OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ANALYSIS/MODEL COVER SHEET

Complete Only Applicable Items

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Marek Mrugala contributed to the development of Section 6.6.
TBV-193 applies to seismic inputs used in this analysis.

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
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2. Analysis or Model Title:
SOUTH RAMP 3.01.X AREA GROUND SUPPORT ANALYSIS

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1. PURPOSE

The purpose of this analysis is to evaluate the stability and determine ground support requirements for the 3.01.X areas in the Exploratory Studies Facility (ESF) South Ramp. The 3.01.X area refers to the ESF tunnel portions that were constructed under Section 3.01.X of the ESF General Construction Specification (Reference 8.4). Four 3.01.X areas in the ESF Main Loop are covered in this analysis that extend from Station 60+15.28 to 60+49.22, 62+04.82 to 62+32.77, 75+21.02 to 75+28.38, and 76+63.08 to 77+41.23. The scope of the analysis is (1) to document the as-built configuration including existing voids and installed ground support, (2) to evaluate the existing ground conditions, (3) to determine applicable design loads, (4) to evaluate the stability and determine a ground support system, and (5) to analyze the recommended system.

This analysis is performed under the Work Direction for ground support analysis for 3.01.X areas (Reference 8.1). This analysis also supplements the work conducted for 3.01.X areas utilizing NLP-3-35, *Exploratory Studies Facility Walk-Down for Quality Affecting Ground Support.*

2. QUALITY ASSURANCE

The quality assurance classification for ground support items discussed in this analysis are presented in Reference 8.2. The work control evaluation for ESF design (Reference 8.3) has determined that the QA program applies to this analysis. The permanent function ground support installed in the ESF Main Loop is classified as QA-1 and QA-5 in Reference 8.2 and is therefore subject to QA controls. Any temporary function ground support installed by the constructor for reasons of personnel safety does not require classification (Reference 8.2).

3. COMPUTER SOFTWARE AND MODEL USAGE

Fast Lagrangian Analysis of Continua (FLAC), Version 3.30 (Reference 8.7) is used to perform the numerical analyses. FLAC is approved for use in design in accordance with M&O Computer Software Quality Assurance procedures. FLAC software is appropriate for the applications used in this analysis. FLAC was obtained from the Software Configuration Management (SCM) in accordance with the applicable M&O procedures. FLAC software was used within the range of validation as specified in software qualification documentation. A complete listing of the input files used in the design analysis are provided in Attachment I. The outputs are presented and described in Section 6.0 and its subsections.

Microsoft Excel 97 was used in this analysis. It was used to perform support activities that are not the controlled source of information in this analysis, and thus not subject to qualification per AP-SI.1Q.

Excel is a commercial spreadsheet program designed to assist in routine calculations. The program provides built-in mathematical functions together with user-defined formulas to automate the calculation process. Output formulas are automatically updated as input data are added or changed. *Excel* also includes a graphical package to assist in data presentation. *Excel* was used to provide graphical presentation of data in Figures 6-53, 6-54, 6-75, and 6-76. *Excel* was also used to tabulate data as presented in Attachment II.

4. INPUTS

4.1 PARAMETERS

4.1.1 Rock Mass Properties for TCw Unit

Modulus of Elasticity (E): 5.31×10^9 Pa	Source: Reference 8.23, Table 9.0
Poisson's Ratio (ν): 0.20	Source: Reference 8.10, Section 4.1
Bulk Density: 2230 Kg/m^3	Source: Reference 8.9, Table 21
Cohesion: 9.0×10^5 Pa	Source: Reference 8.23, Table 10
Friction Angle: 53°	Source: Reference 8.23, Table 11
Tensile Strength: 6.0×10^5 Pa	Source: Reference 8.23, Table 13
Shear Modulus (S): 2.21×10^9 Pa	Calculated as: $S=E/[2(1+\nu)]$; where E is the Modulus of Elasticity and ν represents Poisson's Ratio (Section 4.1, Reference 8.10)
Bulk Modulus (B): 2.95×10^9 Pa	Calculated as $B=E/[3(1-2\nu)]$; where E is the Modulus of Elasticity and ν represents Poisson's Ratio (Section 4.1, Reference 8.10)

4.1.2 Rock Mass Properties for TSw2 Unit

Modulus of Elasticity (E): 7.96×10^9 Pa	Source: Reference 8.23, Table 9.0
Poisson's Ratio (ν): 0.21	Source: Reference 8.10, Section 4.1
Bulk Density: 2360 Kg/m^3	Source: Reference 8.9, Table 21
Cohesion: 1.5×10^5 Pa	Source: Reference 8.23, Table 10
Friction Angle: 43°	Source: Reference 8.23, Table 11
Tensile Strength: 1.27×10^5 Pa	Source: Reference 8.23, Table 13
Shear Modulus (S): 3.29×10^9 Pa	Calculated as: $S=E/[2(1+\nu)]$; where E is the Modulus of Elasticity and ν represents Poisson's Ratio (Section 4.1, Reference 8.10)
Bulk Modulus (B): 4.57×10^9 Pa	Calculated as $B=E/[3(1-2\nu)]$; where E is the Modulus of Elasticity and ν

represents Poisson's Ratio (Section 4.1, Reference 8.10)

4.1.3 Tunnel Dimensions

For the ESF Main Loop a tunnel diameter of 7.62 m was used in the analysis from Reference 8.10, Section 4.1.

4.1.4 Input Properties for Steel Sets

The following input values are used in the analysis of the W6×20 steel sets in FLAC calculations.

Young's Modulus (E): 2.00×10^{11} Pa — Source: Reference 8.11
Poisson's Ratio (ν): 0.3 — Source: Reference 8.12, Page 6.7
Area (A): 3.79×10^{-3} m^2 — Source: Reference 8.11, Page 1-32
Moment of Inertia (I): 1.72×10^{-5} m^4 — Source: Reference 8.11, Page 1-33
Density: 7800 Kg/m^3 — Source: Reference 8.11, Page 1-33
Section Modulus (S): 2.20×10^{-4} m^3 — Source: Reference 8.11, Page 1-33
Plain Strain Equivalent Shear Modulus ($S_{eq\ pl\ sn}$): 1.13×10^{9} Pa — Source: See Section 6.6.2
Plain Strain Equivalent Bulk Modulus ($B_{eq\ pl\ sn}$): 2.46×10^{9} Pa — Source: See Section 6.6.2

4.2 CRITERIA

The ESF ground support analyses (Reference 8.10) followed criteria that were based on the requirements contained in the Exploratory Studies Facility Design Requirements (ESFDR) document (Reference 8.13). The listing of all design requirements applicable to ESF ground support design extracted from ESFDR is provided in Table 1 along with the corresponding design criteria.

Table 1. List of ESFDR-Defined Design Requirements and Corresponding Design Criteria Related to ESF Ground Support for 3.01.X Area (Reference 8.13).

No.	ESFDR Requirement	Design Criteria
1	The permanent and temporary items of the ESF shall be designed to withstand the applicable seismic environment specified in Appendix A. (ESFDR 3.2.1.2.1.2.A)	Seismic input data from Reference 8.13 are used in numerical calculations such that resulting design is capable of accommodating design conditions.
2	The ESF subsurface facilities and equipment shall be designed to withstand and operate in temperatures ranging from a low of 50 degrees F to a high of 70 degrees F. (ESFDR 3.2.1.2.1.2.C).	The ESF ground support system is designed to perform its intended function within the range of temperatures specified.
3	The ESF subsurface facilities and equipment shall be designed to withstand and operate in a relative humidity environment of 13 to 71%. (ESFDR 3.2.1.2.1.2.D).	The ESF ground support system is designed to perform its intended function within the range of relative humidity levels specified.

Table 1. List of ESFDR-Defined Design Requirements and Corresponding Design Criteria Related to ESF Ground Support for 3.01.X Area (Reference 8.13). (Continued)

No.	ESFDR Requirement	Design Criteria
4	The ESF non-permanent items shall be designed for a 25 year maintainable service life. (ESFDR 3.2.1.2.2.A).	A 25-year maintainable service life of the non-permanent items is provided by designing items that from past experience are durable within the required time period.
5	The ESF permanent items shall be designed for a 150-year maintainable service life. (ESFDR 3.2.1.2.2.B).	The 3.01.X area permanent function ground support system is designed for a 150-year maintainable service life.
6	The ESF underground openings CIs design, construction, and in situ testing shall be planned and coordinated with the repository design. (ESFDR 3.7.2.1.2.B).	The repository design and other affected participating organizations' interfaces will be handled during the normal course of design activities. The interfaces will be formalized by using these organizations as participants in the design review process for this analysis.
7	Permanent ESF items shall be designed, constructed, and maintained consistent with the quality controls and record keeping requirements expected for permanent items that are part of a potential repository. (ESFDR 3.7.2.1.2.C).	QA records generated by this design will be handled in accordance with appropriate QA procedures for permanent ESF items.
8	The ground support system shall be designed to include provisions for installation of instrumentation and data collection units as specified by testing requirements. (ESFDR 3.7.3.1.A).	The 3.01.X area ground support system is designed such that it accommodates installation of instrumentation and data collection units.
9	The ground support system design shall limit the use of pressure grouting and shall obtain prior approval from the Test Coordination Office before usage. (ESFDR 3.7.3.1.B).	The 3.01.X area ground support does not incorporate pressure grouting. If pressure grouting in these locations is deemed to be necessary in the field, Test Coordination Office (TCO) approval shall be obtained prior to its application.
10	The ground support system shall be compatible with the excavation methods and equipment. (ESFDR 3.7.3.1.D).	The 3.01.X area ground support system is designed to be compatible with the excavation method and available equipment.
11	The ground support system shall incorporate the use of noncombustible and heat resistant materials in the design. (ESFDR 3.7.3.1.E).	The 3.01.X area ground support system is designed to incorporate the use of noncombustible and heat resistant materials.
12	The ground support system shall be designed to permit periodic inspection, monitoring, testing, and maintenance, as necessary, to evaluate their readiness and to ensure their continued function. (ESFDR 3.7.3.1.F).	The 3.01.X area ground support system is designed to permit inspection and monitoring as needed to evaluate their readiness and to ensure their continued function. The 3.01.X area ground support is designed such that it provides for routine maintenance.
13	The ground support system shall be designed and installed throughout the main access openings and all alcove transition zones to reduce the potential for deleterious rock movement or fracturing. (ESFDR 3.7.3.1.G).	Ground support system is designed to be installed throughout the 3.01.X areas to reduce the potential for deleterious rock movement or fracturing.
14	The ground support system shall be designed to accommodate the anticipated ground conditions at the main access opening, the operations support areas, and the test support areas, utilizing the available site data at that time. (ESFDR 3.7.3.1.I).	The 3.01.X area ground support system is designed utilizing available site data. The ground support is designed to accommodate anticipated ground conditions in these areas.

Table 1. List of ESFDR-Defined Design Requirements and Corresponding Design Criteria Related to ESF Ground Support for 3.01.X Area (Reference 8.13). (Continued)

No.	ESFDR Requirement	Design Criteria
15	The ground support system shall be designed to have the capability to be supplemented as required when identified through additional site characterization data and analyses. (ESFDR 3.7.3.1.J).	The 3.01.X area ground support system is designed to have the capability to be supplemented. The 3.01.X area ground support system provides capability for installation of additional support to supplement it as required.
16	The ground support system shall be designed with sufficient flexibility to allow adjustments where necessary to accommodate specific site conditions encountered during excavation or identified through in situ monitoring and testing. (ESFDR 3.7.3.1.K).	The ground support is designed with the flexibility needed to allow adjustments and to accommodate specific site conditions encountered during excavation or identified through in situ monitoring and testing.

4.3 CODES AND STANDARDS

American Concrete Institute 1995. *Building Code Requirements for Structural Concrete (ACI-95) and Commentary (ACI 318R-95).* ACI 318-95/318R-95 Farmington Hills, Michigan: American Concrete institute. TIC: 233584.

5. ASSUMPTIONS

5.1 INPUT PROPERTIES FOR CONCRETE/SHOTCRETE

Compressive strength (f'_c) value of 2.76×10^7 Pa (4000 psi) was assumed and used in the calculations. This value is based on the strength value in Section 2.01 of Reference 8.18.

Poisson's ratio value of 0.2 was used in the analysis. This is a commonly used value in the industry (for basis of assumption also see Reference 8.12, Page 6.7).

Tensile strength (σ_t) cutoff value of 2.76×10^6 Pa (400 psi) was used in the analysis. This assumption is based on estimating tensile strength as 10% of compressive strength, a standard practice in concrete design per ACI 318 R10.2.5.

Elastic modulus (E) was calculated to be 24.862×10^9 Pa (3.6×10^6 psi) using, $E=57000(f'_c)^{1/2}$ (where f'_c is in psi), based on Section 8.5 of Reference 8.19.

Friction angle (ϕ) was assumed to be 45° based on information in Section R10.17 of Reference 8.19.

Cohesion (C) value of was estimated to be 5.71×10^6 Pa using, $\sigma_c=[2C \times \cos \phi]/(1-\sin \phi)$ or $C=[\sigma_c(1-\sin \phi)]/(2\cos \phi)$, based on Section 4.1 of Reference 8.10.

Shear Modulus value of 1.036×10^{10} Pa was used based on, S=E/[2(1+ν)], (see Section 4.1.2), where E is the Modulus of Elasticity and ν represents Poisson's Ratio for concrete.

Bulk Modulus (B) value of 1.381×10^{10} Pa was used based on, B=E/[3(1-2ν)], (see Section 4.1.2), where E is the Modulus of Elasticity and ν represents Poisson's Ratio for concrete.

5.2 SEISMIC INPUTS (TBV-193)

A 23 m/sec seismic wave velocity earthquake was used in the analysis based on Reference 8.13. A wave frequency of 5 Hz with duration value of 1 second was assumed and used in the analysis. The previous analysis of the ESF ground support system (Reference 8.10) was used as a basis for these assumptions. All seismic parameters will be verified upon resolution of TBV-193.

5.3 ROCK SUPPORT ELEMENTS

Support members available in FLAC are intended to represent props of wooden packs. These are used commonly to stabilize the underground openings. A support member is a spring connected between the two boundaries. The support member intended to impose forces on the boundaries to which it is connected. In this analysis, the support members were used to approximate the stabilizing effect that the wooden props, cribbing, and blocking provide in the 3.01.X areas. The location of these elements were assumed and selected to represent a uniform distribution of the wooden cribbing on the steel sets/rock face within the voids. A rock support element stiffness value of 1×10^{8} N/m was assumed and used in the analysis. This value was based on a conservative assumption to ensure that rock mass deformation loads are transferred to the steel set thus providing interaction between the steel set and the surrounding rock mass.

5.4 IN SITU STRESS ESTIMATES

Initial stresses used in the computer analyses at the two steel set locations are estimated based on the gravitational stresses induced by the weight of the overburden ($h_i \rho_i g$, where h_i and ρ_i are thickness and density for each rock mass unit) as explained in Section 6.6.2. The depth of the rock for steel set locations analyzed here were estimated from the best available geologic model as presented in Reference 8.17, Attachment III. The horizontal to vertical in situ stress ratios of 0.3, and 1.0 are used in this analysis to provide a lower and upper bound for computations. The measured stresses at alcove 5 (Reference 8.20) are used as a basis for this assumption indicating that the actual stress ratios are within the assumed ranges. At steel set #1272 location a tunnel centerline depth of 183 m and at steel set #1699 location a depth of 40.22 m were assumed based on Reference 8.17, Attachment III.

6. ANALYSIS

6.1 BACKGROUND

The 3.01.X areas refer to sections of the ESF Main Loop that were constructed under Section 3.01.X of the Subsurface General Construction specification (Reference 8.4). The specification indicates that special actions may be necessary to continue excavation in the event that adverse ground conditions prevent normal Tunnel Boring Machine (TBM) operations and jeopardize continued advance. The specification allows the Constructor and A/E to jointly develop a plan based on the actual ground conditions in accordance with Technical Document Preparation Plan (TDPP) for documentation of Plans for Continuing TBM Advance (Reference 8.14). During ESF Main Loop construction, eight sections were constructed utilizing provisions of 3.01.X section of the subsurface general construction specification.

Four 3.01.X areas are addressed in this analysis that extend from Station 60+15.28 to 60+49.22, 62+04.82 to 62+32.77, 75+21.02 to 75+28.38, and 76+63.08 to 77+41.23. These 3.01.X areas are grouped together in this analysis because they represent similar ground conditions. The plans for continuing TBM advance in these sections are presented in Reference 8.5. Figure 6-1 shows the locations of the 3.01.X areas addressed in this analysis along the ESF tunnel. This analysis supplements the work conducted utilizing NLP-3-35, *Exploratory Studies Facility Walk-Down for Quality Affecting Ground Support.*

The existing configuration of these sections including installed ground support and extent of voids are required to complete this task. Geotechnical properties of the rock mass and structural features in these sections are also required. Data from construction records, scanline mapping, full peripheral mapping, ESF monitoring program in addition to observations from walk-downs of these sections are utilized to document the as-built configurations. The geotechnical rock mass properties and structural features are estimated based on above data. The evaluation of the stability of the 3.01.X areas will include application of analytical methods using numerical analyses techniques considering the in situ and seismic loading conditions.

6.2 AS-BUILT CONFIGURATION OF 3.01.X AREAS

The first step in evaluation of stability of 3.01.X areas was to establish the as-built configurations of these sections. Steel set support was installed throughout these areas with partial steel lagging. There was practically very little information on the nature of the voids in these areas. The approximate configuration and the depth of the void areas were essential to conduct this analysis. To initiate this task, surveying capabilities were utilized to obtain additional data to establish the as-built configuration of the voids along these sections of the tunnel. The survey data (Reference 8.6) was used to develop the cross sections at steel set locations along the tunnel as presented in Figures 6-2 to 6-52. A more detailed description of the four 3.01.X areas is provided in following four sections.

6.2.1 3.01.X Area from Station 60+15.28 to 60+49.22

This 3.01.X area is approximately 34 meters long and is supported by W6X20 steel sets with partial steel lagging mainly installed above springline. This area is in the curved section between the main and south ramp beginning at steel set #1265 and ending at steel set #1293. The area is located in the Topopah Spring welded, lithophysal-poor (TSw2) thermal-mechanical unit and falls into the crystal-poor middle nonlithophysal zone (Tptpmn) lithostratigraphic unit. The plan for continued TBM advance (Reference 8.5) indicates that prior to steel set installation the void surface should be flash coated by shotcrete for safety purposes and cribbing (steel and or timber) be installed over steel sets. Voids in this area range up to 1.7 m in depth where most of fall-outs occurred in the quarter arches rather than directly in the crown. Extend of voids were measured post construction using surveying equipment (Reference 8.6). The results are presented in Figures 6-2 to 6-12 showing cross sections at steel set locations including approximated extend of voids. During the walk-downs it was observed that steel blocking was used in voids between steel sets #1265 to #1278. The wood blocking was used in the remainder of the section to fill the voids. The deepest void was recorded to be at steel set #1271 in the right quarter arch area. Most of the voids are less than 1 m deep for the entire section. Welded wire fabric (interlocking mesh) was used at the crown and left side instead of lagging between steel sets #1289 and #1293 where the rock quality is good with no voids present. Steel sets #1286 to #1293 appear to be off alignment at the right side with #1286 and #1287 being the worst. There was no blocking at the right side in the voids that may have contributed to the alignment problem initially. There is no instrumentation installed on any of the steel sets in this section.

6.2.2 3.01.X Area from Station 62+04.82 to 62+32.77

This 3.01.X area is about 28 meters long and is supported by W6X20 steel sets with partial steel lagging mainly installed above springline. This area is in the curved section between the main and south ramp beginning at steel set #1366 and ending at steel set #1389. The area is located in the Topopah Spring welded, lithophysal-poor (TSw2) thermal-mechanical unit and falls into the crystal-poor middle nonlithophysal zone (Tptpmn) lithostratigraphic unit. The plan for continued TBM advance (Reference 8.5) indicates that prior to steel set installation the void surface to be flash coated by shotcrete for safety purposes and cribbing (steel and or timber) be installed over steel sets. Voids in this area range up to 1.4 meters in depth. Extend of voids were measured post construction using surveying equipment (Reference 8.6). The results are presented in Figures 6-13 to 6-24 showing cross sections at steel set locations including approximated extend of voids. During the walk-down it was observed that wood blocking was used in this section to fill the voids. The deepest voids were recorded to be at steel sets #1371 (right quarter arch) and #1383 (left side near springline). Most of the voids are less than 1 m deep for the entire section. During the walk-downs, steel sets #1375 and #1382 appeared to be off alignment at the right side. There is no instrumentation installed on any of the steel sets in this section.

6.2.3 3.01.X Area from Station 75+21.02 to 75+28.38

This 3.01.X area is about 9 meters long and is supported by W6X20 steel sets with steel lagging mainly installed tightly above springline over the crown. This area is located in the south ramp beginning at steel set #1624 and ending at steel set #1631. The area is located in the Tiva Canyon welded (TCw) thermal-mechanical unit and falls into the lower nonlithophysal zone (Tpcpln) lithostratigraphic unit. The plan for continued TBM advance (Reference 8.5) indicates that prior to steel set installation the void surface be flash coated by shotcrete for safety purposes, as required, and cribbing (steel and or timber) be installed over steel sets. Voids in this area range up to 1.73 meters in depth. Extend of voids were measured post construction using surveying equipment (Reference 8.6). The results are presented in Figures 6-25 to 6-26 showing cross sections at steel set locations including approximated extend of voids. The measurements were made only at two steel set locations due to tight lagging in this area. During the walk-down it was observed that wood blocking was used in this section to fill the voids. The deepest void was recorded to be at steel set #1625 (right crown area). There is no instrumentation installed on any of the steel sets in this section.

6.2.4 3.01.X Area from Station 76+63.08 to 77+41.23

This 3.01.X area is about 78 meters long and is supported by W6X20 and W8X31 steel sets with steel lagging mainly installed tightly above springline over the crown. This area is located in the south ramp beginning at steel set #1640 and ending at steel set #1704. The area is located in the Tiva Canyon welded (TCw) thermal-mechanical unit and falls into the middle nonlithophysal zone (Tpcpmn) lithostratigraphic unit. The plan for continued TBM advance (Reference 8.5) indicates that prior to steel set installation the void surface be flash coated by shotcrete for safety purposes, as required, and cribbing (steel and or timber) be installed over steel sets. Voids in this area range up to 3 meters in depth. Extend of voids were measured post construction using surveying equipment (Reference 8.6). The results are presented in Figures 6-27 to 6-52 showing cross sections at steel set locations including approximated extend of voids. During the walk-down it was observed that wood blocking was used in this section to fill the voids. The deepest voids were recorded to be at steel set #1699 (crown area). Most of the voids in this section are located at the crown area. There is no instrumentation installed on any of the steel sets in this section. A deformation monitoring station is located in this section at Station 76+96.

6.3 ROCK MASS PROPERTIES AND STRUCTURAL FEATURES

The structural features in these areas were documented by full peripheral mapping of the exposed rock mainly on the sides. The crown area was lagged tightly for the most part to provide for personnel safety. The results of full peripheral mapping of the structures are presented in References 8.21 and 8.22. Installed steel sets and extent of steel lagging are also shown on the full peripheral maps of these areas (References 8.21 and 8.22).

Scanline and full peripheral mapping produced rock quality estimates (Q) for these sections. The range of Q values and modified Q values for each 3.01.X area from Reference 8.8 are presented in Table 2. A detailed presentation of these parameters and methods of estimation are presented in Reference 8.8. The Q values are presented here for information purposes. These values were not directly used in this analysis.

Table 2. Range of Q Values Based on Scanline and Full Peripheral Mapping (Reference 8.8)

Station	Scanline		Full Peripheral	
	Q	$Q_{Modified}$	Q	$Q_{Modified}$
60+15.28 to 60+49.22	0.32 - 1.83	1.5 - 20.41	0.21 - 1.38	0.5 – 13.42
62+04.82 to 62+32.77	0.18 - 0.64	0.63 - 4.23	0.11 - 0.89	0.30 – 1.78
75+21.02 to 75+28.38	0.47 - 12.95	2.88 - 66.03	0.52 - 1.99	1.72 – 4.78
76+63.08 to 77+41.23	0.48 - 233.50	2.61 - 718.92	0.42 – 14.50	1.57 – 25.22

6.4 DEFORMATION MONITORING RESULTS AT STATION 76+96

A type B instrumentation station is located in the 3.01.X area at Station 76+96. This station consists of three borehole extensometers (one MPBX and two SPBX), and six convergence pins. The MPBX was installed at the crown while the SPBXs were installed at the springline. The monitored data were obtained from TDMS (Reference 8.16) and were post processed using EXCEL 97. Deformation monitored from borehole extensometers in this station is presented in Figure 6-53. Deformations measured from tape extensometer for Chords H, L, R, and V are presented in Figure 6-54. As shown in the figure, the last instrumentation reading was recorded in July 15, 1998.

The results of monitoring data are consistent with the conclusion of an earlier deformation monitoring analysis (Reference 8.15) indicating that measured convergence is in general low. In Reference 8.15 it was concluded that data from borehole extensometers have higher accuracy than the tape extensometer with less chance of human error during data acquisition.

6.5 3.01.X AREA GROUND SUPPORT RECOMMENDATIONS

The 3.01.X areas addressed in this analysis represent densely fractured zones in TSw2 and TCw units. Most of the voids were generated during construction prior to the steel set installation. Surface of the voids in some locations were coated with a very thin layer of shotcrete and wood cribbing was installed in the voids above the steel sets, mainly from springline to springline at the crown location. Steel lagging was installed tightly at the crown above springline for the most part but the sides were not lagged in order to accommodate mapping activities in support of site characterization.

In majority of these sections, voids behind steel sets at or below the springline were not blocked. It appears that some of the voids on the sides have occurred due to ongoing raveling since tunnel construction. There is not enough information to determine when the raveling occurred but there are some signs of continued raveling and loosening of rock blocks on the sides, especially where the blocking is inadequate. Continued raveling on the sides will cause further loosening of the block above spring line leading to failure of these blocks. In order to mitigate this problem, the existing ground support system must be supplemented on the sides in these sections.

Timber blocking and cribbing was used extensively in the voids above the springline. The timber blocking is considered to be a temporary support and eventually, for the long-term repository operations, a more permanent support such as lightweight concrete fill must be utilized in the voids at the crown location. The wood blocking could be encased in the concrete and the loads will be evenly spread on the steel sets. For ESF purposes, the voids at the sides of the tunnel must be filled with concrete or shotcrete application. The crown area must be filled with lightweight material preferably lightweight concrete to stop further loosening of rock blocks and potential for deleterious rock movement. The filling of the crown area may be deferred at this time until the site is found to be suitable for the repository. A combination of existing steel set support and timber cribbing with a rigorous monitoring program must be utilized if the crown area concrete fill is deferred at this time. Shoring of the sides of the tunnel in these locations, as described previously with shotcrete application or concrete filling, will further enhance the stability of the crown area and will minimize the overall instability on these sections.

In summary, the failure mode at these locations is the continued raveling of blocks of rock mainly at the sides of the tunnel. The steel sets are installed on a 1.22 m spacing with no lagging on the sides. Therefore, at the sides of the tunnel, there is no effective ground support means to stop the raveling and potential for deleterious rock movement. The existing ground support system must be supplemented on the sides and the crown area in these sections. The voids on the sides, both between the steel sets and behind the sets, must be filled either by shotcrete application or concrete filling. For concrete filling, the installed steel sets could be utilized as a part of construction forms in a very cost-effective manner. The construction plans for this area may be developed by the constructor and shall be submitted to A/E for approval prior to its construction. The A/E shall evaluate the construction method and ensure that steel sets will accommodate the dynamic loading due to concrete filling as well as the dead loads of the fill material. Figure 6-55 illustrates a typical formwork that could be used to fill the voids on the sides of the tunnel. The shotcrete application provides another method for filling the voids on the sides of the tunnel. The shotcrete application may be the preferred choice where the voids are not very large. In some locations where the voids are limited to one side of the tunnel, the shotcrete application will only be required on that side. Figure 6-56 illustrates a two-stage process for filling the voids at these locations. Stage 1 is to be completed to supplement the existing ESF ground support system as soon as practical. Stage 2, as indicated earlier may be deferred at this time, until the site is found to be suitable at which time it shall be completed. If Stage 2 is deferred at this time a more rigorous monitoring program must be implemented in these sections that include installation of strain gauges and programmatic recording/evaluation of readings complemented by routine visual inspection and documentation of their status.

