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Design Analysis Cover Sheet

Complete only applicable items.

1. QA: L
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2. DESIGN ANALYSIS TITLE			
Heated Drift Cast-in-Place Concrete Lining Test Configuration Requirements Analysis			
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12. REMARKS

BLOCK 7: Originators areas of responsibility in this analysis are as follows:
Herold: Paragraphs 2, 3, 4.1, 4.2, 4.3, 4.4, 5, 6, 7.2, 7.3, 7.4,7.7.4, 7.7.5, 7.7.7, 7.7.8,7.7.10, 7.8, & 8.
Nolting: Paragraphs 1, 4.1, 4.2, 5, 7.1, 7.2, 7.5, 7.6.1, 7.6.2, 7.7, 7.7.1, 7.7.2, 7.7.3, 7.7.6, 7.7.9, & 8.

Editorial changes made on p. I.5 of I.7 and p. II.4 of II.7.
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4. Revision No.	**5. Description of Revision**
00	New analysis to develop rationale and basis for test data to be developed from the Heated Drift scale thermal test of a section of cast-in-place concrete tunnel lining.
01	P. 16. Added note describing A/E approval required for application of tests or variations from ASTM C94, Annex A1 or ASTM C685, Annex A1. P. 19. Changed sample requirements for aggregates and timing of petrographic test results. P. 26. Changed Par 8.5.6 to read "All laboratory testing will be performed under an approved QA program."

1. PURPOSE

The purpose of this analysis is to (1) identify the objectives of the cast-in-place (CIP) concrete lining drift scale thermal test in the heated drift portion of the Thermal Testing Facility Alcove; (2) describe the configuration for the heated drift and CIP concrete lining test component; (3) describe the basic features and requirements for the CIP lining concrete mix; (4) identify the materials to be tested, the testing conditions, and tests/measurements required for the lining thermal test; and (5) provide a basis for the selection of critical lining construction and configuration requirements/ controls. The critical requirements/controls are those aspects of the lining construction and configuration that will require construction QA controls to assure that the test results can be qualified for use as design input for analyses of repository emplacement drift concrete lining systems.

2. QUALITY ASSURANCE

The CIP concrete lining in the Thermal Testing Facility Alcove is not being designed as a permanent item. It is a temporary thermal test component, and is not being installed to provide ground support in the heated drift. Therefore, the lining is not subject to QA classification in accordance with QAP-2-3. [Note: As permanent items with no repository function, the heated drift and the ground support (i.e., rock bolts and mesh) in the drift have both been determined to be conventional quality in accordance with QAP-2-3].

This analysis will be used to establish requirements for the CIP concrete lining in order to assure proper conditions for collection of test results which may be used as input to the design of the repository ground support, a potentially Q-listed item. Since these requirements are associated with the development of design inputs for a potentially Q-listed item, these requirements, and this analysis used to develop them, are subject to QARD requirements in accordance with QAP-2-0.

Construction and operation (i.e., thermal testing) of the CIP concrete lining will also be subject to QARD requirements as indicated in any applicable DIE(s). However, these DIE requirements are not allocated through this analysis. The DIE controls for the drift scale thermal test will be implemented through the test implementing documents (currently under development) in accordance with NLP-2-0, and DIE controls for CIP lining construction will be implemented by reference to Specification Section 01501 (Ref. 5.17) on the lining construction drawings.

3. METHOD

A rational descriptive method is used in this analysis. There are no numerical calculations or analytical results included.

4. DESIGN INPUTS

4.1 Design Parameters

The following design parameters and inputs are used in this analysis:

4.1.1 Heated drift maximum rock wall test temperatures will be in the range of 200° to 300° C based on temperature gradient profiles furnished with Ref. 5.1.

4.1.2 The finished inside diameter of the CIP lining will be a minimum of 5.0 meters in diameter (Ref. 5.4).

4.2 Criteria

The following criteria are considered applicable to the in situ thermal testing of a CIP concrete lining during the ESF drift scale thermal test located in the heated drift portion of the Thermal Testing Facility. These criteria are taken from the Exploratory Studies Facility Design Requirements Document (ESFDR, Ref. 5.6) and from Test Coordination Office (TCO) criteria memoranda (Refs. 5.2 and 5.3).

Data to assist in meeting the identified criteria will be provided by heating the drift to temperatures in the range from 200° to 300° C, by performing a full-scale concrete lining test; by monitoring the test section for temperatures, strains, and deformations; by visually observing the lining throughout the duration of the test; and by performing mechanical property tests on the lining material both before and after the drift scale thermal test.

4.2.1 <u>Coordination with Repository Design:</u> The design, construction and in situ testing of the heated drift CIP concrete lining will be planned and coordinated with the repository design. This has been accomplished by applying the applicable requirements of the ESFDR as noted below, and by following the emplacement lining design concepts currently under development. [ESFDR, 3.7.2.1.2.B]

4.2.2 <u>Coordination with TCO:</u> The CIP concrete lining can be installed only after mapping (see 4.2.6, below) and other observations by Scientific Programs personnel have been completed. To assure this requirement is addressed, the Constructor will coordinate with the ESF TCO prior to installation of the lining. [Ref. 5.3]

4.2.3 <u>Test Constraints:</u> Test areas will be separated so that they are not affected by the excavation disturbed zone and any thermal, chemical, and hydrological interactions. This has been accomplished by locating the heated drift well away from other test areas and from the TS Main Drift of the ESF in a side extension of the Thermal Testing Facility Alcove. [ESFDR, 3.2.1.1.4.A]

4.2.4 <u>Survey Accuracy:</u> Survey accuracy for survey and mapping will be (±) two centimeters horizontally and vertically. This (or a more restrictive) requirement will be applied to the survey of the as-excavated surface in the heated drift, to the inside surface of the lining, and to the lining thickness. [ESFDR, B.13.3H]

4.2.5 Instrumentation: The Constructor will coordinate and assist the TCO in the placement and protection of instrumentation in and on the CIP concrete lining. This requirement will be passed on to the Constructor through the work implementing documents. [Ref. 5.2].

4.2.6 Mapping: Mapping, including profiling of the excavated opening, will be performed prior to placement of the CIP lining to permit coordination and correlation with CIP lining displacement and closure measurements during the drift scale thermal test (see 4.2.2, above). [ESFDR, Appendix B, Section B.13]

Although the drift scale test (and this analysis) will not directly address criteria from the Repository Design Requirements Document (RDRD, Ref. 5.18), and the Engineered Barrier Design Requirements Document (EBDRD, Ref. 5.19), selected results from the test may be used as input to future repository analyses which will meet the applicable criteria in those documents. Use of the test results in future analyses will occur only after further evaluation as to the applicability of those results.

4.3 Assumptions

There are no assumptions in this analysis.

4.4 Codes and Standards

4.4.1 American Concrete Institute (ACI):

ACI 117-90	Standard Specification for Tolerances for Concrete Construction and Materials
ACI 211.1-91	Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete
ACI 301-89	Specifications for Structural Concrete for Buildings
ACI 318-95	Building Code Requirements for Structural Concrete
ACI 347R-89	Guide to Formwork for Concrete
ACI 544.2R-89	Measurement of Properties of Fiber Reinforced Concrete
ACI 544.3R-89	Guide for Specifying, Mixing, Placing, and Finishing Steel Fiber Reinforced Concrete

ACI 544.4R-88	Design Considerations for Steel Fiber Reinforced Concrete

4.4.2 American Society for Testing and Materials (ASTM):

ASTM A820-90	Standard Specification for Steel Fibers for Fiber Reinforced Concrete
ASTM C31-91	Standard Practice for Making and Curing Concrete Test Specimens in the Field
ASTM C33-90	Standard Specification for Concrete Aggregates
ASTM C39-86	Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
ASTM C42-94	Standard Test Method for Obtaining and Testing Cores and Sawed Beams of Concrete
ASTM C94-92	Standard Specification for Ready-Mixed Concrete
ASTM C109-92	Standard Test Method for Compressive Strength of Hydraulic Cement Mortars
ASTM C143-90a	Standard Test Method for Slump of Hydraulic Cement Concrete
ASTM C150-92	Standard Specification for Portland Cement
ASTM C172-90	Standard Practice for Sampling Freshly Mixed Concrete
ASTM C231-91b	Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method
ASTM C469-94	Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression
ASTM C496-96	Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens

ASTM C512-87(92)	Standard Test Method for Creep of Concrete in Compression
ASTM C685-95a	Standard Specification for Concrete Made by Volumetric Batching and Continuous Mixing
ASTM C939-94a	Standard Test Method for Flow of Grout for Preplaced Aggregate Concrete (Flow Cone Method)
ASTM C995-94	Standard Test Method for Time of Flow of Fiber-Reinforced Concrete Through Inverted Slump Cone
ASTM C1018-94b	Standard Test Method for Flexural Toughness and First-Crack Strength of Fiber-Reinforced Concrete (Using Beam with Third-Point Loading)
ASTM C1064-86	Test Method for Temperature of Freshly-Mixed Portland Cement concrete
ASTM C1116-95	Standard Specification for Fiber Reinforced Concrete and Shotcrete
ASTM C1240-95	Standard Specification for Silica Fume for Use in Hydraulic-Cement Concrete and Mortar
ASTM D75-87	Standard Practice for Sampling Aggregates

4.4.3 U.S. Department of the Interior, Bureau of Reclamation (USBR):

USBR 4910-89	Procedure for Coefficient of Thermal Expansion of Concrete

5. REFERENCES

5.1 *Transmittal of Temperature Gradient Profiles for Design and Construction of the Exploratory Studies Facility Thermal Testing Facility Drift Scale Test*; Transmittal Memorandum No. LA-EES-13-LV-07-96-028; J. Hollins/ LANL to A. Segrest/CRWMS M&O; July 26, 1996.

5.2 *Transmittal of Design and Test-Related Information for the Placement and Protection of Instrumentation in and on the Cast-in-Place Lining*; Transmittal Memorandum No. LA-ESS-13-LV-11-96-044; J. Hollins/ LANL to A. Segrest/CRWMS M&O; November 25, 1996.

5.3 *Transmittal of Design and Test-Related Information for Design and Construction of the Exploratory Studies Facility Thermal Testing Facility Connecting Drift and Heated Drift*; Transmittal Memorandum No. LA-ESS-13-LV-06-96-005; J. Hollins/LANL to A. Segrest/CRWMS M&O; June 5, 1996.

5.4 *Transmittal of Updated Design and Test-Related Information for Design and Construction of the Thermal Testing Facility Heated Drift*; Transmittal Memorandum No. LA-EES-13-LV-09-96-028; J. Hollins/ LANL to A. Segrest/CRWMS M&O; September 17, 1996.

5.5 Not Used.

5.6 *Exploratory Studies Facility Design Requirements* (ESFDR), YMP/CM-0019, Rev. 02.

5.7 *Mined Geologic Disposal System Advanced Conceptual Design Report* (ACD); B000000-01717-5705-00027, Rev. 00.

5.8 Not Used

5.9 Not Used

5.10 *TS Main Drift Thermal Testing Facility Alcove Plan,* Sheet 1 of 3, DI:BABEAF000-01717-2100-40230, Rev. 01.

5.11 *TS Main Drift Thermal Testing Facility Alcove Sections,* Sheet 3 of 3, DI:BABEAF000-01717-2100-40250, Rev. 00.

