is the required joint sealant.

11.9.1. Preformed Chloroprene (Neoprene). This is the common sealant preferred for Air Force pavements. The neoprene appeared to catch on fire on the first exposure, although the flow (on the first cycle) and charring (on subsequent cycles) appeared to extinguish the flame. The seal did last five cycles before the fire penetrated through the top surface, at which point the seal collapsed. Neoprene seals are not permitted for VL pads, safety zones, and safety zone shoulders.

11.9.2. Insulflex[®] End Dip[™] LSR-2112. This is a specialty silicone based material manufactured to coat fiberglass fire-resistant sleeves to prevent fraying. Due to its temperature performance, it was tested as a pavement sealant. Its wear is ablative, losing 0.51 millimeters (20 mils) per exposure (25 cycles for 12.5-millimeter (½-inch) depth). The manufacturer provides no warranty or assurances for its performance for the VLZs, and its performance as a joint sealant in concrete for typical climatic conditions is unknown. The Insulflex[®] product is about twice the cost of conventional ASTM D5893/D5893M, *Standard Specification for Cold Applied, Single Component, Chemically Curing Silicone Joint Sealant for Portland Cement Concrete Pavements* silicone. It does not have a significant improvement in performance life compared to ASTM D 5893 silicones; therefore, ASTM D 5893 silicones are required for use in the safety zone and the VL pad perimeter isolation joint.

11.9.3. ASTM D 5893, Silicone Sealants

11.9.3.1. DOW 890-SL Self-leveling and 888 Tooling-Grade are the common sealants preferred by the Navy. Under previous testing, NAVFAC EXWC determined these materials resisted long-term exposure at temperatures ranging from 288 °C to 316 °C (550 °F to 600 °F) before burning and decomposing. However, when exposed to the high temperatures addressed by this ETL for a short duration, testing showed that neither silicone melted or burned, but ablated, similar to the LSR-2112. The 890-SL lost about 0.76 millimeters (30 mils) per concentrated exposure, and the 888 about 0.51 millimeters (20 mils) per exposure. Depending on the sealant depth, this indicates the sealant could survive approximately 17 heat exposures in the same location, which is sufficient for the safety zone including shoulders.

11.9.3.2. Sealant needs to be 12.5 millimeters (½-inch) thick to provide sufficient ablative life and better resistance to flow from exhaust velocities.

Joint seal reservoirs must be 19 millimeters ($\frac{3}{4}$ -inch) for the isolation joints and 9.5 millimeters ($\frac{3}{8}$ -inch) for the PCC contraction and construction joints. Attachment 1 provides typical joint design details to be followed.

11.10. Joint Seal Back-up Material

11.10.1. Joint seals must be prevented from bonding to the bottom of the seal reservoir. If not, the seal will debond from the concrete face due to normal temperature movements of the concrete. Conventional bond-breaking tape or a cross-linked polyethylene backer rod may be used. It is imperative that the backer rod be cross-linked to provide additional heat resistance.

11.10.2. At the Eglin AFB VLZs, it was observed that the HTC lanes experienced a total of about 12.5 millimeters ($\frac{1}{2}$ -inch) of shrinkage; therefore, the perimeter isolation joints were 6 millimeters ($\frac{1}{4}$ -inch) wider. To accommodate this extra width, the bond breaker tape or backer rod needs to be larger. Use the backer rod diameters as specified in the standard drawings in Attachment 1.

11.11. Joint Sealing Procedure

11.11.1. VLZ designers need to edit the appropriate UFGS for field-molded sealants to reflect preparation requirements. This includes flushing and vacuuming slurry after all sawcutting, and sandblasting both faces of the joint seal reservoir. All sand and debris must be blown and vacuumed from the joint after sand-blasting. Water-blasting of joint faces is not permitted, as it will delay the time for sealant application. The procedure in paragraph 11.11.2 is provided in the HTC specification.

11.11.2. After the concrete has wet-cured for 14 days, prepare the concrete areas indicated on plans for joint sealant in accordance with the following:

- (1) Sawcut final joint seal reservoir, flush and vacuum slurry.
- (2) Clean concrete surface using pressure washer fitted with rotary water scrubbing attachment (handheld pressure washer wands are not acceptable). Protect the concrete surface from any type of traffic or debris to avoid having to repeat rotary scrubbing. Do not install joint sealant until after rotary scrubbing is completed.
- (3) Allow concrete to dry for 14 days after rotary scrubbing. Clean both joint sealant reservoir faces by sandblasting (water blasting not permitted for VLZ as it will increase time for drying) and supplement with air blowing.
- (4) Seal the prepared joints using the ASTM D 5893 silicones following referenced UFGS procedures.

11.12. HTC Sodium Silicate Sealing. Testing using a water-saturated specimen surface has demonstrated that a surface sealer such as sodium silicate is required

to prevent water intrusion and resist high exhaust temperatures. Sodium silicate solution absorbs into the top 3 millimeters (1/8-inch) of the concrete. This sealer must be a colorless, water-based solution containing nine percent sodium silicate. A nine percent solution provides the optimum penetration into the concrete for the three required applications. Many manufacturers provide a product with this concentration. Higher-concentration products need to be diluted to the 9 percent sodium silicate. Apply the sodium silicate sealer to the VL pad, the safety area, and the safety area shoulder. It may also be applied to the PCC connecting taxiway, if desired by the local airfield manager.

11.12.1. Surface Cleaning. Prior to application, clean the VLZ concrete areas (including the VL pad and safety zone, at a minimum) using a rotary power washer/scrubber. This is more efficient than using a pressure washer. The goal is to remove tire rubber, and to the extent possible, fuel and oil spills.

11.12.2. Sealer Application

11.12.2.1. Apply the sodium silicate sealer after the last continuously-reinforced HTC pour is 90 days old (70 days for non-continuously reinforced HTC) and the joints have been sealed, and after pavement markings and glass beads have been applied. NAVFAC EXWC testing determined that applications of sodium silicate solution prior to 90 days result in surface-flaking of the HTC. The concrete surface must be dry for 24 hours prior to applying the sealer. Air temperature must be 4.4 °C (40 °F) or higher and relative humidity must be 80 percent or less, both during application and the 48 hours following application.

