UNIFIED FACILITIES CRITERIA (UFC)

DESIGN AND CONSTRUCTION OF CONVENTIONALLY REINFORCED RIBBED MAT SLABS (RRMS)

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U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	Date	Location

This UFC supersedes TI 809-28, dated 15 September 1999. The format of this UFC does not conform to UFC 1-300-01; however, the format will be adjusted to conform at the next revision. The body of this UFC is the previous TI 809-28, dated 15 September 1999.

FOREWORD

\1\
The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD(AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA.) Therefore, the acquisition team must ensure compliance with the more stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Support Agency (AFCESA) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective service proponent office by the following electronic form: Criteria Change Request (CCR). The form is also accessible from the Internet sites listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide web site http://dod.wbdg.org/.

Hard copies of UFC printed from electronic media should be checked against the current electronic version prior to use to ensure that they are current.

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TI 809-28
15 September 1999

US Army Corps
of Engineers®

Technical Instructions

Design and Construction of Conventionally Reinforced Ribbed Mat Slabs

Headquarters
U.S. Army Corps of Engineers
Engineering and Construction Division
Directorate of Military Programs
Washington, DC 20314-1000

CEMP-E

TI 809-28
15 September 1999

TECHNICAL INSTRUCTIONS

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Approved for public release; distribution is unlimited.

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FOR THE COMMANDER:

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Directorate of Military Programs

DEPARTMENT OF THE ARMY
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Technical Instructions
No. 809-28
15 September 1999

Design and Construction of Conventionally Reinforced Ribbed Mat Slabs

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DESIGN AND CONSTRUCTION OF CONVENTIONALLY REINFORCED RIBBED MAT SLABS

1. PURPOSE AND SCOPE. This document provides guidance for the design and construction of conventionally reinforced ribbed mat slab (RRMS) foundation systems. For the purpose of this document, RRMS is defined as a system of stiffening beams and slab constructed of conventionally reinforced cast-in-place concrete to perform monolithically. RRMS must fully meet customer requirements including:

a. Appropriate utilization of RRMS foundation type.

b. Adequate structural and architectural performance.

c. Aesthetically acceptable exposed area floor slabs; that is, minimum cracking in high visibility areas.

2. APPLICABILITY. These instructions are applicable to all USACE elements and their contractors responsible for design and construction of RRMS foundation systems.

3. REFERENCES.

Government Publications:

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ACI 226.3R	Use of Fly Ash in Concrete
ACI 223	Standard Practice for the Use of Shrinkage-Compensating Concrete

Designing Floor Slabs on Grade by Ringo and Anderson.

4. BACKGROUND. RRMS foundations have been used extensively for MILCON projects since the 1970's. They were designed to resist structural distortion and resultant structural and architectural distress. RRMS resists foundation movement potential at expansive soil sites. Other type foundation systems experienced structural damage. The problem was most severe for drilled piers and shallow footing foundations. These were designed to industry standards for projects at moderate to highly expansive sites. Similar conditions were experienced with both Corps and private sector projects. Similar performance problems occurred where foundation design did not adequately address deformation potential. Damage due to the inability of foundation and structural systems to resist foundation movement was severe. Damage included distortion and cracking of concrete frames, wall cracking, pier and footing heave, separation of piers from columns, tensile failure at piers, wrenching and breakage of stem walls, grade beams and slabs, severed utility connections, massive architectural distress, and extreme distortion of floor slabs. Some structures were unserviceable. Although there was no structural collapse, distress was so severe that the term "failure" could be applied in some cases.

The RRMS system, taken in modified form from the housing industry, was adapted to MILCON-class structures. Evolution of design and construction criteria continued through the 1980's within CESWD. Several hundred million dollars of MILCON projects were placed on RRMS foundations yearly in the Fort Worth District during this period. CESWD's experience indicates the RRMS structural foundation to be cost effective and constructible solution for projects of various types, performance requirements, and site conditions.