6.6 3.01.X AREA GROUND SUPPORT ANALYSIS

In this section, the numerical methods are applied to analyze the existing ground support system subjected to in situ and seismic loads. Then the supplemented ground support system (steel sets plus the concrete/shotcrete fill) is subjected to same loads and the overall stability is evaluated.

6.6.1 Scope of Analysis

Analysis of the impact of an earthquake remains an integral part of ground support design, as the dynamic loads may affect the tunnel performance. In this analysis, evaluation of the rock/ground support performance was performed at two selected locations. The first location was at steel set #1272, Station 60+24.70, that was selected as representative of stress and rock performance for the structures located within the TSw2 thermomechanical unit at the depth in the range of 182.9 meters. The second location analyzed was at the steel set #1699, Station 77+35.22, that was chosen to represent the performance of steel set-supported strata, located at relatively shallow depth (40.22 m) within the TCw thermomechanical unit. These two locations were chosen because they represented the two of the largest void areas within the four 3.01.X areas analyzed. They were also representative of the both thermomechanical units.

FLAC Version 3.3 was used to analyze the steel set/rock mass interaction under in situ and seismic loading conditions. The void areas corresponding to these two locations were incorporated in the calculations. The steel sets were blocked against the rock with support elements defined in the FLAC manual as springs with constant $kn=1\times10^8$ N/m (see Section 5.3). The steel set was represented as a ring composed of five layers of regular plane strain elements. To account for an asymmetrical load distribution within the irregular rock void, a full opening was used, with the overall grid dimensions of being equal to 76 m (width) and 76 m (height). Figure 6-57 shows a typical finite difference mesh used in the numerical analysis. Figure 6-58 illustrates the mesh refinement around the ESF opening.

The computer analyses were performed in four stages. First, a mesh with a 7.62 m circular opening and steel sets represented by the five inner-layers followed by voids corresponding to surveyed dimensions was generated. Next, the analyses were performed under in situ loading conditions. Third, the seismic loads were applied and opening stability was evaluated. Finally, the concrete/shotcrete fill was incorporated and analyzed under in situ and seismic loading.

6.6.2 In Situ Loads Analyses

For the in situ loading condition, the Mohr-Coulomb failure criterion was used to capture the post-elastic rock behavior. The in situ stress field is gravitational, with the vertical and horizontal stresses approximated using overburden rock mass. The in situ stress measurements in the field (Reference 8.20) indicate that the horizontal-to-vertical stress ratio commonly expressed as a Ko factor ranges approximately from 0.36 to 0.62 at Alcove #5 location within the ESF Main Loop. Two bounding cases were used in the analyses to estimate the in situ loading effects. The first case was solved for Ko value of 0.3 representing a lower bound, while Ko value of 1.0 provided the upper bound for the computations. The vertical stresses were computed using overburden rock mass loads for both cases.

To represent the steel sets in FLAC, a plane-stress beam formulation was transformed to a plane-strain formulation according to the following procedure. The properties of the equivalent plane-strain element were derived as follows:

The force across both plane-stress and equivalent plane-strain elements is equal, therefore:

$$E * A = E_{eq} * b * h \qquad \text{Equation (1)}$$

$$E_{eq} = (E * A)/(b * h) \qquad \text{Equation (2)}$$

Where:

E = Young's Modulus, A = Cross sectional area, b = spacing between the plane-stress elements, and h = thickness of the equivalent element

Considering a typical spacing b equal to 1 m, we obtain:

$$E_{eq} = E * A / h \qquad \text{Equation (3)}$$

The moment of inertia for the equivalent rectangular cross-section equals:

$$I_{eq} = (1/12) * b * h^3 \qquad \text{Equation (4)}$$

Also

$$E * I = E_{eq} * I_{eq} \qquad \text{Equation (5)}$$

Substituting for I_{eq} from Equation (4) results in,

$$E * I = E_{eq} (b * h^3 / 12) \qquad \text{Equation (6)}$$

Solving for E_{eq} results in,

$$E_{eq} = 12 * E * I / (b * h^3) \qquad \text{Equation (7)}$$

Letting b=1 as above results in,

$$E_{eq} = 12 * E * I / h^3 \qquad \text{Equation (8)}$$

Substituting E_{eq} from Equation (2) and I_{eq} from Equation (4) into Equation (5),

$$E * I = [(E * A) / (b * h)] * (b * h^3 / 12) \qquad \text{Equation (9)}$$

Solving for h,

$$h = (12 * I / A)^{1/2} \qquad \text{Equation (10)}$$

The density transformation is performed according to the following:

$$\rho_o * A = \rho_{oeq} * b * h \qquad \text{Equation (11)}$$

Considering b=1 as above, we obtain:

$$\rho_{oeq} = \rho_o * A / h \qquad \text{Equation (12)}$$

The equivalent shear modulus (G_{eq}) equals:

$$G_{eq} = [E_{eq} / 2(1+\nu)] * (1-\nu^2) \qquad \text{Equation (13)}$$

Where:

ν = Poisson's Ratio

$(1-\nu^2)$ = Scaling Factor based on Reference 8.7.

The equivalent bulk modulus (K_{eq}) equals:

$$K_{eq} = [E_{eq} / (3(1-2v))] * (1-v^2) \quad \text{Equation (14)}$$

The equivalent shear and bulk modulus were used in the FLAC computations. Additional detailed discussions on FLAC input parameters are presented in Reference 8.7.

After mesh construction and assignment of rock mass properties void areas around the opening were generated. The five layer inner ring was assigned the properties of the equivalent steel set and then the boundary conditions were set. The vertical and horizontal stresses were imposed to simulate the conditions at the specific location in the ESF. The numerical computations were continued using FLAC to obtain equilibrium under static gravity loading. Figures 6-59 and 6-61 show the results of the in situ loading calculations at steel set #1272 location for Ko values of 0.3 and 1.0, respectively. Figures 6-67 and 6-69 show the results of the in situ loading calculations at steel set #1699 location for K_o values of 0.3 and 1.0, respectively. The in situ loads analysis was repeated incorporating the enhanced ground support system by addition of concrete fill. For steel set #1272 location, the results are presented in Figures 6-63 and 6-65 for Ko values of 0.3 and 1.0, respectively. The results of in situ load calculations for steel set #1699 location are presented in Figures 6-71 and 6-73. The rock mass properties corresponding to Category 1 was used in the analysis representing the worst conditions encountered in the ESF excavation. The results indicate a small plastic zone near the excavated rock face at steel set #1272 location under in situ loads (Figure 6-59).

6.6.3 Seismic Loads Analyses

Note: This analysis (all parameters used for seismic analysis) needs to be re-evaluated when the seismic criteria for ESF is finalized and more data is available (removal of TBV-193). The ground support designed here does not preclude the option to supplement the installed ground support to satisfy more stringent seismic criteria (higher mean peak velocities).

Ground motion associated with earthquakes is considered in the design of the 3.01.X area ground support system. Dynamic analysis of the 3.01.X area ground support system was performed at both steel set #1272 and #1699 locations. The seismic loads were superimposed on in situ loads by applying a sinusoidal velocity wave at the bottom boundary and propagating upward. Boundary conditions were set to prevent the outward propagating waves from reflecting back into the model at the boundaries. Amplitude of the sine wave corresponds to maximum allowable velocity of 23 cm/sec (Reference 5.13, Appendix A). Attenuation with depth was not considered in the analyses for added conservatism. A frequency of 5 Hz was assumed and used in the dynamic analysis with a duration value of 1 second (see Section 5.3).

The results of the dynamic analysis at steel set #1272 location are presented in Figures 6-60 and 6-62 for K_o values of 0.3 and 1.0 respectively. By comparing the results to the in situ loading cases, it can be seen that the yield zone around the opening is slightly larger for the seismic case. This indicates a potential for failure and loosening of the rock mass at the opening boundaries. At steel set #1699 location similar results are observed as presented in Figures 6-68 and 6-70 representing K_o values of 0.3 and 1.0 respectively. Results incorporating concrete/shotcrete fill at the sides for steel set #1272 location are presented in Figures 6-64 and 6-66 for K_o values of 0.3 and 1.0 respectively. At steel set #1699 location, the dynamic analysis with concrete/shotcrete filled sides are presented in Figures 6-72 and 6-74 for K_o values of 0.3 and 1.0 respectively. The numerical results indicating stress factors due to bending, compressive axial loads, and combined bending and axial loads are presented in detail in Appendix II. The combined stress calculations are based on the methods prescribed in Chapter H of Reference 8.11. The similar method was used in steel set design for ESF Main Loop as described in Reference 8.10. The results for combined loads are presented in Figures 6-75 and 6-76 indicating that stress factors for all cases are below 1 at both steel set #1272 and #1699 locations.

6.7 3.01.X AREA PERMANENT FUNCTION GROUND SUPPORT

The existing ground support system in 3.01.X areas addressed in this analysis must be supplemented to meet the 150 year maintainable life requirement for permanent function item. For area between Stations 60+15.28 and 60+49.22, shotcrete/concrete fill shall be applied as follows. From steel set #1265 to #1289 both sides shall be supplemented with shotcrete/concrete fill application implementing Stage 1 as prescribed in Figure 6-56. From steel set #1289 to #1293 only the right hand side will require shotcrete/concrete fill application. In addition, steel sets #1272 and #1287 shall be instrumented with strain gauge prior to filling of the voids.

For area between Stations 62+04.82 and 62+32.77, shotcrete/concrete fill shall be applied as follows. From steel set #1366 to #1389 both sides shall be supplemented with shotcrete/concrete fill application implementing Stage 1 as prescribed in Figure 6-56. In addition, steel sets #1375 and #1383 shall be instrumented with strain gauge prior to filling of the voids.

For area between Stations 75+21.02 and 75+28.38, shotcrete/concrete fill shall be applied as follows. From steel set #1624 to #1630 both sides shall be supplemented with shotcrete/concrete fill application implementing Stage 1 as prescribed in Figure 6-56. In addition, steel set #1626 shall be instrumented with strain gauge prior to filling of the voids.

For area between Stations 76+63.08 and 77+41.23, shotcrete/concrete fill shall be applied as follows. From steel set #1640 to #1662 both sides shall be supplemented with shotcrete/concrete fill application implementing Stage 1 as prescribed in Figure 6-56. From steel set #1662 to #1665 no work is required. From steel set 1665 to 1670 spot shotcrete both sides as needed to prevent further raveling. Interlocking mesh was used between steel sets #1664 and #1670. From steel sets #1670 to #1704 both sides shall be supplemented with shotcrete/concrete fill application implementing Stage 1 as prescribed in Figure 6-56. From steel set #1662 to #1665 no work is required. In addition, steel sets #1652, #1676, and #1695 shall be instrumented with strain gauge prior to filling of the voids.

The Stage 2 treatment as prescribed in Figure 6-56 may be deferred and implemented after the site is recommended for repository. It should be noted that this area must be monitored more rigorously until the Stage 2 is completed. The monitoring plan for this area shall be developed and submitted to A/E for approval if the construction is deferred.

7. CONCLUSIONS

Four 3.01.X areas in the ESF Main Loop located between Stations 60+15.28 to 60+49.22, 62+04.82 to 62+32.77, 75+21.02 to 75+28.38, and 76+63.08 to 77+41.23 were considered in this analysis. These sections were constructed in accordance with Section 3.01.X of the Subsurface General Construction specification (Reference 8.4). Constructor and A/E developed a plan to advance the TBM in these sections in accordance with TDPP for documentation of plans for continuing TBM advance (Reference 8.14).

The main objectives of this analysis were to document the as-built configuration of the 3.01.X area including existing voids and installed ground support, and to design a ground support system that meets the requirements of the ESF permanent function items. The as build configuration showing the void areas at cross sections along 3.01.X areas were developed and presented in Figures 6-2 through 6-52 with a detailed description provided in Sections 6.2.1 to 6.2.4.

The existing ground conditions and state of the installed ground support system were evaluated in numerous visits to the ESF site as part of the ESF quality affecting ground support walk-downs. The failure mode at these locations was identified to be the continued raveling of blocks of rock mainly at the sides of the tunnel. The steel sets were installed at a 1.22 m spacing with no lagging on the sides. Presently, there is no effective ground support means at the sides to stop the raveling and potential for deleterious rock movement. The voids at the crown area, which are relatively large ranging from less than 1 m up to 3 m deep, were blocked with timber cribbing from the steel sets to the rock surface. Timber cribbing is considered to be a temporary means of support in these areas. Based on the field observations and the analyses of the existing structure, it was concluded that the existing ground support system in the 3.01.X areas must be supplemented on the sides and the crown in order to meet the requirements for the permanent function ground support system. The rock in these sections is highly fractured creating unstable conditions with a high probability of continued raveling unless an effective means of support is incorporated. The fractured exposed rock on the sides must be sealed and the voids behind steel sets must be filled to prevent further loosening of rock on the sides and ultimately above the crown. These sections are also highly susceptible to sustain damage during an earthquake which could cause further loosening and falling of rock blocks if remain unsupported.

The evaluation of the existing conditions and the installed ground support (steel sets) indicates that requirements 1, 5, 12, and 13 in Table 1 are not being addressed with the existing ground support. The existing ground support system in these areas is recommended to be supplemented, as prescribed in this analysis, to address these requirements. The existing ground support system does not meet the seismic requirement (requirement 1) and 150 year long term performance requirement (requirement 5). The monitoring program must be upgraded as prescribed in this analysis to satisfy requirement 12 in Table 1. The supplemental ground support recommendations as prescribed in this analysis will mitigate the potential for deleterious rock movement as shown in requirement 13 in Table 1.

The 3.01.X areas addressed in this analysis are located in rock mass representing TSw2 and TCw thermomechanical units. Computer analysis utilizing FLAC software (Reference 8.7) was used to analyze the existing ground support system representing both thermomechanical units at steel sets #1272 and #1699 locations. The data from field survey was used to incorporate the voids in the analyses of these section subjected to in situ and seismic loading conditions. The shotcrete/concrete backfill recommended for Stage 1 was also incorporated and analyzed. The main objective was to evaluate the supplemented ground support system's performance under seismic loading conditions. The results are presented in terms of stress factors in Figures 6-75 and 6-76. For both locations and for both K_o values, the stress factors considering combined bending and axial loads remain below 1. It should be noted that the analyses represented the rock at these locations as a continuum media with rock mass properties set incorporating the worst measured conditions in the field (Category 1 rock mass). The results provides good estimates of the state of the stresses within the rock mass and resultant loads on the ground support system under in situ and seismic loading conditions.

Based on the results of the detailed observations of the ground conditions at these locations and results of computer analyses, it is recommended to supplement the existing steel set support with additional support to be installed in two stages as illustrated in Figure 6-56. For the first stage, a minimum 50 mm (2 in) thick shotcrete is to be applied from the invert segment up to the lowest void. Then the void is recommended to be filled either by shotcrete application or by preparing a construction form and using concrete fill. The constructor shall determine the back fill method and obtain A/E concurrence prior to construction. For Stage 1, the voids between the steel set and the rock shall be filled to a height of approximately 2 m ($\pm$300 mm), measured up from the centerline (Figure 6-56). The extent of the height of fill above 2 m shall be determined in the field by the constructor and with A/E concurrence based on the field conditions. For monitoring purposes, Stage 1 backfill shall not exceed the crown level if the decision is made to defer Stage 2 construction for a later date. The plans for method of construction including the forms to be used shall be submitted to A/E for approval prior to start of construction. The A/E shall evaluate the method and ensure that the existing steel sets will support the dynamic loading of concrete emplacement as well as dead loads due to fill material. The calculations considered blocking points of approximately 500 mm apart, therefore, the contact voids behind steel sets shall not exceed 500 mm for Stage 1. For Stage 1 the concrete/shotcrete shall have a minimum compressive strength value of 2.76×10^7 Pa (4000 psi) at 28 days with placement slump of 100 mm (4 in) $\pm$ 25 mm (1 in). For Stage 2, lightweight materials, preferably lightweight concrete shall be installed to entirely fill cavities and encase existing wood blocking. The Stage 2 backfill material (e.g. lightweight concrete) shall have a minimum 3.45×10^6 (500 psi) compressive strength to account for tributary rock loads with adequate safety factors. The material to be used in Stage 2 construction (e.g. concrete mix) shall be submitted to A/E for approval prior to the start of construction. The A/E shall evaluate the steel sets to ensure it can accommodate loads due to dynamic loading caused by concrete backfill and dead loads of the fill material. To ensure maximum filling of the voids during Stage 2, vent/top off return pipes should be installed at the highest points of the fallout area. The return material will indicate proper filling of these voids. Concrete used in both stages shall follow the recommendations of applicable ACI standards.

The two stage process was adopted to provide the project with flexibility to either complete the task by finishing both stages or perform the minimum required to stabilize these sections with finishing the first stage and completing the second stage at a later date (when the site is found suitable for repository). This will provide short-term cost savings and will not have any significant long-term impacts on the total cost. A programmatic and rigorous monitoring of the crown section and the steel sets must accompany if the second stage is deferred. The ground support system recommended for the 3.01.X areas drastically minimizes the continued maintenance problem in these sections and eliminates the potential for deleterious rock movement.

In summary, for area between Stations 60+15.28 and 60+49.22, shotcrete/concrete fill shall be applied as follows. From steel set #1265 to #1289 both sides shall be supplemented with shotcrete/concrete fill application implementing Stage 1 as prescribed in Figure 6-56. From steel set #1289 to #1293 only the right hand side will require shotcrete/concrete fill application. In addition, steel sets #1272 and #1287 shall be instrumented with strain gauge prior to start of Stage 1 construction.

For area between Stations 62+04.82 and 62+32.77, shotcrete/concrete fill shall be applied as follows. From steel set #1366 to #1389 both sides shall be supplemented with shotcrete/concrete fill application implementing Stage 1 as prescribed in Figure 6-56. In addition, steel sets #1375 and #1383 shall be instrumented with strain gauge prior to start of Stage 1 construction.

For area between Stations 75+21.02 and 75+28.38, shotcrete/concrete fill shall be applied as follows. From steel set #1624 to #1630 both sides shall be supplemented with shotcrete/concrete fill application implementing Stage 1 as prescribed in Figure 6-56. In addition, steel set #1626 shall be instrumented with strain gauge prior to start of Stage 1 construction.

For area between Stations 76+63.08 and 77+41.23, shotcrete/concrete fill shall be applied as follows. From steel set #1640 to #1662 both sides shall be supplemented with shotcrete/concrete fill application implementing Stage 1 as prescribed in Figure 6-56. From steel set #1662 to #1665 no additional work is required. From steel set #1665 to #1670 spot shotcrete both sides as needed to prevent further raveling with no backfill required. From steel sets #1670 to #1704 both sides shall be supplemented with shotcrete/concrete fill application implementing Stage 1 as prescribed in Figure 6-56.

Steel sets #1652, #1676, and #1695 shall be instrumented with strain gauge prior to start of Stage 1 construction.

The Stage 2 construction for all four sections may be deferred until the site is found suitable for repository. The crown area must be routinely monitored to detect any raveling or changes in the status of wood blocking. The instruments shall be read routinely and analyzed. Any changes in ground conditions and unusual readings of the instruments shall be reported to A/E and dealt with swiftly. If the first stage construction is being deferred for a short time, a more rigorous monitoring of these areas must be conducted utilizing weekly observations and monthly readings of the steel set load cells. It should be noted that this monitoring will only address the static conditions and will not be able to address the seismic loading conditions. The monitoring plan must be submitted to A/E for their approval prior to its implementation if the decision is made to defer the construction in these areas. TBV-193 applies to the seismic inputs used in this analysis. The results must be reevaluated at the time of the closure of the TBV for impacts on the conclusions.

8. REFERENCES

The following is a complete list of references used in this analysis. Data Tracking Numbers (DTN), Record Processing Center Accession numbers (ACC), and Technical Information Center catalog numbers (TIC) are noted as appropriate for each reference. The legacy data from following references were not used as direct inputs in the analyses and therefore are not assigned a TBV number. The changes in these data will not impact the conclusions of this analysis.

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8.3 CRWMS M&O 1998. *Activity Evaluation: SC50560 Resolve Q Ground Support Issues.* Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981229.0130.

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8.8 CRWMS M&O 1997. *Confirmation of Empirical Design Methodologies.* BABEE0000-01717-5705-00002 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980219.0104.

8.9 CRWMS M&O 1998. *ESF Ground Support Confirmation.* BABEE0000-01717-5705-00003 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980727.0308.

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9.0 ATTACHMENTS

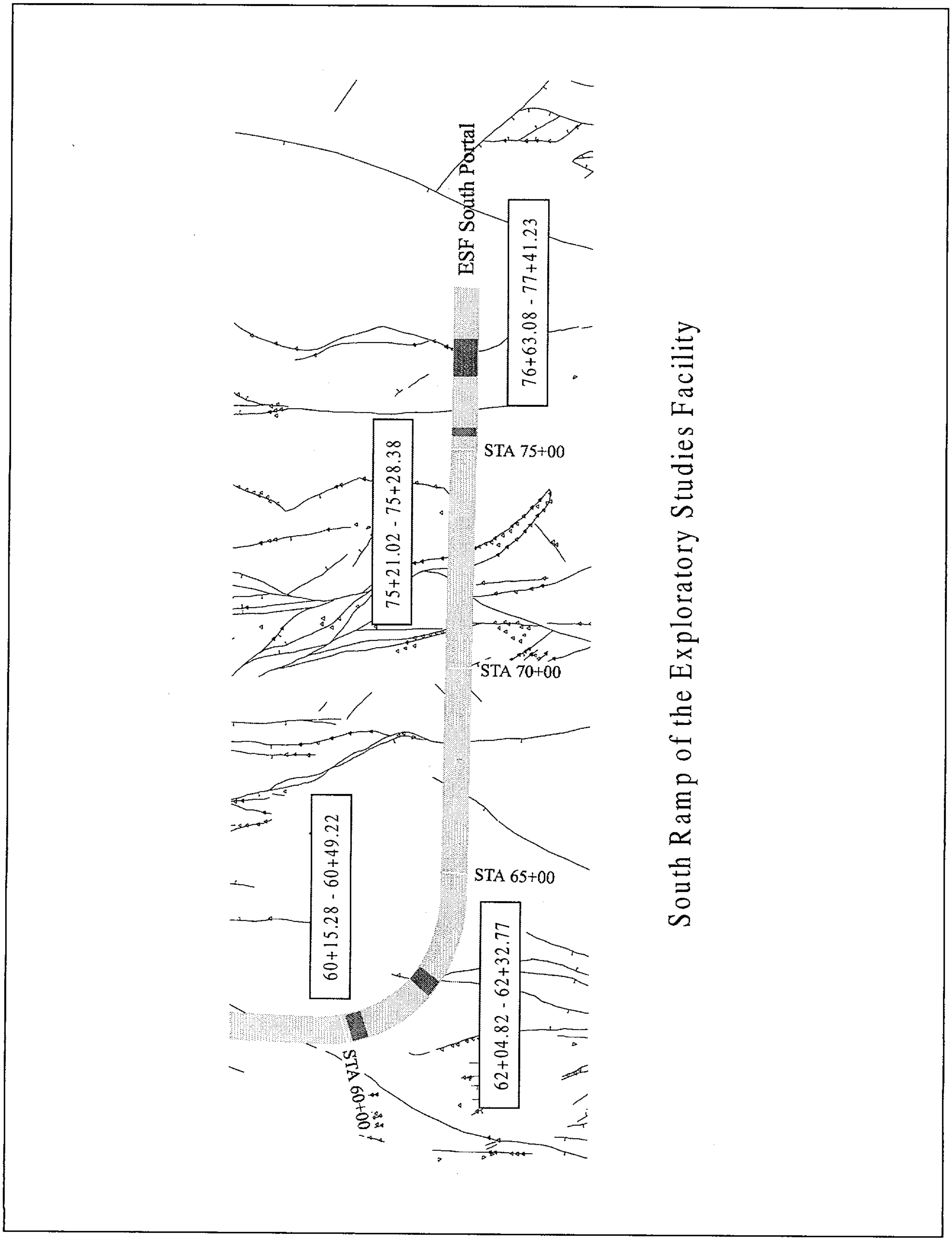


Figure 6-1. Locations of the 3.01.X Areas Addressed in This Analysis

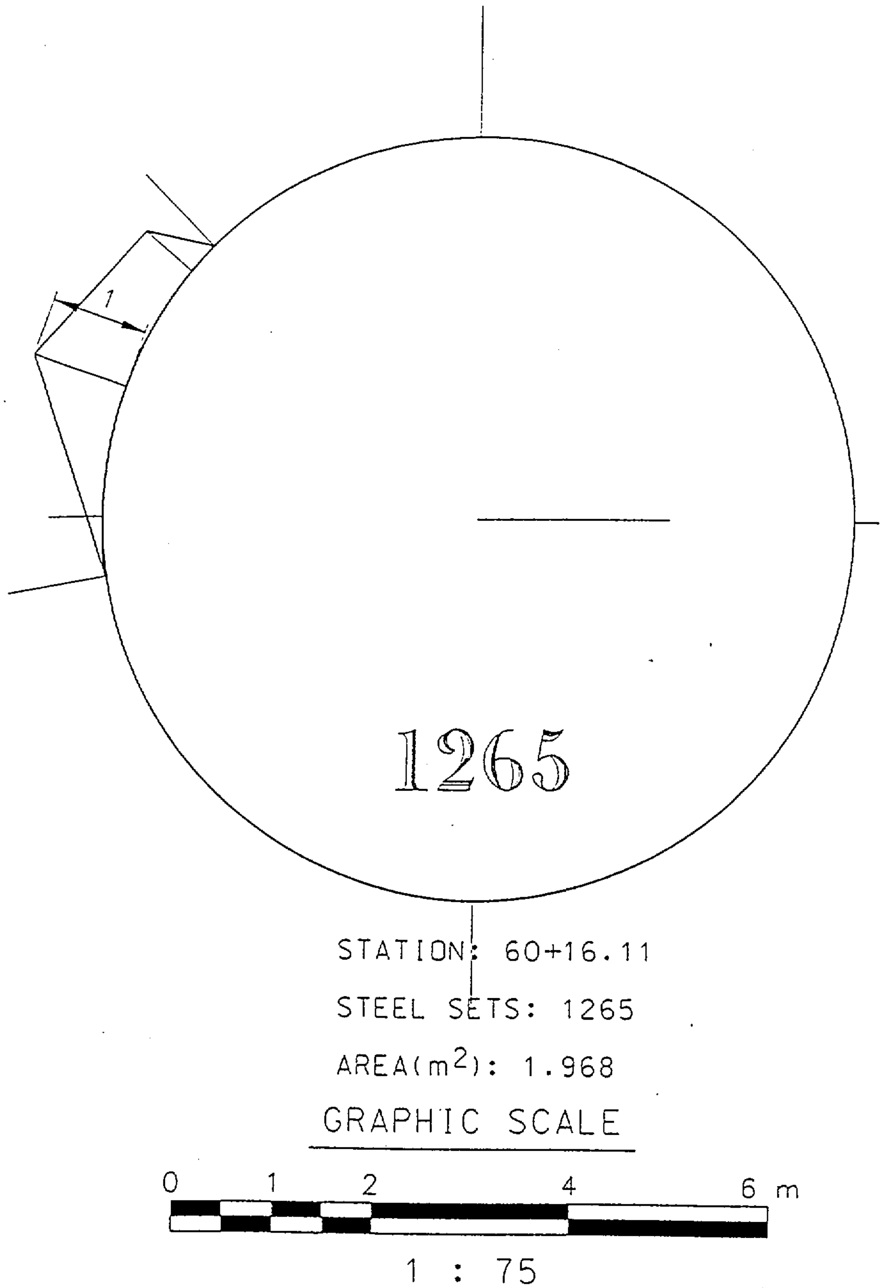
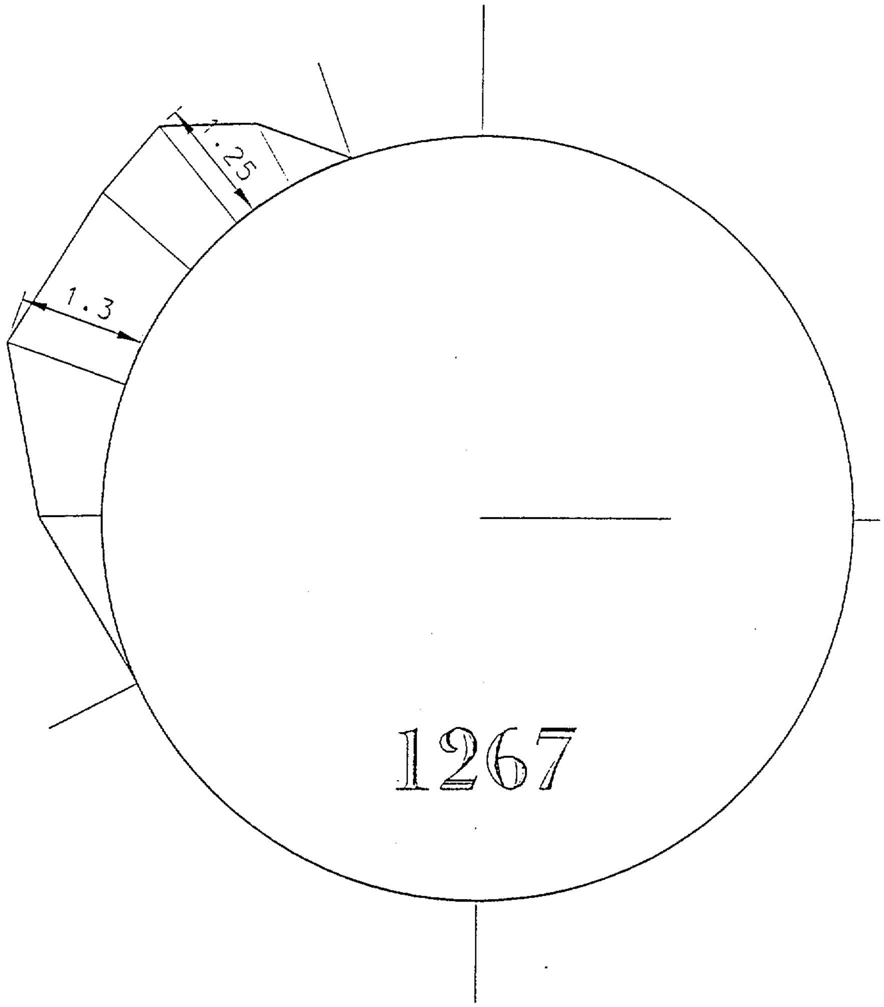