11.12.2.2. Apply three coats of sodium silicate solution using low pressure airless spraying equipment that ensures uniform application. Start applying the solution at the highest point in the pavement and continue downgrade. Each coat must cover not more than 4.9 square meters per liter (200 square feet per gallon). Avoid excess application; it will cause efflorescence and reduce friction. Allow sodium silicate to penetrate for two hours, then wash off any visible excess (ponded) solution. Allow the area to dry for at least 24 hours between each coat.

11.12.2.3. After allowing the last coat to dry for 24 hours, evaluate the surface for any excess silica or dusting. Wash off any excess silica or dusting as needed. Protect application from any pedestrian or vehicular traffic until the last coat has dried. The solution must be reapplied if surface wear becomes apparent.

11.13. HTC Construction Specification. The contractor will comply with UFGS 32 13 13.43 as tailored for the construction of the VLZ. This ETL addresses only requirements for HTC and CRC. Designers are required to edit additional UFGSs in

accordance with UFC criteria, agency tailoring, installation requirements, and this ETL.

11.13.1. Test Sections. Part of the technical specification is a requirement for test batches and test sections. The purpose is to enable the contractor to understand how the materials chosen will mix and perform with the available equipment. Each VLZ project will be new to the construction force, so an adaptation period will be needed. Test batches and test sections will not be part of the pavement production area.

11.13.1.1. Test batches are used to make pads 3 meters by 3 meters (10 feet by 10 feet) and 305 millimeters (12 inches) thick. Their purpose is to experience how the materials combine and behave as a mixture. They also allow evaluation of how workable the mixture may be during VL pad placement and the amount of paste available to seal the surface and corners. Typically, achieving tight, dense corners in the test pads indicates that mixture proportions are near the optimum for paving. Note that if using an off-site plant and ready-mix trucks, the mixture should be held for a period of time to simulate the haul time to the actual project site.

11.13.1.2. The specification requires two test sections. Each test section matches the size of a VL pad lane and thickness, 6.1 meters (20 feet) wide, 30.5 meters (100 feet) long, 305 millimeters (12 inches) thick. Each test section has the full amount of continuous reinforcement and joint couplers. Test sections at Eglin AFB and MCAS Yuma, both with crews having 20 years of concrete placing experience, have shown that test sections are vital to adapting the mixture to the placing, finishing, brooming, and curing procedures prior to building an operational VL pad. If HTC is used outside the VL pad, then test sections must also be used to determine the optimum time for saw cutting.

11.13.1.3. The reason for steel and couplers in the test sections is to determine if abnormal cracking may occur. Similarly, the reason for the delay between placements of adjacent test sections is to determine if the differential shrinkage between the two lanes would cause diagonal cracking across a lane. At Eglin AFB and Duke Field, the slabs did not crack; however, both projects used the same Stalite aggregate and nearly the same mixture proportions. The MCAS Yuma VL pad with Utelite and the MCAS Beaufort VL pads which used traprock also have not cracked.

11.13.1.4. Note that due to the substantial amount of steel involved, removal of the test sections will be difficult. It is permissible to build the test sections in an area where they may be abandoned in place and not interfere with other operations, yet still close enough to the VL pad site to represent the haul and placement conditions.

11.13.1.5. Mixtures can be prone to segregation until the proportions are optimized. Cutting of test slots, shown in Figure 26, is required in addition to cores to evaluate segregation and surface paste. Slots should be about 50 millimeters (2 inches wide), at least 300 millimeters (12 inches) long, and 75 millimeters (3 inches deep). The slots can be sawcut the day after placing.



Figure 26. Slots in Test Section to Evaluate Segregation

11.13.1.6. Figure 27 is an example of an optimized mixture with good aggregate distribution with minimal surface paste. Figure 28 is an example of inadequate coarse and intermediate aggregate components, resulting in segregation, no coarse fraction at the surface, and excess surface paste.



Figure 27. Example from Test Slot of Acceptable Aggregate Distribution, No Segregation and Minimal Surface Paste with Traprock



Figure 28. Example of Segregation and Excess Surface Paste with Traprock

12. Pavement Markings

12.1. The pavement marking plan for the VL pad is shown in Attachment 1, Figure 8. Apply pavement markings after the concrete has cured in accordance with UFGS. Pavement markings need to be applied and cured before applying sodium silicate solution. Additionally, the paint available for airfields is likely to degrade from repeated STOVL operations.

12.2. Pavement markings must be retro-reflective white or yellow paint, as shown in Attachment 1. Pavement markings must be outlined with 152-millimeter (6-inch) wide non-reflective black paint. Other than as specified in this ETL, pavement markings comply with AFI 32-1042, *Standards for Marking Airfields*, and ETL 04-2, *Standard Airfield Pavement Marking Schemes*. The designer must edit the appropriate UFGS specification for markings.

12.3. Note that marking requirements for the VLZ may require modifications to adapt to the siting and local operating procedures and requirements. For example, VFR or IFR hold lines may be required. Taxiway markings and signage may be required; the standard drawings in Attachment 1 must be modified to include these requirements. Additional markings and signage on the existing taxiways, aprons, and runway may also be required, depending upon the siting and local procedures and requirements.

13. Perimeter Lighting

13.1. Design Requirements and Applicable Specifications

13.1.1. Provide perimeter yellow lights for the VL pad as shown in Attachment 1. Perimeter lights are located 1.5 meters (5 feet) from the edge of the safety zone. The designer must coordinate on the particular type of equipment and manufacturer that is compatible with the facility manager's current and future maintenance needs.

13.1.2. Use in-pavement light fixtures meeting Federal Aviation Administration Advisory Circular (FAA AC) 150/5345-46, *Specifications for Runway and Taxiway Light Fixtures*, Type L-852-E with yellow filters. Note that the installation tolerance for these light fixtures requires that the outside edge of the light fixture may be +1.58 millimeters (+0.0625 inches) and -0.0 millimeters (-0.0 inches) relative to the low side of the adjacent pavement.

13.1.3. Provide a minimum three-step (five-step may also be used) 6.6 amp series circuit to power the landing pad perimeter lights. Provide an isolation transformer for each light fixture, sized per the light fixture manufacturer's recommendations, that meets the requirements of FAA AC 150/5345-47, *Specification for Series to Series Isolation Transformers for Airport Lighting*

Systems. Provide L-824 #8 American Wire Gauge (AWG) cables that meet FAA AC 150/5345-7, *Specification for L-824 Underground Electrical Cable for Airport Lighting Circuits*. Install the cable in 50.8-millimeter (2-inch) diameter, Schedule 40, polyvinyl chloride (PVC) conduit buried in earth. Install lights similar to the Attachment 1 drawings.