5.12 *Yucca Mountain Project Repository Design Consulting Board Report No. 1*; S.H. Bartholomew, R.E. Heuer, J.K. Lemley, and L. Snyder; 36 Pages; August 21, 1996.

5.13 *Segmental Tunnel Linings, Steel Fibre Reinforced Concrete Segments*, World Tunneling Magazine, pp. 38-39, February 1996.

5.14 *Cast-in-Place Concrete, Subsurface,* Specification Section DI:BAB000000-01717-6300-03301, Rev. 00.

5.15 *Constructor Quality Control/Quality Assurance*, Specification Section DI:BAB000000-01717-6300-01400, Rev. 02.

5.16 *Material and Equipment*, Specification Section DI:BAB000000-01717-6300-01600, Rev. 02.

5.17 *Subsurface General Construction,* Specification Section DI:BAB000000-01717-6300-01501, Rev. 04.

5.18 *Repository Design Requirements Document* (RDRD), YMP/CM-0023 REV 0, ICN 01.

5.19 *Engineered Barrier Design Requirements Document* (EBDRD), YMP/CM-0024, Rev. 00, ICN 1.

5.20 *Submittals,* Specification Section BAB000000-01717-6300-01300, Rev. 01.

5.21 *Concrete Formwork - Subsurface,* Specification Section BAB000000-01717-6300-03101, Rev. 00.

6. USE OF COMPUTER SOFTWARE

Not Used

7. DESIGN ANALYSIS

7.1 Introduction

The following sections provide the test objectives developed by the repository design organization for the planned Exploratory Studies Facility (ESF) drift scale thermal test of the CIP concrete lining located in the heated drift portion of the Thermal Testing Facility Alcove. Following the listing of test objectives, subsequent sections provide a brief discussion of how each objective was developed and how it will be achieved. The overall scope of the drift scale thermal test of the CIP concrete lining is to provide information that will be used for analyses of concrete linings for repository emplacement drifts, and for waste package concept evaluations and assessment of lining performance.

7.2 Test Objectives

For repository design, data from the drift scale thermal test are expected to provide the following (paragraph numbers in parentheses identify where in the body of this analysis each test objective is addressed):

7.2.1 Development of a higher level of confidence in the thermomechanical modeling approach for repository analysis (Paragraphs 7.7.3 and 7.7.9),

7.2.2 An advance in the understanding of the interaction between a cast-in-place concrete lining and the rock mass under thermal loading conditions (Paragraphs 7.7.1, 7.7.2, 7.7.6, and 7.7.7), 7.2.3 An evaluation of the qualitative performance of a concrete lining subjected to high temperatures (Paragraphs 7.7.2, 7.7.3, 7.7.6, and 7.7.7),

7.2.4 A quantitative estimate of initial concrete mechanical properties prior to exposure to the high test temperatures (Paragraph 7.7.4),

7.2.5 Numerical data that will be used to confirm or modify analytical models used to predict lining behavior under thermal load conditions (Paragraphs 7.7.7 and 7.7.9),

7.2.6 A suite of (spare) test specimens that may be tested to confirm empirical expressions used in predicting long-term mechanical degradation effects on site specific concrete exposed to high temperatures (Paragraph 7.7.4), and

7.2.7 An estimate of concrete mechanical properties after exposure to the high test temperatures. This will be accomplished by removing (core drilling and cutting) samples from the concrete lining after completion of the thermal testing and cool-down of the drift and/or performing additional laboratory tests on the suite of specimens noted in Paragraph 7.2.6, above (Paragraphs 7.7.4 and 7.7.10).

7.3 Drift & Lining Configuration

The ESF drift scale thermal test will be conducted in a horizontal, approximately 47.5 meter long drift (see Attachment I, Fig. 1) located at the end of the Thermal Testing Facility Alcove (Refs. 5.10 & 5.11). From a bulkhead at the near end of the test drift, the first 33.0 meters of the drift: will be circular in cross-section with a diameter of 5.0 meters, will be used principally for hydrological monitoring, will be unlined, and will be supported by rock bolts and wire mesh. After an approximate two meter long transition section, the last 12.5 meters of the heated drift will be excavated to a minimum diameter of 5.6 meters, will be stabilized with rock bolt/wire mesh supports, and will then be lined with a CIP concrete lining (see 7.3.3, below). The outside diameter of the heated drift section was selected to provide a nominal 5.2 meter inside diameter of the lined section based on a nominal (minimum) lining thickness of 200 mm. This inside diameter represents the currently proposed (approximate) configuration of a typical emplacement drift.

7.3.1 Excavated Profile: It is expected that the drift will be excavated to a rough circular shape by a road header and/or by use of drill-and-blast techniques. If excavation is by road header, controlled drill-and-blast may be necessary to shape the invert. As a result of these techniques, the cross section will be irregular and unlike that of a smooth circular TBM-excavated drift. Profile irregularities due to mechanical or drill and blast excavation methods are acceptable. The thickness of the lining will depend on the excavated profile, and will, therefore, not be of uniform thickness (See Refs. 5.10 and 5.11).

7.3.2 Initial Support: Ground support components, namely rock bolts (ungrouted friction bolts) and welded wire fabric (WWF), will be installed in the heated drift. These components will be installed for the full length of the test drift for worker safety and for rock stabilization.

7.3.3 Lining: In the case of the CIP concrete lining, installation will be similar in the test configuration to that of a CIP concrete lining in the repository design. In the heated drift, the erection of the forms for the lining will not occur until after completion of mapping (Criteria 4.2.6). The CIP concrete lining configuration will be as follows (See Attachment I, Figures 1 through 6):

- Diameter: The diameter of repository emplacement drifts is expected to be in the range of 5.0 to 5.5 meters (Ref. 5.12). Repository analyses currently in progress are using a drift diameter of 5.5 meters. It is expected that the results of further repository analyses will be within this range of values. The selection of 5.6 meters as the as-excavated diameter of the heated drift is consistent with the high end of the range of diameters being considered for the emplacement drifts. This excavated diameter, combined with a nominal wall thickness of 200 millimeters (see below), equates to a nominal lining inside diameter of 5.2 meters which is also consistent with expected repository emplacement configurations (Ref. 5.7).

- Length: The 12.35 meter (nominal) length of the concrete-lined section of the heated drift was chosen to be at least twice the outside diameter of the heated drift to provide a sufficiently long and uniform section for ease of monitoring and to minimize possible end effects, e.g., stress gradients due to the transition from a lined to an unlined rock surface. This length, being nominally 0.15 meters less than the 12.5 meter length of the 5.6 meter diameter section of the drift, allows for construction forming access at the near end of the lining.

- Lining Thickness: A CIP concrete lining with a concrete compressive strength of 34.47 MPa (5000 psi) and a thickness of 150 mm was analyzed for excavation, thermally-induced, and seismic loads in the ACD Report (Ref. 5.7, Table B-10) and was shown to be close to the limiting compressive strength. A somewhat thicker lining of 200 mm has been chosen for the thermal test to provide a greater margin of safety for subsequent analyses which are currently in progress. In addition, the nominal 200 millimeter lining thickness will be compatible with current, in-process repository design efforts. The adequacy of this selected thickness will be confirmed on completion of the thermal test and evaluation of data.

- SFRC Lining Section: A steel fiber reinforced concrete (SFRC) section of lining approximately 4.12 meters long and located at the bulkhead end of the lined section was selected to provide some information on this material for possible use in the repository. The length selected represents approximately 1/3 of the total lining length or slightly less than one drift diameter. The location of the section will assure that the SFRC concrete section is exposed to the highest test temperatures (Ref. 5.1).

The selection of the type (ASTM A820, Type 1, deformed with aspect ratio less than 100) and amount (nominally 0.5% by volume) of steel fibers to be used in a trial mix was based on the recommendations contained in ACI 544.4R (see Attachment II). The amount of fiber was selected at the low end of the range recommended by ACI 544.4R (0.5% to 1.5%) so that a minimum amount of fiber would be used. These parameters were also consistent with current industry practice as evidenced by Ref. 5.13, which used SFRC precast tunnel lining segments with 0.4% of fibers by volume.

For the heated drift SFRC lining section, the fiber reinforced concrete will be: distributed in accordance with ASTM C1116; conveyed, placed, and consolidated in accordance ACI 301, Chapter 8, Specification Section 03301 (Ref. 5.14), and ACI 544.3R; and selected properties measured in accordance with the applicable ASTM standards of Paragraph 7.7.4 (supplemented by ACI 544.2R recommendations).

- Construction Tolerances: Construction tolerances for the heated drift lining will be based on current nationally recognized concrete construction practices as identified in ACI 117 for the concrete lining, and ACI 347R for the forming system (modified to suit field conditions). ACI 347R refers to ACI 117 for construction tolerances; therefore, using ACI 117, Chapter 4 as a basis, the tolerances that will be applied to the lining are summarized as follows:

  (±) 25 mm (1 inch) for vertical and horizontal alignment,

  (±) 19 mm (3/4 inch) for levelness,

  (±) 10 mm (3/8 inch) for cross-sectional dimensions less than 300 mm (12 inches),

  (±) 13 mm (½ inch) for cross-sectional dimensions greater than 300 mm (12 inches), but less than 1 meter (3.28 feet),

  (±) 25 mm (1 inch) for cross-sectional dimensions greater than 1 meter (3.28 feet),

  (±) 10 mm in 3 meters (3/8 inch in 10 feet) for slopes, and

(±) 13 mm (½ inch) for Class C form offsets.

- Bleeder Holes: Small diameter bleeder holes will be placed in the lining (to be identified in the test implementing documents), to control the release of water that may be trapped behind the lining during the heat-up phase of the thermal test. These holes will consist of a circumferential pattern of approximately eight, evenly spaced holes that penetrate the entire thickness of the lining with each pattern repeated at a nominal one meter spacing along the lining length. Because of the small diameter of these holes and the relatively large spacing between holes, their presence should not affect the results of the CIP lining thermal test.

7.3.4 Construction Joints: The need for joints, for either construction or for thermal expansion, in a concrete lining for repository use has not been established. Therefore, there is no requirement for joints in the concrete lining installed for testing. However, a transverse construction joint will be needed between the section of steel fiber reinforced concrete and the section of plain concrete. This joint should be smooth (no key) to avoid differential interaction between the two types of material. Although none are anticipated, other transverse and/or longitudinal construction joints may be provided by the Constructor to facilitate placement of the lining (optional joint in Figures 2 and 3 of Attachment I, detailed in Figure 5). Keying of these joints is recommended to ensure that the adjacent sections of the plain (unreinforced) concrete lining will react monolithically thus avoiding unwanted differential movement.

7.3.5 Cover: A minimum cover of 75 mm will be provided over the ground support rock bolts and wire mesh unless otherwise approved by the A/E. This depth of cover is conservatively consistent with ACI 318 recommendations for concrete cover over reinforcing steel, and will encapsulate these items within the lining wall. By necessity, this requirement will not apply to form support pins and standoffs if they are left in place after placement of the concrete and removal of the forms. These form support components should have little or no effect on the lining thermal test results.

7.3.6 Contact Grouting: Voids between the lining and the rock surface caused by the non-uniform excavation, shrinkage, and concrete placement restrictions need to be minimized to ensure firm contact between the lining and the rock. Therefore, contact grouting of voids in the crown will be required, and will assure positive lining/rock contact in the crown to the extent practical. In the case of large fallout of material from the tunnel crown, alternate means, other than contact grouting, may be required to fill these larger voids. On completion of contact grouting, if there is inadequate grout return or other evidence of incomplete void filling, then core drilling, and as-built measurement of crown thickness may be performed to confirm the extent of void filling and to verify lining thickness. The performance requirements for contact grouting deemed necessary to achieve the desired results are as follows:

- Cement will conform to ASTM C150, Type II and sand aggregates will conform to ASTM C33 to be compatible with the materials used in the mix for the concrete used in the lining.