Figure 6-2. Estimates of Voids at Steel Set #1265 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)



STATION: 60+18.58

STEEL SETS: 1267

AREA(m^2): 5.509

Figure 6-3. Estimates of Voids at Steel Set #1267 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

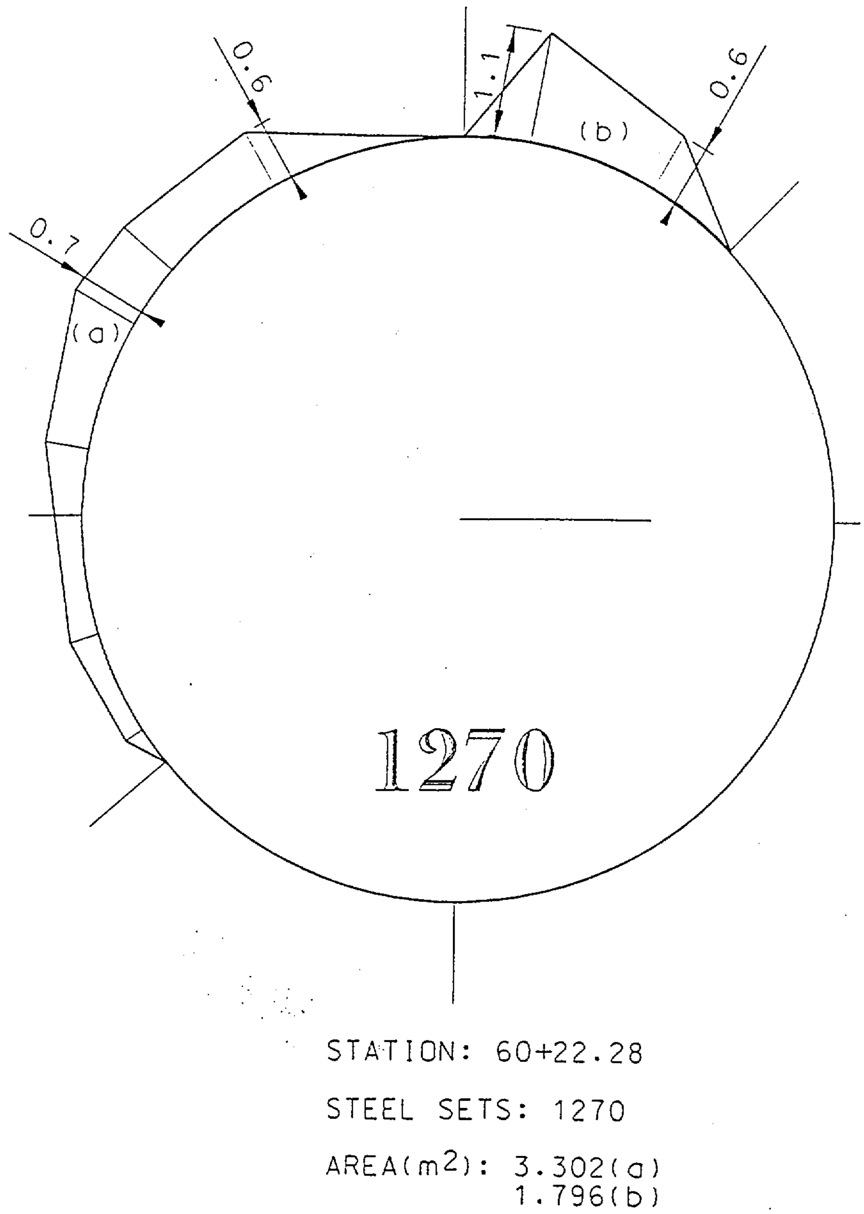


Figure 6-4. Estimates of Voids at Steel Set #1270 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

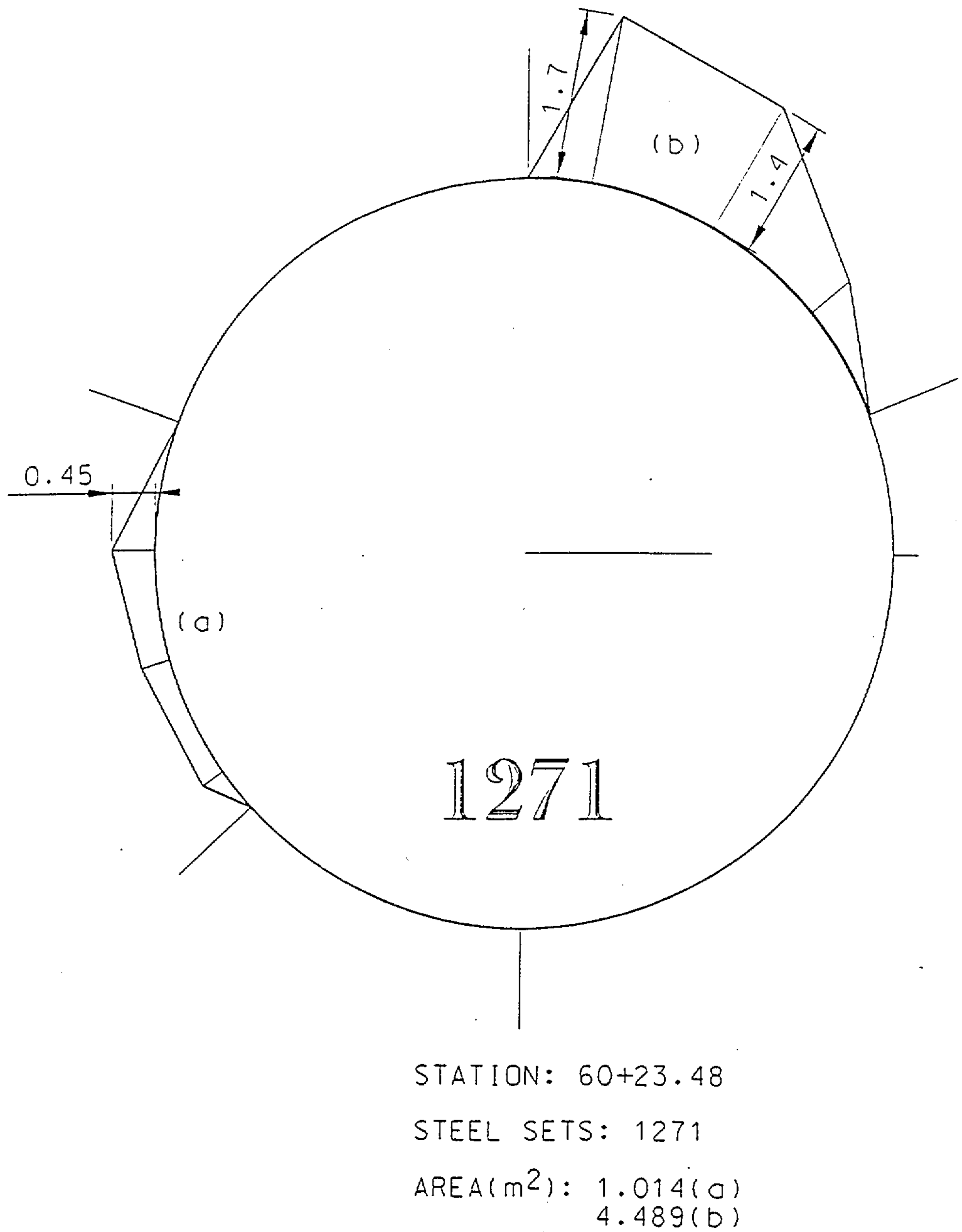


Figure 6-5. Estimates of Voids at Steel Set #1271 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

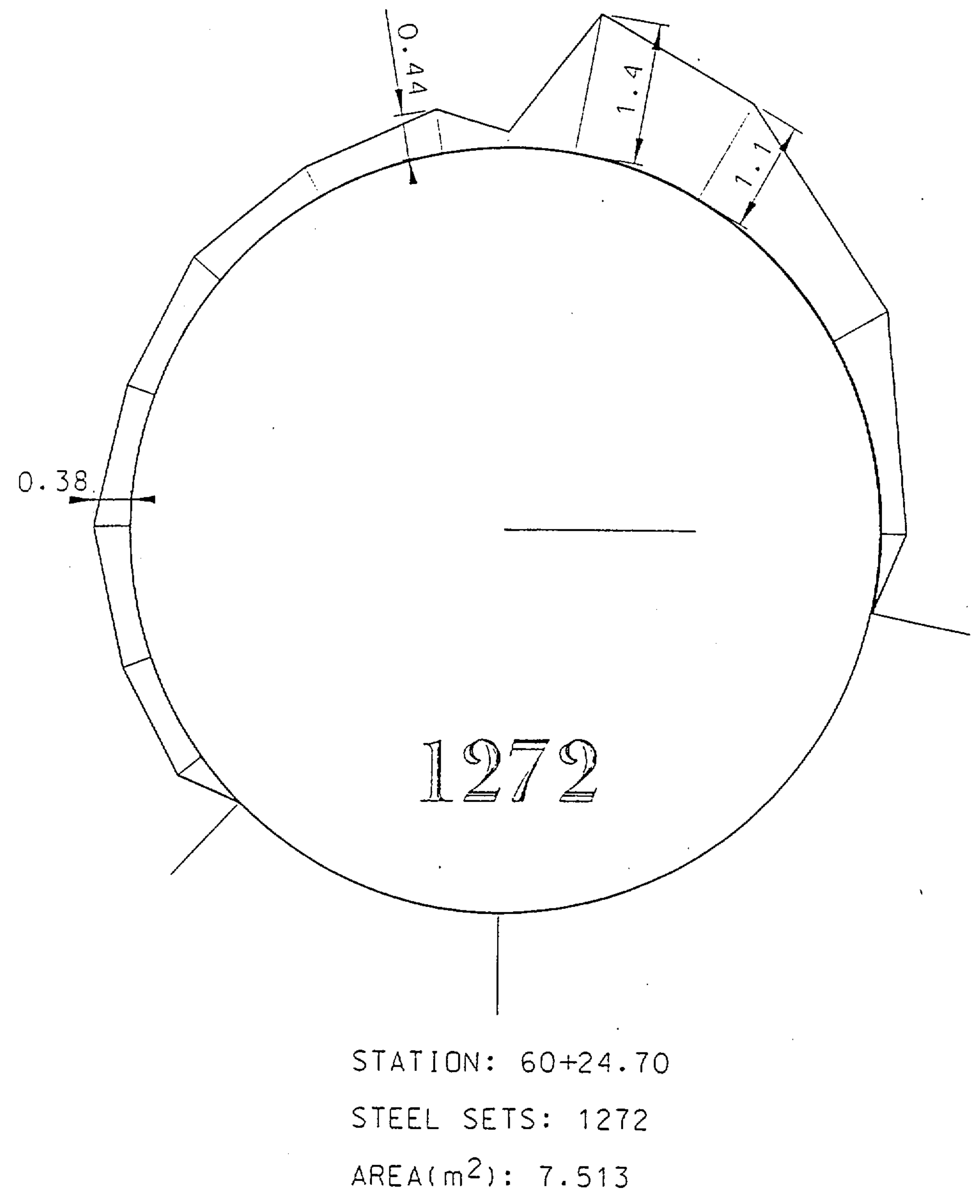


Figure 6-6. Estimates of Voids at Steel Set #1272 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

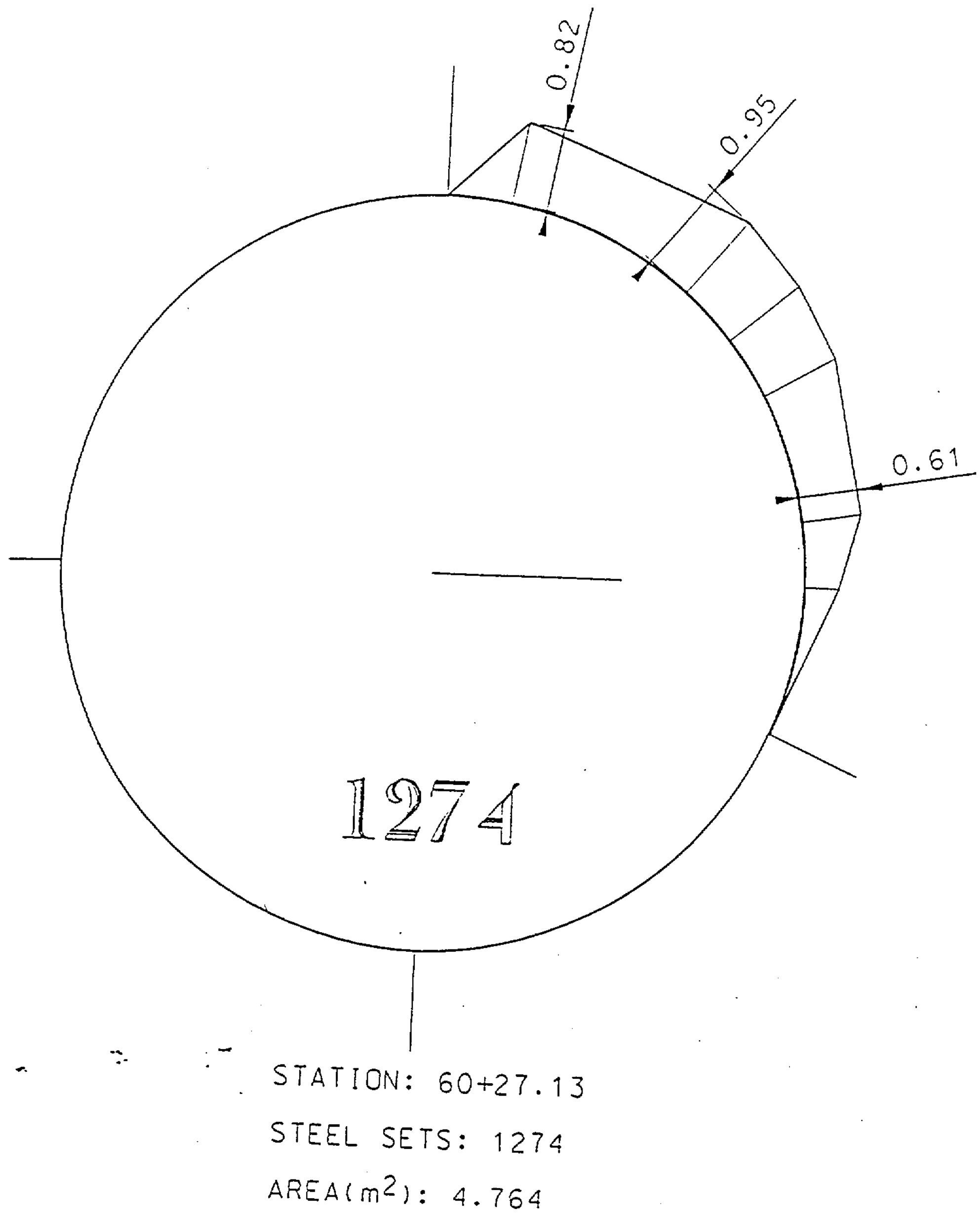


Figure 6-7. Estimates of Voids at Steel Set #1274 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

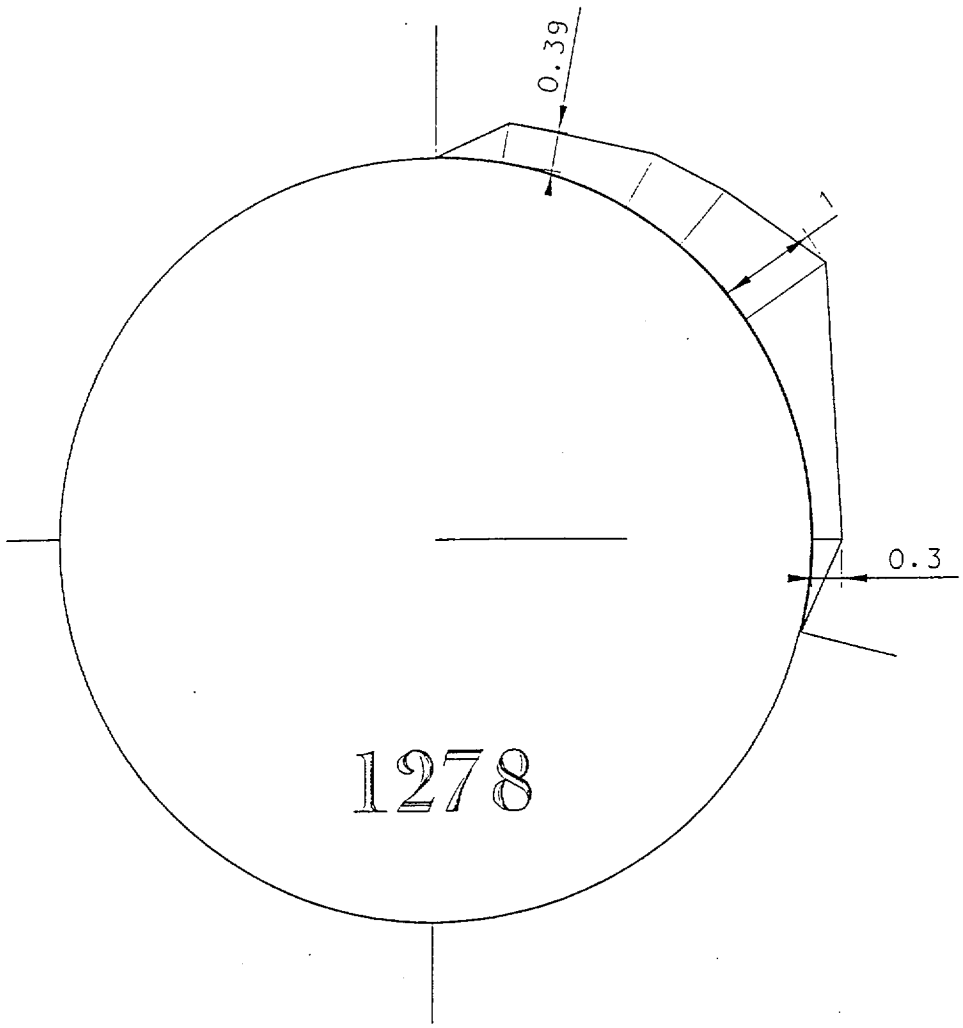
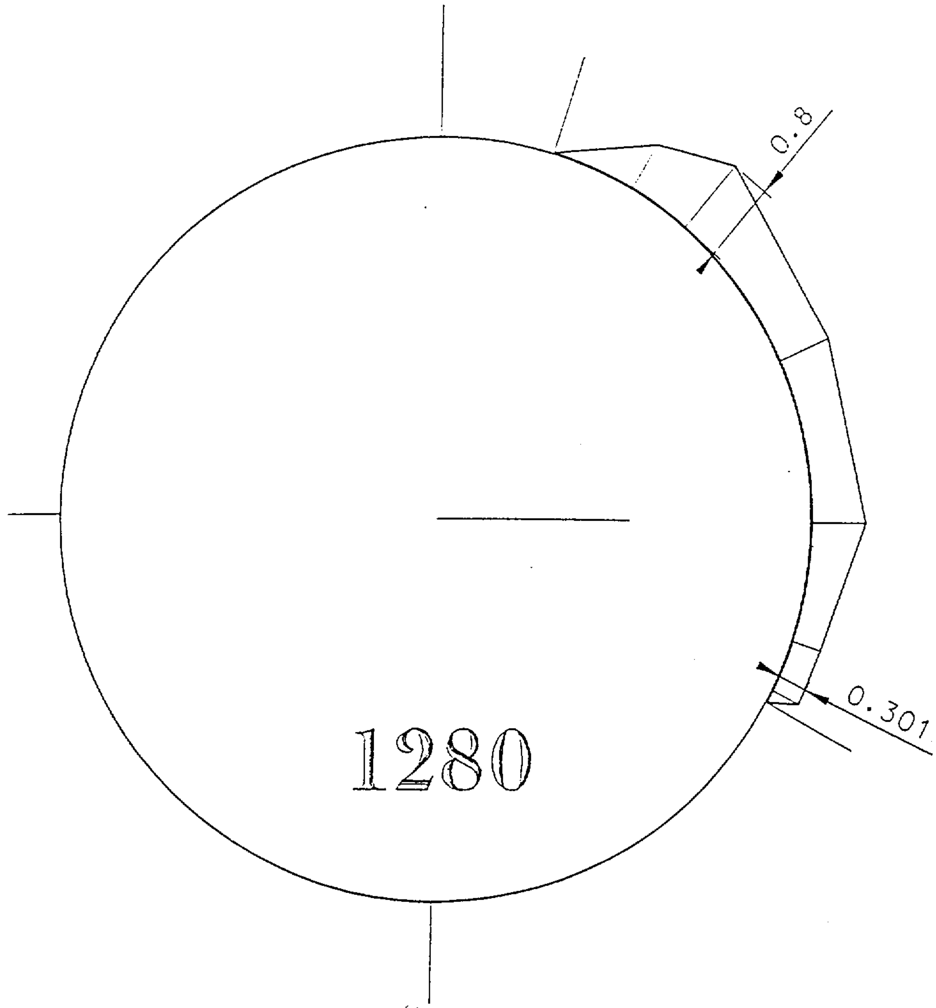


Figure 6-8. Estimates of Voids at Steel Set #1278 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)



STATION: 60+34.38

STEEL SETS: 1280

AREA(m^2): 3.256

Figure 6-9. Estimates of Voids at Steel Set #1280 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

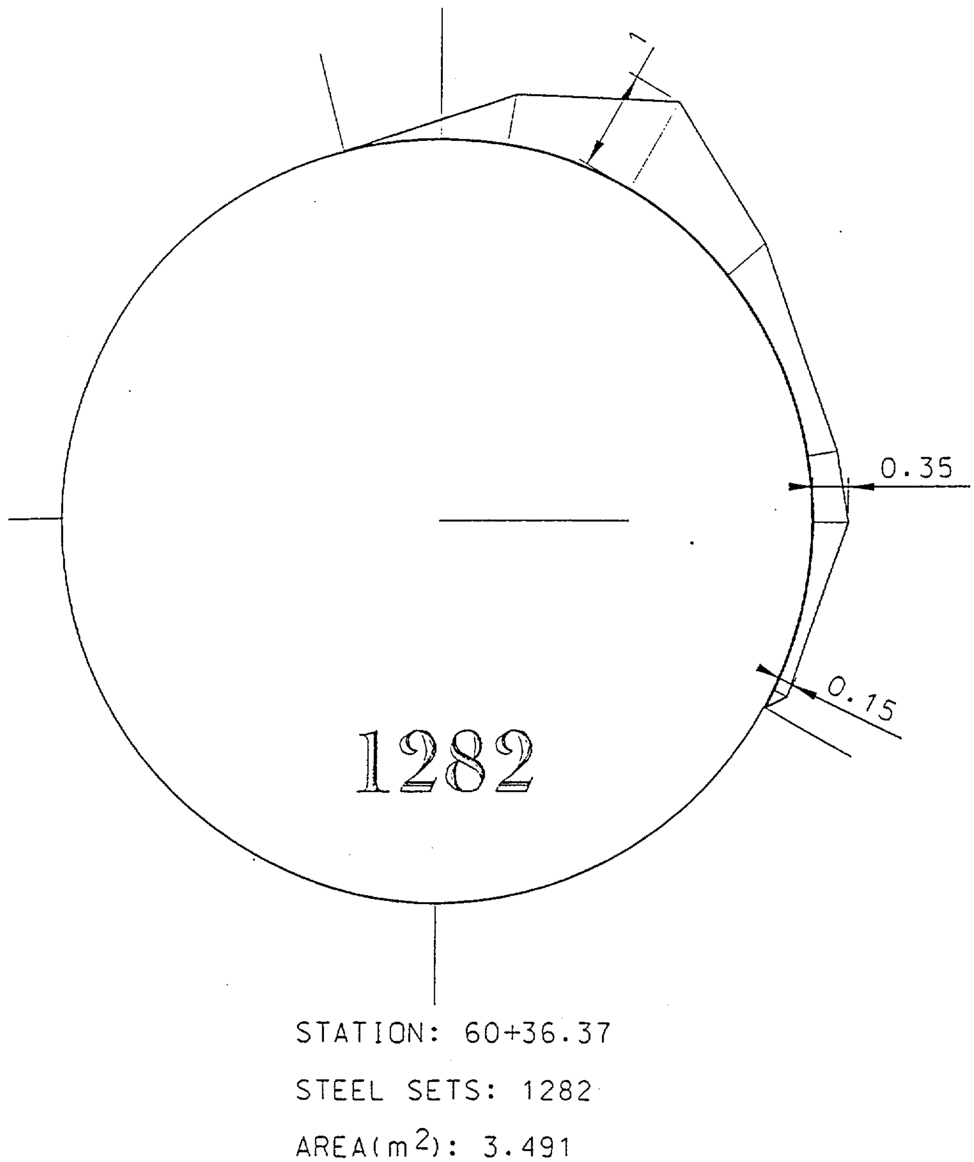


Figure 6-10. Estimates of Voids at Steel Set #1282 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

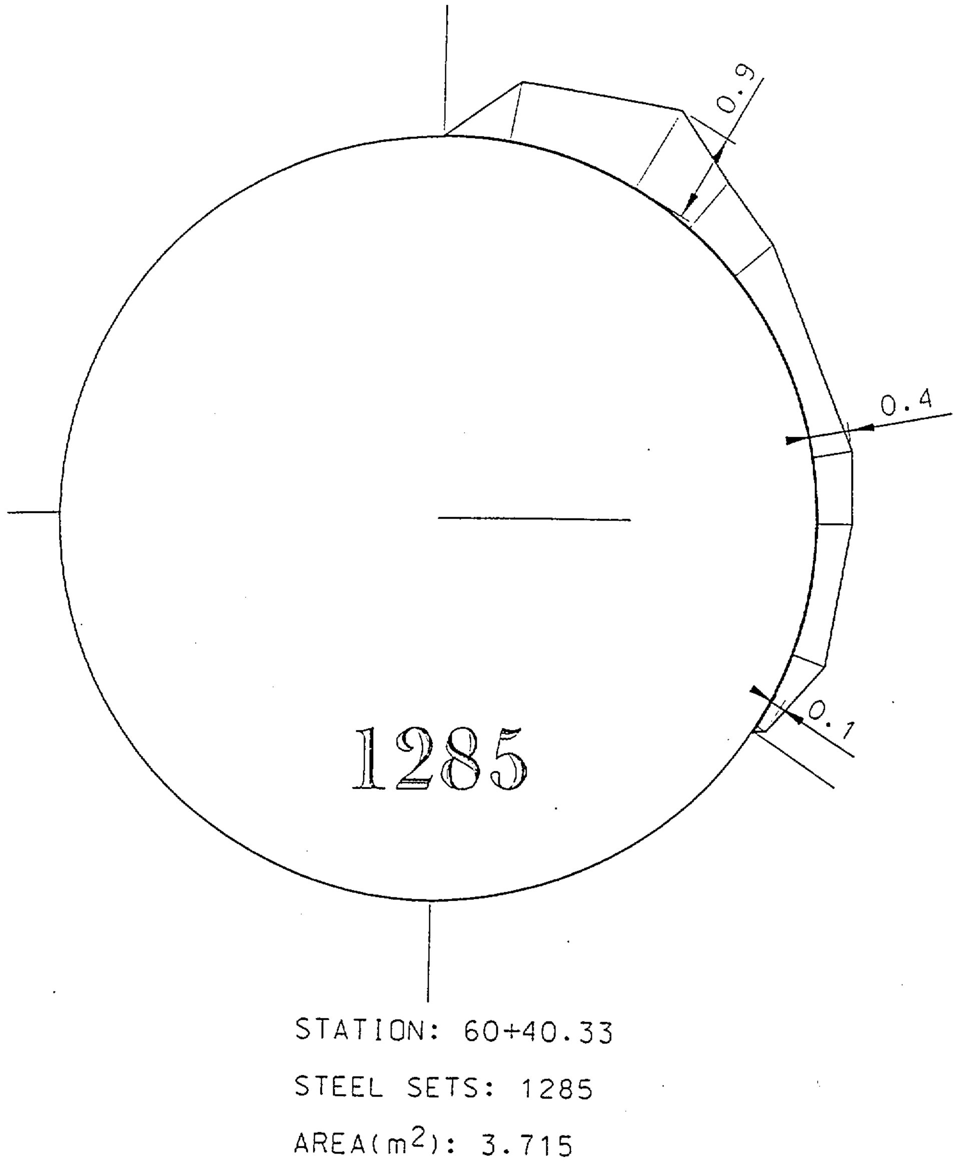


Figure 6-11. Estimates of Voids at Steel Set #1285 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