13.2. Light Fixtures. As already noted, aircraft on the high temperature range will place unprecedented thermal loads on aircraft operating surfaces during VL operations. The following design features have not been tested, but are intended to reduce failure due to thermal load on lighting equipment.

13.2.1. Quartz-Incandescent. Use quartz-incandescent fixtures, not light-emitting diode (LED) fixtures. LEDs and their electronic modules fail at lower temperatures than quartz-incandescent fixtures.

13.2.2. Light Bases. Use 300-millimeter- (12-inch-) diameter Type L-868 light bases meeting FAA AC 150/5345-42, *Specification for Airport Light Bases, Transformer Housings, Junction Boxes, and Accessories*. Light bases must be 600 millimeters (24 inches) deep.

13.3.2. In-Pavement. Use in-pavement light fixtures meeting FAA AC 150/5345-46, Type L-852-E, with yellow filters. In-pavement light fixtures are expected to be more durable than an elevated light fixture.

14. Maintenance and Repair. Material and construction requirements are intended to provide the longest performance available for VLZs. However, these requirements were developed from laboratory testing and extensive materials research and experience. Periodic maintenance will be required at STOVL installations.

14.1. Pavement Markings. Commonly available pavement marking paints are not expected to maintain a bond or survive repeated heat applications from VL operations from aircraft on the high temperature range. Markings are on the perimeter of the VL pad, so they will experience damage only when aircraft land near the safety zone. Paint may not adhere to pavement surfaces coated with sodium silicate. Avoid overspraying areas treated with surface sealers.

14.2. VL Pad Surface Grinding. Tests indicate the HTC used for the VL pad may need 3.2 to 6.4 millimeters (0.125 to 0.25 inches) ground off the surface after about 500 landings in the same location. The time required for 500 landings in the exact same location is a function of the operational tempo of the VL pad and landing accuracy. It is reasonable to expect that grinding will be required every three to seven years to reduce spalling and potential FOD. Grinding removes damaged HTC and maintains the slope for required surface drainage.

14.2.1. Frequency and Depth. Frequency and depth of grinding must be determined by visual examination of the VL pad pavement surface. Total depth

of grinding during the lifetime of the VL pad pavement must not exceed 50 millimeters (2 inches). Beyond this depth, the concrete cover over the continuous reinforcement will be too thin for proper performance. Distresses, such as additional cracking or spalling, may begin to develop. The surface area to be ground includes the VL pad, plus a limited portion of the adjacent safety zone. Grinding of the remainder of the safety zone or the shoulder areas is not required. Pavement markings and the isolation joint sealant will need to be replaced in areas affected by grinding.

14.2.2. Grinding Procedures

14.2.1.1. Prior to grinding, consult the as-built drawings for the particular VLZ to determine the surface grades and better plan the grinding depth and area to maintain drainage. If the as-built drawings cannot be located, field-survey the pad using conventional survey equipment. A survey grid of 3 meters by 3 meters (10 feet by 10 feet) should be adequate; however, the grid should also be matched to the width of the grinding machine cutting head for enhanced control of final surface elevations.

14.2.1.2. Use concrete grinding machines, not milling machines with hardened teeth. Grinding machine saw blades must be impregnated with an industrial diamond abrasive. Saw blades must be assembled in a cutting head mounted on a machine designed specifically for diamond grinding, which will produce the required texture and smoothness level without damage to the concrete pavement or joint faces.

14.2.1.3. Saw blades must be 3 millimeters (1/8-inch) wide, with a minimum of 60 blades per 300 millimeters (12 inches) of cutting head width, depending on the hardness of the aggregate. Each machine must be capable of cutting a path 0.9 meters to 1.2 meters (3 feet to 4 feet) wide. Grinding equipment that causes ravels, aggregate fractures, spalls, or disturbance to the joints is not be permitted. Finished surfaces must be free of raised slivers (commonly referred to as “fins”).

14.2.1.4. It may be possible to remove the 6 millimeters (¼ inch) using special high-pressure water-cutting machines fitted to pavement surface scrubbers. These are substantially more advanced machines than a conventional pressure washer, and are typically trailer-mounted with a pressure rating of approximately 68.9 megapascals (10,000 pounds per square inch). This procedure has not been validated at the time of this ETL and would need to be validated with HQ USACE (CEMP-ET), the appropriate Air Force MAJCOM pavements engineer, or the NAVFAC EXWC for up-to-date guidance.

14.2.3. Surface Sealing. Sodium silicate solution must be re-applied after grinding. Prior to application, clean the VLZ concrete areas (including the VL pad

and safety zone, at a minimum) using a rotary power washer/scrubber. To remove tire rubber and, to the extent possible, fuel and oil spills, use a rotary power washer/scrubber. Apply the sealer as described for a new installation. Ensure all joint seals are in good condition prior to any application of surface sealers. Replace any damaged, cracked, debonded, or missing joint seals in accordance with UFC 3-250-08 before applying any surface sealer.

14.3. HTC Patching Materials

14.3.1. Material for patching the HTC surfaces must match the material used to originally construct the pad. Patches will be 75 millimeters (3 inches) deep, ± 6 millimeters ($\pm 1/4$ -inch), instead of the standard 50-millimeter (2-inch) minimum used for conventional concrete pavements. The reason for the increased depth is that shallower repairs can separate from the rest of the pavement due to thermal expansion cycles. Patches deeper than 75 millimeters (3 inches) are not recommended, as the depth of cover of the longitudinal reinforcement is 100 millimeters (4 inches). Consult HQ USACE (CEMP-ET), the appropriate Air Force MAJCOM pavements engineer, or the NAVFAC EXWC for up-to-date guidance.

14.3.2. Prepackaged rapid repair materials available on the GSA Schedule that will survive high temperature applications are Phoscrete™ and Firerok™. If the original HTC materials are not readily available, the contractor may use these alternate materials if approved by the contracting officer in consultation with the MAJCOM pavement engineer. They may also be used for standard PCC repairs.