The RRMS system has been used extensively to provide cost effective support to a variety of structural and architectural systems for varying site conditions. This system has had limited use worldwide. Most Corps projects using RRMS are located in the Southwestern Division. While competent structural performance has been achieved, many RRMS projects have experienced significant cosmetic cracking of floor slabs. Although these cracks have no significant structural or functional consequence, users have expressed dissatisfaction with the extent of cracking in high visibility areas.

5. SLAB CRACKING. Excessive shrinkage cracking in concrete slabs has been a persistent problem. A small percentage of moderate to severe slab cracking is experienced on RRMS projects resulting from volumetric shrinkage during concrete curing. Cracking remains a universal problem with reinforced slabs of large lateral dimensions. ACI 224R, ACI 302.1R, and ACI 360R present criteria for crack sizes permissible in engineering practice. Due to additional lateral restraint created by the stiffening beams, slabs for RRMS foundations have greater cracking potential than flat slabs. These cracks do not affect RRMS performance, but can be unsightly. Several factors contribute to increased potential for cracking; these factors are as follows:

a. High concrete mix water/cement ratio.
b. Large slab placement dimensions.
c. Minimal slab reinforcement percentage.
d. Large, widely spaced reinforcement.
e. Small aggregate in the concrete mix.
f. High range water reducer additives.
g. High cement content.
h. Addition of water during placement.
i. Substitution of membrane curing in lieu of the specified wet mat curing.

6. RRMS DESIGN. There are several items presented in this document as minimum design and construction criteria. Final design values are those developed during the design process based on sound engineering principles and judgment. This document presents data that should form a base line for design and construction.

a. Geotechnical considerations for RRMS foundations are covered in TM 5-818-7, CESWD-ED-TS/G Criteria Letter, and CESWD Architectural and Engineering Instruction Manual.

b. RRMS is a specialized procedure and must be targeted to address specific design requirements, including such items as specific site, structural, architectural, economical, and other project-specific requirements. RRMS must be considered when the following situations exist:

(1) A requirement for a high degree of structural continuity and ability to resist subgrade movement.

(2) Expansive subgrade at the site.

(3) Suitable stratum for founding alternate foundation types is not present at a reasonable depth.

(4) RRMS is readily adaptable to the structural and/or architectural system of the proposed project.

(5) Structures with uniform loads and repetitively spaced columns and walls.

(6) Structures with deformation sensitive architectural finishes.

(7) Alternate foundation types are not as economical, constructible, or would not produce equal or better performance.

c. Generally, RRMS should not be used in the following situations where:

(1) Continuity and level of performance is not required.

(2) RRMS is not reasonably adaptable to the structural and/or architectural system.

(3) Site topography and/or subsequent site development create large fill differential.

(4) Floor elevations vary due to depressed pits, channels, partial basements or other split level arrangements.

(5) There are large open functional areas without interior loaded columns.

(6) There are widely spaced and/or very heavily loaded column and/or wall loads.

(7) More constructible and/or economical foundation types will produce equal or better performance.

(8) The concrete is exposed on Air Force projects; thence it is required that RRMS be used only in areas covered by carpet or other appropriate covering that will not reflect cracks.

d. The recommended method of analysis and design of RRMS is presented in CESWD-ED-G Criteria Letter; additionally, the following items must be incorporated into the design of RRMS:

(1) A water/cement ratio of less than or equal to 0.42.

(2) Maximum 230 mm (9 inches) spacing for slab steel reinforcement.

(3) Reinforcement at “t/4” (t = slab thickness in inches) below the slab surface with a minimum of 38 mm (1.5 inches) and a maximum of 64 mm (2.5 inches) clear.

(4) Minimum reinforcement of 0.5% and maximum bar size of 15M (#5).

(5) Maximum coarse aggregate size of 25 to 38 mm (1.0 to 1.5 inches) with aggregate gradations corresponding with ACI 301; coarse aggregate size must be compatible with clear cover requirements.

(6) Specified 28-day compressive strength between 21 and 28 MPa (3.0 and 4.0 ksi).