- Admixtures, consisting of water soluble non-chloride sodium silicates or aluminum silicates may be used at the Constructor's option if needed to improve flowability and penetration of the grout into the voids.

- Silica fume, conforming to ASTM C1240, may be added as an optional filler to the grout mix to reduce settling during injection of the grout.

- The grout should achieve a minimum compressive strength of 20.68 MPa (3000 psi) as determined by ASTM C109. This strength value is deemed adequate to transmit thermal rock loads to the lining and, although somewhat lower in strength, it is still consistent with the 34.47 MPa (5000 psi) compressive strength of the lining since the grout layer will transfer load in a confined compression state.

- The grout will be pumpable, which is indicated by the time of flow or "efflux time" as measured by ASTM C939. The efflux time at time of placement as measured in the field should be within 5 seconds of that for the approved mix design. This tolerance should be reasonably achievable as it is equivalent to approximately two times the predicted laboratory precision as identified in ASTM C939, Section 10.

- Candidate grouts which are considered adequate for the stated purpose of filling the voids are: cementitious grout with or without sodium silicate or aluminum silicate admixtures, and cement grout with sand or silica fume filler.

- Contact grouting will be performed only after the concrete has cured for a minimum of 7 days, and in such a manner that minimal pressure buildup occurs behind the liner (other than the self-weight of the fluid grout and low grouting pressure). This will assure that grouting pressures are low enough, and the concrete has gained sufficient strength to avoid damage to the liner.

- Any holes located or core-drilled in the lining to determine effectiveness of grouting, to measure lining thickness, or for any other purpose will be dry-packed with cementitious grout to provide a uniform, continuous surface and to mitigate local points of weakness.

- The Constructor will prepare a contact grouting work plan which addresses, as a minimum: grouting equipment proposed for use, grouting schedules, grout mix design, grouting methods, and a sketch of piping layouts.

7.3.7 Lining Placement: the Constructor will develop a lining placement plan which addresses the following items: conveying, placing, consolidating, curing, repairs, preventing form movement during placement, method for removal of slick line lubricating grout, plan for equipment failure, and other concrete placement topics as appropriate.

7.4 Concrete Mix Requirements:

7.4.1 Description: The repository concrete mix requirements for either precast segments or for CIP concrete has not been developed and will not be known at the time of the drift scale thermal test. For example, one portion (approximately 4.12 meters long) of the CIP concrete lining test section will contain steel fibers. It has not been determined to what extent steel fibers will be used for repository design. In addition, the type of aggregate to be used in repository concrete (tuff or sandstone/quartz) is yet to be determined. Although properties and behavior of the concrete lining will vary with the types and proportions of materials used, the general behavior of the CIP concrete lining is expected to be similar enough to the eventual repository formulation that the information obtained will fulfill the test objectives. The basic concrete mix requirements for the CIP lining are as follows:

- The 28 day target compressive strength will be 34.47 MPa (5000 psi) to be consistent with concrete formulations which have a successful history of use in the ESF, and with concrete strengths expected to be used in repository design. However, concrete strengths less than 27.58 MPa (4000 psi) will not be accepted

- Cement will conform to ASTM C150, Type II which is the same type that was used for the ESF concrete (Ref. 5.14).

- The mix will be pumpable which may require the addition of a high range water reducing (HRWR) agent.

- Coarse and fine aggregates will conform to ASTM C33. The coarse aggregate will be a maximum size of ½ inch (ASTM C33, Table 2, size 7) to enhance pumpability and flowability in the lining form.

- Slump of the mix as measured at the point of placement will be within plus 25.4 and minus 50.8 millimeters of the slump indicated on the approved mix design. In addition, slump of concrete using an HRWR agent will be between 152 and 203 millimeters (from Ref. 5.14).

- The mix need not be air entrained, unless needed to improve pumpability, since it will not be exposed to freeze-thaw cycles.

- Water reducing and silica fume admixtures may be added to the mix to improve water/cement ratio, strength, workability, pumpability, and durability.

- One mix will contain deformed steel fibers at a nominal content of 0.5% by volume (see Paragraph 7.3.3).

- Mix designs will be developed in accordance with ACI 211.1 (ACI 544.3R for SFRC), and ready-mixed concrete will comply with ASTM C94.

- Concrete mix designs and the results of mix compressive strength tests will be reviewed and approved by the A/E.

- Concrete will be conveyed and placed in accordance with ACI 301, Chapter 8 (from Ref. 5.14) and ACI 544.3R for SFRC.

- Concrete, at the time of delivery to the pump hopper, will have a satisfactory degree of uniformity as determined by ASTM C94, Annex A1 for plain concrete or ASTM C685, Annex A1 for SFRC. Required application of uniformity tests, and variation from parameters as given in ASTM C94, Annex A1 or ASTM C685, Annex A1, shall be reviewed and approved by A/E.

- Temperature of the concrete at time of placement will be within the range of from 10° to 32° C based on ACI 301, Table 7.6.1.1 and ASTM C94, Section 11.8.

- Certified material test reports (CMTRs) and/or certificates of compliance (C of Cs) will be provided for: cement, steel fiber reinforcement, aggregates, and admixtures.

- The concrete for use in the heated drift CIP concrete lining will be produced in compliance with the applicable requirements (with modifications as noted above) contained in Specification Section 03301 (Ref. 5.14). This will provide a concrete mix compatible with that used in the ESF which, although not exposed to high temperatures, has a successful history of performance, and will be similar to concrete formulations currently under consideration for use in the repository.

7.5 Ground Support Materials to be Tested

7.5.1 Ground Support Systems: Three types of support systems; (1) expanded precast concrete segments, (2) cast-in-place (CIP) concrete, and (3) structural steel sets with steel lagging, are being considered for use as repository emplacement drift ground support. However, it has been determined, and supported by a recommendation from the Repository Design Consulting Board (Ref. 5.12), that CIP concrete will be the only support system tested in the heated drift.

7.5.2 CIP Lining: As previously stated, the CIP lining will be unreinforced except for a section approximately 4.12 meters long which will contain steel fibers. This will allow for a comparative evaluation of a reinforcing material that is being considered for use in the repository design to mitigate cracking and spalling, improve resistance to handling impact forces, improve surface tensile characteristics, and increase the durability of repository concrete. Although the CIP lining will not be subjected to long-term rock loads, it will provide a limiting case (Ref. 5.12) for a preliminary analysis of repository lining thermal loads which are expected to be the dominant load on the lining (Ref. 5.7).

7.6 Testing Conditions and Durations

7.6.1 Heat Source/Duration: In-drift heaters, the approximate size of repository waste packages, are currently being designed to be placed along the centerline of the heated drift. Their operating power will be sufficient to heat the drift to the desired temperatures. "Wall heaters" will be installed in horizontal boreholes to provide additional heating power to more quickly elevate the temperature of the large mass of rock (see Ref. 5.3). The open end of the heated drift will be equipped with an insulated thermal bulkhead with access openings as required. The duration of heating is estimated to be at least 2 years at full power. The remainder of the test time will depend on a decision as to whether heating should be continued or whether a cooling phase should begin. The drift heaters and thermal bulkhead configurations are conceptually shown in Attachment I, Figure 1.

7.6.2 Heating Rates/Temperatures: In order to heat a significant volume of rock around the test drift to repository temperature levels, the rates of heating in the test drift will be several times higher than predicted repository heating rates due to the relatively short duration of the test. Concrete behavior may be a function of the rate of heating and/or cooling, as well as the magnitude of the maximum temperature. These relationships are not known at this time, and future additional testing beyond the scope of the heated drift scale thermal test may be required. In addition, temperature monitoring and remote visual observation of the concrete are planned to aid in understanding these effects. A goal for rate of heating will be to achieve, within two years, test drift wall rock temperatures in the range of from 200° to 300° C, which should approximate the limiting temperature of the wall rock of a repository emplacement drift (Ref. 5.1). If heating is continued beyond two years, the heater power may be decreased to stabilize the drift wall temperatures to within the acceptable range.

7.7 Tests and Measurements

Tests that provide repository design-related information on the installed ground support test component (CIP concrete lining) are listed below, along with the purpose of each test. Especially challenging are the high-temperature environment and limited access to this test, which will require robust instrumentation, remote monitoring, and redundant measurements and instrumentation to ensure successful data acquisition.

7.7.1 Lining Displacement: Measurements of lining displacement or closure will be made. Measured values will provide valuable data on interaction effects between the rock and a concrete lining. This test activity will aid in satisfying the test objective of Paragraph 7.2.2

7.7.2 Convergence/Strain Monitoring: Convergence measurements of the CIP concrete lining will be required. The purpose of these measurements is to determine the manner in which the drift/lining deforms in response to loading (primarily thermal loading). Measurement points will be located on the inside surface of the CIP concrete lining, and results will include deformation of the concrete structure acting together with the rock mass. Strain gauge monitoring will supplement rock mass displacements as well as rock and lining convergence measurements, and will provide information on lining deformation with time and temperature. This strain gauge monitoring will measure internal concrete strain, and will provide information on the magnitude and distribution of thermally-induced deformation. Specific details of these testing activities will be defined in the test implementing documents, based on continuing discussions between the TCO and the repository design organization, and may be subject to field modifications depending on conditions encountered. These testing activities will aid in satisfying the test objectives of Paragraph 7.2.2 and 7.2.3.

7.7.3 Observation of Concrete Lining: Remote (video camera) visual examination of the concrete lining will detect changes that may occur during the test as an aid in understanding the lining behavior. This will also be the first indication of differences (if any) between the behavior of the unreinforced lining section and the SFRC lining section. The frequency of observation will be relatively high during initial stages of testing, but will be reduced further along into the test unless observable anomalies (cracking, spalling, etc.) begin to appear. Details of remote observation will be defined in the test implementing documents, based on continuing discussions between the TCO and the repository design organization, and may be subject to field modifications depending on conditions encountered. This test activity will aid in satisfying the test objectives of Paragraphs 7.2.1 and 7.2.3.

7.7.4 Laboratory Materials Testing: Laboratory tests will be conducted on concrete cores and cast specimens of lining concrete before and after heating using a qualified testing laboratory that has an approved QA program. Tests will be done to determine compressive strength, modulus of elasticity, Poisson's ratio, split cylinder tensile strength, flexural toughness and first-crack strength of SFRC, and coefficient of thermal expansion (optional, based on laboratory availability, may be deferred to future testing). All of these tests have been identified as necessary to provide important physical concrete parameters for use in future analyses. In addition, creep specimens may be tested to determine complete, long term creep behavior of the concrete (may also be deferred to future testing). These tests are necessary for accurate characterization of the particular concrete mix to be placed and monitored, and to provide data on important physical properties of the concrete which will be used in future analytical models.