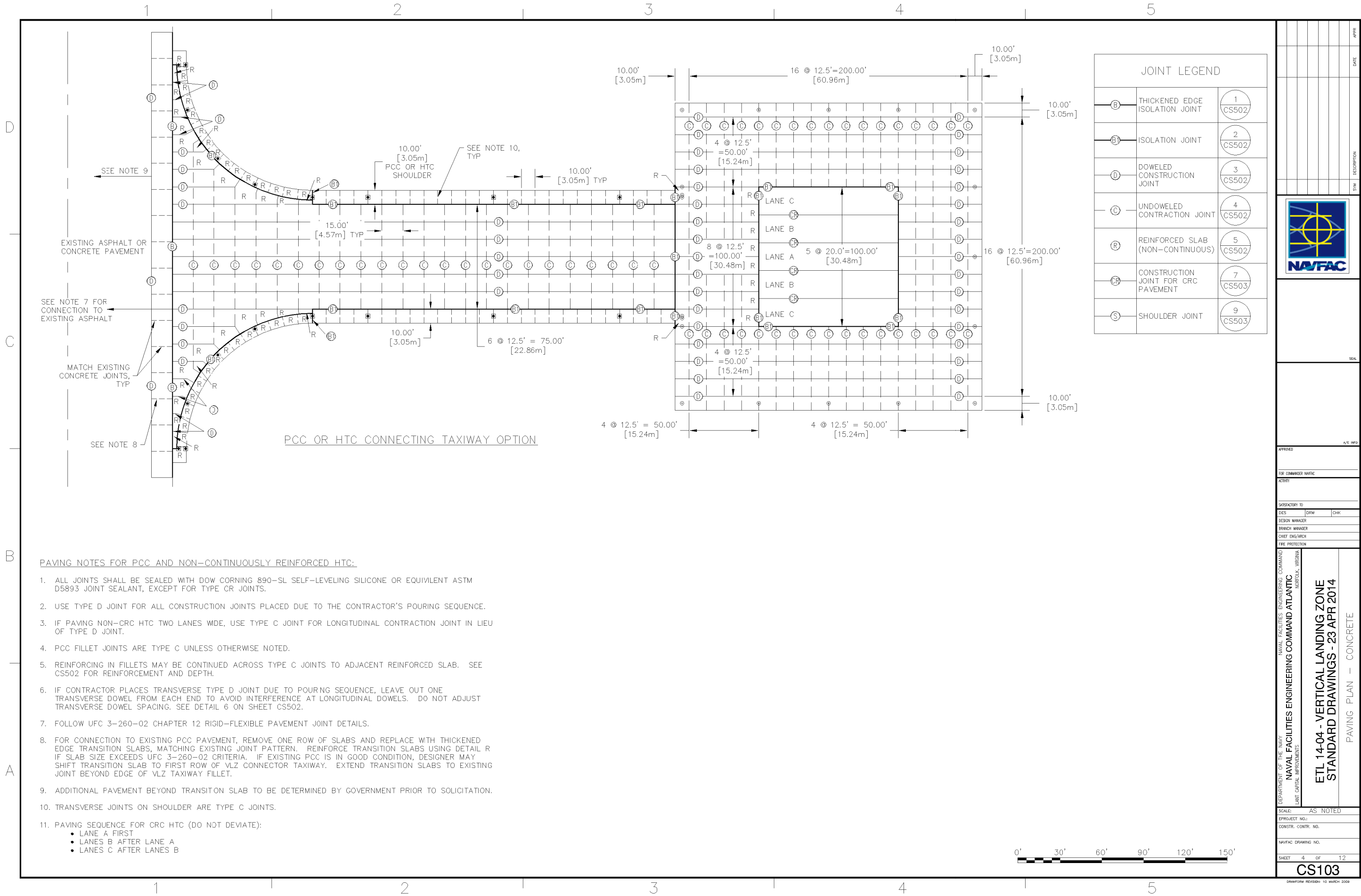
14.4. PCC Patching. If high temperatures are applied to a PCC safety area, the PCC surface may spall. The surface sealer may allow the PCC to survive a few landings per location. Landing on PCC may also result in very thin delamination which can be corrected by brooming and resealing with sodium silicate. Repeated landings at the same PCC location or over-exposure to high temperatures will result in more severe spalling. The PCC should be repaired using the HTC patching materials, but may also be repaired using PCC (do not use rapid spall repair materials such as epoxy-based or activated fly-ash products if the location is near the VL pad and could receive future high-temperature exposures). For PCC patches, follow the procedures in UFC 3-270-03, *Concrete Crack and Partial-Depth Spall Repair*, and UFC 3-270-04, *Concrete Repair*, as appropriate.

15. Waivers. Forward requests for waivers to the VL pad and related pavement surface geometry, cross-section, materials, construction, and repair to the MAJCOM pavements engineer through the contracting officer. Forward requests for waivers to the siting, marking, lighting, flight surfaces, or obstructions to the MAJCOM CV and coordinate with the MAJCOM pavement engineer and director of operations through the contracting officer. Waiver requests will comply with UFC 3-260-0, UFC 3-260-02, UFC 3-535-01, *Visual Air Navigation Facilities*; and ETL 04-2. Note: Waivers may or may not be granted.

16. Point Of Contact. Questions or comments about this ETL are encouraged and should be directed to the Pavements Subject Matter Expert, AFCEC/COSC, DSN 523-6495, commercial (850) 283-6495, afcec.rbc@tyndall.af.mil.

