DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, DC 20314-1000

ETL 1110-2-542

CECW-EG

Technical Letter
No. 1110-2-542

30 May 1997

Engineering and Design
THERMAL STUDIES OF MASS CONCRETE STRUCTURES

1. Purpose

This engineer technical letter (ETL) provides guidance for performing thermal studies of mass concrete structures (MCS) as required by Engineer Manual (EM) 1110-2-2000.

2. Applicability

This ETL applies to HQUSACE elements and USACE commands having responsibilities for the design of civil works projects.

3. References

References are listed in Annex 4.

4. Discussion

a. *Background*. The effects of heat generation in mass concrete were first recognized in the 1920's and 1930's, including the development of artificial cooling of mass concrete using chilled water flowing through embedded pipe. Early thermal analysis of mass concrete made use of very simple concepts and various stepwise hand calculation methods of determining temperature changes. Later development of finite element (FE) techniques made possible more accurate and realistic thermal analysis, culminating in the current development of nonlinear incremental structural analysis (NISA). Current mass concrete thermal analysis practice may employ a variety of methodologies, varying from simple hand calculations and charts using broad assumptions for conditions and concrete properties, to computer spreadsheet temperature balance methods, to FE temperature and stress/strain analysis, and finally NISA.

b. *Types of mass concrete structures*. Three types of MCS are commonly used in civil works projects: (1) gravity structures such as dams and lock walls; (2) thick shell structures such as arch dams; and (3) thick reinforced structures such as U-frame locks, large pumping stations, powerhouses, large foundations, and massive bridge piers. MCS constructed using the roller-compacted concrete (RCC) construction method are treated in this ETL identically to structures constructed using traditional construction methods.

c. *ETL content*. Thermal studies for MCS have been categorized into three levels of increasing complexity to provide a convenient frame of reference. This ETL specifically provides information and guidance for thermal studies of MCS and provides methodology for the first two levels of thermal studies. The methodology for the more complex third level is provided by ETL 1110-2-365, which includes many subjects pertinent to Level 1 and Level 2 thermal analyses. EM 1110-2-2201 contains explicit procedures for preliminary temperature studies for arch dams that eventually lead to NISA.

(1) Appendix A provides detailed information and practice for mass concrete thermal studies.

(2) Annex 1 presents current practice for determination of concrete tensile strain capacity for use in cracking analysis.

(3) Annex 2 provides a stepwise procedure for simple, Level 1 thermal analysis, including an example.

(4) Annex 3 provides a procedure for more intensive Level 2 thermal analysis, including an example using simple FE, one-dimensional (1-D) strip models and an example using more complex two-dimensional (2-D), FE methodology.

5. Guidance

a. *Descriptions and applications of thermal analysis methods*. Thermal analysis is categorized into three levels of complexity. These levels are identified to provide a convenient frame of reference for the analytical processes available to the designer. The level of thermal analysis selected should be appropriate for the size, type, function and risk, and stage of design of the structure, as well as the potential for cost savings resulting from the analysis. Appendix A provides a suggested process for selecting and conducting thermal analysis appropriate for MCS. Small, low-head MCS may require no more than a very simplified thermal analysis. A larger structure, such as a concrete gravity dam, may need only a simplified thermal study at the feasibility level of design, but a more thorough study during preconstruction engineering and design (PED) phase. Certain MCS such as complex lock walls, high gravity dams, and arch dams, may require a NISA during PED. Cost savings may be realized through an adequate thermal study when unnecessary joints can be eliminated or construction controls, such as concrete placing temperatures, can be relaxed. Each higher level of analysis may provide more detailed information but, generally, at a price of increasing complexity and cost of the analytical effort.

(1) Level 1 analysis. This is the simplest level of thermal analysis, using very basic methodology, requiring little or no laboratory testing, and incorporating broad assumptions for site conditions and placement constraints. This level of analysis should be used in thermal evaluations of a general nature, where the consequences of thermal cracking are a concern but pose little safety or stability concerns. The method is appropriate for the project feasibility stage to determine if higher level analysis is necessary for PED and for initial verification of construction controls and structural features such as joint spacing and lift heights. It is applicable to small and low-head structures and those structures where thermal cracking poses little risk of loss of function. These structures may include diversion structures for irrigation canals, low-head flood protection structures, low-head MCS that impound water on an infrequent basis for short durations, and thick reinforced structures such as foundations and massive bridge piers. Annex 2 of Appendix A illustrates this level of analysis.