These tests will be performed on: specimens taken at the time of concrete placement and cured for 28 days, spare specimens stored in the heated drift during the thermal test, spare or laboratory molded specimens tested under laboratory conditions that simulate the heated drift thermal test temperatures, and/or cored and sawed specimens removed from the concrete lining after completion of the drift scale thermal test (it is anticipated that there will be no entry into the heated drift at any time for the duration of the thermal test). Tests of SFRC will be modified as recommended by ACI 544.2R. All samples of fresh concrete will be taken as near to the point of placement as practical in accordance with ASTM C172 unless otherwise noted. These testing activities will aid in satisfying the test objectives of Paragraphs 7.2.4, 7.2.6, and 7.2.7, and are summarized as follows:

- Sampling/Testing Plan: The Constructor will prepare a sampling and testing plan that addresses all aspects of the following testing program requirements, and will submit it to the A/E for review and approval.

- Aggregates: Aggregates will be sampled in accordance with ASTM D75, and tested for compliance with ASTM C33 for gradation, fineness modules, unit weight, organic impurities, soundness, alkali reactivity, abrasion, and petrographic properties unless otherwise approved by the A/E. Quantity of samples may vary with A/E prior approval of Constructor's Sampling Plan. Petrographic properties tests are required for future test information purposes only and are not required at the time of aggregate use.

- Compressive Strength: From the samples of fresh concrete, a minimum of 5 specimens (cylinders) will be molded and standard cured for each 5 cubic meters placed in accordance with ASTM C31. Three specimens from each set of 5 specimens will be tested in accordance with ASTM C39 for a minimum 28-day compressive strength of 34.47 MPa (5000 psi). This strength is compatible with existing mixes used in the ESF construction and is anticipated to be adequate for repository construction. A minimum of 8 core drilled specimens (plus 4 of the SFRC) will be tested in accordance with ASTM C42, unless directed otherwise by the A/E. The core drilled specimens will be obtained from the cores drilled for wing heater holes located in the lined section of the drift. In addition, molded specimens may be tested at younger ages for determination of form removal time (average of 2 tests as a minimum).

- Modulus of Elasticity and Poisson's Ratio: From the samples of fresh concrete, a minimum of 3 specimens will be molded and standard cured for each 5 cubic meters placed in accordance with ASTM C31. Two specimens from each set of 3 specimens will be tested at an age of 28-days for modulus of elasticity and Poisson's ratio in accordance with ASTM C469. In addition, undamaged specimens used for modulus of elasticity/ Poisson's ratio tests may also be saved for later compressive strength testing.

- Tensile Strength: From the samples of fresh concrete, a minimum of 4 specimens will be molded and standard cured for each 5 cubic meters placed in accordance with ASTM C31. Two specimens from each set of 4 specimens will be tested at an age of 28-days for split cylinder tensile strength in accordance with ASTM C496.

- Flexural Toughness and First-Crack Strength (SFRC only): From the samples of fresh concrete, a minimum of 3 specimens will be molded and standard cured for each 5 cubic meters placed in accordance with ASTM C31. One specimen from each set of 3 specimens will be tested at an age of 28-days for flexural toughness and first-crack strength in accordance with ASTM C1018.

- Coefficient of Thermal Expansion: From the samples of fresh concrete, a minimum of 4 specimens will be molded and standard cured for each 5 cubic meters placed in accordance with USBR 4910. These specimens may be tested at a later date for coefficient of thermal expansion in accordance with USBR 4910.

- Creep: From the samples of fresh concrete, a minimum of 3 specimens will be fabricated and standard cured for each 5 cubic meters placed in accordance with ASTM C512. These specimens may be tested at a later date for complete, long-term creep behavior in accordance with ASTM C512.

- Spare Specimens: Specimens that have not been tested by 28-days of age will be considered spare specimens, and will be placed in storage and protected from damage for possible future testing. These specimens may be exposed to long-term high temperatures at some future date, either in the laboratory or in the heated drift, if adequate storage space exists, and then tested for those important physical properties noted above.

- Quantity of specimens molded and/or tested may vary with A/E approval of the Constructor's sampling plan.

7.7.5 Field Testing: Selected concrete properties will be measured in the field at time of placement and as close to the point of placement as practical. These tests are:

- Slump: Test for slump at the delivery truck or at the pump hopper in accordance with ASTM C143. Additional slump tests may be made any time there is a variation in consistency.

- Entrained Air: Test for entrained air at the pump hopper in accordance with ASTM C231.

- Temperature: Test for temperature of fresh concrete at time of placement in accordance with ASTM C1064.

- Time of Flow (SFRC): Test for time of flow of SFRC at the pump hopper in accordance with ASTM C995. If a HRWR agent is used in the mix, this test is not required as noted in ACI 544.2R.

- Time of Flow (Grout): Test for time of flow (efflux time) of cementitious grout at time of placement in accordance with ASTM C939.

7.7.6 Temperature Measurement: Temperature measurements will be required. Rock mass temperature, drift wall temperature, and drift air temperature measurements are needed at various locations and times. Interpretation of displacement instrumentation depends on accurate temperature monitoring. Maximum temperatures and heat-up rates are also key information to be derived from the test. Measured lining temperatures will provide data for confirming or adjusting values of rock and/or concrete thermal properties. Specific locations for temperature measurements will be defined in the test implementing documentation, and will provide a sufficient amount of data to spatially define the temperature profile of the lining and of the heated drift. This test activity will aid in satisfying the test objectives of Paragraphs 7.2.2 and 7.2.3.

7.7.7 As-Built Measurements: The CIP lining geometry is based on preliminary evaluations, and is used only for the drift scale thermal test configuration design. However, the as-installed lining configuration needs to be known and documented to properly evaluate the test results and to aid in satisfying the test objectives of Paragraphs 7.2.2, 7.2.3, and 7.2.5. Therefore, the lining thickness and cross-sectional shape will be as-built measured and documented. The cross-sectional (perpendicular to the drift centerline) excavated shape of the drift and the final inside diameter of the CIP concrete lining will be surveyed. The accuracy of this survey will be in accordance with Criteria 4.2.4. With these data, the actual lining thickness can be determined. Measurement of the actual thickness of the lining at all locations may also be needed after completion of contact grouting.

7.7.8 Concrete Documentation: The type of cement, aggregate, admixtures, characteristics of steel fiber reinforcement, physical properties (see 7.7.4, above) and type/strength of grout used for contact grouting will be documented on material test reports or certificates of compliance. In addition, test specimens, both cast and cored, will be marked and documented (Paragraph 7.8.2) according to established project procedures.

7.7.9 Comparison of Results: After completion of the test and compilation of the test data, both qualitative and quantitative test results will be compared to analytical models of the rock/lining system. The models and analytical techniques will be adjusted, based on the test results, to provide a correlation between predicted and actual lining behavior. This activity will aid in satisfying the test objectives of Paragraph 7.2.1 and 7.2.5.

7.7.10 Post Thermal Test Concrete Testing: In addition to molded test specimens which may be placed in the heated drift during the thermal test, sawed and cored specimens of the lining will be taken after completion of the drift scale thermal test, and these samples will be tested for the same mechanical properties as were initially tested (Paragraph 7.7.4). Molded specimens exposed to (unheated) ambient tunnel conditions may also be tested and used as a control group. These testing activities will aid in satisfying the test objective of Paragraph 7.2.7.

7.8 Construction Requirements to Support Test Objectives

Information derived from the drift scale thermal test of the CIP concrete lining will be used to plan and evaluate future emplacement drift concrete lining systems. Therefore, selected aspects of the construction of the CIP lining will require more stringent controls than those normally applied to non-Q items in order to consider the data derived from the tests as "qualified data". The following aspects define as-built dimensions and properties of the CIP concrete lining, are critical to understanding and correctly interpreting the data, and identify those construction activities that will require QA controls:

7.8.1 As-Built Configurations:

The following qualified surveys will be performed by the Surveyor of Record (Ref. 5.16, Paragraph 3.01G), and may be supplemented by the TCO's surveying/mapping activities:

- Survey of the as-excavated rock surface profile (including ground support components) of that portion of the heated drift to be lined. Profiling techniques, stationing and frequency of survey points will be field determined based on the extent of drift profile irregularities encountered. Survey accuracy will be to within (±) 20 millimeters in accordance with Criteria 4.2.4.

- Survey of the inside diameter of the CIP concrete lining. Survey accuracy will also be to within (±) 20 millimeters in accordance with Criteria 4.2.4.

The following measurement will be performed by the Constructor's QC organization if incomplete void filling is evidenced (as determined by the A/E):

- Measure the thickness of the CIP concrete lining and the grout at the crown after completion of contact grouting and at all bore hole locations by measurement of core sample lengths or hole depths.

7.8.2 Concrete Sampling/Testing:

- Sampling, molding, curing, and field testing (Paragraph 7.7.5) of concrete test specimens will be by certified concrete technician(s) using an approved QA program.

- Sampling of fresh concrete will be taken on delivery of each batch as close to point of placement as practical.

- Testing of the concrete specimens for compressive strength, split cylinder tensile strength, modulus of elasticity, Poisson's ratio, flexural toughness/ first-crack strength, and possibly coefficient of thermal expansion and creep behavior will be performed by a qualified testing laboratory that has an approved QA program.

- Molding and curing of test specimens will be in accordance with applicable ASTM standards as referenced in Paragraph 7.7.4, above.

- Testing of specimens will be in accordance with applicable ASTM standards as referenced in Paragraph 7.7.4, above.

- Spare concrete test specimens will be handled and stored to protect them from damage in accordance with established applicable procedures for protection of quality affecting items.

- Concrete test specimens will be permanently marked with a unique specimen identification number traceable to, as a minimum, the truck delivery number, date of placement, location of placement in the lining, molding standard used, and test standard to be used.

7.9 Miscellaneous Additional Construction Controls

Applicable requirements of the following specification sections (as supplemented by this analysis), including the applicable QA controls contained therein, will be used to control selected aspects of the lining construction:

- Submittals will be in accordance with Specification Section 01300 (Ref. 5.20).
- The Constructor's QA/QC program will comply with the applicable requirements of Specification Section 01400 (Ref. 5.15).
- Packing, shipping, delivery, receipt, handling, storage and protection of materials will comply with the applicable requirements of Specification Section 01600 (Ref. 5.16).
- General construction activities in the heated drift will be performed in compliance with the applicable requirements of Specification Section 01501 (Ref. 5.17).
- Concrete formwork will be in accordance with Specification Section 03101 (Ref. 5.21).

8. CONCLUSIONS

Following are the conclusions and recommendations derived from this analysis:

8.1 Test Objectives

The objectives of the heated drift CIP concrete lining drift scale thermal test are identified in Paragraph 7.2 of this analysis.

8.2 CIP Concrete Lining Configuration

The configuration of the CIP concrete lining is discussed in Paragraph 7.3 of this analysis and summarized as follows (also see Figures in Attachment I):

8.2.1 Lining to be located at the far end of the heated drift.

8.2.2 Lining outside diameter of 5.6 meters (minimum).

8.2.3 Lining inside diameter of 5.2 meters (nominal).

8.2.4 Lining overall (nominal) length of 12.35 meters (at least 2 times the lining OD).

8.2.5 Nominal lining wall thickness of 200 mm.

8.2.6 Nominal length of SFRC portion of lining of 4.12 meters and located nearest to the bulkhead end of the test section.

8.2.7 Construction tolerances based on ACI 117 Chapter 4 for both concrete and formwork.

8.2.8 A pattern of bleeder holes placed in the CIP lining at nominal 1 meter spacing.

8.2.9 Unkeyed transverse construction joint located between the SFRC and unreinforced lining sections. Keyed construction joints (if needed) elsewhere.