ANTHONY A. HIGDON, Colonel, USAF
Deputy Director

2 Atchs
1. VL Pad Drawings
2. Distribution List



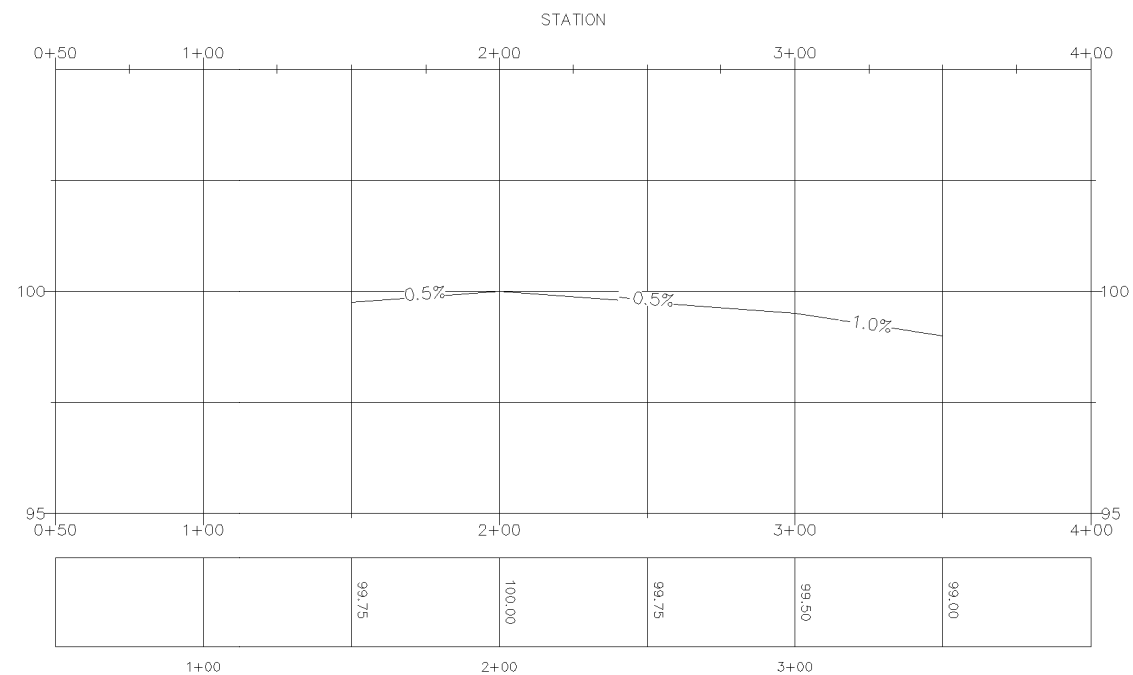
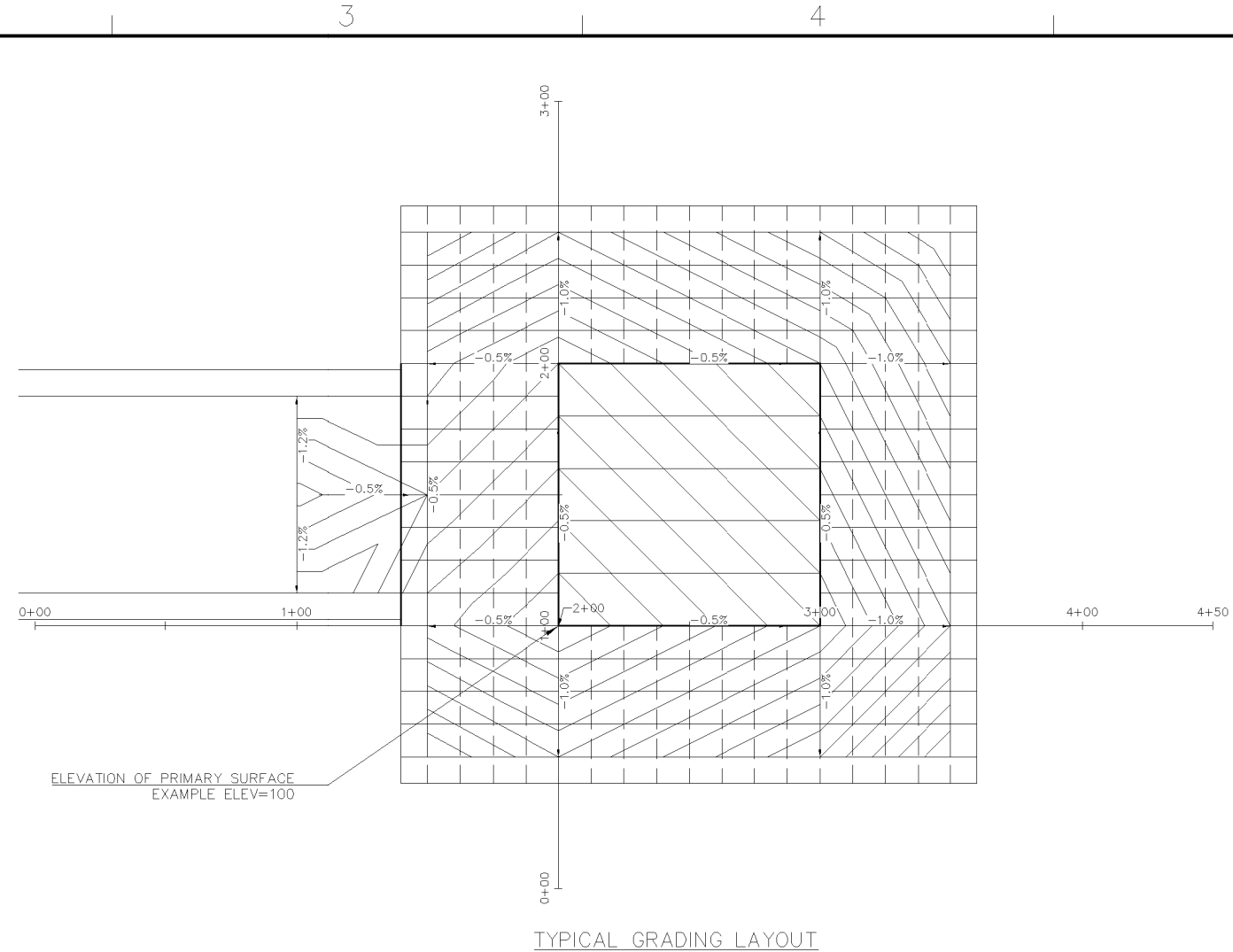
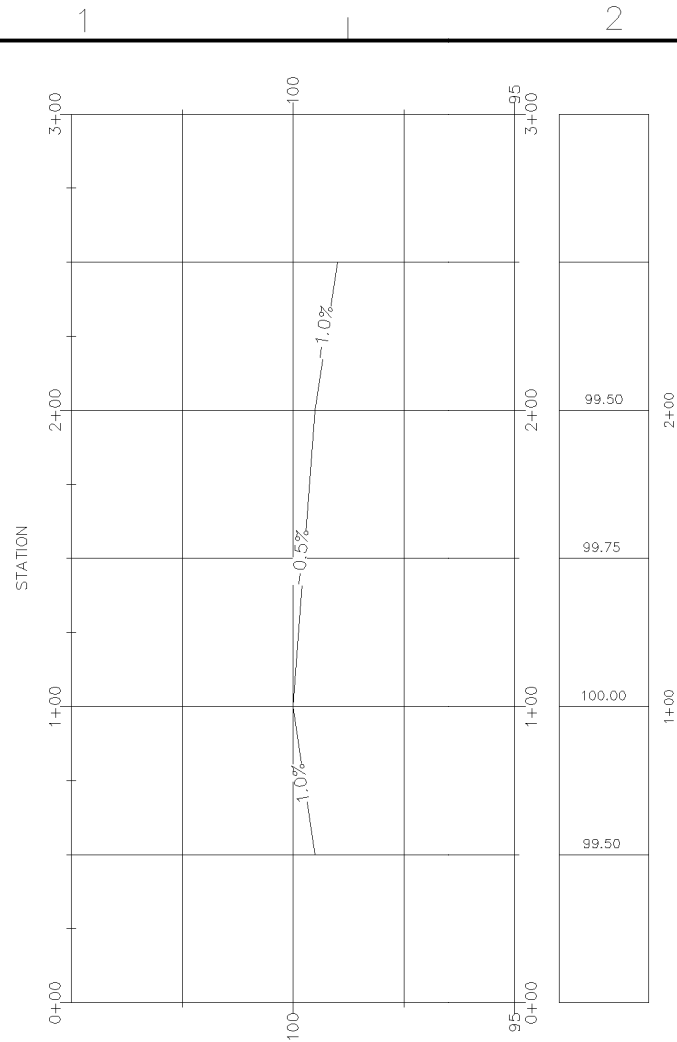
PAVING NOTES FOR PCC AND NON-CONTINUOUSLY REINFORCED HTC:

