ANNEX 1: DETERMINATION OF TENSILE STRAIN CAPACITY

A1-1. Purpose

Tensile strain capacity (TSC) is the change in length per unit length that can be sustained in concrete prior to cracking. This property is used with the results of temperature analysis to determine whether a mass concrete structure (MCS) will crack and the extent of cracking. This annex describes testing to determine TSC, methods to estimate TSC, and methodology for its use in thermal analysis.

A1-2. Background

The Corps of Engineers introduced TSC testing of concrete several decades ago to provide a basis for evaluating crack potential for strain-based thermal studies of MCS (Houghton 1976). This property is also used to compare different aggregates and different concrete mix proportions in MCS. TSC varies primarily based on age, strength, aggregate type, shape, and texture. TSC tests are conducted on large concrete beams instrumented to measure strain to failure. TSC is determined in a series of tests, including rapid and slow loading of beams. The slow-load test was designed to simulate the strain conditions occurring in a mass concrete structure during long-term cooling. By conducting tests at several loading ages, TSC data can be used to evaluate mass gradient cracking resistance in a structure under long-term cooling. Surface gradients generally develop during the first several days or weeks after placement of concrete, particularly following the removal of insulated forms. Hence, strains due to surface gradients develop more rapidly than tested using the slow-load TSC test, and more slowly than a standard TSC test failed at a normal loading rate. This annex describes one method used to estimate TSC for surface gradient analyses.

A1-3. Description of Test Method

Tensile strain capacity is determined according to CRD-C 71 (WES 1949). The test method requires a minimum of three beams for each test, and generally a minimum of three tests is recommended for each test set to allow for variation in the test results. Rapid-load (0.28 Mpa/min)(40 psi/min) and slow-load (0.17 MPa)(25 psi/week) tests are usually conducted in test series consisting of three beam tests each. TSC test specimens are 300-mm by 300-mm by 1,680-mm-long (12-in. by 12-in. by 66-in.-long) beams tested in third-point loading. Strain gauges are located at or near the top and bottom (compression and tension) surfaces to measure strain during the tests. At the age of test, a rapid-load test is conducted and a slow-load test is begun. Loading continues at the prescribed rate until failure. During the slow-load beam test, strain measurements are made on the beam under load. In addition, measurements of autogenous strain are made on the third beam. The autogenous shrinkage strains are used to correct the strain measurements on the beam under slow load. Upon failure of the slowly-loaded beam, a rapid-load test is performed on the third beam. A TSC test series usually contains a suite of rapid- and slow-load tests typically initiated at 3, 7, 28 days, and/or other ages. The differences in TSC capacity from the slow- and rapid-load beams provide an indication of the cumulative creep strain during the slow-load test. The strains measured in the slow-load beam test containing both elastic and creep strains are expressed in millionths (1×10^{-6} in./in).

A1-4. Tensile Strain Capacity Test Results

TSC test results can vary widely depending on a variety of factors. Use of test results for the specific materials and mixture(s) to be used in an MCS should be used whenever possible. Actual values for TSC of mass concrete for slow-load tests for specimens loaded at 7 days and failing at about 90 days range from 88 to 237 millionths. Corresponding values for rapid-load tests conducted at 7 days range from 40 to 105 millionths. For tests conducted upon failure of the slow-load beam, rapid-load results range from 73 to 136 millionths. Ratios of slow-load tensile strain capacity to

rapid-load tensile strain capacity tested at the same age as the slow-load specimens range from 1.0 to 2.0 and averages 1.4. This average is relatively insensitive to age.

A1-5. Use of Tensile Strain Capacity for Mass Gradient Cracking Analyses

Mass gradient tensile loading in an MCS occurs over an extended period of time. The standard slow-load tensile strain capacity test was specifically designed for this condition. Standard slow-load TSC tests provide a reasonable limiting strain in mass gradient cracking analyses for the condition of restrained slow loading of mass concrete which occurs in a slowly cooling mass. Using an appropriate loading time period, the slow-load tensile strain capacity can be used directly for mass gradient cracking analysis.

A1-6. Use of Tensile Strain Capacity for Surface Gradient Cracking Analyses

a. Surface gradient strains. Surface gradient strains can be initiated at a very early age, particularly after the removal of insulated formwork, and can develop over a few days or weeks of loading due to the initial temperature rise and subsequent development of the surface temperature gradient. Because loading under surface gradient conditions is more rapid than the standard tensile strain capacity slow-load test, the results of that test may not well represent surface gradient conditions. Very accurate tensile strain capacity values may not be necessary for surface gradient analysis, except for critical situations. For most situations, the standard test values will suffice for surface gradient cracking analysis as well as mass gradient cracking analysis. In some structures, concrete placed near the surface of the MCS may differ significantly from internal concrete mixtures. Tests for TSC used in surface gradient analysis should be conducted on the appropriate concrete mixture(s).

b. Simulated surface gradient strains. For critical situations, slow-load TSC tests conducted at more rapid rates of loading than the standard slow-load test may be conducted to simulate the development of surface gradient thermal strains. In lieu of such special load rate testing, an estimate can be made of TSC for use in preliminary surface gradient TSC determinations, using the ratio of 1.4 described above. An estimate of TSC for surface gradient analysis is determined by testing TSC at the rapid load rate and at the age of interest. This value is then multiplied by 1.4, to determine a TSC under the slow loading reflective of surface gradient strain development. This estimate is believed to be reasonably conservative at ages from 1 to 14 days. Because creep rates are greatest at early ages, it is possible that slow-load TSC may be considerably higher especially from 1 to 7 days. Until test data are available, this may be used for developing surface gradient tensile strain capacity values.