(7) Rigid control on the use of high-range, water-reducing admixtures in accordance with ACI 212.4R.

(8) Fly ash required as an admixture for a portion of the cement per ACI 226.3R.

(9) RRMS to be placed in 6 to 7.6 m (20 to 25 foot) wide lanes using lane placement techniques. For Air Force projects use 6 m (20 foot) lane widths. For vehicular slabs, lanes will have transverse joints spaced 20 to 30 times the slab thickness.

(10) Large and irregularly shaped slabs should be subdivided into smaller units. Ensure compatibility with the architectural and/or structural framing systems and area functions.

(11) The use of shrinkage-compensating cement for extreme cases should be investigated and applied in accordance with ACI 223.

(12) Special concrete requirements for RRMS should be included in the specifications.

(13) For Air Force projects, beam spacing should be limited to 6 m (20 feet).

(14) Beam trench bottoms should be moist (not soaked) prior to concrete placement.

(15) High plasticity soil should be removed to a depth of 1 m (3 feet) below the water barrier and 600 mm (2 feet) below the perimeter beams and replaced with non-expansive soil.

7. DRAWINGS AND SPECIFICATIONS. Appropriate sections of the drawings and specifications should address items essential to limiting shrinkage cracking and other RRMS details to ensure proper and complete conveyance to the Contractor. The following items should be addressed.

a. Slab details.

(1) Slab reinforcement “t/4” (t = slab thickness in inches) clear below top of slab; where “t/4” will not be less than 38 mm (1.5 inches) nor greater than 64 mm (2.5 inches). Minimum slab reinforcement will be 0.5% with a maximum spacing of 230 mm (9 inches) each way.

(2) Thickness.

(3) Capillary water barrier.

(4) Vapor barrier.

b. Drawings.

(1) Construction joint spacing and details.

(2) Place-in lanes should be a maximum of 7.6 m (25 feet) wide. For Air Force projects lanes should be a maximum of 6 m (20 feet).

(3) Weakened plane joints in vehicular loaded slabs should be spaced a maximum of 20 to 30 times the slab thickness for adequate crack control.

(4) Details of reinforcement at re-entrant corners and around openings in the slab. Slab reinforcing steel should be anchored into perimeter beams.

(5) Detailed foundation preparation instructions should be provided.

(6) Compressive 28-day concrete strength and yield strength of reinforcing steel.

(7) Beam size, spacing and reinforcement.

c. Specifications.

(1) The minimum 28-day compressive strength should be 21 Mpa (3.0 ksi) for RRMS concrete. Vehicular loaded slabs require 28 Mpa (4.0 ksi) 28-day compressive strength. Flexural strengths should not be specified.

(2) Water/cement ratio should be a maximum of 0.42.

(3) Slump at placement should not be greater than the design mix slump. If contractor elects to pump mix, pumping aids will be allowed, provided shrinkage potential does not increase.

(4) High range water reducers (HRWR) will be allowed, if it is shown that concrete produced with HRWR is not subject to increased shrinkage, segregation, and retarding/flash setting. Testing will be performed on concrete with the proposed HRWR to determine shrinkage potential.

(5) Guidelines for the use of shrinking-compensating cements, as outlined in ACI 223, should be provided if they are to be used in the construction of RRMS.

(6) The mix design must incorporate a 25 to 38 mm (1.0 to 1.5 inches) coarse aggregate maximum size with appropriate gradation specification. Follow ACI guidance for use of well- graded aggregates.

(7) Cold and hot weather concrete placement guidelines must be provided. Place at a lower initial concrete temperature.

(8) Require reduction of cement content by using fly ash. The volume of fly ash when combined with Portland cement should be 20% plus or minus 5% of the volume of Portland cement plus fly ash.

(9) Require 7-day, wet mat, moist curing unless the project is in an area of restricted water usage.