- ALL JOINTS SHALL BE SEALED WITH DOW CORNING 890-SL SELF-LEVELING SILICONE OR EQUIVALENT ASTM D5893 JOINT SEALANT, EXCEPT FOR TYPE CR JOINTS.
- USE TYPE D JOINT FOR ALL CONSTRUCTION JOINTS PLACED DUE TO THE CONTRACTOR'S POURING SEQUENCE.
- IF PAVING NON-CRC HTC TWO LANES WIDE, USE TYPE C JOINT FOR LONGITUDINAL CONTRACTION JOINT IN LIEU OF TYPE D JOINT.
- PCC FILLET JOINTS ARE TYPE C UNLESS OTHERWISE NOTED.
- REINFORCING IN FILLETS MAY BE CONTINUED ACROSS TYPE C JOINTS TO ADJACENT REINFORCED SLAB. SEE CS502 FOR REINFORCEMENT AND DEPTH.
- IF CONTRACTOR PLACES TRANSVERSE TYPE D JOINT DUE TO POURING SEQUENCE, LEAVE OUT ONE TRANSVERSE DOWEL FROM EACH END TO AVOID INTERFERENCE AT LONGITUDINAL DOWELS. DO NOT ADJUST TRANSVERSE DOWEL SPACING. SEE DETAIL 6 ON SHEET CS502.
- FOLLOW UFC 3-260-02 CHAPTER 12 RIGID-FLEXIBLE PAVEMENT JOINT DETAILS.
- FOR CONNECTION TO EXISTING PCC PAVEMENT, REMOVE ONE ROW OF SLABS AND REPLACE WITH THICKENED EDGE TRANSITION SLABS, MATCHING EXISTING JOINT PATTERN. REINFORCE TRANSITION SLABS USING DETAIL R IF SLAB SIZE EXCEEDS UFC 3-260-02 CRITERIA. IF EXISTING PCC IS IN GOOD CONDITION, DESIGNER MAY SHIFT TRANSITION SLAB TO FIRST ROW OF VLZ CONNECTOR TAXIWAY. EXTEND TRANSITION SLABS TO EXISTING JOINT BEYOND EDGE OF VLZ TAXIWAY FILLET.
- ADDITIONAL PAVEMENT BEYOND TRANSITION SLAB TO BE DETERMINED BY GOVERNMENT PRIOR TO SOLICITATION.
- TRANSVERSE JOINTS ON SHOULDER ARE TYPE C JOINTS.
- PAVING SEQUENCE FOR CRC HTC (DO NOT DEVIATE):
 - LANE A FIRST
 - LANES B AFTER LANE A
 - LANES C AFTER LANES B

JOINT LEGEND		
	THICKENED EDGE ISOLATION JOINT	1 CS502
	ISOLATION JOINT	2 CS502
	DOWELED CONSTRUCTION JOINT	3 CS502
	UNDOWELED CONTRACTION JOINT	4 CS502
	REINFORCED SLAB (NON-CONTINUOUS)	5 CS502
	CONSTRUCTION JOINT FOR CRC PAVEMENT	7 CS503
	SHOULDER JOINT	9 CS503



APPROVED	DATE	APPR
FOR COMMANDER NAVFAC		
ACTIVITY		
SUBSIDIARY TO		
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DESIGN MANAGER		
BRANCH MANAGER		
CHIEF ENG/ARCH		
FIRE PROTECTION		
DEPARTMENT OF THE NAVY NAVAL FACILITIES ENGINEERING COMMAND ATLANTIC NAVFAC NAVFAC DRAWING NO.	ETL 14-04 - VERTICAL LANDING ZONE STANDARD DRAWINGS - 23 APR 2014 PAVING PLAN - CONCRETE	CS103
SCALE: AS NOTED		
PROJECT NO.		
CONSTR. CONTR. NO.		
NAVIFAC DRAWING NO.		
SHEET 4 OF 12		
CS103		
DRAWING REVISION: 10 MARCH 2009		



NOTES:

1. GRADE SHOULDERS AND TAXIWAYS IN ACCORDANCE WITH UFC 3-260-01.
2. MINIMUM LONGITUDINAL AND TRANSVERSE SLOPE OF VLPAD IS 0.5 PERCENT MAXIMUM RESULTANT SLOPE OF WARPED SURFACE IS 1.5 PERCENT.
3. SURFACE GRADING IS TYPICAL, MAY SHIFT PRIMARY SURFACE ELEVATION TO ANY CORNER AND REGRADE.