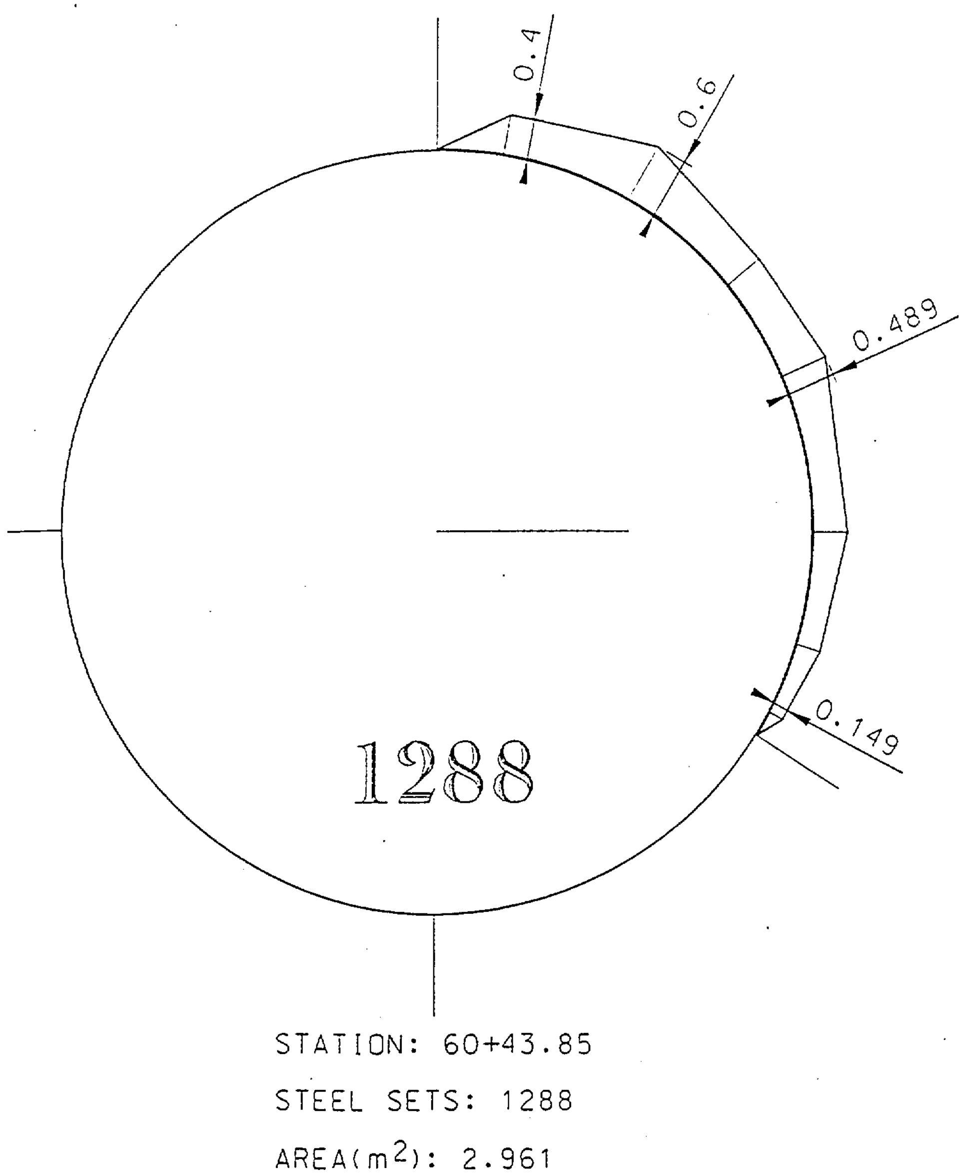
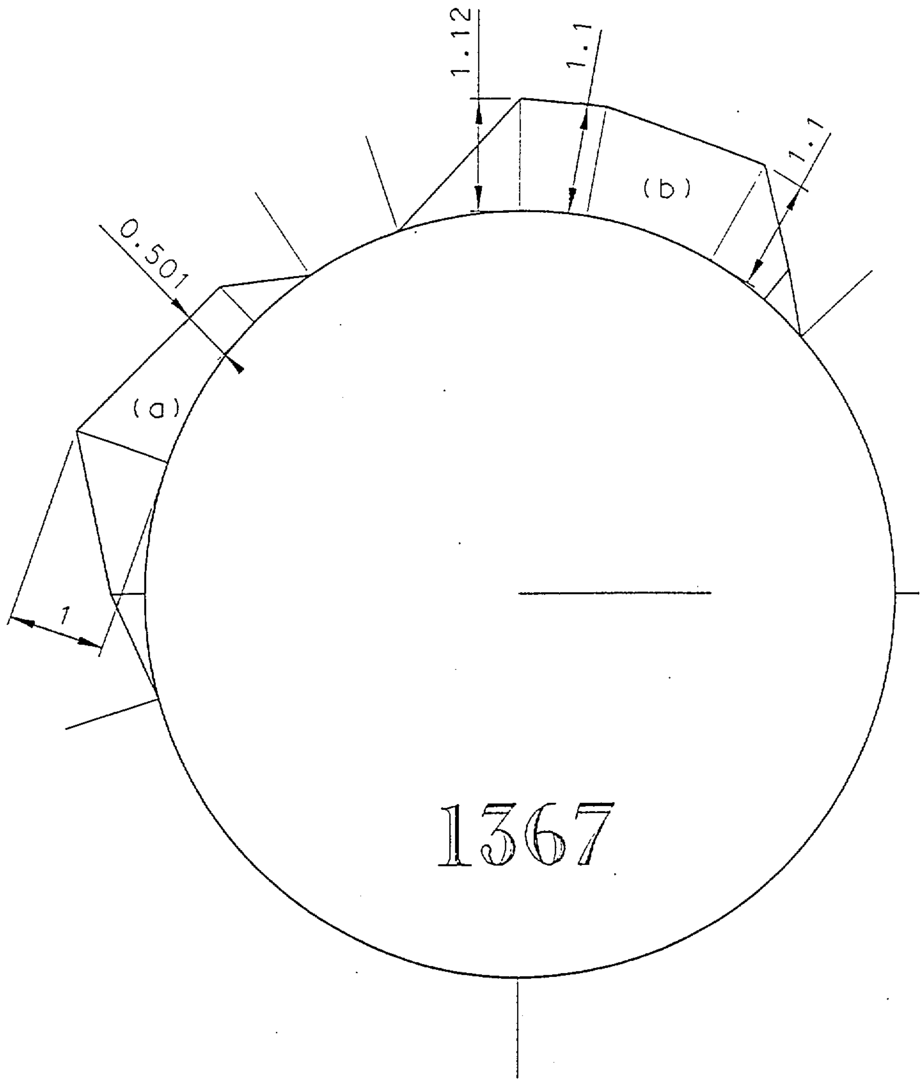


Figure 6-12. Estimates of Voids at Steel Set #1288 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

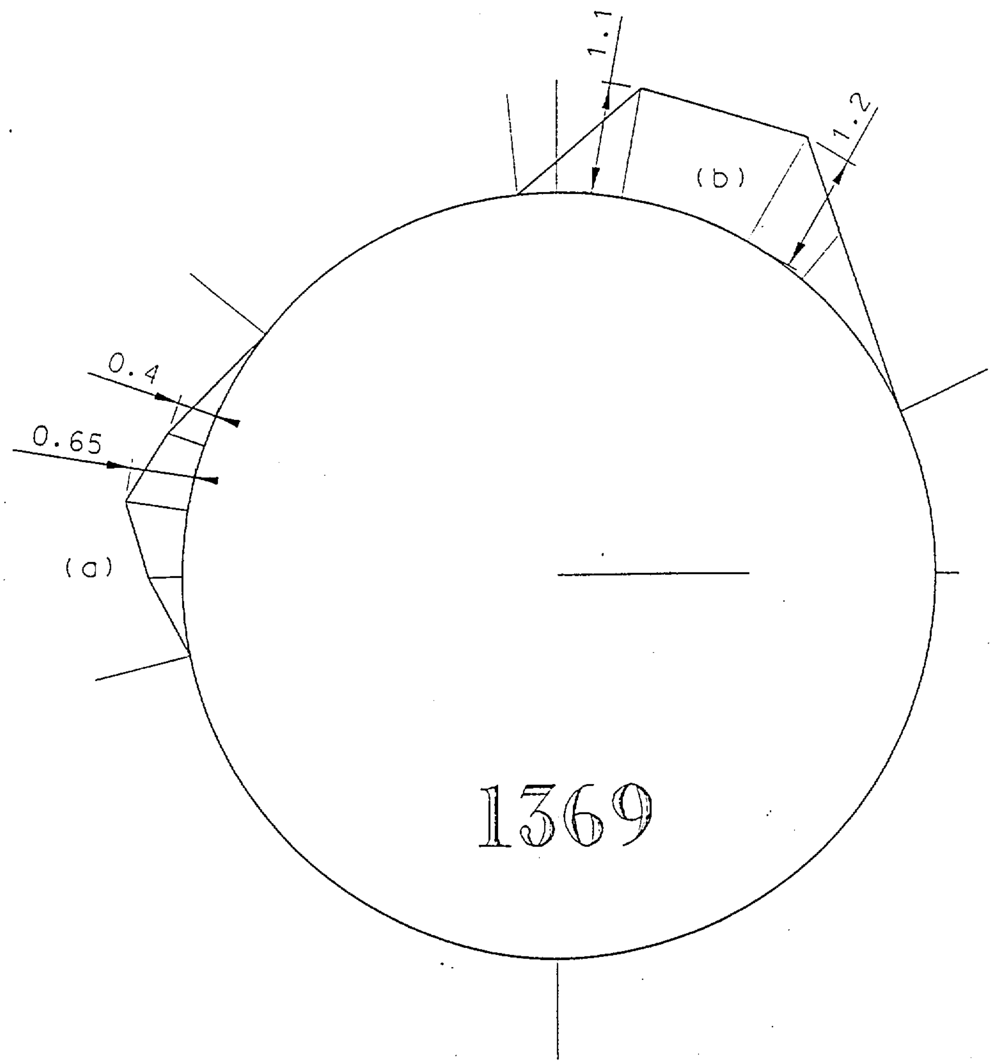


STATION: 62+05.46

STEEL SETS: 1367

AREA(m^2): 2.429(a)
3.704(b)

Figure 6-13. Estimates of Voids at Steel Set #1367 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)



STATION: 62+07.90

STEEL SETS: 1369

AREA(m^2): 1.035(a)
3.257(b)

Figure 6-14. Estimates of Voids at Steel Set #1369 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

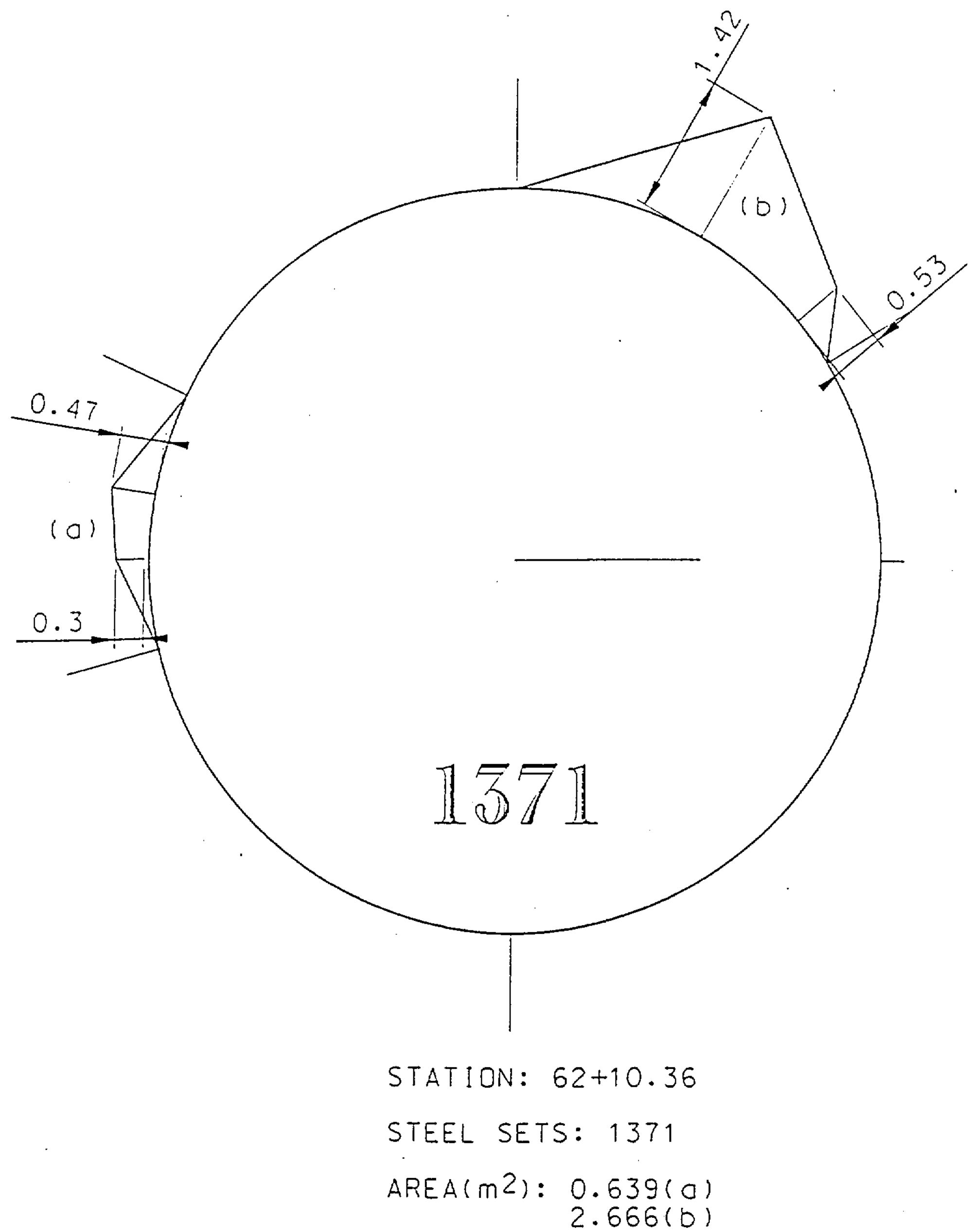
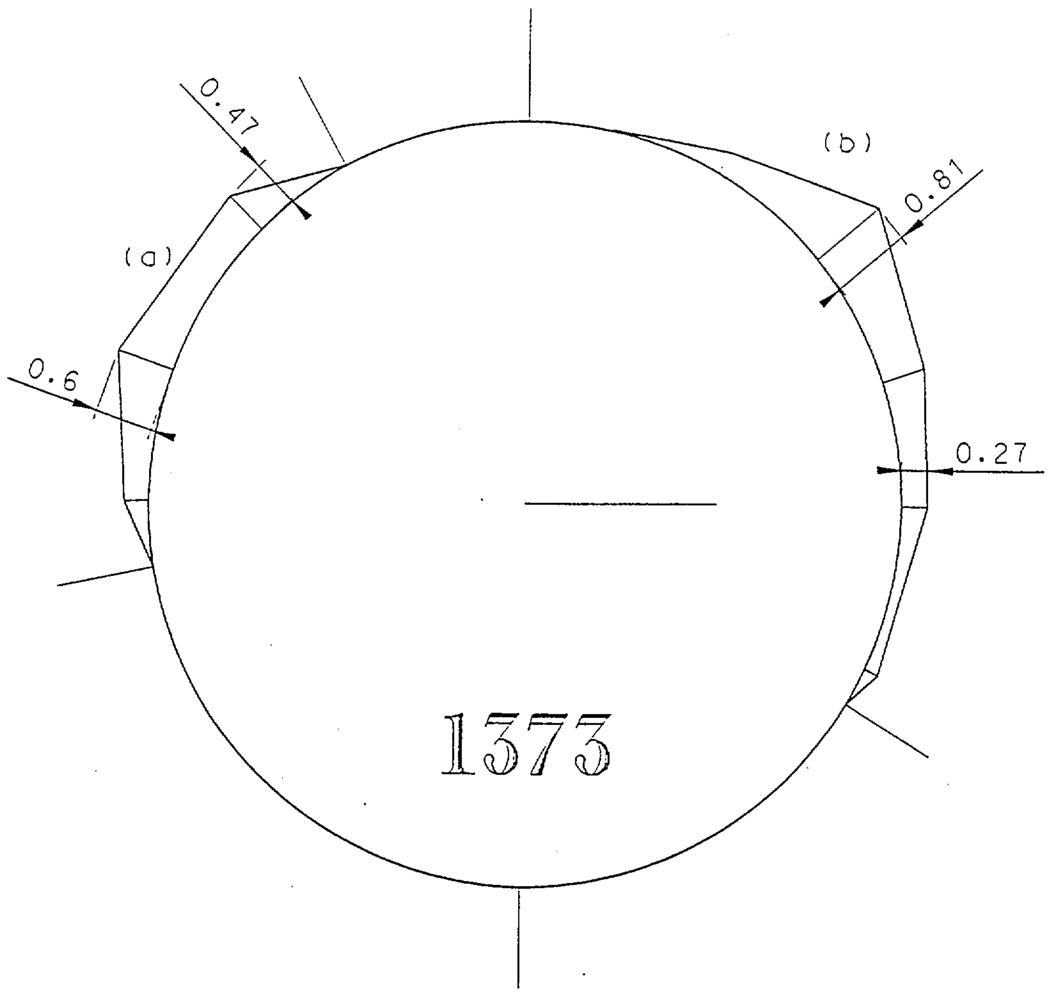


Figure 6-15. Estimates of Voids at Steel Set #1371 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)



STATION: 62+12.79

STEEL SETS: 1373

AREA(m^2): 1.638(a)
2.348(b)

Figure 6-16. Estimates of Voids at Steel Set #1373 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

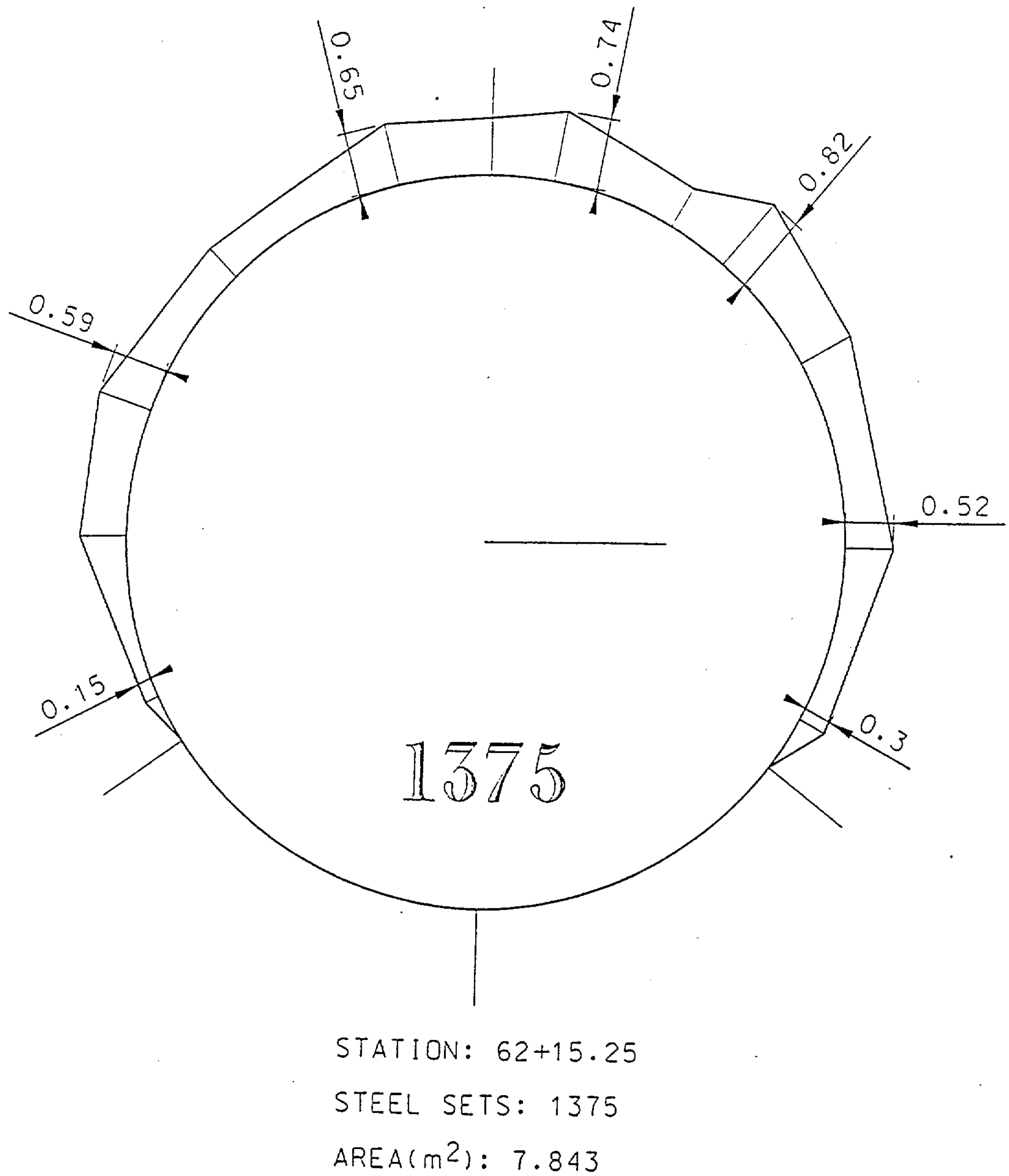
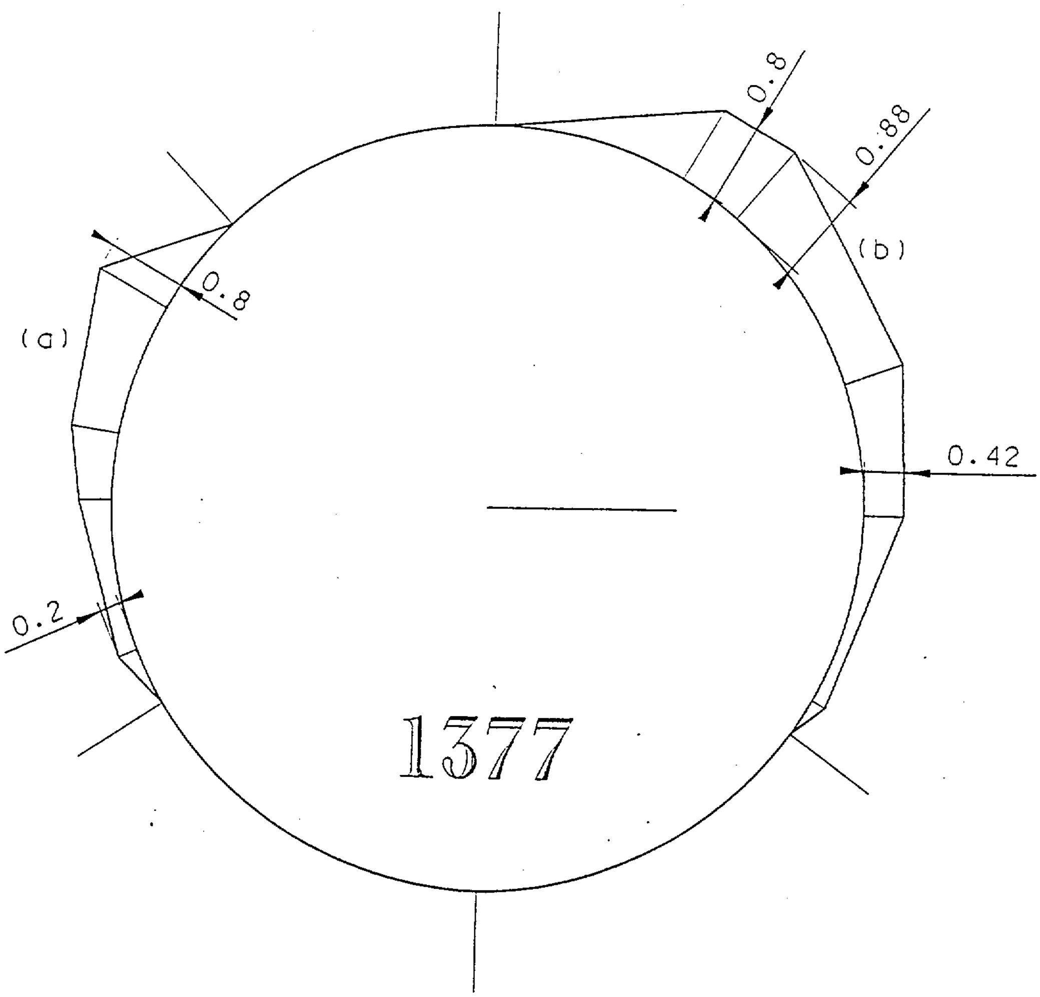


Figure 6-17. Estimates of Voids at Steel Set #1375 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

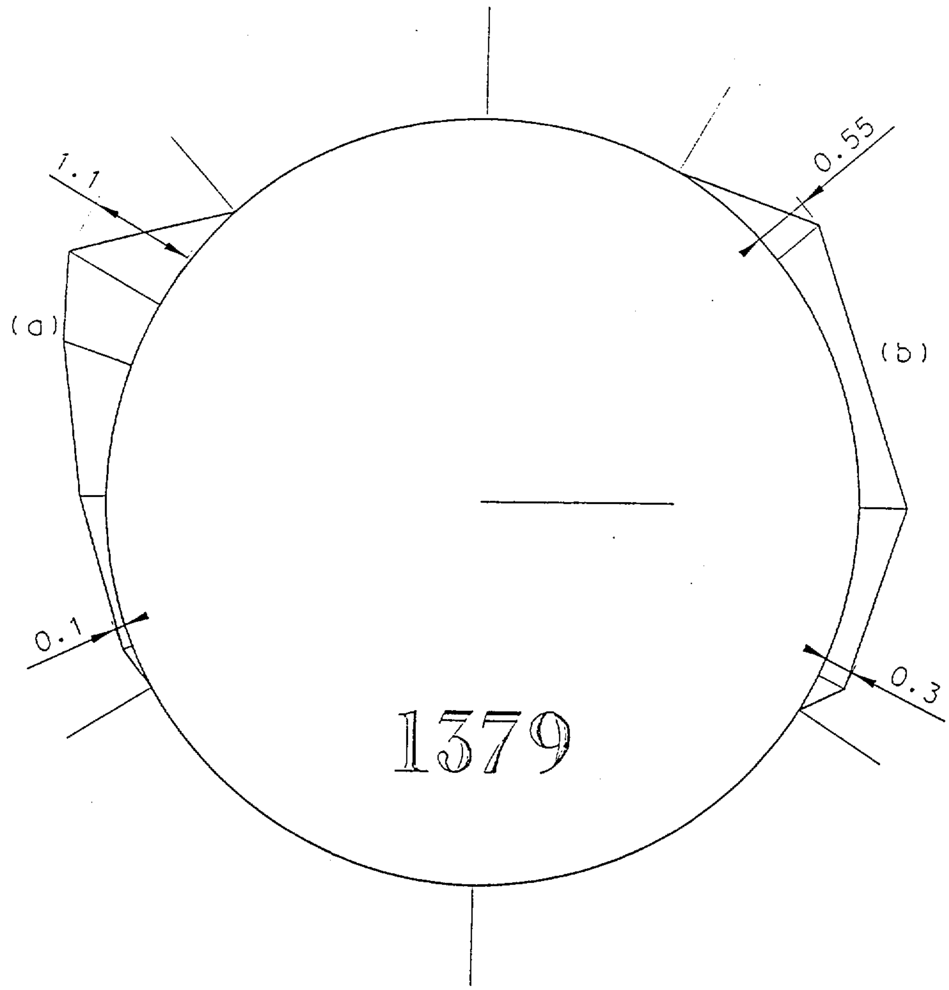


STATION: 62+17.68

STEEL SETS: 1377

AREA(m^2): 1.908(a)
3.722(b)

