DESFA Hellenic Gas Transmission System Operator	**HELLENIC GAS TRANSMISSION SYSTEM OPERATOR** 357-359 MESSOGION AVE., 15231 ATHENS, GREECE Tel.: 210 6501258 Fax : 210 6501551	**TECHNICAL JOB SPECIFICATION** **A-1** **REVISION 1** DATE 23/09/2011

LIQUEFIED NATURAL GAS PLANTS

SPECIFICATION FOR LOW TEMPERATURE TESTING OF CONCRETE

QUALITY ASSURANCE PAGE

CHANGES LOG

REVISIONS LOG

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CONTENTS

1

REFERENCE DOCUMENTS

ELOT EN 206/A1 & /A2
"Concrete - Part 1: Specification, performance, production and conformity"

ELOT EN 12350 series
"Testing fresh concrete"

ELOT EN 12390-2
"Testing hardened concrete - Part 2: Making and curing specimens for strength tests"

ELOT EN 14620-3
"Design and manufacture of site built, vertical, cylindrical, flat-bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperature 0°C and -165°C – Part 3: Concrete Components".

ASTM C 215
"Standard Test Method for Fundamental Transverse, Longitudinal, and Torsional Frequencies of Concrete Specimens"

BS 1881-209
"Testing concrete - Recommendations for the measurement of dynamic modulus of elasticity"

CEN/TS 12390-9:2006
"Testing hardened concrete - Part 9: Freeze-thaw resistance – Scaling"

CEN/TR 15177:2006
"Testing the freeze-thaw resistance of concrete - Internal structural damage"

1. GENERAL

1.1 This specification defines the requirements for low temperature testing of concrete to be performed by CONTRACTOR. These requirements are additional to the requirements of the relevant standards governing the use of materials at normal temperatures. All concrete used in the construction of the storage tanks shall fulfill the following requirements which must be checked in Qualification Testing prior to use in the works and later for Routine Control Testing during construction.

1.2 Two major tests are specified with related acceptance criteria;

(a) To determine compressive strength after one cycle between ambient and product temperature.

Product temperature shall mean -170^0 C for LNG service.

(b) To determine compressive strength after 20 freezing/thawing cycles between +5^{0}C and -25^{0}C.

1.3 Additionally other tests shall be performed to determine or to check design values of important parameters as defined below.

2. COMPRESSIVE STRENGTH AFTER ONE CYCLE TO PRODUCT TEMPERATURE

2.1 Specimens

2.1.1 Specimens shall be prepared from the proposed concrete mix including any proposed admixtures.

2.1.2 3 sets of 10 standard cylinders shall be cast. Each set of cylinders shall be cast with concrete from different batches.

2.1.3 For each set:

3 specimens shall be tested after normal curing.

3 specimens shall be tested after normal curing and thermal cycling.

4 specimens shall be kept in reserve.

2.2 Curing

All specimens shall be cured for a minimum of 28 days at 30^{0}C ± 2^{0}C at a minimum Relative Humidity of 90%.

NOTE: The period of curing may be extended subject to compliance with the overall project schedule.

2.3 Thermal Cycle

2.3.1 After curing, specimens are to be immersed in the low temperature liquid for one hour. Specimens shall then be allowed to warm in the curing conditions (30 ^{0}C, RH – 90%) for 48 hours.

2.3.2 Low temperature liquid should be the stored product i.e. LNG. For convenience, liquid nitrogen at -196 ^{0}C may be used.

NOTE: From published literature the reduction of compressive strength after one cycle at -196 ^{0}C, is expected not to be larger than after one cycle at -170 ^{0}C.

2.4 Testing

2.4.1 Dynamic modulus of concrete shall be determined prior to compressive testing on the 18 specimens in accordance with the procedure defined in standard **ASTM C 215 or BS 1881-209.**

2.4.2 Compressive testing of the 18 specimens in accordance with the relevant specification shall be carried out not earlier than 48 hours after commencement of rewarming.

2.4.3 The water content shall be determined on cycled and uncycled specimens after completion compression tests.

2.5 Acceptance Criteria

2.5.1 The compressive strength measured on uncycled specimens shall be In compliance with the specified compressive strength of the concrete.

2.5.2 No individual result on thermally cycled specimens may be less than 80% of the specified strength of the concrete.

2.5.3 The average compressive strength computed for the 9 thermally cycled specimens shall he compared with that computed for the 9 uncycled specimens. The reduction due to thermal cycling must not be greater than 20%.

2.5.4 Ratio of average elastic modulus of cycled and uncycled specimens must be 0.8 or greater.

3. COMPRESSIVE STRENGTH AFTER 20 CYCLES BETWEEN +5^{0}C AND -25^{0}C

3.1 Specimens

3.1.1 Specimens shall be prepared from the proposed concrete mix including any proposed admixtures.

3.1.2 3 sets of 10 standard cylinders shall be cast. Each set of cylinders shall be cast with concrete from different batches.

3.1.3 For each set:

3 specimens shall be tested after normal curing.

3 specimens, complete with a thermocouple cast in the middle (for temperature checking) shall be tested after normal curing and completion of thermal cycling.

2 plain specimens and 2 specimens complete with thermocouples as described above shall be kept in reserve.

3.2 Curing

All specimens shall be cured for a minimum of 28 days at $30^0C \pm 2^0C$ at a minimum Relative Humidity of 90%.

3.3 Thermal Cycles

3.3.1 Specimens shall be sealed in polyethylene sheet and thermally cycled in cooling chamber. A total of 20 complete thermal cycles shall be performed.

3.3.2 Before commencing thermal cycling specimens shall be pre-cooled from 30^0C to 5^0C in a cooling chamber for a minimum of 2 hours.