8.2.10 A minimum of 75 mm of concrete cover over rock bolt ends and wire mesh unless otherwise approved by the A/E.

8.2.11 Contact grout voids in the crown region of the lining. See Paragraph 7.3.6 for detailed performance requirements for contact grouting.

8.2.12 Constructor will prepare a lining placement plan.

8.3 Concrete Mix Requirements

The concrete mix requirements for a 34.47 MPa (5000 psi), ½" maximum aggregate size, pumpable concrete mix are identified in Paragraph 7.4 of this analysis.

8.4 Ground Support Materials to be Tested

A cast-in-place concrete lining consisting of both unreinforced plain concrete and SFRC sections is the only ground support material to be tested in the drift scale thermal test, as noted in Paragraph 7.5 of this analysis.

8.5 Test Conditions and Tests/Measurements Required

Test conditions and measurements are discussed in Paragraphs 7.6 and 7.7 of this analysis and are summarized as follows:

8.5.1 The test drift will be heated to within a range of from 200 ° to 300 ° C for the estimated minimum 2 year duration of the drift scale thermal test.

8.5.2 Measurements will be made of: lining displacement/closure, lining convergence, and lining strain by the TCO.

8.5.3 The lining will be visually observed using remote video camera equipment during the test by the TCO.

8.5.4 The concrete material will be tested before exposure to the high test temperatures for: compressive strength, modulus of elasticity, Poisson's ratio, split cylinder tensile strength, flexural toughness/first-crack strength, and possibly coefficient of thermal expansion.

8.5.5 The concrete material will also be tested after (or during) exposure to the high test temperatures for: compressive strength, modulus of elasticity, Poisson's ratio, split cylinder tensile strength, flexural toughness/first-crack strength, and possibly coefficient of thermal expansion and long term creep behavior of the concrete.

8.5.6 All laboratory testing will be performed under an approved QA program.

8.5.7 Field tests will be conducted on the concrete at time of placement for: slump, entrained air content, temperature, and time of flow for SFRC and grout.

8.5.8 The temperatures of the lining will be measured at various locations throughout the duration of the test by the TCO.

8.5.9 The lining cross-sectional configuration will be as-built by the Constructor.

8.5.10 Material test reports and/or certificates of compliance will be furnished for selected concrete materials.

8.5.11 Test results will be compared to analytical models of the rock/lining.

8.5.12 Cored/sawed concrete samples will be taken and tested after completion of the two year thermal test.

8.6 Critical Lining Requirements

Critical lining requirements related to as-builting, concrete sampling and testing, and miscellaneous construction activities that are needed to support the test objectives and that will require QA controls are detailed in Paragraph 7.8 of this analysis.

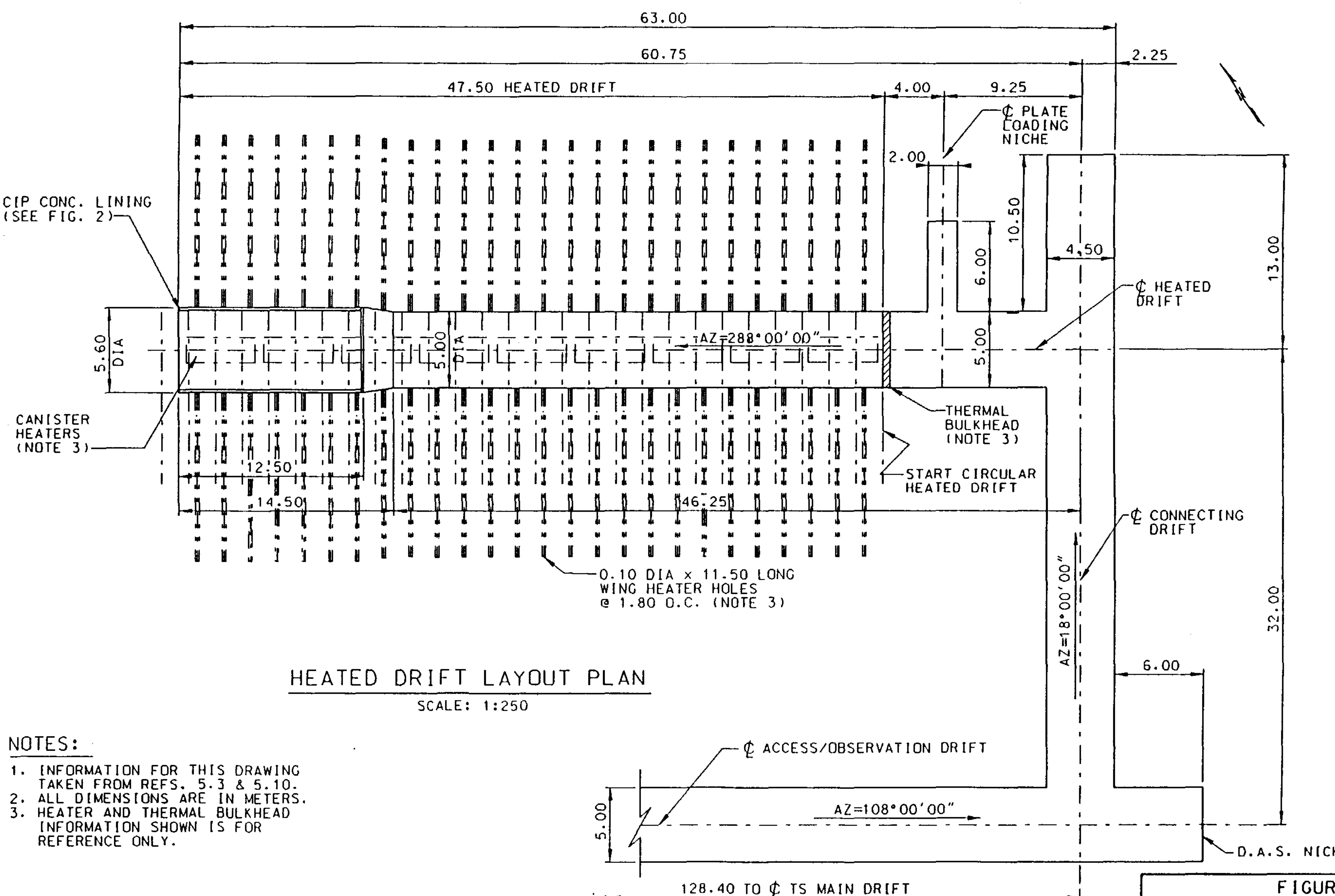
9. ATTACHMENTS

Attachment I	Figures 1 thru 6
Attachment II	SFRC Information

ATTACHMENT I

FIGURES

(**NOTE**: All dimensions are in millimeters unless shown otherwise)



HEATED DRIFT LAYOUT PLAN

SCALE: 1:250

NOTES:

1. INFORMATION FOR THIS DRAWING TAKEN FROM REFS. 5.3 & 5.10.
2. ALL DIMENSIONS ARE IN METERS.
3. HEATER AND THERMAL BULKHEAD INFORMATION SHOWN IS FOR REFERENCE ONLY.

FIGURE 1
THERMAL TESTING FACILITY ALCOVE AND HEATED DRIFT LAYOUT PLAN

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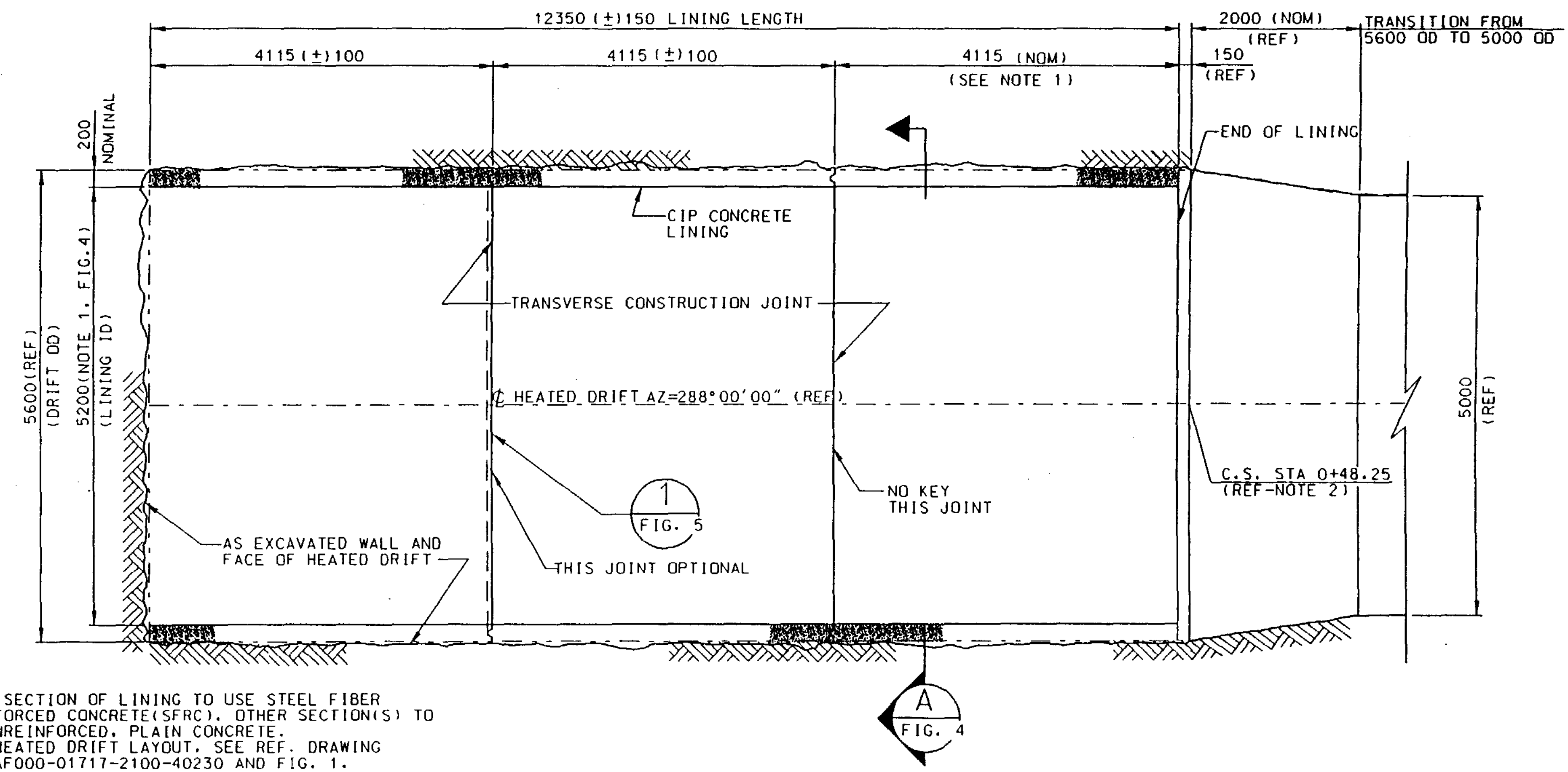