8. THREE-PHASE CONTROL PROCESS. There are certain items listed in the specifications and shown on the drawings that require close scrutiny during the construction of RRMS. The districts and operating divisions must inform Area/Resident Engineer Offices of these items. The Area/Resident Engineer must assure that they are addressed by the Quality Assurance Staff during the Three Phase Control Process; the following is a list of items that must be addressed:

a. Mix proportions for RRMS will be Government approved (GA) to ensure suitability of the mix design.

b. Area/Resident Engineers will perform the following quality assurance checks to verify the Contractor's QC Inspector's compliance with the drawings and specifications:

(1) Assure adequate drainage is established and maintained so that water does not pond in or adjacent to the footprint area of the RRMS during construction.

(2) Assure that removal of existing site materials complies with the drawings and specifications.

(3) Assure fill materials used to replace existing site soils comply with the specified plasticity, gradation and compaction requirements.

(4) Prior to placement, perform quality assurance of subgrade, required excavation, fill material, capillary water barrier, vapor barrier, and reinforcement as shown on the drawings.

(5) Assure lane placement widths are as shown on the drawings.

(6) Assure continuity of mixing is maintained on the job with no deviations.

(7) Assure that all required tests are conducted.

(8) Assure that the 7-day, wet mat, moist curing is carried out if required by the specifications.

(9) Assure temperature of concrete, at time of placement, is between 10 and 32 degrees C (50 and 90 degrees F). Follow the guidance of ACI 301 concerning ambient conditions.

(10) Assure that no water is added to the truck mixer after design water/cement ratio has been reached.

(11) Assure concrete slump conforms to the specified requirements.

c. Qualified Government personnel must be onsite to ensure that all quality control testing is accomplished and all tests are passed. Accurate daily logs are required.

d. District technical staff must be notified if slab cracking occurs within the first week of slab placement.

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(3) Slump at placement should not be greater than the design mix slump. If contractor elects to pump mix, pumping aids will be allowed, provided shrinkage potential does not increase.

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(5) Guidelines for the use of shrinking-compensating cements, as outlined in ACI 223, should be provided if they are to be used in the construction of RRMS.

(6) The mix design must incorporate a 25 to 38 mm (1.0 to 1.5 inches) coarse aggregate maximum size with appropriate gradation specification. Follow ACI guidance for use of well- graded aggregates.

(7) Cold and hot weather concrete placement guidelines must be provided. Place at a lower initial concrete temperature.

(8) Require reduction of cement content by using fly ash. The volume of fly ash when combined with Portland cement should be 20% plus or minus 5% of the volume of Portland cement plus fly ash.

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a. Mix proportions for RRMS will be Government approved (GA) to ensure suitability of the mix design.

b. Area/Resident Engineers will perform the following quality assurance checks to verify the Contractor's QC Inspector's compliance with the drawings and specifications:

(1) Assure adequate drainage is established and maintained so that water does not pond in or adjacent to the footprint area of the RRMS during construction.

(2) Assure that removal of existing site materials complies with the drawings and specifications.

(3) Assure fill materials used to replace existing site soils comply with the specified plasticity, gradation and compaction requirements.

(4) Prior to placement, perform quality assurance of subgrade, required excavation, fill material, capillary water barrier, vapor barrier, and reinforcement as shown on the drawings.

(5) Assure lane placement widths are as shown on the drawings.

(6) Assure continuity of mixing is maintained on the job with no deviations.

(7) Assure that all required tests are conducted.

(8) Assure that the 7-day, wet mat, moist curing is carried out if required by the specifications.

(9) Assure temperature of concrete, at time of placement, is between 10 and 32 degrees C (50 and 90 degrees F). Follow the guidance of ACI 301 concerning ambient conditions.

(10) Assure that no water is added to the truck mixer after design water/cement ratio has been reached.

(11) Assure concrete slump conforms to the specified requirements.

c. Qualified Government personnel must be onsite to ensure that all quality control testing is accomplished and all tests are passed. Accurate daily logs are required.

d. District technical staff must be notified if slab cracking occurs within the first week of slab placement.