(2) Level 2 analysis. Level 2 thermal analysis is characterized by a more rigorous determination of concrete temperature history in the structure and the use of a wide range of temperature analysis tools. This level of analysis should be applied to thermal evaluations of more critical structures where the consequences of thermal cracking may pose a significant risk to people or property, may present stability concerns or loss of function, or may result in significant cost savings. This level of analysis is recommended to better identify thermal cracking potential and minimize specific requirements necessary for thermal crack control that can add significant cost to construction. Level 2 analysis may be appropriate for the feasibility study phase of significant structures and may be used to determine if higher-level analysis is necessary during PED. Level 2 thermal analysis is also appropriate for PED for significant MCS. It is applicable to medium to high-head flood protection structures and other significant MCS. These structures may include complex lock walls, medium to high gravity dams, tunnel plugs involving postcooling and grouting, pumping stations, powerhouses, and low-head arch dams. Annex 3 of Appendix A illustrates this level of analysis.

(3) Level 3 analysis. This level is the most complex level of thermal analysis. ETL 1110-2-365 describes the computational methodology and application of Level 3 (NISA) analysis, and ETL 1110-2-536 presents an example of NISA application to the Zintel Canyon Dam. This level of analysis is suitable for very critical structures where cracking poses significant risks. The designer must weigh the high costs of NISA evaluation against the potential benefits of increased analysis detail and capability of simultaneously analyzing thermal and

other structure loading. The method is applicable to critical, high-risk projects, complex or unprecedented structures with little or no previous experience, and structures subject to stress interaction from several simultaneous loading conditions. This level of analysis may also be appropriate for normal thermal studies of more ordinary MSC to optimize thermal controls and potentially reduce construction costs. Candidates for NISA include high gravity dams, arch dams, large and complex lock walls.

b. *Cracking analysis methods*. Analysis of cracking for Levels 1 and 2 MCS thermal analysis is performed based on the computed concrete temperature distributions, using simplified procedures to relate thermal changes in volume of the MCS to estimate cracking potential. The procedures involve approximations and require assumptions regarding conditions of restraint. Cracking analysis methodology for Levels 1 and 2 thermal analysis is described in Appendix A. For NISA, the cracking analysis is integral with the incremental FE thermal stress-strain analysis as described in ETL 1110-2-365.

6. Action

a. *Thermal analysis needs.* As required in EM 1110-2-2000, concrete thermal studies are to be performed for any important concrete structure where thermal cracking potential exists. The design team must evaluate the necessity of a thermal study and select the appropriate level of analysis in accordance with the criteria outlined herein. Guidance for performing thermal studies is given in Appendix A.

b. *Stage of project development.* Evaluation of the thermal study requirements should be done during the Feasibility Phase of project development. Necessary design studies and resources should be included in the Project Management Plan. Proper identification of objectives is the key to determining the required scope of studies. Contact CECW-EG and CECW-ED for assistance in determining appropriate levels of investigation and the necessary resources. Thermal studies are usually performed during the PED phase when project concrete materials and mixtures have been identified. However, the most basic studies may be performed during a feasibility study for a major project or for a complex structure where thermal cracking issues may control subsequent design changes and more complex analysis. Testing requirements should be coordinated to ensure test data are ready at the appropriate time of the study. Appendix A contains more detailed information related to thermal analysis and stages of project development.

c. *Testing.* The material properties for thermal studies should be based on test results of proposed concrete mixtures for the project, if appropriate to the level of study, the phase of project study, and requirements of the particular project. If concrete properties testing is not appropriate for a specific project, data will be obtained from various published sources and from consultation with concrete specialists at various Field Operating Activities (FOA) and CEWES, and with outside technical specialists.

d. *Responsible parties.* The materials or structural engineer primarily responsible for the thermal study must ensure that adequate input is obtained from materials, structural, geotechnical, and construction engineers. Coordination is required for selection of environmental conditions, concrete properties, foundation properties, and construction parameters. Review of the thermal study should be conducted at levels commensurate with the scope of the thermal study to ensure that the plan of action being pursued is appropriate. Concrete specialists at various FOA and CEWES, or outside technical specialists, should be consulted for guidance during Level 2 or 3 thermal analysis of MCS.

e. *Construction.* If construction conditions or requirements change significantly from that assumed during the thermal analysis, the designer should evaluate the need to conduct additional thermal studies. Instrumentation should be installed in important MCS to verify design assumptions and analysis.

f. *Documentation.* Results of the thermal study should be documented in an appropriate design report.

FOR THE COMMANDER:

1 Appendix
App A - Techniques for Performing
  Concrete Thermal Studies

Steven L. Stockton, P.E.
Chief, Engineering Division
Directorate of Civil Works