Figure 6-18. Estimates of Voids at Steel Set #1377 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

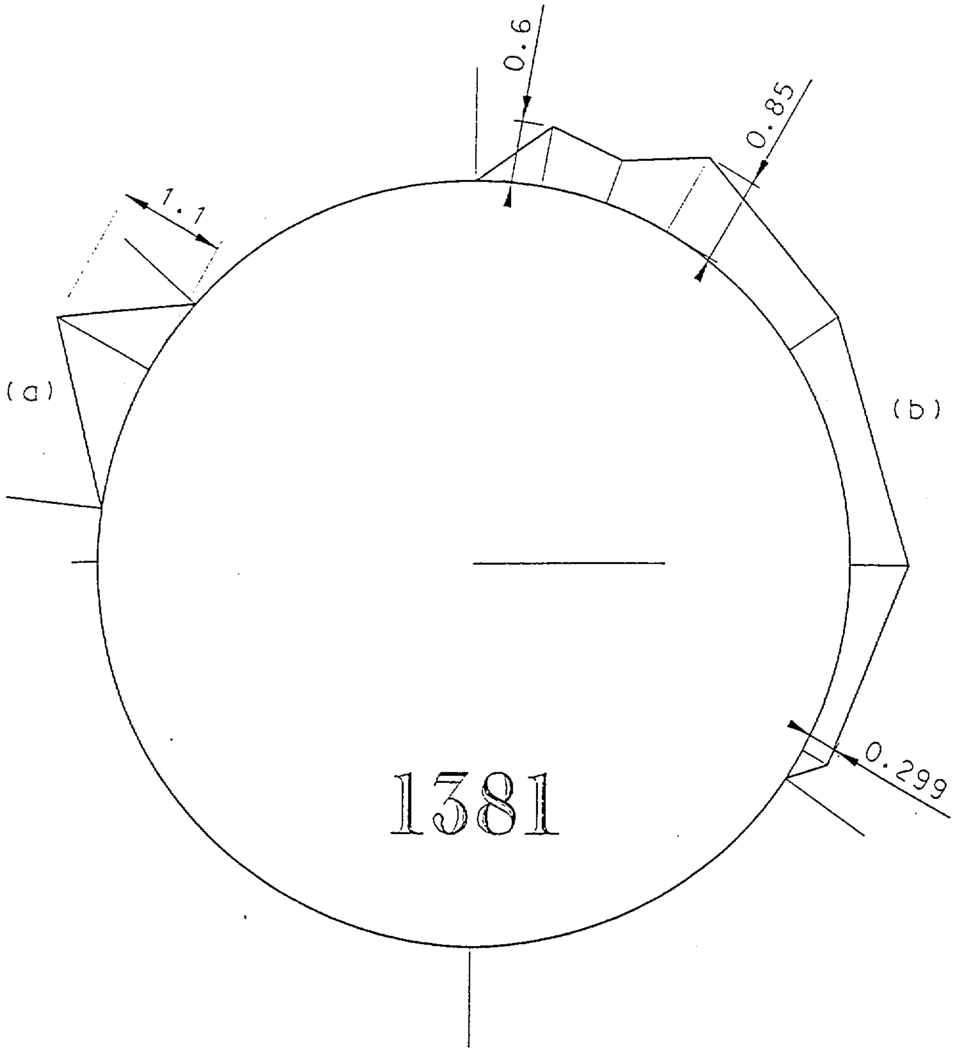


STATION: 62+20.10

STEEL SETS: 1379

AREA(m^2): 2.154(a)
1.934(b)

Figure 6-19. Estimates of Voids at Steel Set #1379 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

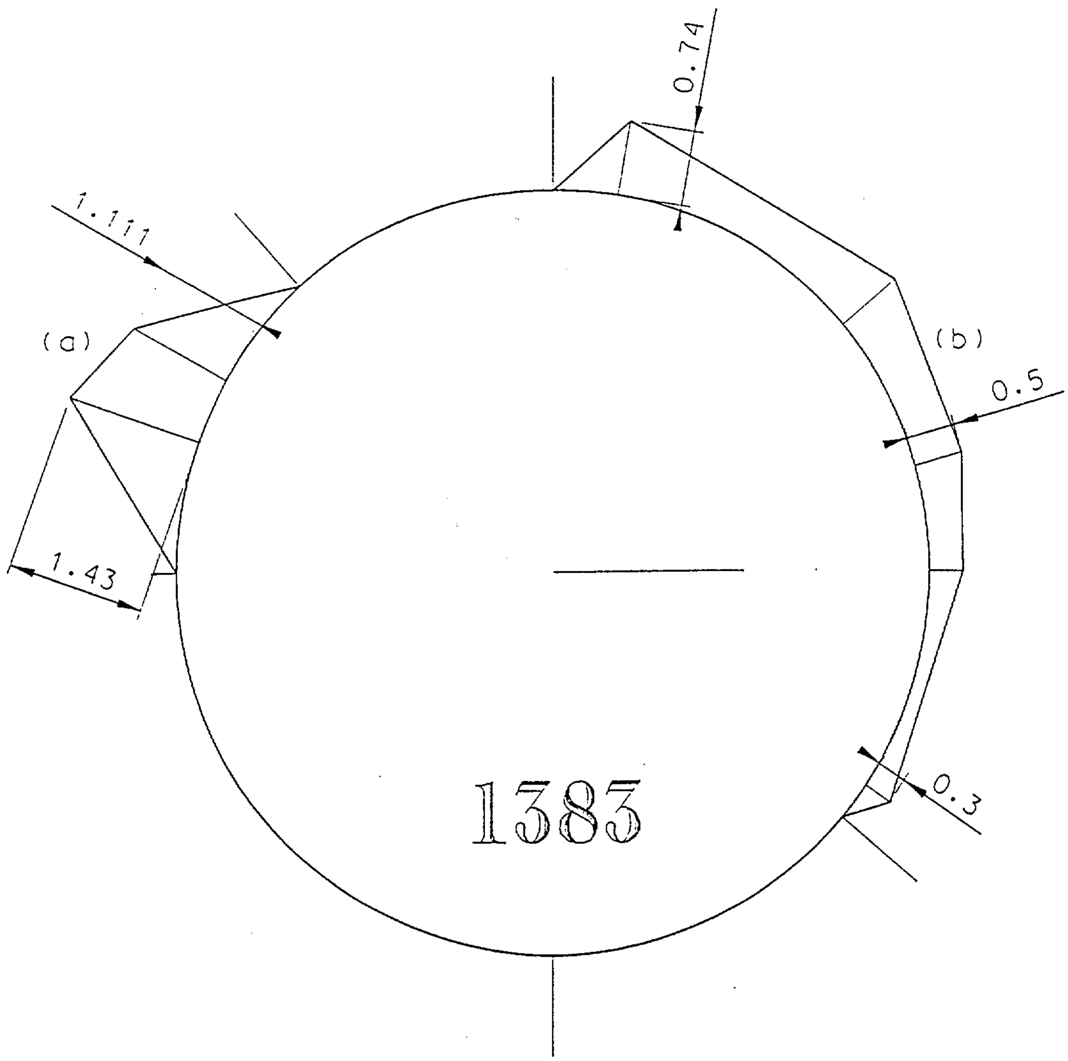


STATION: 62+22.50

STEEL SETS: 1381

AREA(m^2): 1.140(a)
4.168(b)

Figure 6-20. Estimates of Voids at Steel Set #1381 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)



STATION: 62+24.97

STEEL SETS: 1383

AREA(m^2): 2.464(a)
3.662(b)

Figure 6-21. Estimates of Voids at Steel Set #1383 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

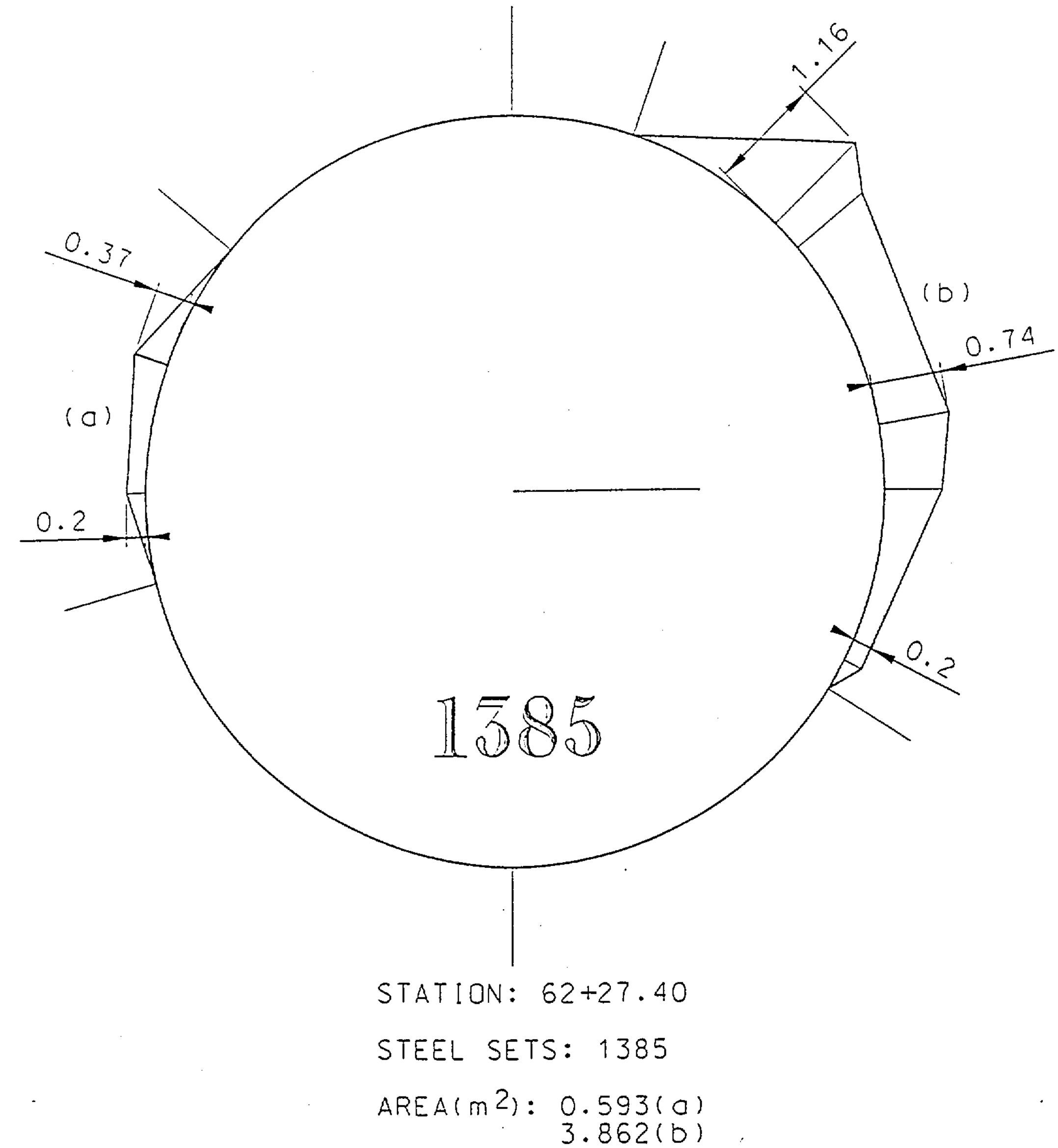


Figure 6-22. Estimates of Voids at Steel Set #1385 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

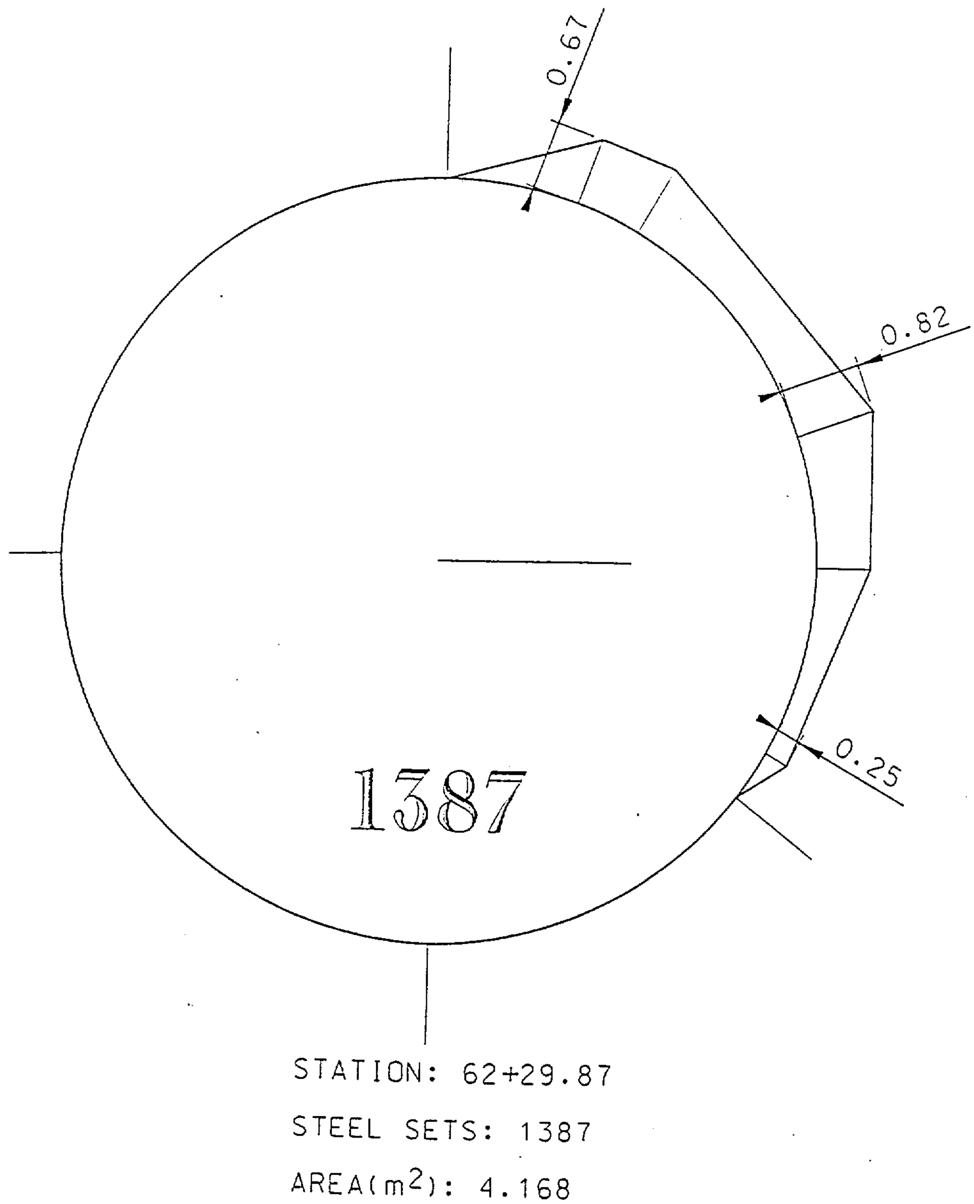


Figure 6-23. Estimates of Voids at Steel Set #1387 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

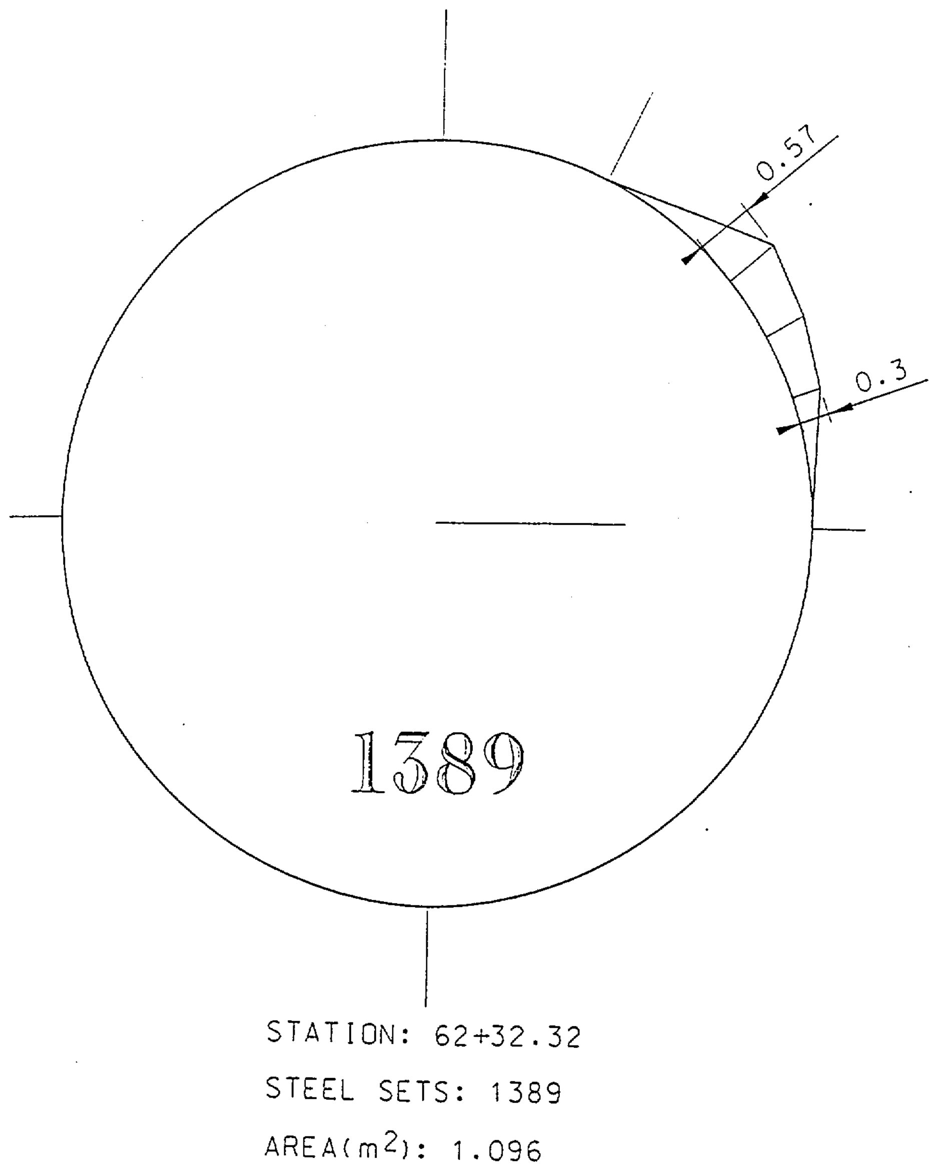


Figure 6-24. Estimates of Voids at Steel Set #1389 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

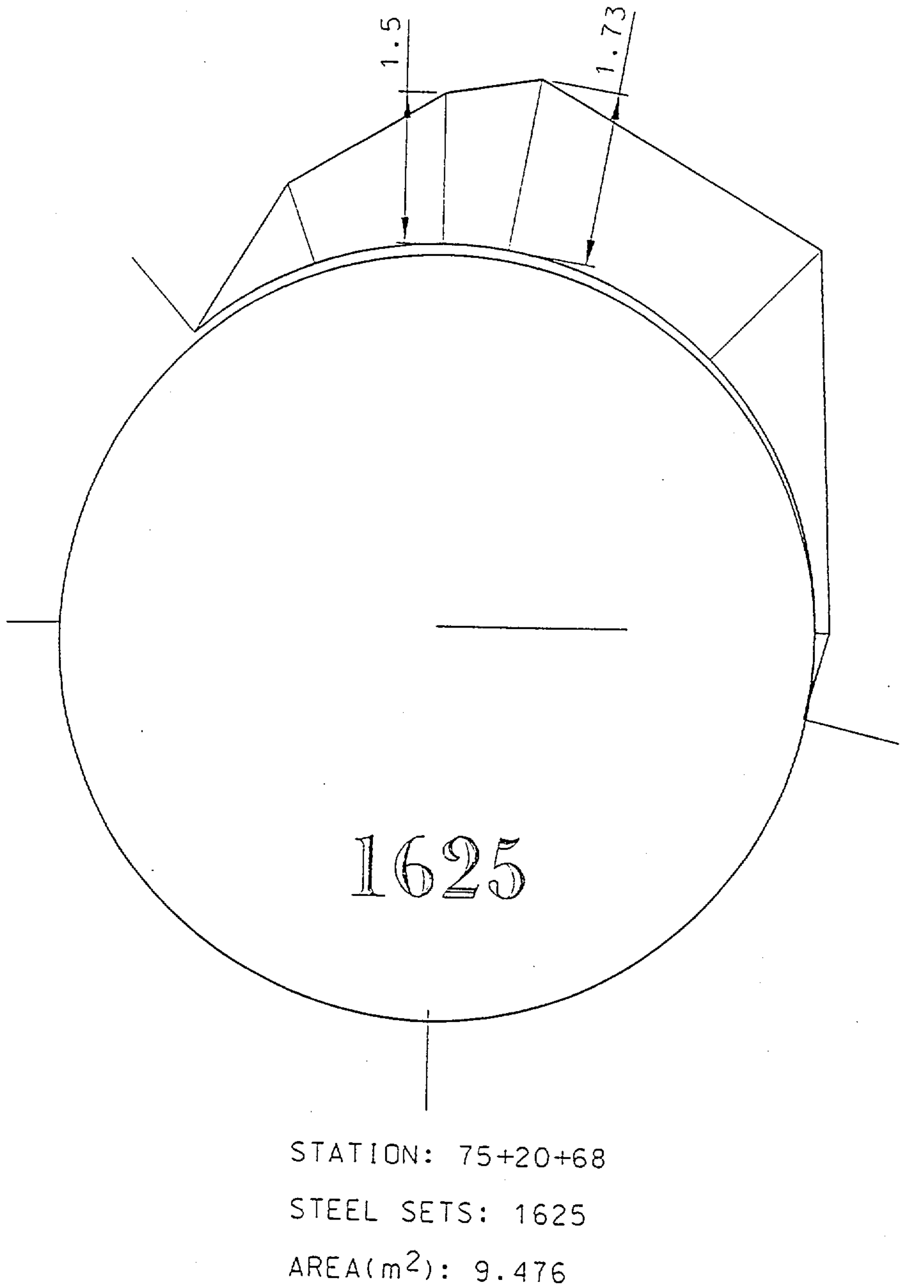


Figure 6-25. Estimates of Voids at Steel Set #1625 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

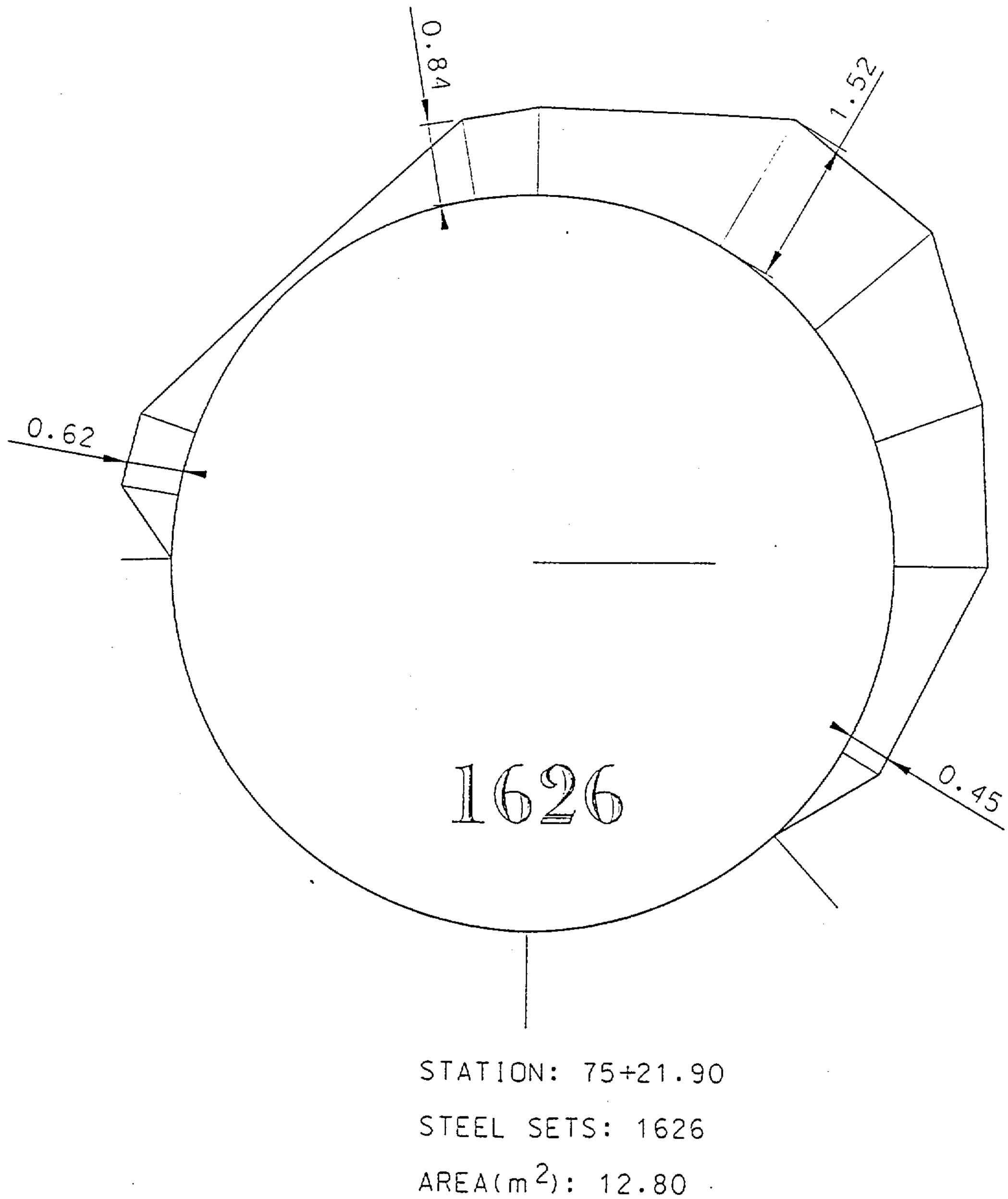


Figure 6-26. Estimates of Voids at Steel Set #1626 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