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DESIGN MANAGER		
BRANCH MANAGER		
CHIEF ENG/ARCH		
FIRE PROTECTION		

DEPARTMENT OF THE NAVY
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NAVAL FACILITIES ENGINEERING COMMAND ATLANTIC
NORFOLK, VIRGINIA
ANT CAPITAL IMPROVEMENTS

ETL 14-04 - VERTICAL LANDING ZONE
STANDARD DRAWINGS - 23 APR 2014

SCALE: AS NOTED

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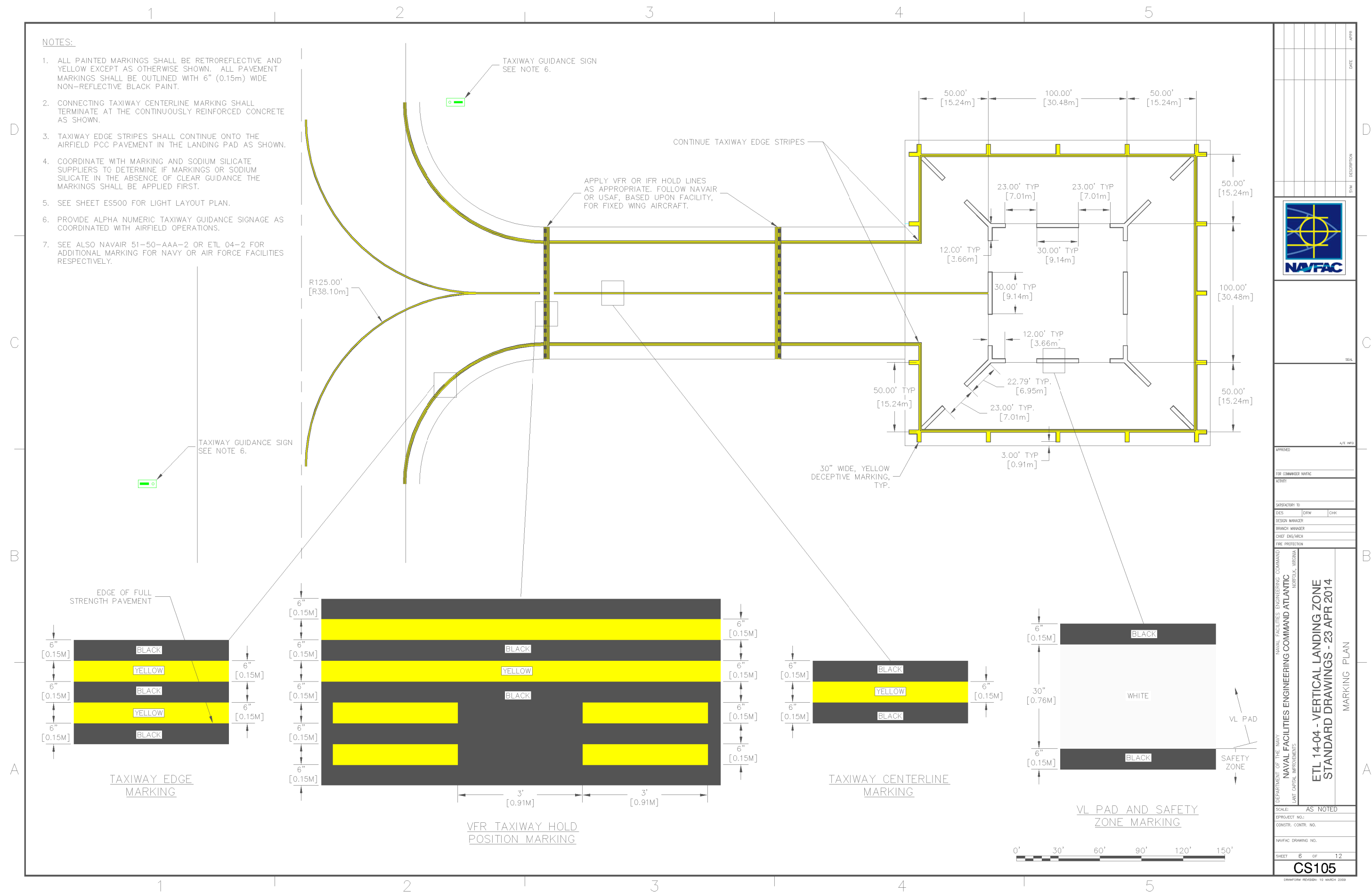
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CS104