3.3.3 Each complete thermal cycle shall comprise:

Step 1 - Cooling phase in chamber from 5^0C to -25^0C with a cool down rate of 10^0C / hour. Terminal internal temperature of specimen to be $-25^0C \pm 2^0C$.

Step 2 - Maintain temperature at -25^0C.

Step 3 - Rewarming of specimen from -25^0C to 5^0C at a rate of 10^0C / hour.

Step 4 - Maintain temperature at 5^0C.

Complete cycle is 12 hours ± 2 hours each step is approximately 3 hours.

Records of temperature using the thermocouples shall be made throughout the testing cycles.

3.4 Testing

3.4.1 Dynamic modulus will be determined on the 18 specimens in accordance with the procedure of Standard **ASTM C 215 or BS 1881-209**.

3.4.2 Compressive testing of the 18 specimens in accordance with the relevant standards shall be carried out not earlier than 48 hours after the completion of thermal cycling.

3.4.3 The water content shall be determinated on cycled and uncycled specimens after completion of compression tests.

3.5 Acceptance Criteria

3.5.1 The compressive strength measured on uncycled specimens shall be in compliance with the specified compressive strength of the concrete.

3.5.2 No individual result on thermally cycled specimens may be less than 80% of the specified strength of the concrete.

3.5.3 The average compressive strength computed for the 9 thermally cycled specimens shall be compared with that computed for the 9 uncycled specimens. The reduction in compressive strength due to thermal cycling shall not be greater than 20%.

3.5.4 Ratio of average elastic modulus of cycled and uncycled specimens shall be equal to or greater than 0.8.

4. PHYSICAL PROPERTIES OF CONCRETE AT LOW TEMPERATURES

4.1 Tests

4.1.1 CONTRACTOR shall perform tests to determine the parameters at the relevant temperatures which are to be used in the final design.
Parameters of first importance are:

Lambda – Thermal conductivity
Alpha – Co-efficient of thermal contraction
E – Elastic modulus
Stress/strain diagram

4.2 Test Procedures

4.2.1 CONTRACTOR is to develop detailed procedures for the performance of the tests detailed in 4.1. Procedures shall be subject to agreement by OWNER.
General recommendations are specified in the following sections 4.1 to 5.1.2.

4.3 Curing

4.3.1 All specimens shall be cured for a minimum of 28 days at 30°C with a Relative Humidity (R.H.) equal to or greater than 90%. A longer curing period may be adopted by CONTRACTOR subject to compliance with the overall project schedule. Influence of the longer actual curing period on the result shall be anticipated by CONTRACTOR and used in the design.

4.4 Water Content of Concrete

4.4.1 Water content has a determining effect on concrete properties at low temperature.

4.4.2 CONTRACTOR shall determine with regard to local atmospheric conditions, upper and lower bounds for water content in the different parts of the actual structure which shall be used in the tests.

Without further information relating to the actual conditions, the and lower bounds of water content may result from an additional 28 days at 30^{0}C after curing period respectively at 50% R.H. and 90% R.H.

4.4.3 All tests shall be run for the upper to lower bounds of water content.

4.5 Test Temperature

4.5.1 Parameters may be determinate at a temperature interval of 50^{0}C or less from normal condition down to the lower temperature in accidental conditions.

4.6 Type of Test and Specification

4.6.1 CONTRACTOR shall select a Laboratory with previous experience in the testing of concrete a low temperature. Tests shall be executed in accordance with recognized standards for the testing required under this section.

4.6.2 Detailed specifications must be prepared by CONTRACTOR and agreed with OWNER prior to carrying out of testing.

4.6.3 Tests shall be performed on specimens having a minimum smaller dimension of at least 3.5 x D, where D equals the size of the largest aggregate.

5. TENSILE STRENGTH OF CONCRETE AT LOW TEMPERATURE

5.1 Tests

5.1.1 The tensile strength of concrete shall be determinate by testing in both direct tension and split failure. The requirements relating to curing, water content of concrete, test temperature, type of test and specification as defined in Section 4 above shall be adhered to.

5.1.2 Direct tension testing shall be carried out by either:

1) Maintaining zero deformation during cooling of the specimen and measuring the resulting load up to failure.

2) Conventional direct tension test at different low temperature and determination of elastic modulus.

Preference should be given to test method (1) for assessment of low temperature behavior.

6. ROUTINE CONTROL TESTING

6.1 Routine control testing as specified in Sections 2 and 3 above shall be regularly performed during the construction period to ensure that the quality of materials derived during Qualification Testing are being maintained.

6.2 Samples

A sample batch shall consist of 15 standard cylinders.

3 cylinders shall be tested in compression without thermal cycling.

3 cylinders shall be tested after one cycle at low temperature.

3 cylinders shall be tested after 20 cycles of freezing/thawing.

6 cylinders shall be kept in reserve.

6.3 Frequency of Routine Control Testing

The frequency of control testing shall be to satisfy the most stringent of the following conditions:

1) Every three months.
2) Or each 5000 m^3 of concrete poured.
3) Or each change in concrete mix or constituents.

i.e. Cement	–	Origin and percentage
Water	–	Water origin, water/cement ratio
Admixtures Aggregates	–	Origin and percentage

6.4 Specification and Acceptance Criteria

6.4.1 Routine control testing relates only to:

1) Strength of concrete after one cycle to product temperature.

2) Strength of concrete after 20 cycles of freezing/thawing.

6.4.2 Specifications and acceptance criteria are identical to the requirements of Sections 2 and 3 above relating to Qualification Testing.

6.4.3 In the event of non-compliance with the acceptance criteria defined above CONTRACTOR shall immediately carry out additional investigations and propose suitable corrective measures which shall be agreed with OWNER.