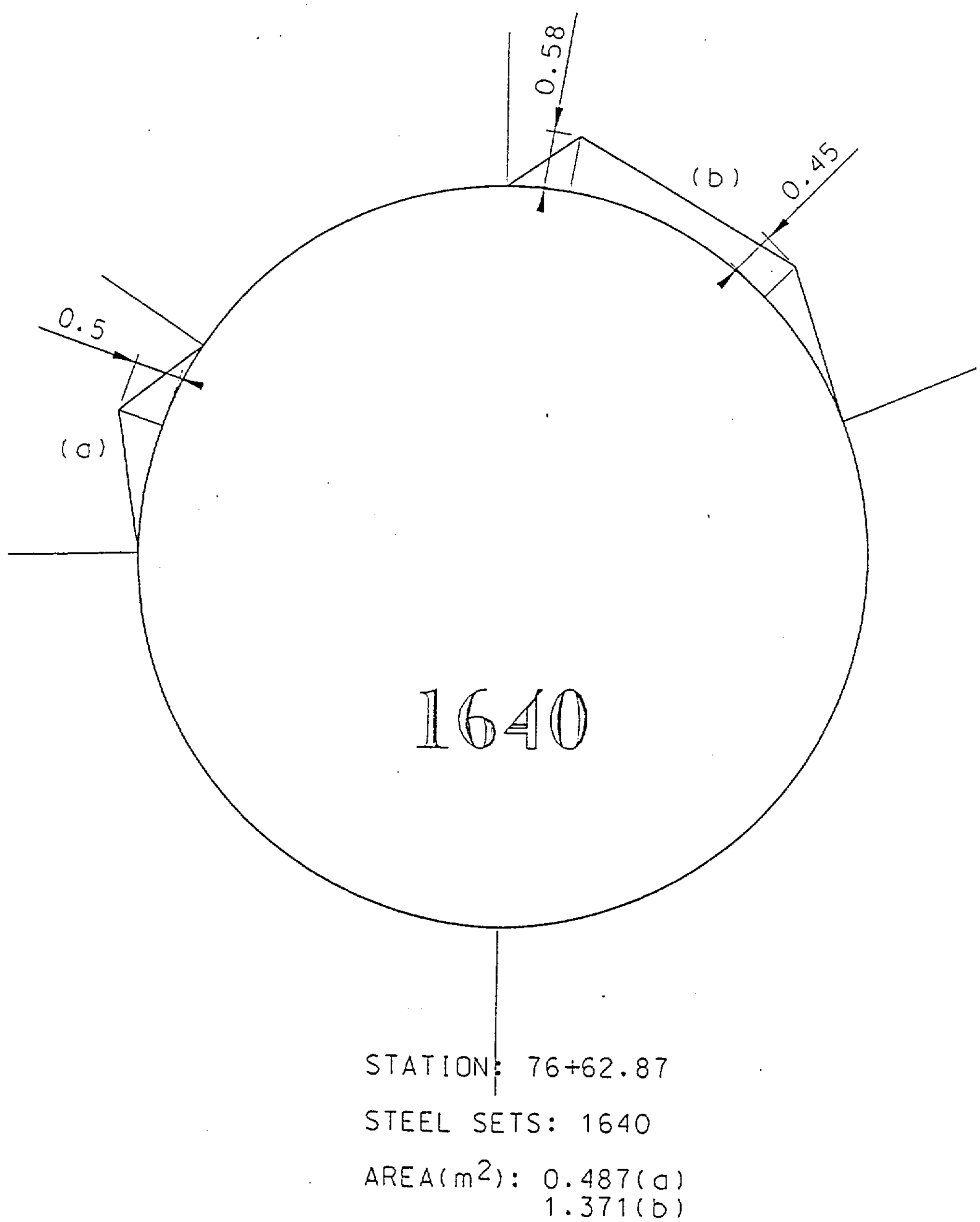


Figure 6-27. Estimates of Voids at Steel Set #1640 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

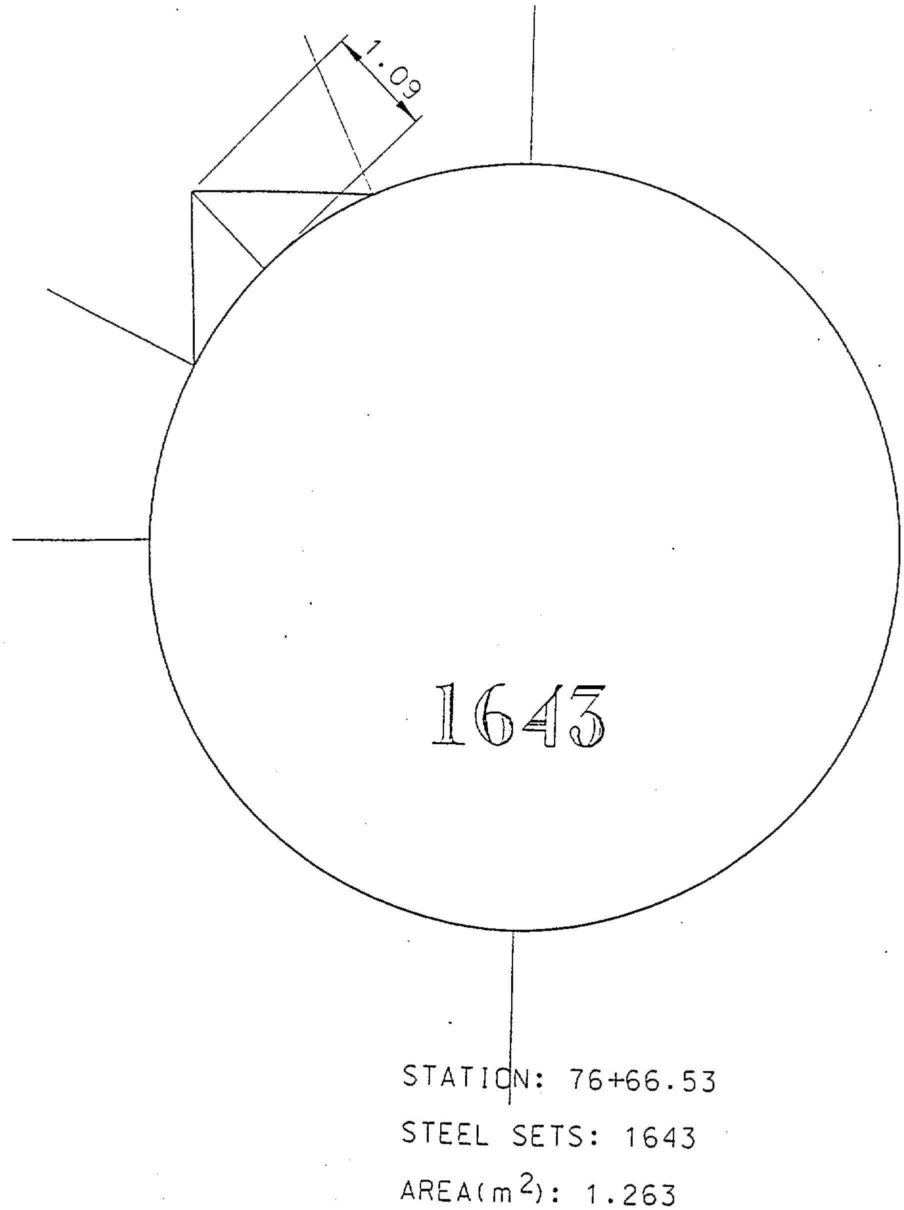


Figure 6-28. Estimates of Voids at Steel Set #1643 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

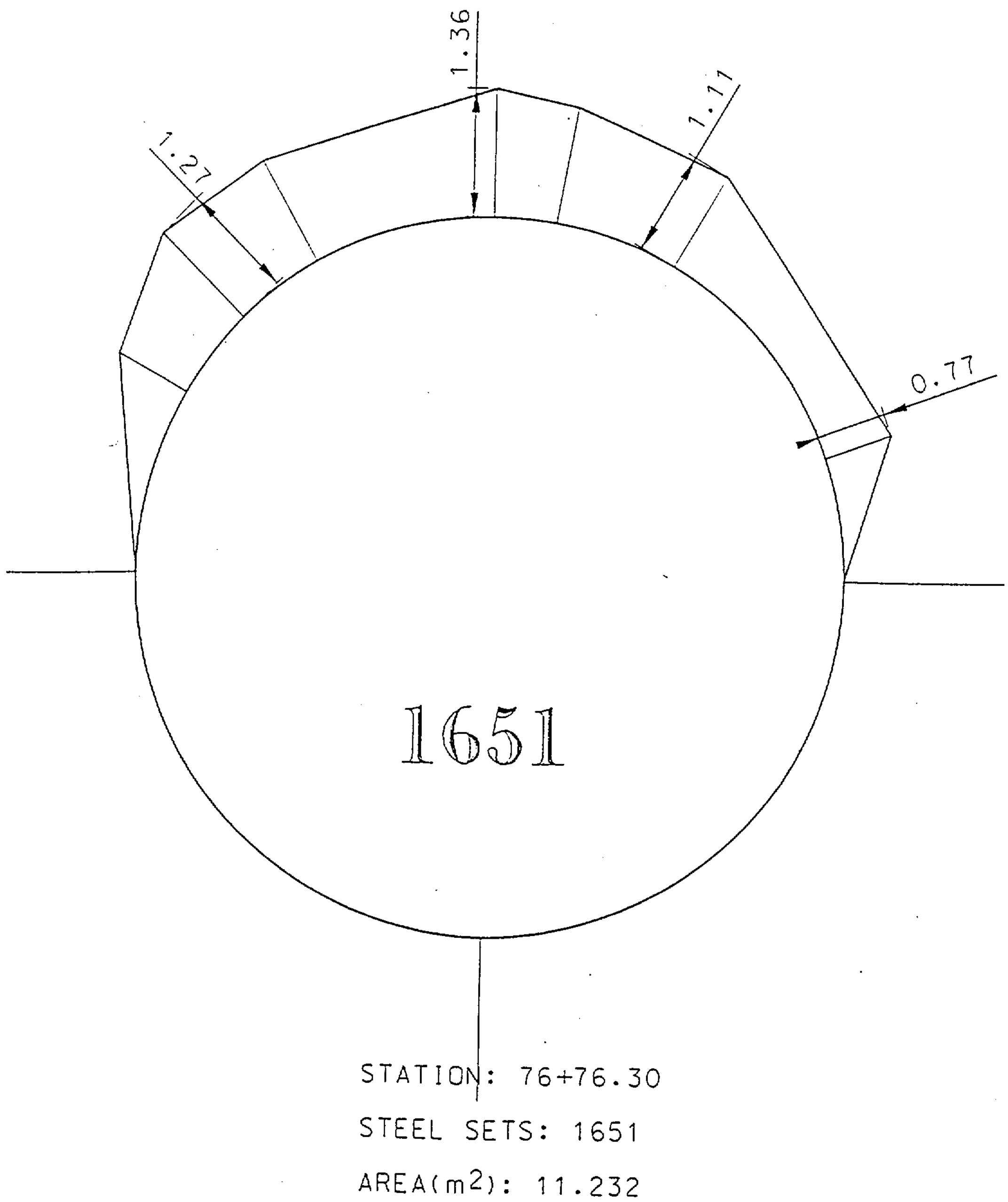


Figure 6-29. Estimates of Voids at Steel Set #1651 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

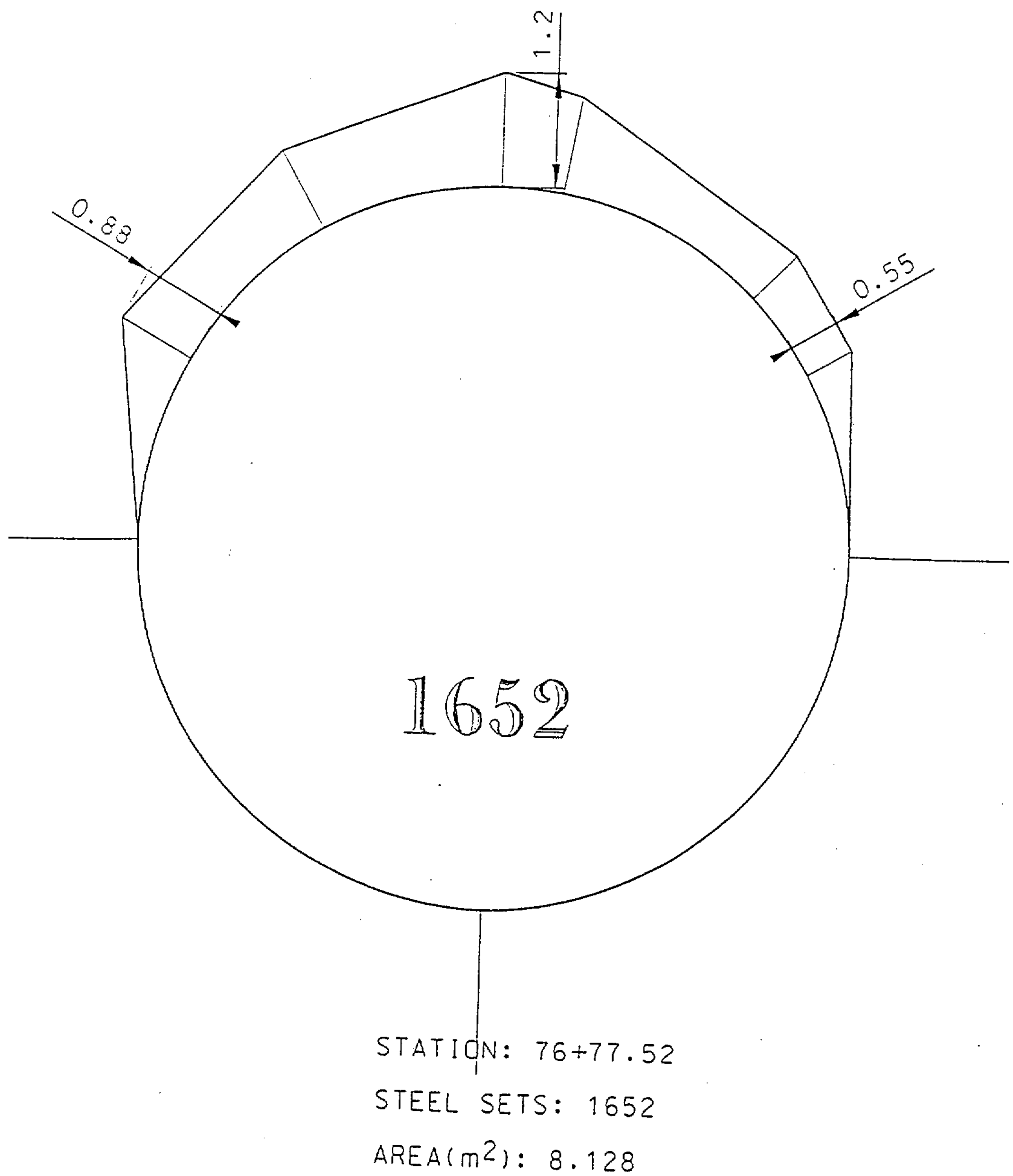


Figure 6-30. Estimates of Voids at Steel Set #1652 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

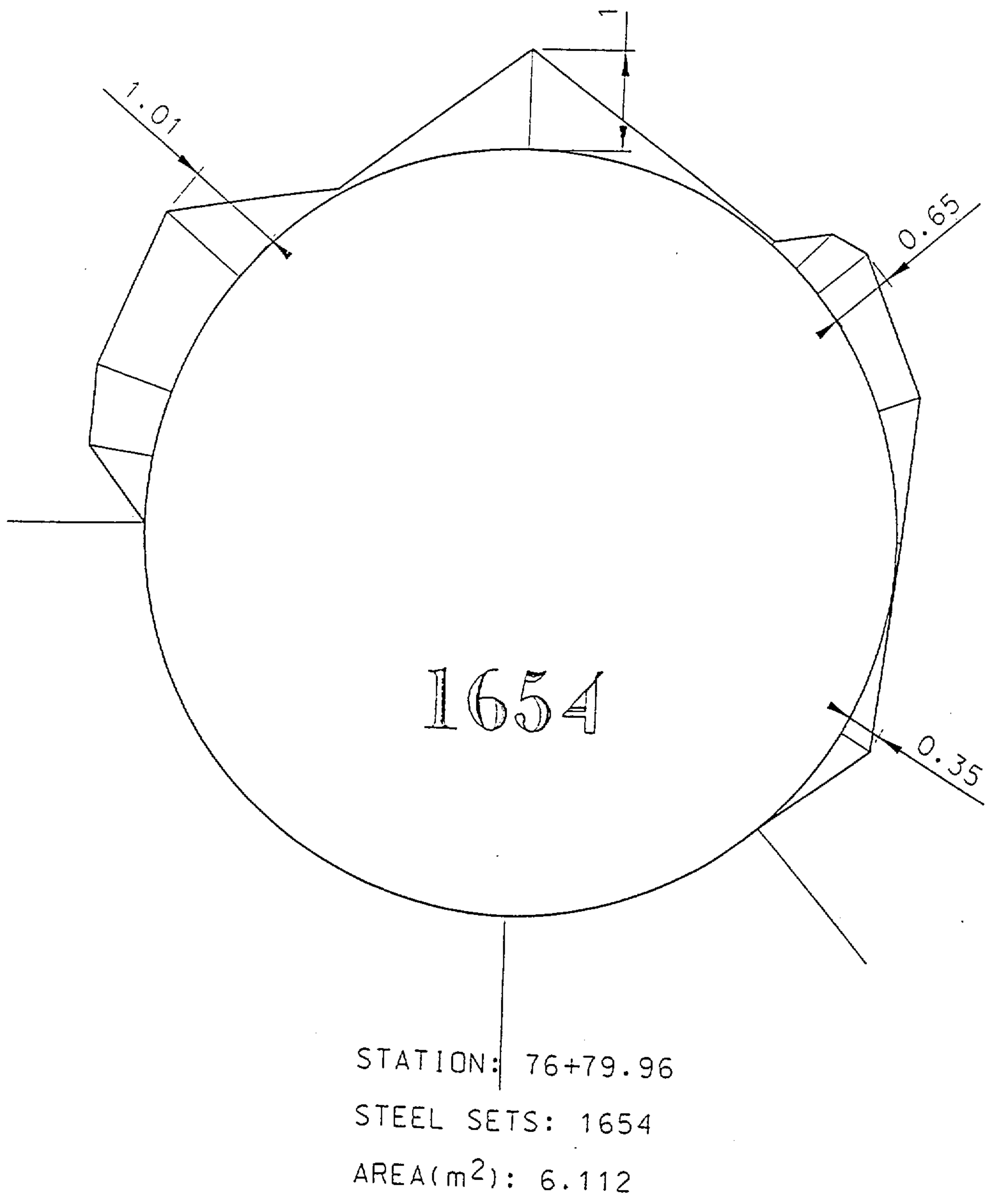


Figure 6-31. Estimates of Voids at Steel Set #1654 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

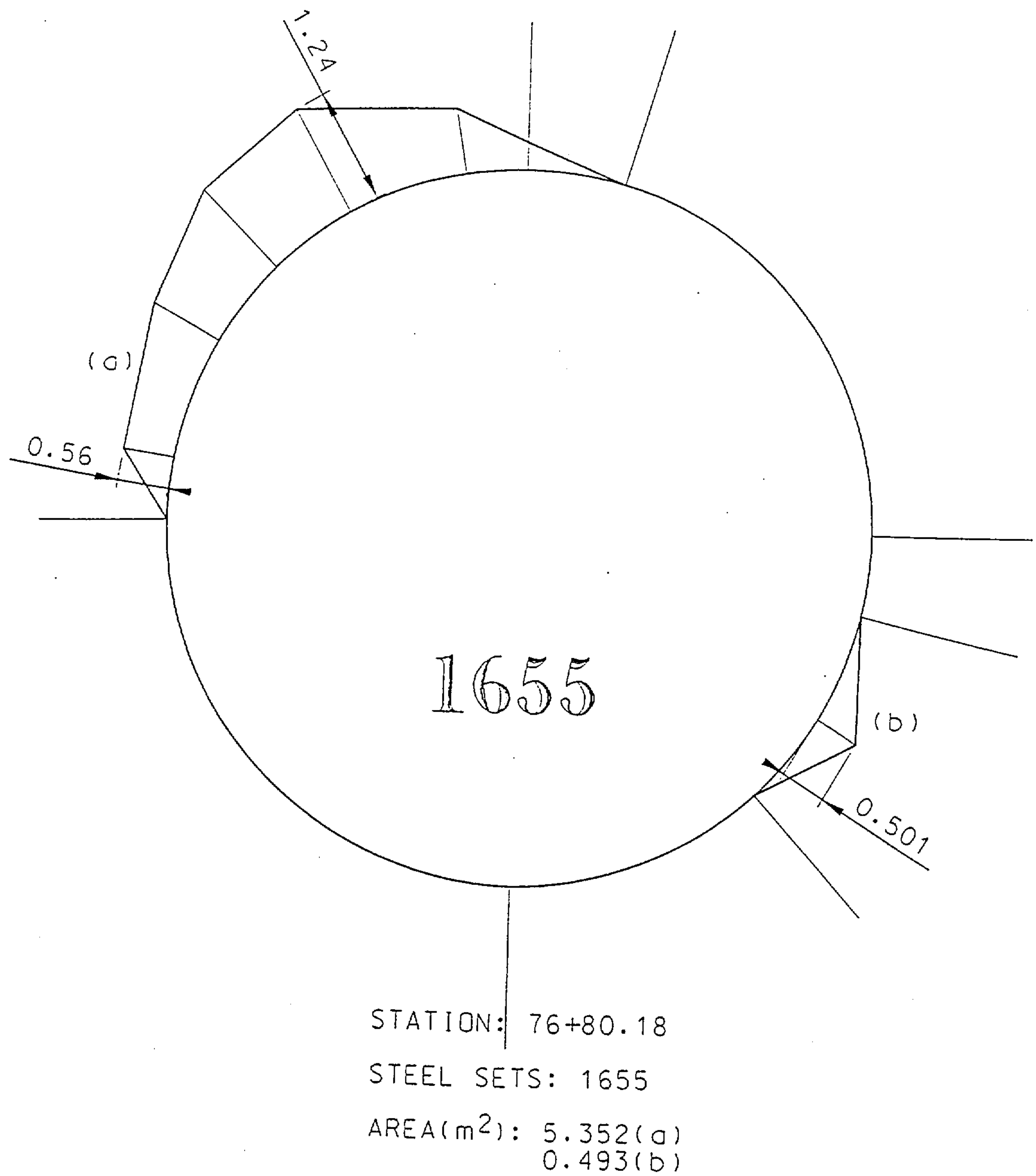


Figure 6-32. Estimates of Voids at Steel Set #1655 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

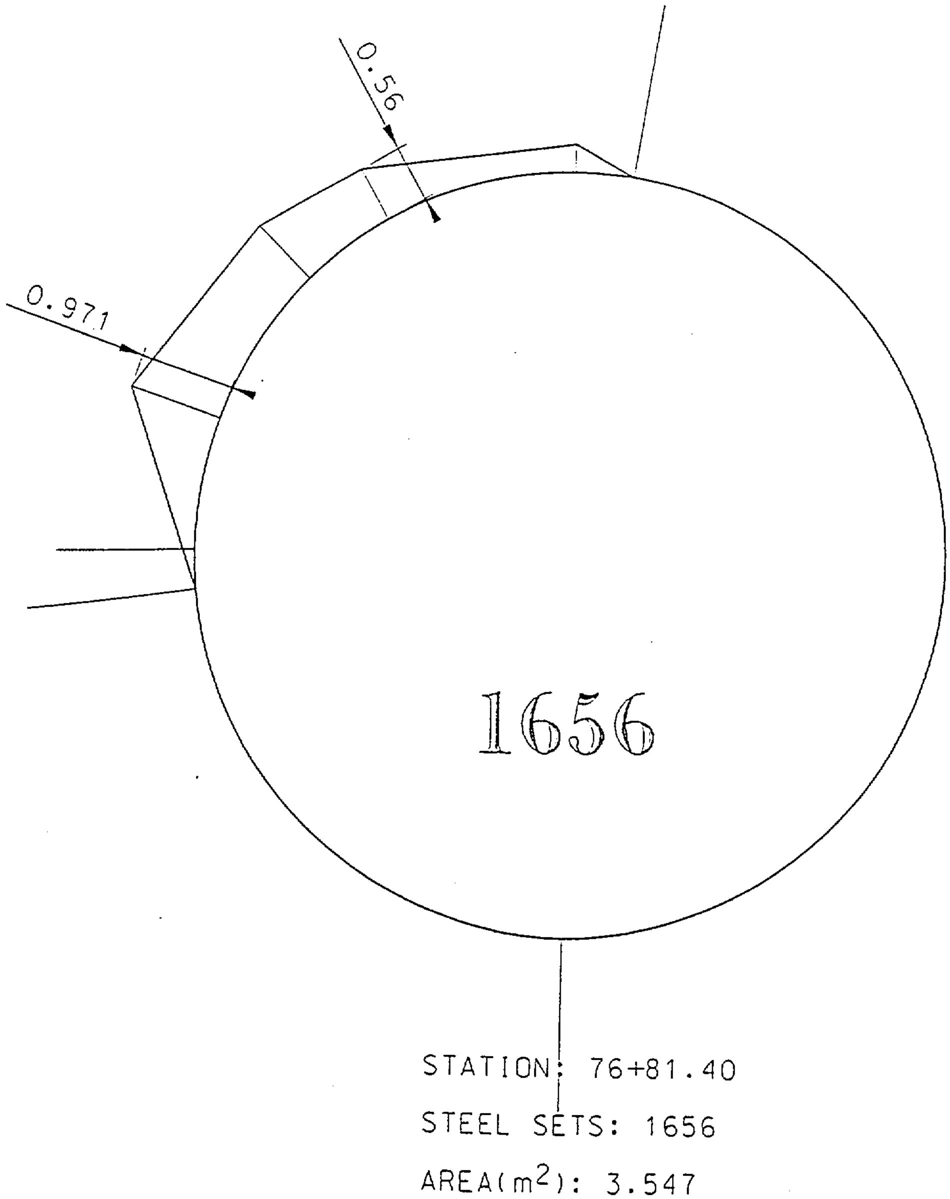


Figure 6-33. Estimates of Voids at Steel Set #1656 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

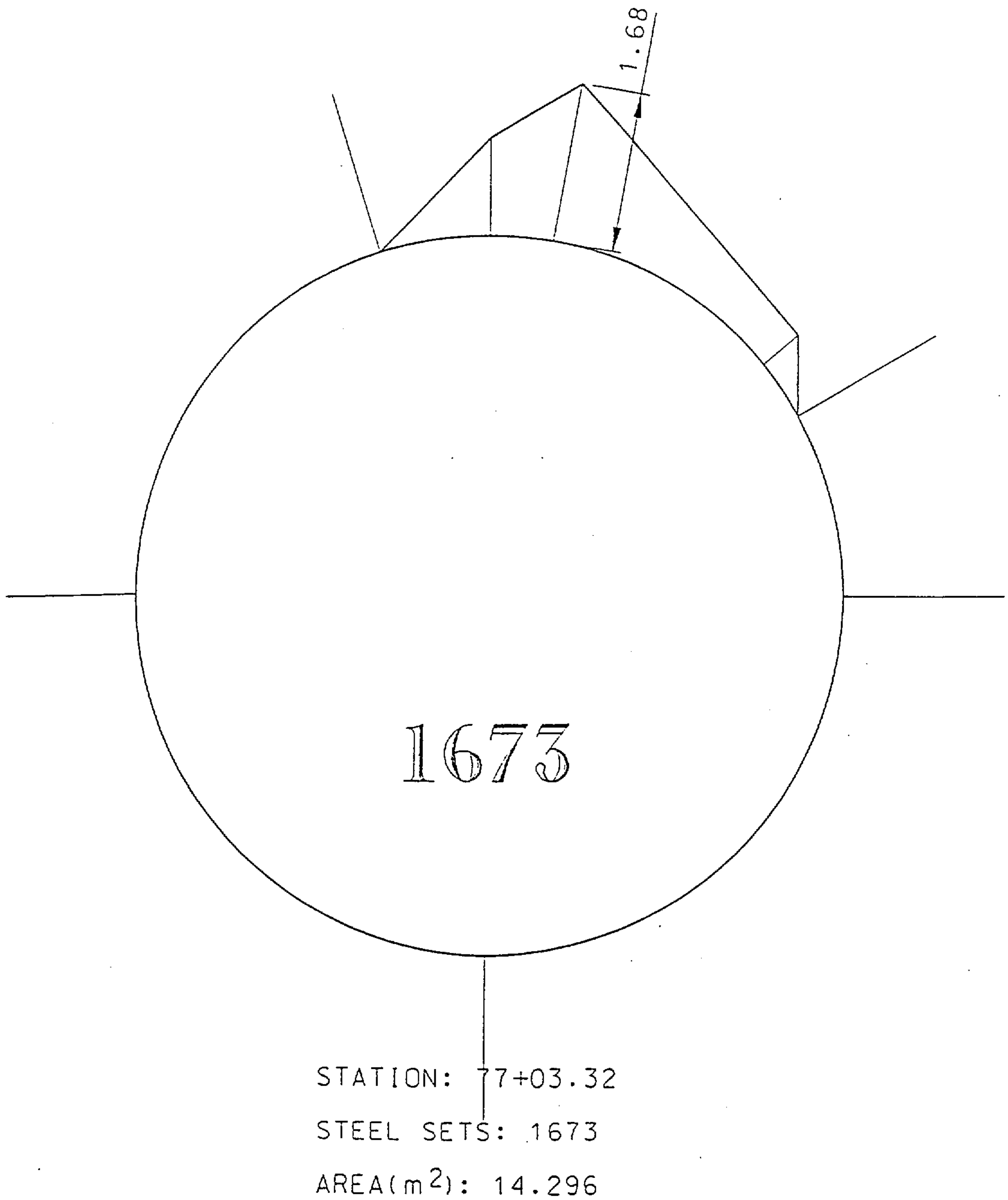


Figure 6-34. Estimates of Voids at Steel Set #1673 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