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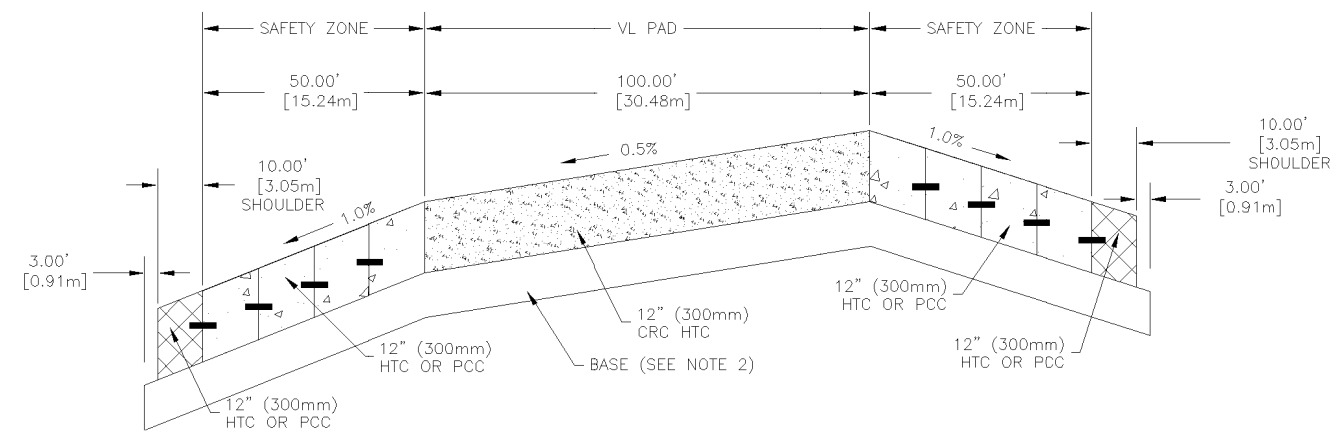
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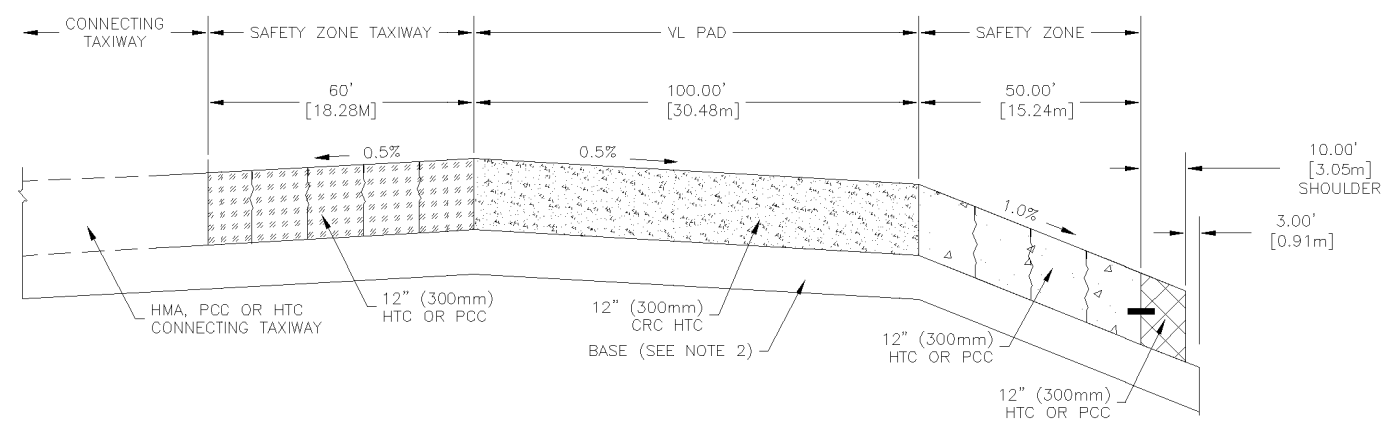
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A TYPICAL PAD TRANSVERSE SECTION
CS501 SCALE: NONE



B TYPICAL PAD LONGITUDINAL SECTION
CS501 SCALE: NONE

- NOTES:
1. SEE PAVING PLAN FOR MATERIAL TYPES.
 2. DESIGN BASE MATERIAL AND THICKNESS IN ACCORDANCE WITH ETL 14-04.

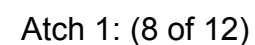
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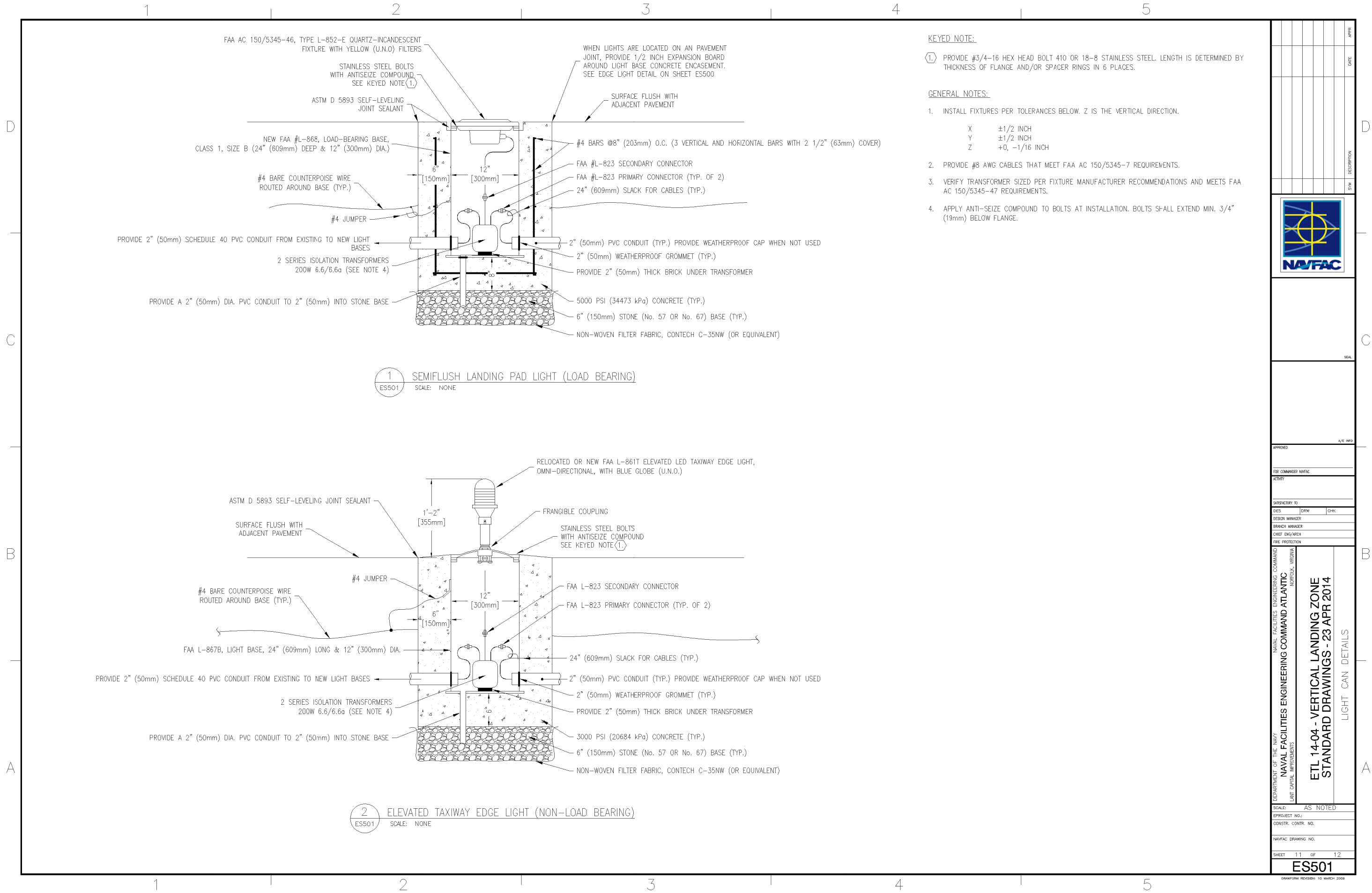
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