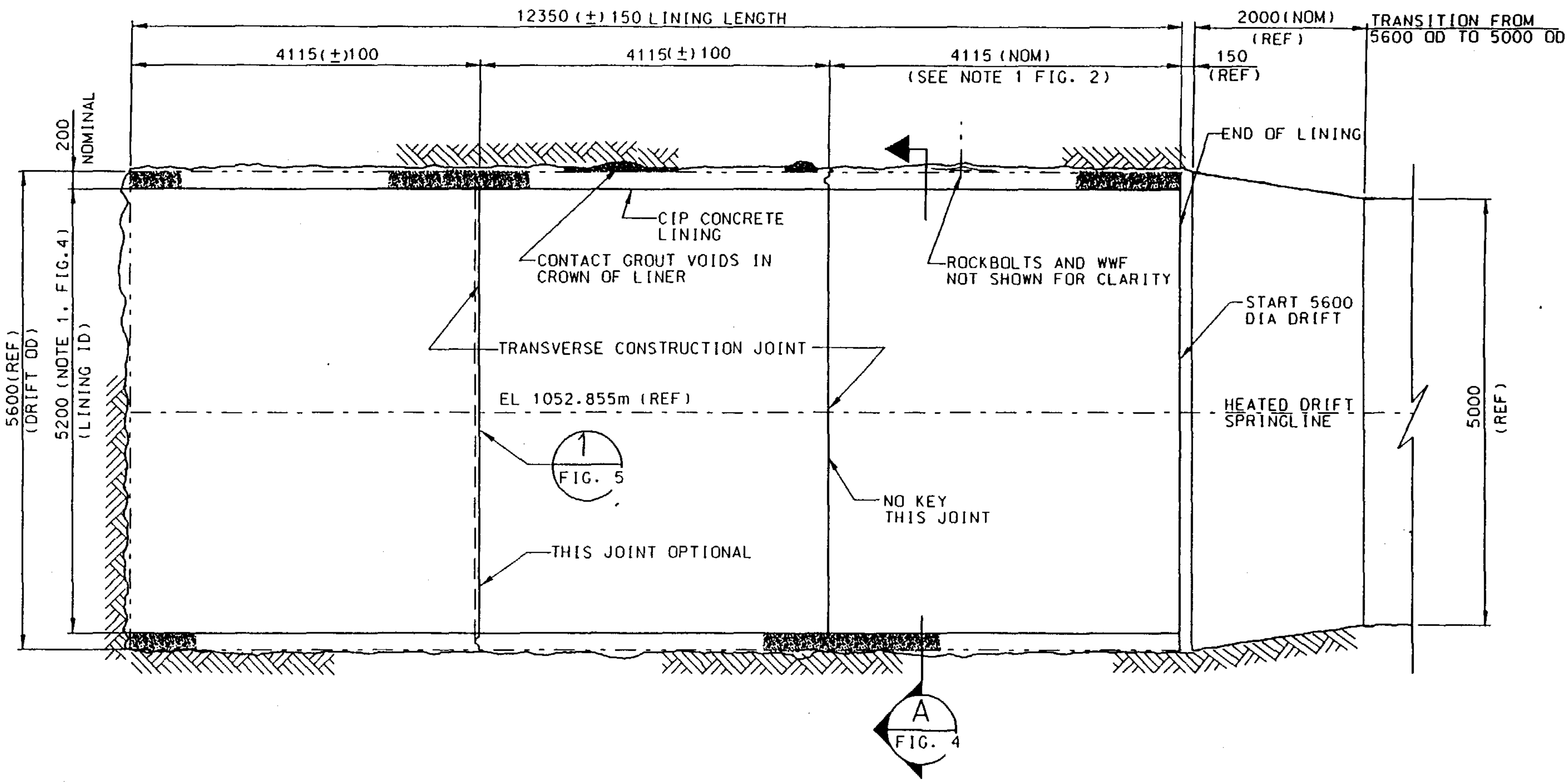
NOTE:

1. THIS SECTION OF LINING TO USE STEEL FIBER REINFORCED CONCRETE(SFRC). OTHER SECTION(S) TO BE UNREINFORCED, PLAIN CONCRETE.
2. FOR HEATED DRIFT LAYOUT, SEE REF. DRAWING BABEAF000-01717-2100-40230 AND FIG. 1.

PLAN OF CAST-IN-PLACE CONCRETE LINING

SCALE: 1:50

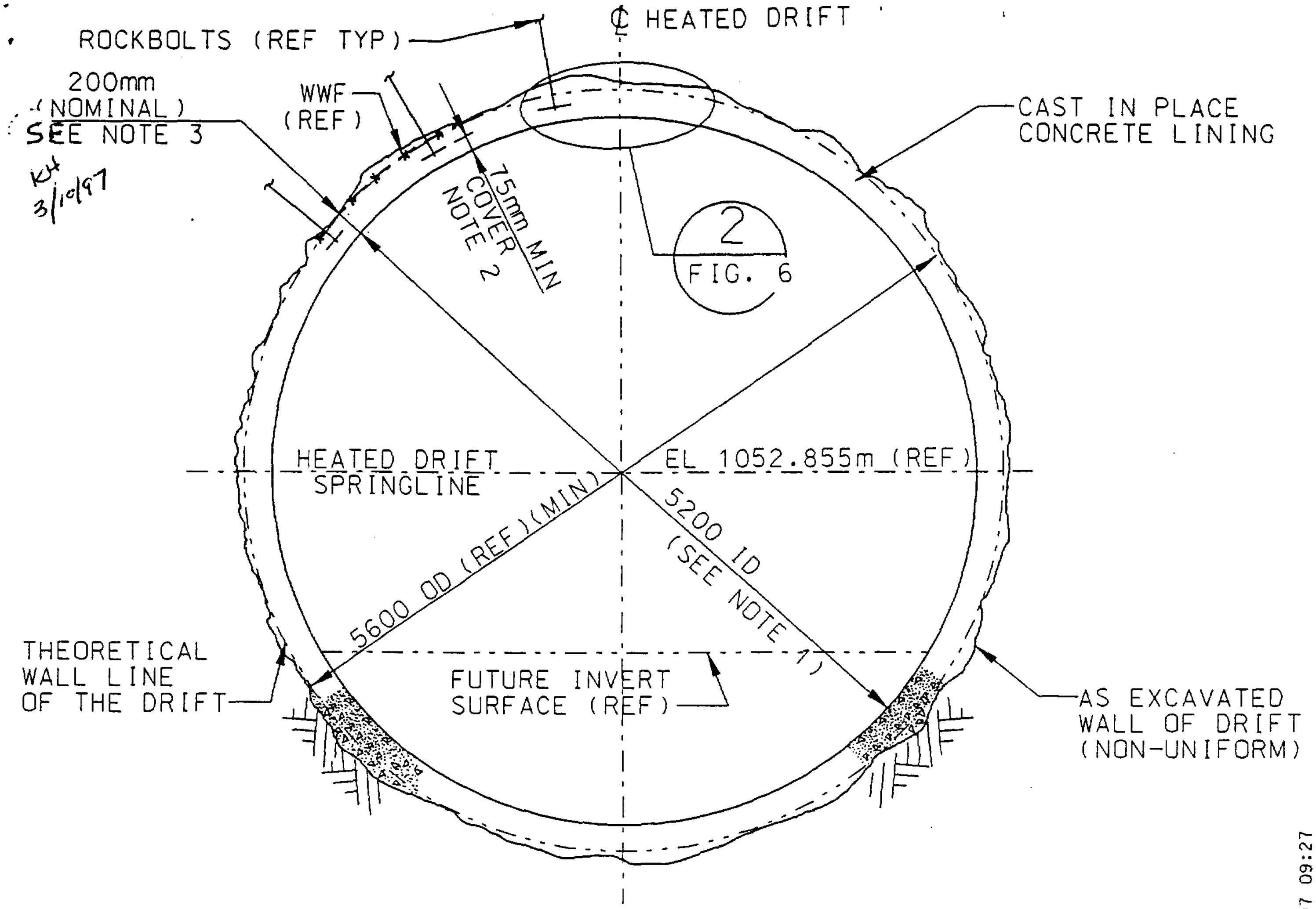
FIGURE 2
CONCRETE CAST-IN-PLACE
LINING PLAN



ELEVATION OF CAST-IN-PLACE CONCRETE LINING

SCALE: 1 : 50

FIGURE 3
CONCRETE CAST-IN-PLACE
LINING ELEVATION



SECTION A

SCALE: 1 : 50 FIGS. 2 & 3

NOTE:

1. ID OF CIP LINING MAY VARY WITHIN FORMING TOLERANCES AS LONG AS DIMENSIONS ARE AS-BUILT AND DOCUMENTED.
2. GROUND SUPPORT COMPONENTS (ROCKBOLTS, WWF ETC.) SHALL HAVE A MINIMUM OF 75mm OF CONCRETE COVER (DOES NOT APPLY TO FORM SUPPORTS), UNLESS OTHERWISE APPROVED BY A/E.
3. LINING THICKNESS AS SHOWN IS A "TARGET MINIMUM", BUT MAY VARY WITHIN FORMING TOLERANCES.

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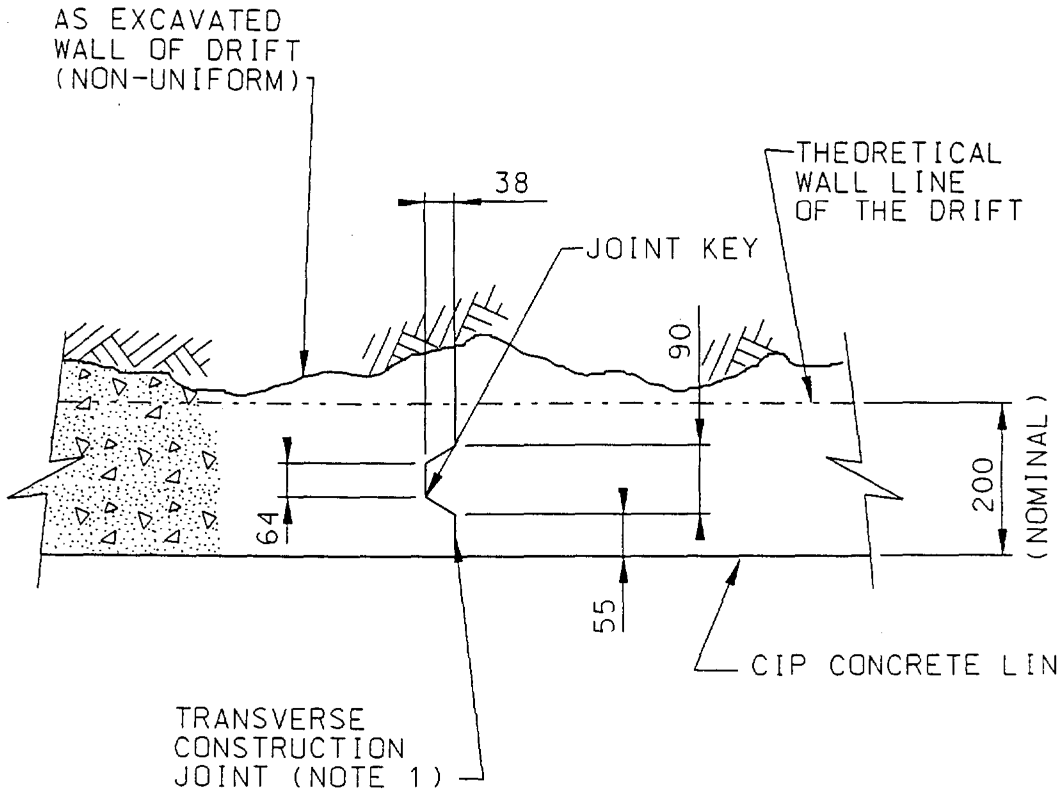
FIGURE 4
HEATED DRIFT CIP LINING
SECTION