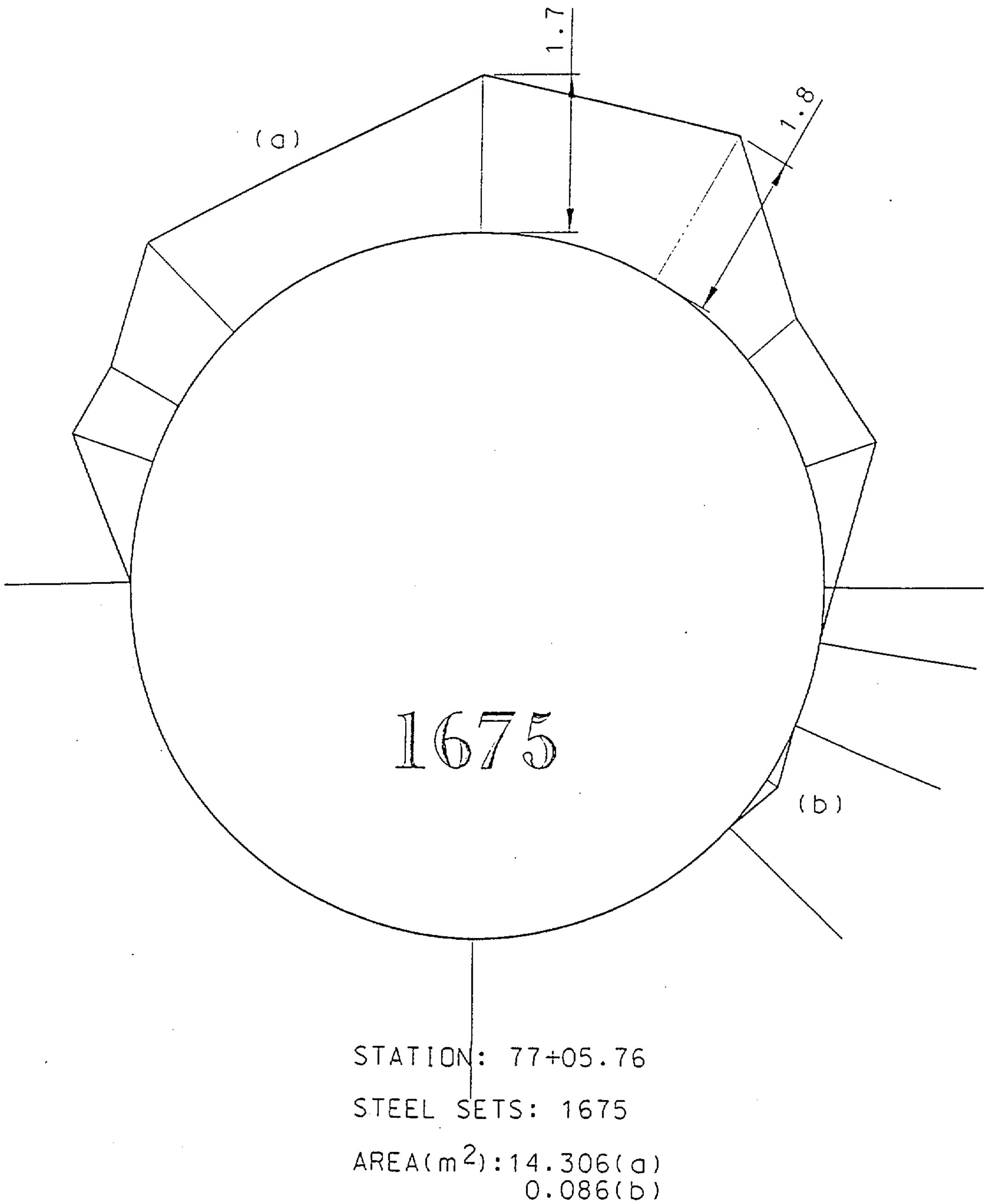


Figure 6-35. Estimates of Voids at Steel Set #1675 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

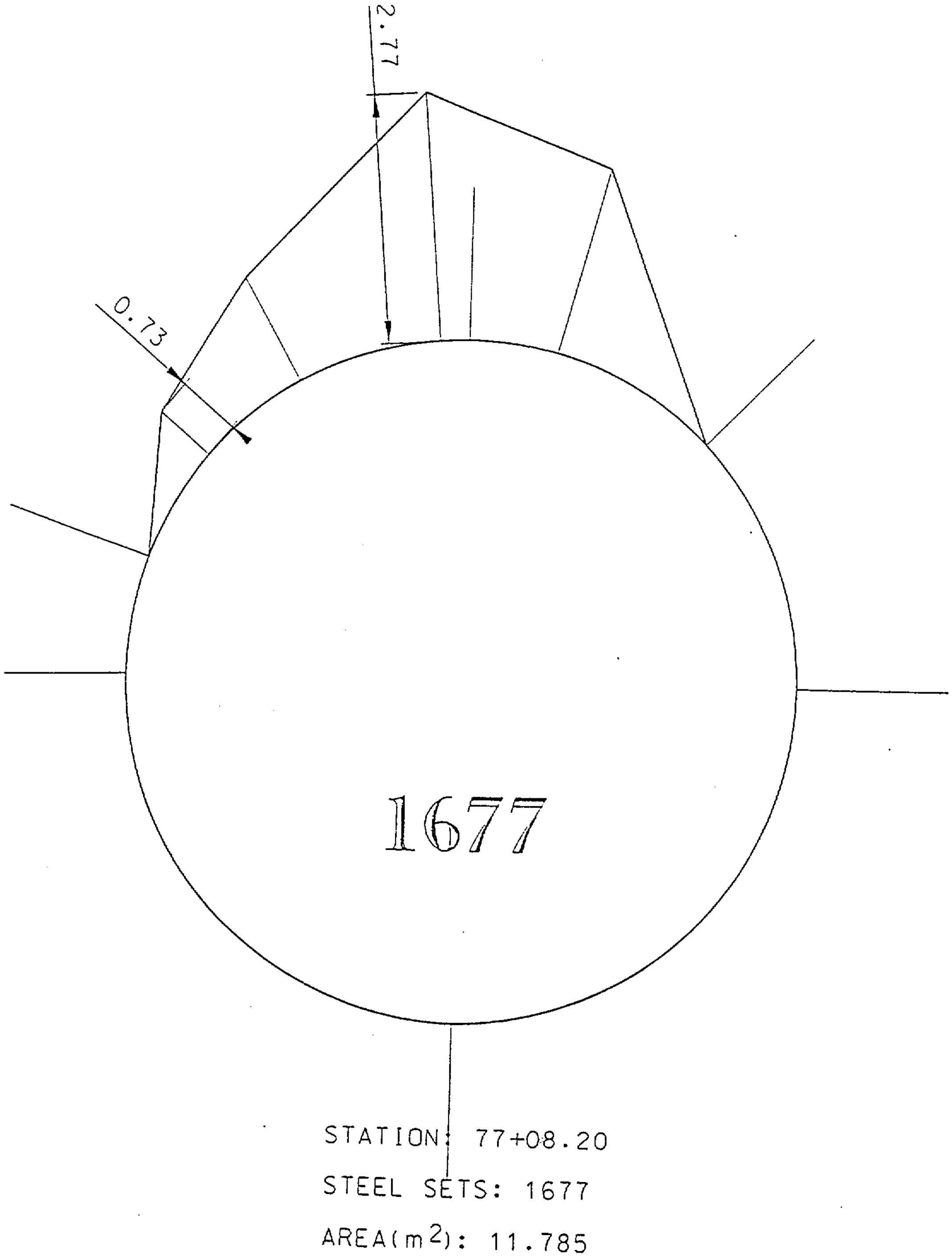


Figure 6-36. Estimates of Voids at Steel Set #1677 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

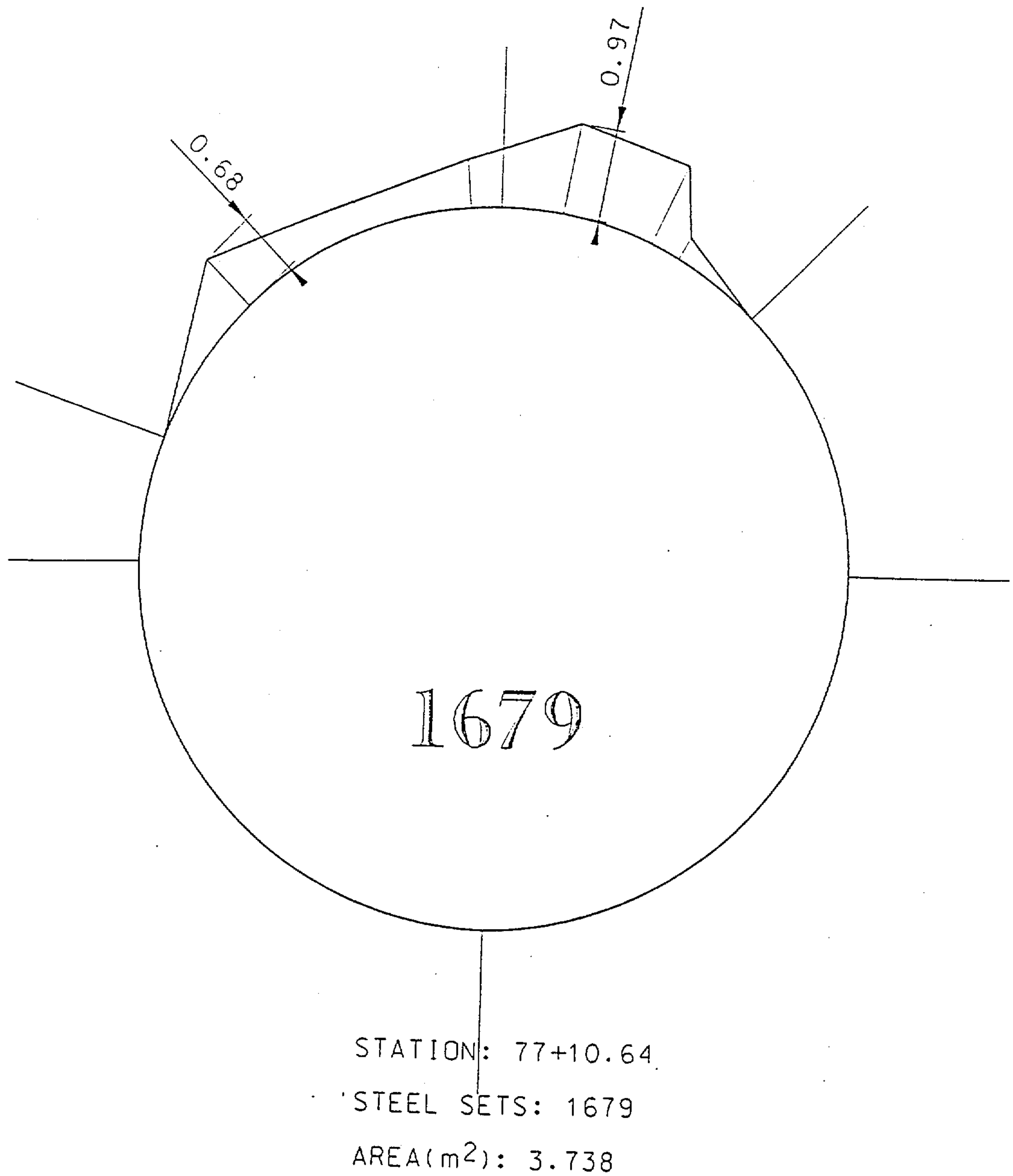


Figure 6-37. Estimates of Voids at Steel Set #1679 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

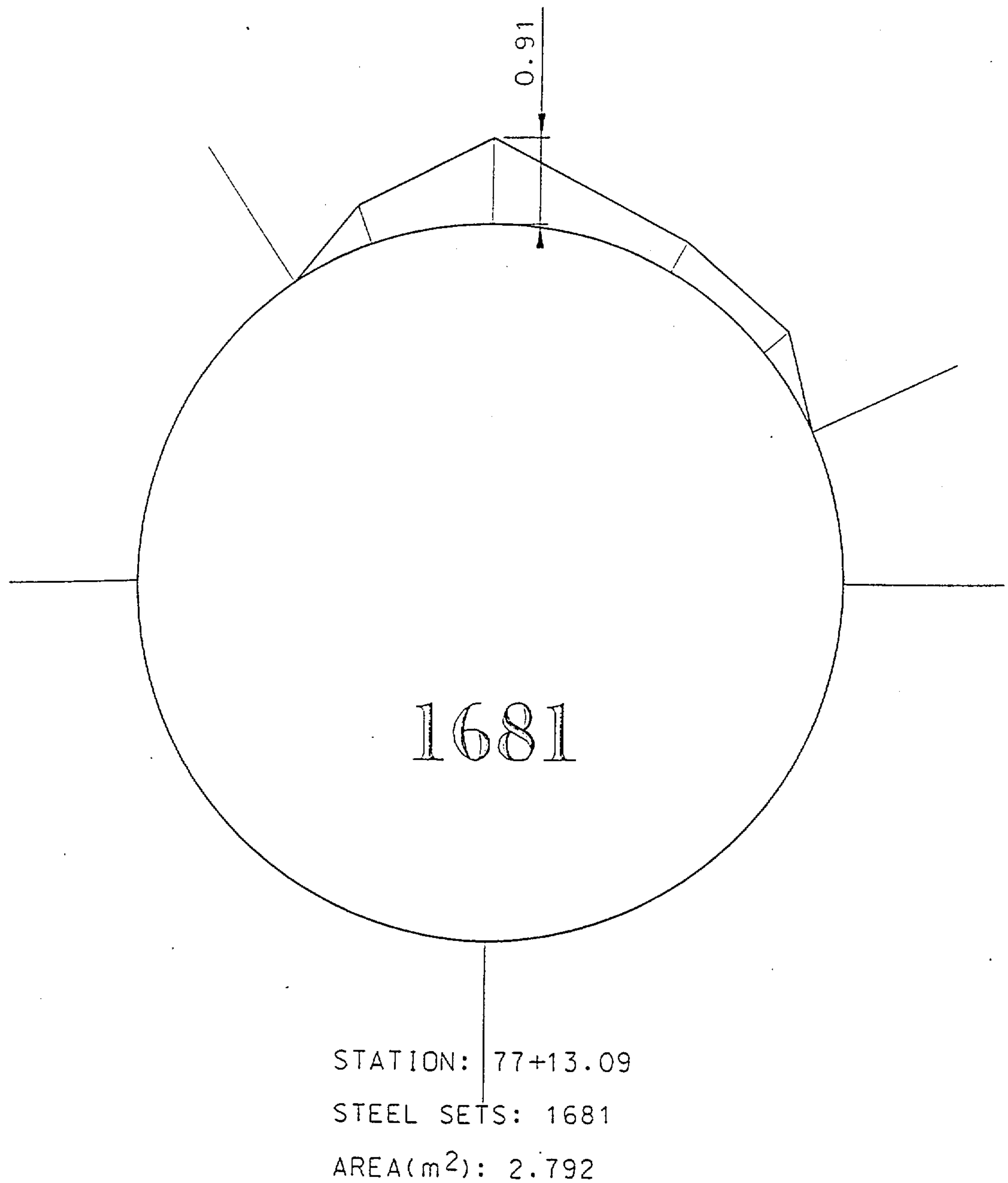


Figure 6-38. Estimates of Voids at Steel Set #1681 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

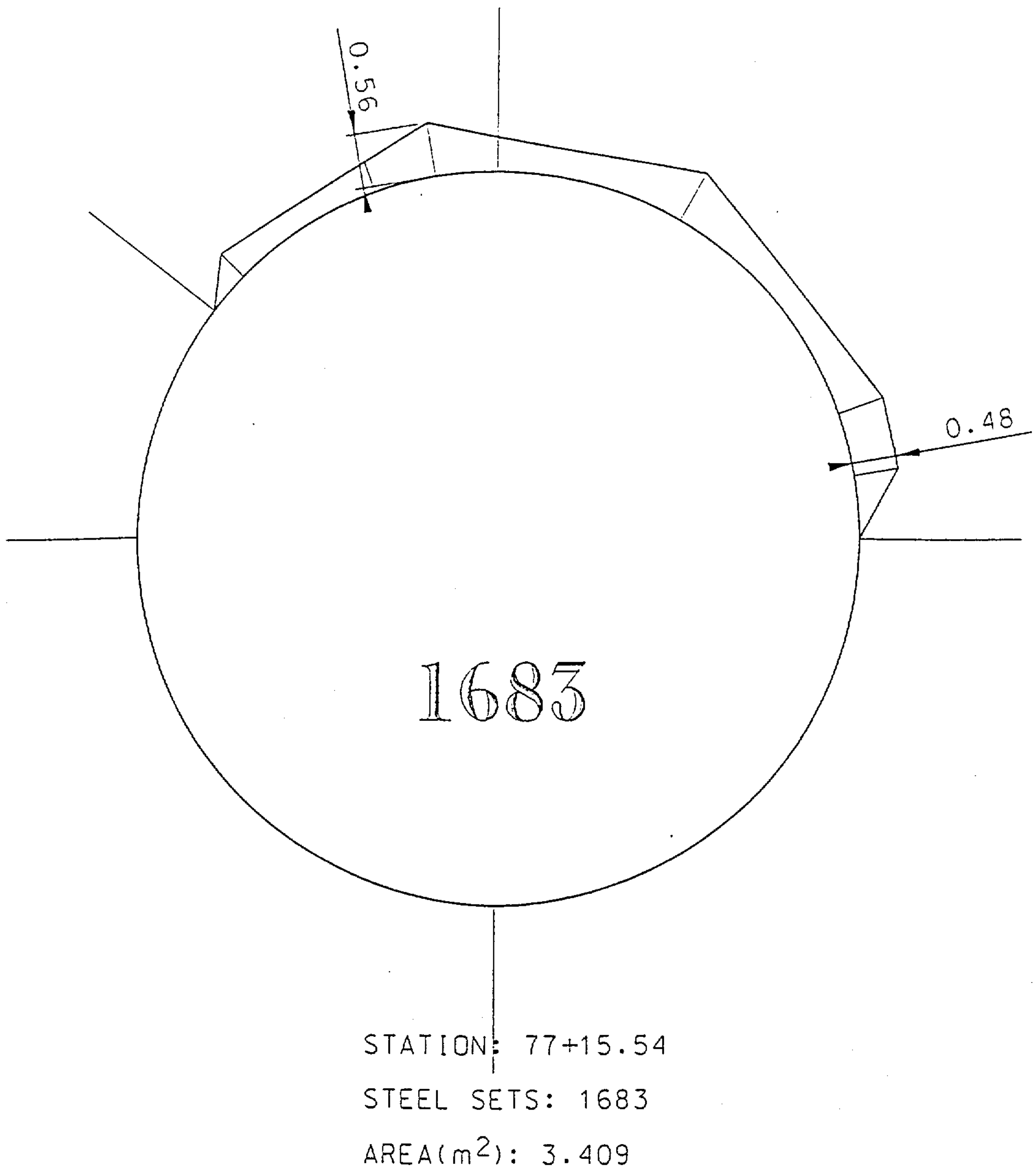


Figure 6-39. Estimates of Voids at Steel Set #1683 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

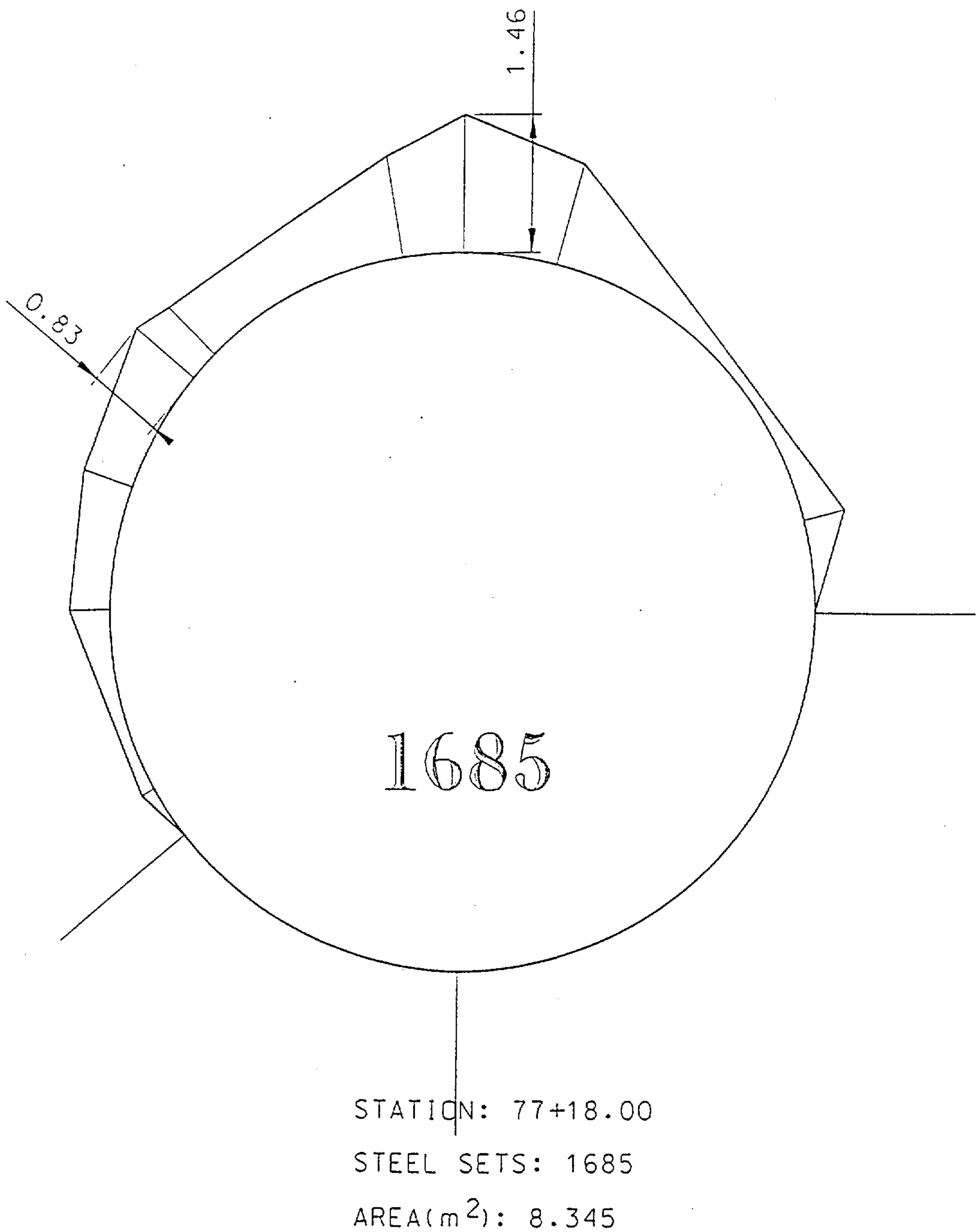


Figure 6-40. Estimates of Voids at Steel Set #1685 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

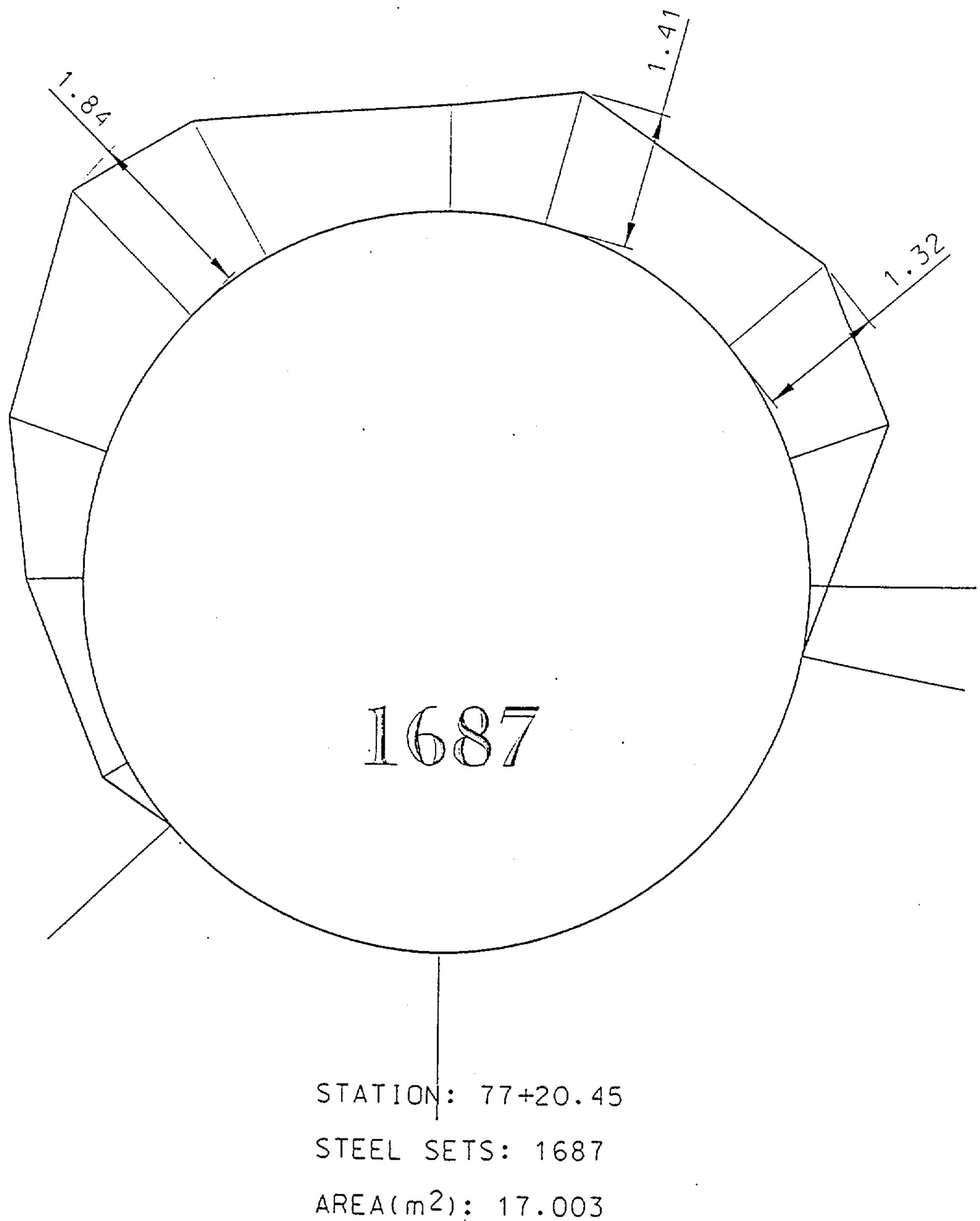


Figure 6-41. Estimates of Voids at Steel Set #1687 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