NOTE: ALL KEY DIMENSIONS ARE NOMINAL

DETAIL 1
SCALE: 1 : 10 FIGS.2 & 3

NOTE:

1. LONGITUDINAL CONSTRUCTION JOINTS (IF USED) SHALL ALSO CONFORM TO THIS DETAIL.

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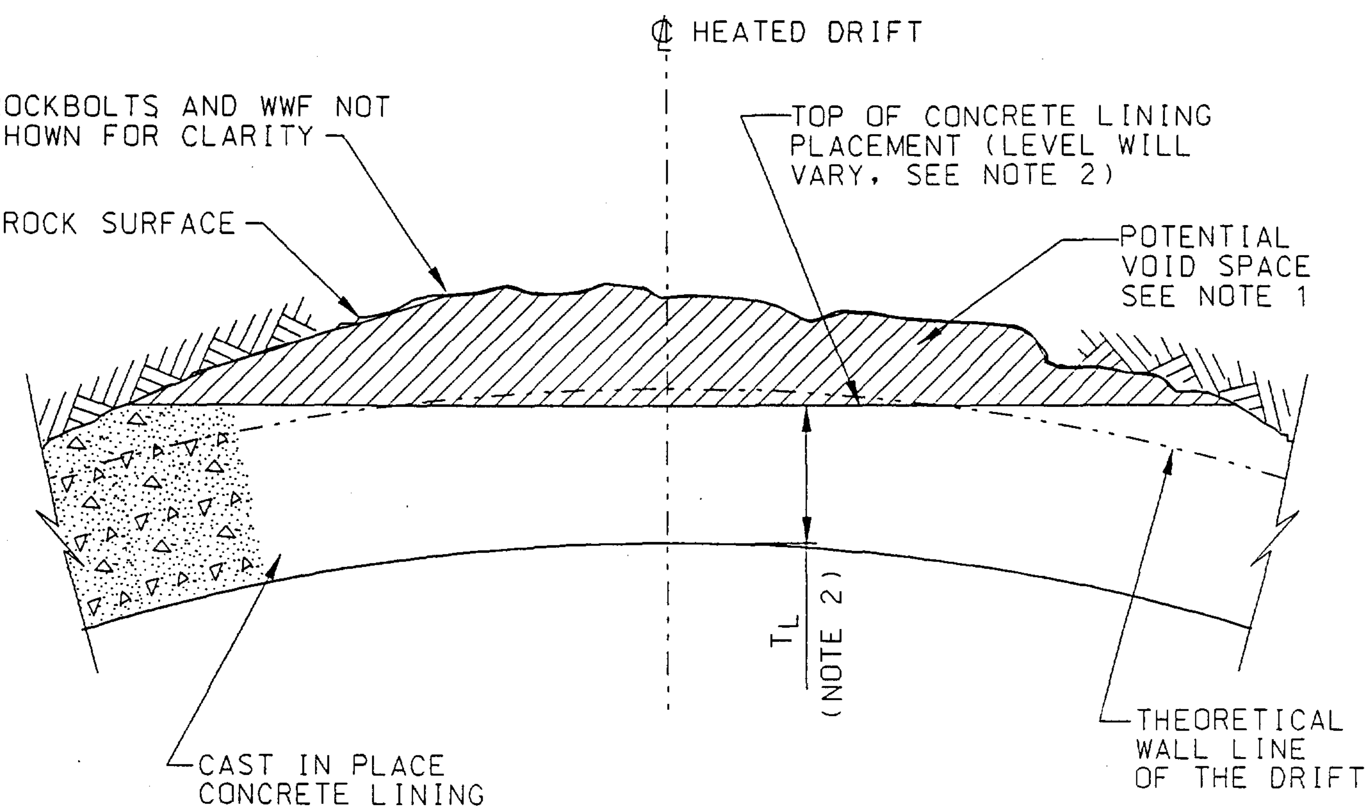
FIGURE 5
HEATED DRIFT CIP LINING
CONSTRUCTION JOINT DETAIL



DETAIL 2

SCALE: 1 : 10 FIG. 4

NOTE:

1. CONTACT GROUT VOID SPACES IN CROWN OF LINING WITH CEMENTITIOUS GROUT. SEE PARA 7.3.6 FOR CONTACT GROUTING REQUIREMENTS.
2. PLACE CONCRETE LINING IN CROWN REGION USING METHODS THAT MAXIMIZE LINING THICKNESS, T_L , AND MINIMIZE VOID SPACE.

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FIGURE 6
HEATED DRIFT CIP LINING
CROWN DETAIL

ATTACHMENT II

SFRC INFORMATION:

ACI 544.4R Excerpts
Bekaert Dramix Catalog Excerpts

ACI 544.4R-88

Design Considerations for Steel Fiber Reinforced Concrete

Reported by ACI Committee 544

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The present state of development of design practices for fiber reinforced concrete and mortar using steel fibers is reviewed. Mechanical properties are discussed, design methods are presented, and typical applications are listed.

Keywords: beams (supports;) cavitation; compressive strength; concrete slabs; creep properties; fatigue (materials); fiber reinforced concretes; fibers; flexural strength; freeze-thaw durability; metal fibers; mortars (material); structural design.

CONTENTS

CHAPTER 1—INTRODUCTION

Steel fiber reinforced concrete (SFRC) and mortar made with hydraulic cements and containing fine or fine and coarse aggregates along with discontinuous discrete steel fibers are considered in this report. These materials are routinely used in only a few types of ap-

*Members of the subcommittee that prepared the report.
†Co-chairmen of the subcommittee that prepared the report.
‡Deceased.

plications at present (1988), but ACI Committee 544 believes that many other applications will be developed once engineers become aware of the beneficial properties of the material and have access to appropriate design procedures. The contents of this report reflect the experience of the committee with design procedures now in use.

The concrete used in the mixture is of a usual type, although the proportions should be varied to obtain good workability and take full advantage of the fibers. This may require limiting the aggregate size, optimizing the gradation, increasing the cement content, and perhaps adding fly ash or other admixtures to improve workability. The fibers may take many shapes. Their cross sections include circular, rectangular, half-round, and irregular or varying cross sections. They may be straight or bent, and come in various lengths. A convenient numerical parameter called the aspect ratio is used to describe the geometry. This ratio is the fiber length divided by the diameter. If the cross section is not round, then the diameter of a circular section with the same area is used.

The designer may best view fiber reinforced concrete as a concrete with increased strain capacity, impact resistance, energy absorption, and tensile strength. However, the increase in these properties will vary from substantial to nil depending on the quantity and type of fibers used; in addition, the properties will not increase at the same rate as fibers are added.

Several approaches to designing members with steel fiber reinforced concrete (SFRC) are available that are based on conventional design methods supplemented by special procedures for the fiber contribution. These methods generally modify the internal forces in the member to account for the additional tension from the fibers. When supported by full-scale test data, these approaches can provide satisfactory designs. The major differences in the proposed methods are in the determination of the magnitude of the tensile stress increase due to the fibers and in the manner in which the total force is calculated. Other approaches that have been used are often empirical, and they may apply only in certain cases where limited supporting test data have been obtained. They should be used with caution in new applications, only after adequate investigation.

Generally, for structural applications, steel fibers should be used in a role supplementary to reinforcing bars. Steel fibers can reliably inhibit cracking and improve resistance to material deterioration as a result of fatigue, impact, and shrinkage, or thermal stresses. A conservative but justifiable approach in structural members where flexural or tensile loads occur, such as in beams, columns, or elevated slabs (i.e., roofs, floors, or slabs not on grade), is that reinforcing bars must be used to support the total tensile load. This is because the variability of fiber distribution may be such that low fiber content in critical areas could lead to unacceptable reduction in strength.

In applications where the presence of continuous reinforcement is not essential to the safety and integrity of the structure, e.g., floors on grade, pavements, overlays, and shotcrete linings, the improvements in flexural strength, impact resistance, and fatigue performance associated with the fibers can be used to reduce section thickness, improve performance, or both.

ACI 318 does not provide for use of the additional tensile strength of the concrete in building design and, therefore, the design of reinforcement must follow the usual procedure. Other applications provide more freedom to take full advantage of the improved properties of SFRC.

There are some applications where steel fibers have been used without bars to carry flexural loads. These have been short-span elevated slabs, e.g., a parking garage at Heathrow Airport with slabs 3 ft-6 in. (1.07 m) square by 2½ in. (10 cm) thick, supported on four sides (Anonymous 1971). In such cases, the reliability of the members should be demonstrated by full-scale load tests, and the fabrication should employ rigid quality control.

Some full-scale tests have shown that steel fibers are effective in supplementing or replacing the stirrups in beams (Williamson 1978; Craig 1983; Sharma 1986). Although it is not an accepted practice at present, other full-scale tests have shown that steel fibers in combination with reinforcing bars can increase the moment capacity of reinforced concrete beams (Henager and Doherty 1976; Henager 1977a).

Steel fibers can also provide an adequate internal restraining mechanism when shrinkage-compensating cements are used, so that the concrete system will perform its crack control function even when restraint from conventional reinforcement is not provided. Fibers and shrinkage-compensating cements are not only compatible, but complement each other when used in combination (Paul et al. 1981). Guidance concerning shrinkage-compensating cement is available in ACI 223.1R.

ASTM A 820 covers steel fibers for use in fiber reinforced concrete. The design procedures discussed in this report are based on fibers meeting that specification.

Additional sources of information on design are available in a selected bibliography prepared by Hoff (1976-1982), in ACI publications SP-44 (1974) and SP-81 (1984), in proceedings of the 1985 U.S.-Sweden joint seminar edited by Shah and Skarendahl (1986), and the recent ACI publication SP-105 edited by Shah and Batson (1987).

For guidance regarding proportioning, mixing, placing, finishing, and testing for workability of steel fiber reinforced concrete, the designer should refer to ACI 544.3R.

CHAPTER 2—MECHANICAL PROPERTIES USED IN DESIGN

2.1—General

The mechanical properties of steel fiber reinforced concrete are influenced by the type of fiber; length-to-diameter ratio (aspect ratio); the amount of fiber; the strength of the matrix; the size, shape, and method of preparation of the specimen; and the size of the aggregate. For this reason, mixtures proposed for use in design should be tested, preferably in specimens representing the end use, to verify the property values assumed for design.

SFRC mixtures that can be mixed and placed with conventional equipment and procedures use from 0.5 to 1.5 volume percent* fibers. However, higher percentages of fibers (from 2 to 10 volume percent) have been used with special fiber addition techniques and placement procedures (Lankard 1984). Most properties given in this chapter are for the lower fiber percentage range. Some properties, however, are given for the higher fiber percentage mixtures for information in applications where the additional strength or toughness may justify the special techniques required.

Fibers influence the mechanical properties of concrete and mortar in all failure modes (Gopalaratnam and Shah 1987a), especially those that induce fatigue and tensile stress, e.g., direct tension, bending, impact, and shear. The strengthening mechanism of the fibers involves transfer of stress from the matrix to the fiber by interfacial shear, or by interlock between the fiber and matrix if the fiber surface is deformed. Stress is thus shared by the fiber and matrix in tension until the matrix cracks, and then the total stress is progressively transferred to the fibers.

Aside from the matrix itself, the most important variables governing the properties of steel fiber reinforced concrete are the fiber efficiency and the fiber content (percentage of fiber by volume or weight and total number of fibers). Fiber efficiency is controlled by the resistance of the fibers to pullout, which in turn depends on the bond strength at the fiber-matrix interface. For fibers with uniform section, pullout resistance increases with an increase in fiber length; the longer the fiber the greater its effect in improving the properties of the composite.

Also, since pullout resistance is proportional to interfacial surface area, nonround fiber cross sections and smaller diameter round fibers offer more pullout resistance per unit volume than larger diameter round fibers because they have more surface area per unit volume. Thus, the greater the interfacial surface area (or the smaller the diameter), the more effectively the fibers bond. Therefore, for a given fiber length, a high ratio of length to diameter (aspect ratio) is associated with high fiber efficiency. On this basis, it would appear that the fibers should have an aspect ratio high enough to insure that their tensile strength is approached as the composite fails.

Unfortunately, this is not practical. Many investigations have shown that use of fibers with an aspect ratio greater than 100 usually causes inadequate workability of the concrete mixture, non-uniform fiber distribution, or both if the conventional mixing techniques are used (Lankard 1972). Most mixtures used in practice employ fibers with an aspect ratio less than 100, and failure of the composite, therefore, is due primarily to fiber pullout. However, increased resistance to pullout without increasing the aspect ratio is achieved in fibers with deformed surfaces or end anchorage; failure may involve fracture of some of the fibers, but it is still usually governed by pullout.

* Percent by volume of the total concrete mixture.

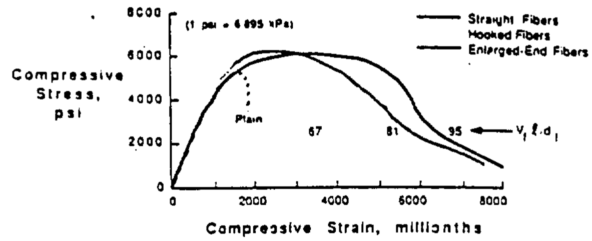

Fig. 2.1—Stress-strain curves for steel fiber reinforced concrete in compression, ⅜-in. (9.5-mm) aggregate mixtures (Shah 1978)

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An advantage of the pullout type of failure is that it is gradual and ductile compared with the more rapid and possibly catastrophic failure that may occur if the fibers break in tension. Generally, the more ductile the steel fibers, the more ductile and gradual the failure of the concrete. Shah and Rangan (1970) have shown that the ductility provided by steel fibers in flexure was enhanced when the high-strength fibers were annealed (a heating process that softens the metal, making it less brittle).

An understanding of the mechanical properties of SFRC and their variation with fiber type and amount is an important aspect of successful design. These properties are discussed in the remaining sections of this chapter.

2.2—Compression

The effect of steel fibers on the compressive strength of concrete is variable. Documented increases for concrete (as opposed to mortar) range from negligible in most cases to 23 percent for concrete containing 2 percent by volume of fiber with ℓ/d = 100, ¾-in. (19-mm) maximum-size aggregate, and tested with 6 x 12 in. (150 x 300 mm) cylinders (Williamson 1974). For mortar mixtures, the reported increase in compressive strength ranges from negligible (Williamson 1974) to slight (Fanella and Naaman 1985).

Typical stress-strain curves for steel fiber reinforced concrete in compression are shown in Fig. 2.1 (Shah et al. 1978). Curves for steel fiber reinforced mortar are shown in Fig. 2.2 and 2.3 (Fanella and Naaman 1985). In these curves, a substantial increase in the strain at the peak stress can be noted, and the slope of the descending portion is less steep than that of control specimens without fibers. This is indicative of substantially higher toughness, where toughness is a measure of ability to absorb energy during deformation, and it can be estimated from the area under the stress-strain curves or load-deformation curves. The improved toughness in compression imparted by fibers is useful in

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Dramix® Steel Fibers: Used Worldwide For Concrete Reinforcement.

Dramix® Steel Fibers: A Unique Concept

Through continuous research by the Bekaert Research Center and other agencies worldwide, we have taken the concept of steel fiber-reinforcement a quantum leap forward. The result: Dramix® steel fibers.

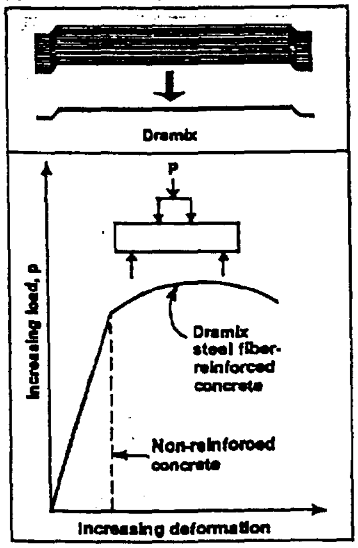
Dramix® is a patented steel fiber with a hooked end design. The steel fibers are collated into a clip of up to 48 individual fibers, joined together with a special adhesive that releases during mixing.

As soon as the mixing process starts, the Dramix® bundles separate and begin to spread throughout the entire mix. The moisture in the mixture and the scouring effect of the aggregates further separates the bundles into individual steel fibers.

This guarantees a homogeneous mixture. And in comparison with low aspect ratio fibers, the percentages by volume can be reduced drastically.

Loose individual fibers are used in applications where there is not sufficient moisture in the mix to separate the glued bundles, such as: dry process shotcrete, some precast and specialty concrete applications.

Concrete reinforced with Dramix® offers stronger mechanical anchorage capabilities, which in turn result in a high degree of toughness and fatigue resistance.



The load-deflection curve shows the difference in the post crack load capacity between Dramix® steel fiber-reinforced concrete and non-reinforced concrete. This improved behavior and toughness is due to the enhanced bond characteristics of Dramix®.

Dramix® also eliminates the disadvantages associated with conventional fibers: Dramix® fibers don't tangle or ball; distribution is uniform throughout the mix; no special equipment or manpower is required.

Properties of Dramix® Steel Fiber-Reinforced Concrete

This homogeneously reinforced concrete offers high flexural strength combined with high crack resistance. It also delivers exceptional impact resistance, high energy-absorption capacity, high fatigue resistance and increased shear strength.

Industrial Floor Slabs On Grade

Concrete floors must satisfy your tough requirements; they must resist dynamic wheel loads, static rack loads and uniformly-distributed loads. They must also withstand the damaging effect of fork truck traffic and impact from falling loads or equipment.

Steel fiber concrete, which is designed as a homogeneous material, combines easy processing and high reliability.

Applications
- Industrial floor slabs on grade in:
  - factories
  - warehouses
- Hangars
- Concrete overlays

Economic advantages
- Elimination of traditional mesh environment, labor and materials
- Reduction in slab thickness
- Increased joint spacing possibilities
- Less complicated construction leading to earlier completion
- Lower maintenance costs

Technical advantages
- Suppresses propagation of cracks and spalling
- Assures a homogeneously reinforced product
- Achieves considerable increase in flexural strength
- Remarkably increased toughness; provides high resistance to impact loadings
- Dramatic increase in fatigue endurance

Fiber Properties	
Low carbon, cold drawn, steel wire	
Tensile yield strength:	150,000 psi minimum (1040 MPa)
Tolerances: Length:	±5% maximum
Diameter:	±4% maximum
Aspect ratio:	±10% maximum

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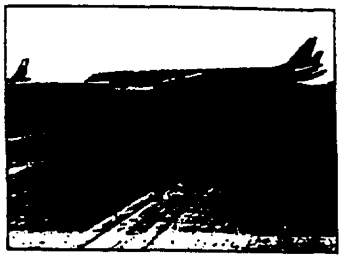

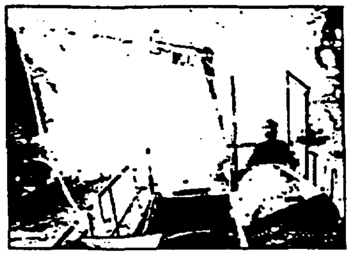

Pavements

The inclusion of steel fibers in concrete can greatly enhance its resistance to dynamic loading, impact and fatigue which results in a significant extension in the useful working life of the pavement.

Applications

- Airport pavements: runways, aprons and taxiways
- Highways and roads
- Parking areas
- Bridge decks
- Pavement repairs
- Overlays
- Canal and reservoir linings

Economic advantages

Simplicity: steel fiber-reinforced concrete is extremely suitable for placement by slip-form paver and other standard concrete placing equipment.

- Savings in maintenance
- Longer useful concrete life
- Reduced cost in maintaining relative grades
- Increased joint spacings are possible

Technical advantages

- High flexural strength
- High fatigue endurance
- High resistance to static and dynamic loading
- High impact resistance
- High strain capacity
- High shear strength
- Reduces cracks and spalling

Shotcrete

Shotcrete, the method of spraying a mortar or concrete mixture under pneumatic pressure onto a surface, is a rapidly expanding construction practice. When steel fibers are added to the concrete, both are mixed and placed in one simple operation.

Applications

- Mine and tunnel linings
- Ground and slope stabilization
- Repairs to concrete structures
- Construction of complex shapes: shells, thin arches and rugged rock surfaces
- Fire and corrosion protection of steel structures
- Sewer rehabilitation

Economic advantages

- Significant decrease in placement time, labor and materials
- Elimination of mesh reinforcement
- Savings in concrete; contour maintained; thickness reduced

Technical advantages

- High degree of safety, due to greater ductility and capacity for deformation
- Eliminates cavities behind mesh reinforcement
- Applicable to either wet or dry processes
- Reduces employees' exposure to hazards

Miscellaneous

The use of steel fiber-reinforced concrete can improve mechanical properties, reduce labor costs and increase productivity. The result: cost-effective, quality products.

Precast concrete products

- Monobloc precast garages
- Cladding and partition panels
- Concrete pipe
- Manholes and other three-dimensional structures
- Mine cribbing

Security

- Safes
- Vault doors
- Strongrooms

Hydraulic structures

- Coastal protection
- Stilling basins
- Flip lips
- Spillway repairs
- Navigation lock repairs

Other applications

- Machine foundations
- Prefabricated machine bases
- Certain applications of slip-forming: for example, pipe-casing
- Prepacked mixes
- Blast-resistant structures

ASTM Statement

Dramix® Steel Fibers meet or exceed the requirements of ASTM A 820-85, (Standard Specification for Steel Fibers for Fiber Reinforced Concrete), for Type I, Deformed Fibers.

Standard Types Of Dramix® And Their Applications

	Steel Fibers				
Size	ZL 30/.50	ZC 30/.50	ZC 50/.50	ZC 60/.80	ZC 60/.100
Dimensions	ℓ: 30mm (1.2") d: .50mm (.02") Z: hooked L: loose l/d: 60	ℓ: 30mm (1.2") d: .50mm (.02") Z: hooked C: glued l/d: 60	ℓ: 50mm (2.0") d: .50mm (.02") Z: hooked C: glued l/d: 100	ℓ: 60mm (2.4") d: .80mm (.03") Z: hooked C: glued l/d: 75	ℓ: 60mm (2.4") d: 1.00mm (.04") Z: hooked C: glued l/d: 60
Packaging	40# box 60 boxes/pallet 2400#/pallet	66# bag 42 bags/pallet 2772#/pallet	66# bag 42 bags/pallet 2772#/pallet	66# bag 42 bags/pallet 2772#/pallet	66# bag 42 bags/pallet 2772#/pallet
Applications	— dry shotcrete — thin overlays — zero slump concrete	— wet shotcrete — thin overlays — small precast	— airport pavements — high performance precast and floors	— industrial floor — pavements — machine foundations	— industrial floors — composite metal decks — pavements