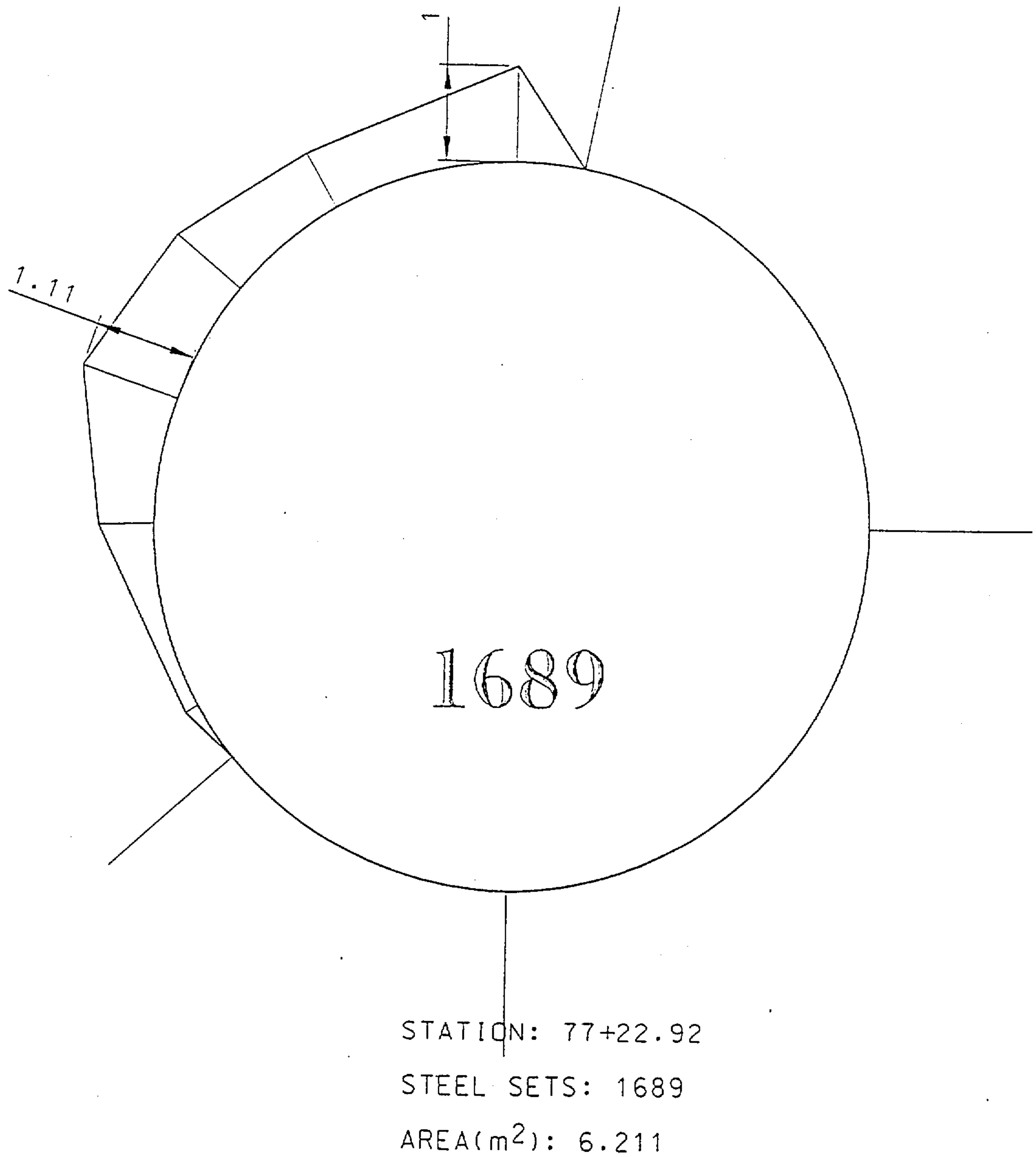


Figure 6-42. Estimates of Voids at Steel Set #1689 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

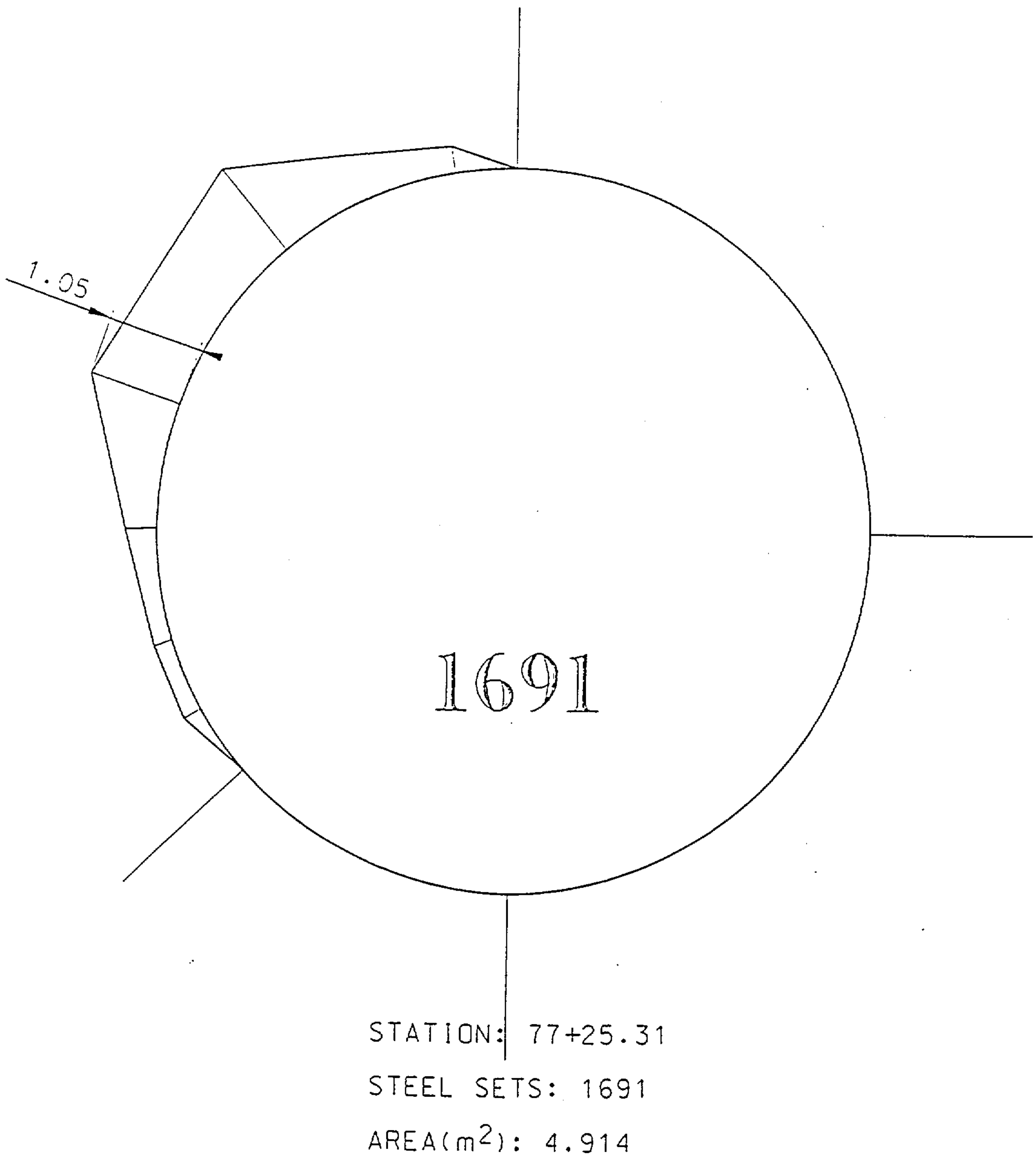


Figure 6-43. Estimates of Voids at Steel Set #1691 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

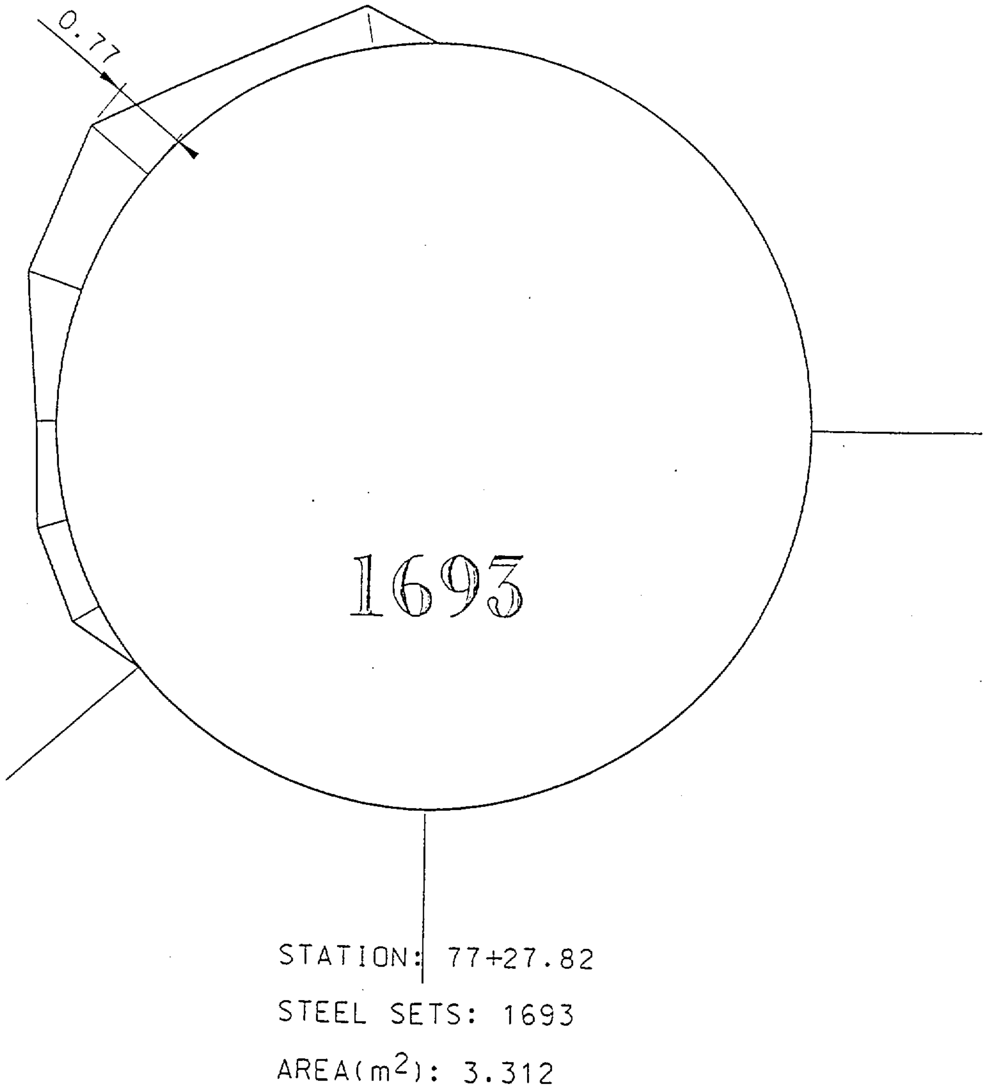


Figure 6-44. Estimates of Voids at Steel Set #1693 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

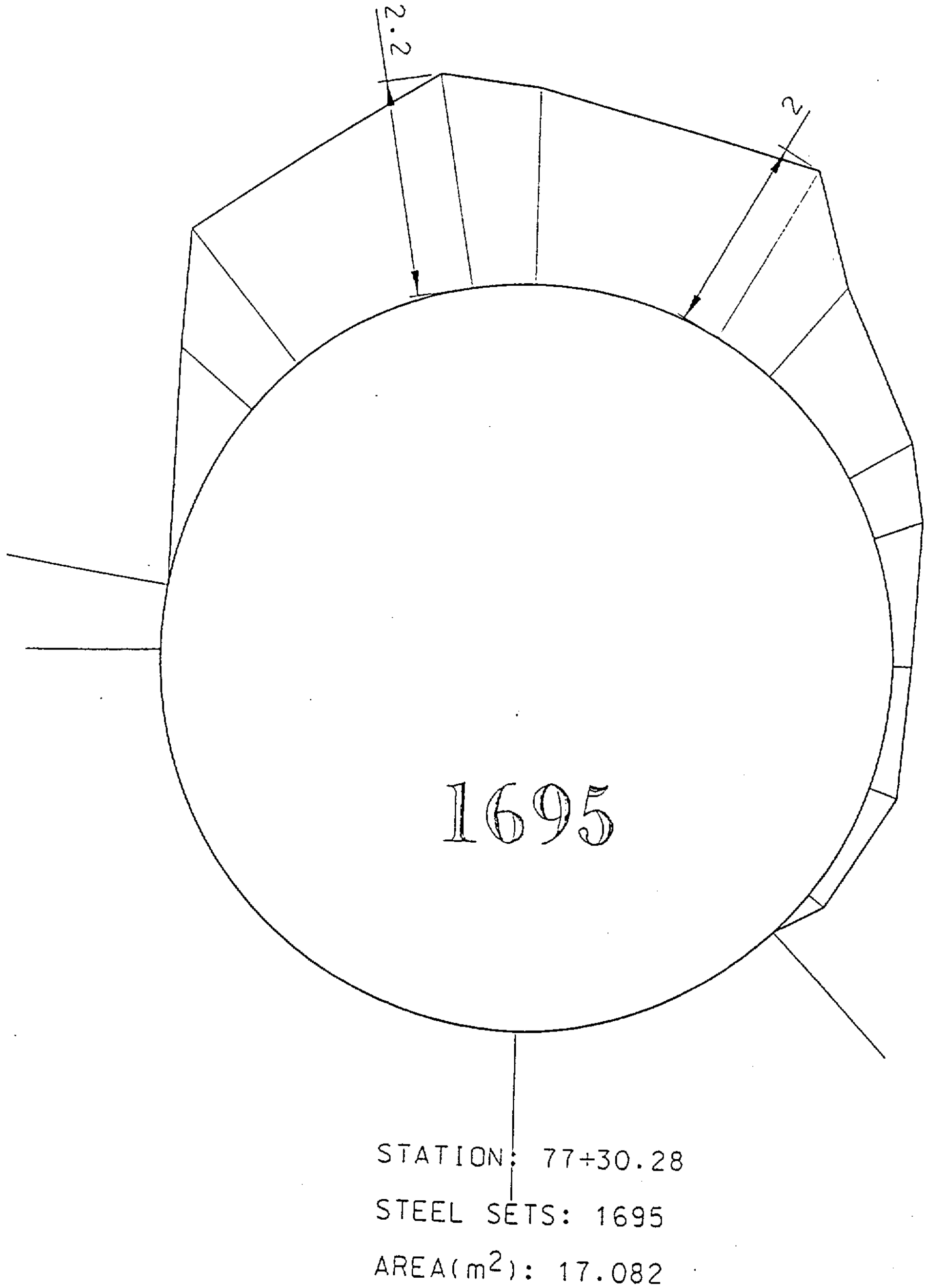


Figure 6-45. Estimates of Voids at Steel Set #1695 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

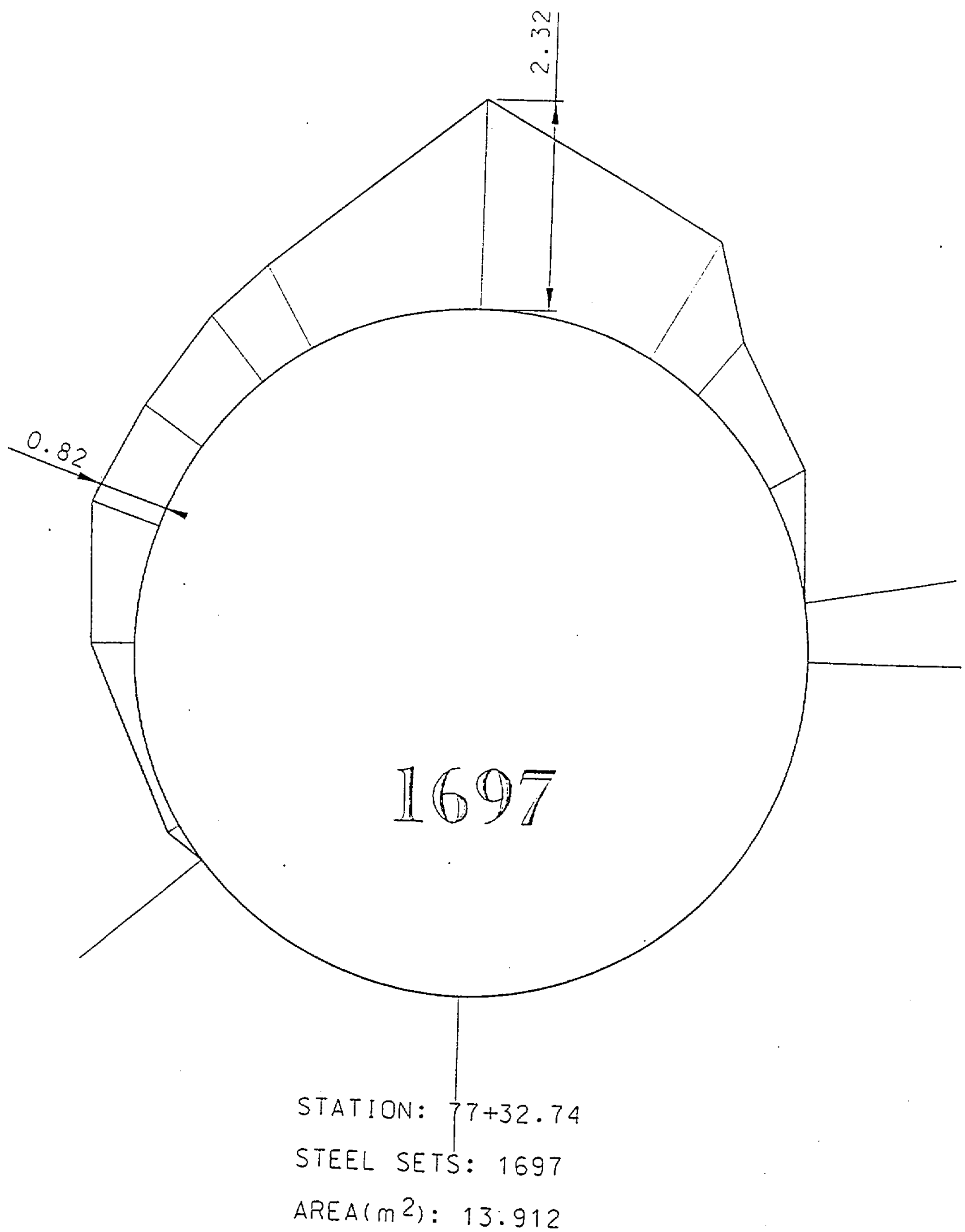


Figure 6-46. Estimates of Voids at Steel Set #1697 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

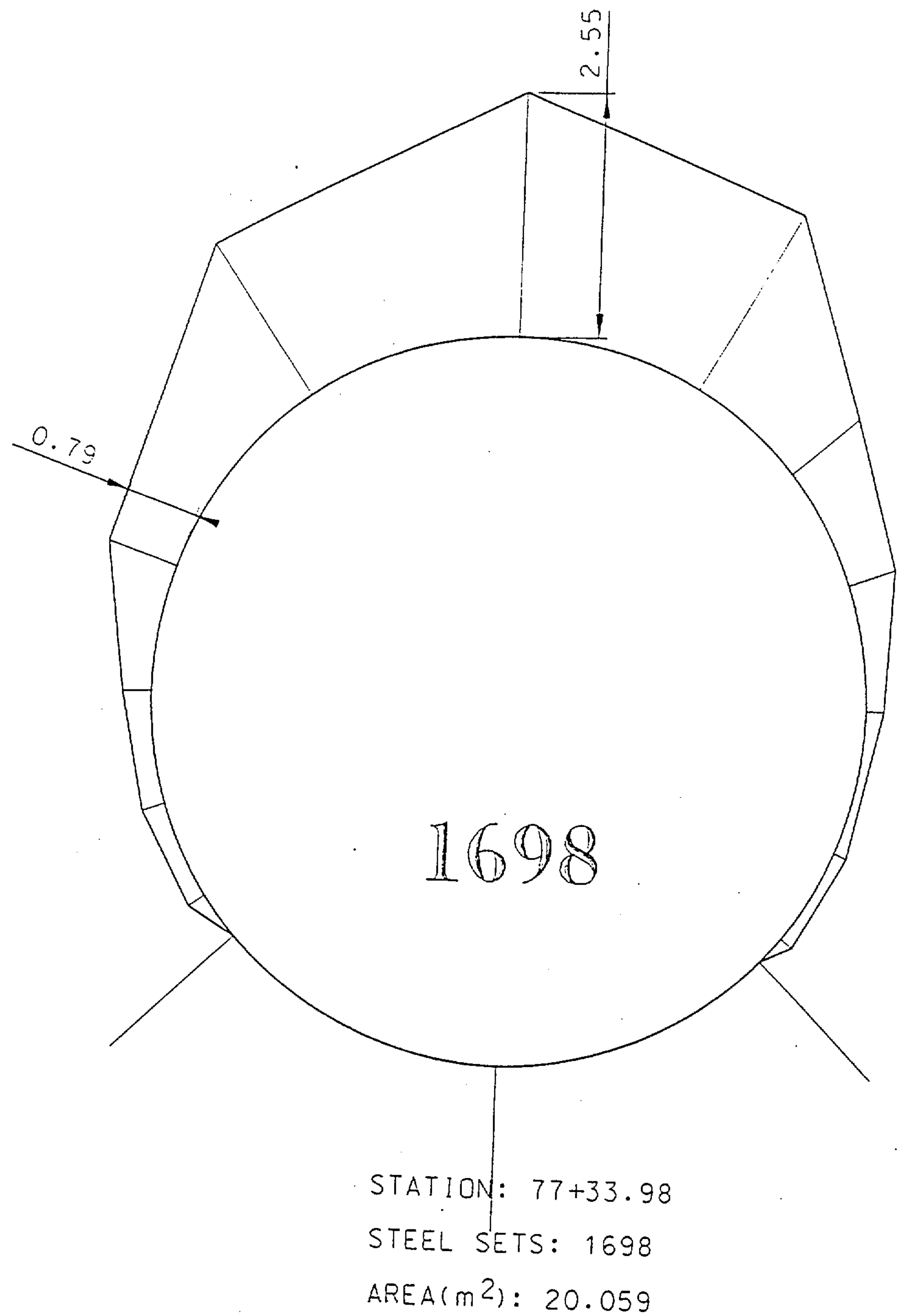


Figure 6-47. Estimates of Voids at Steel Set #1698 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

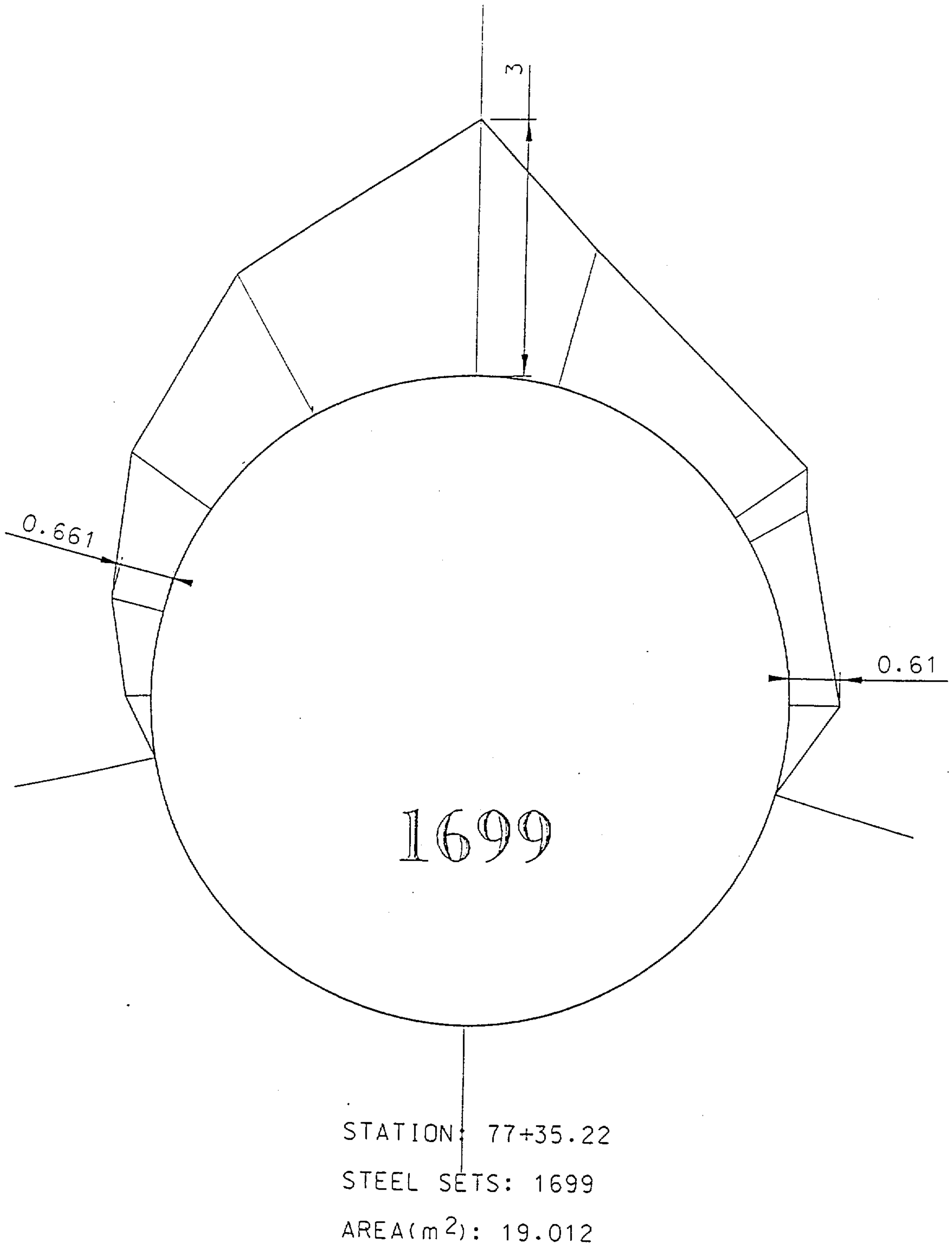


Figure 6-48. Estimates of Voids at Steel Set #1699 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

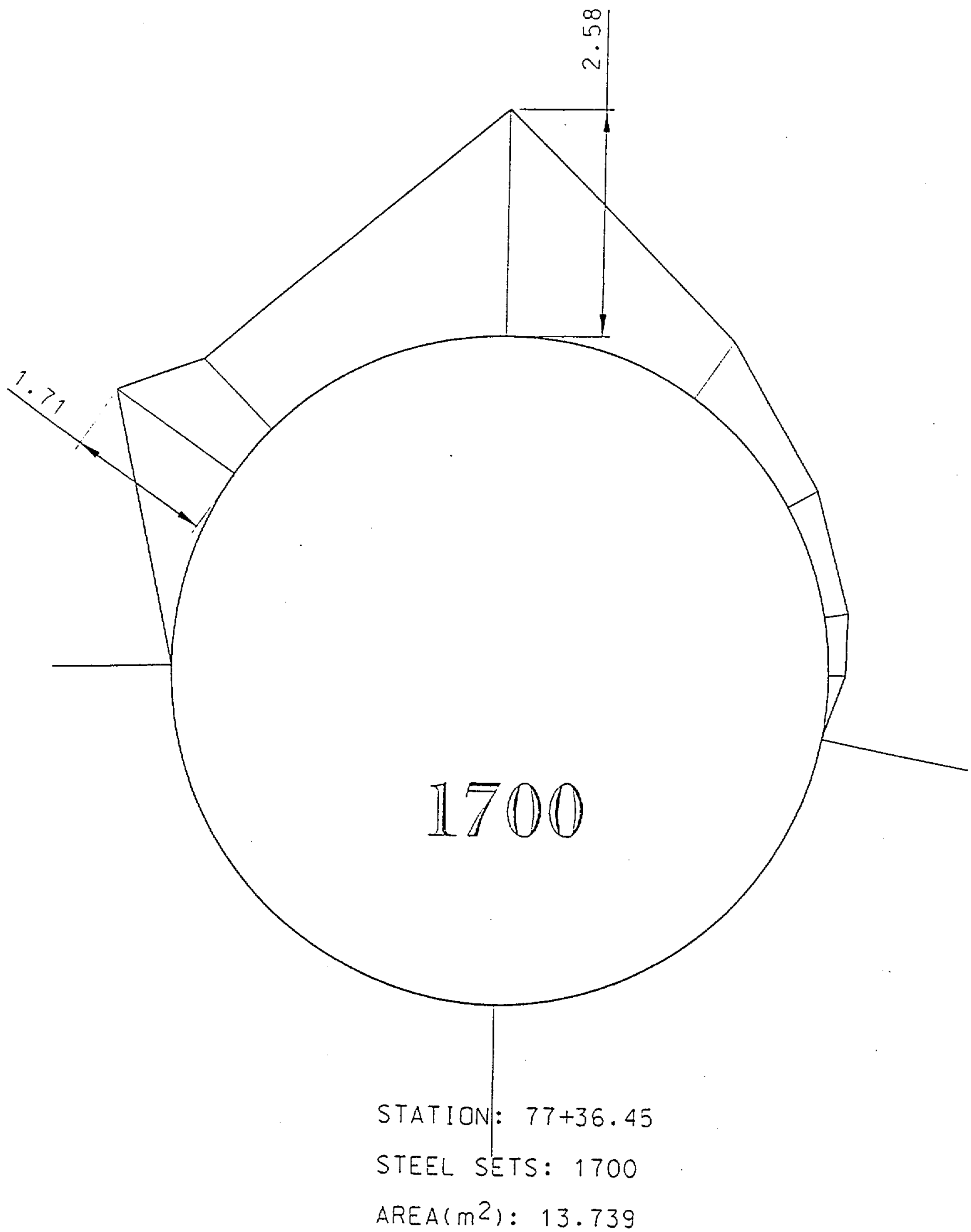


Figure 6-49. Estimates of Voids at Steel Set #1700 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

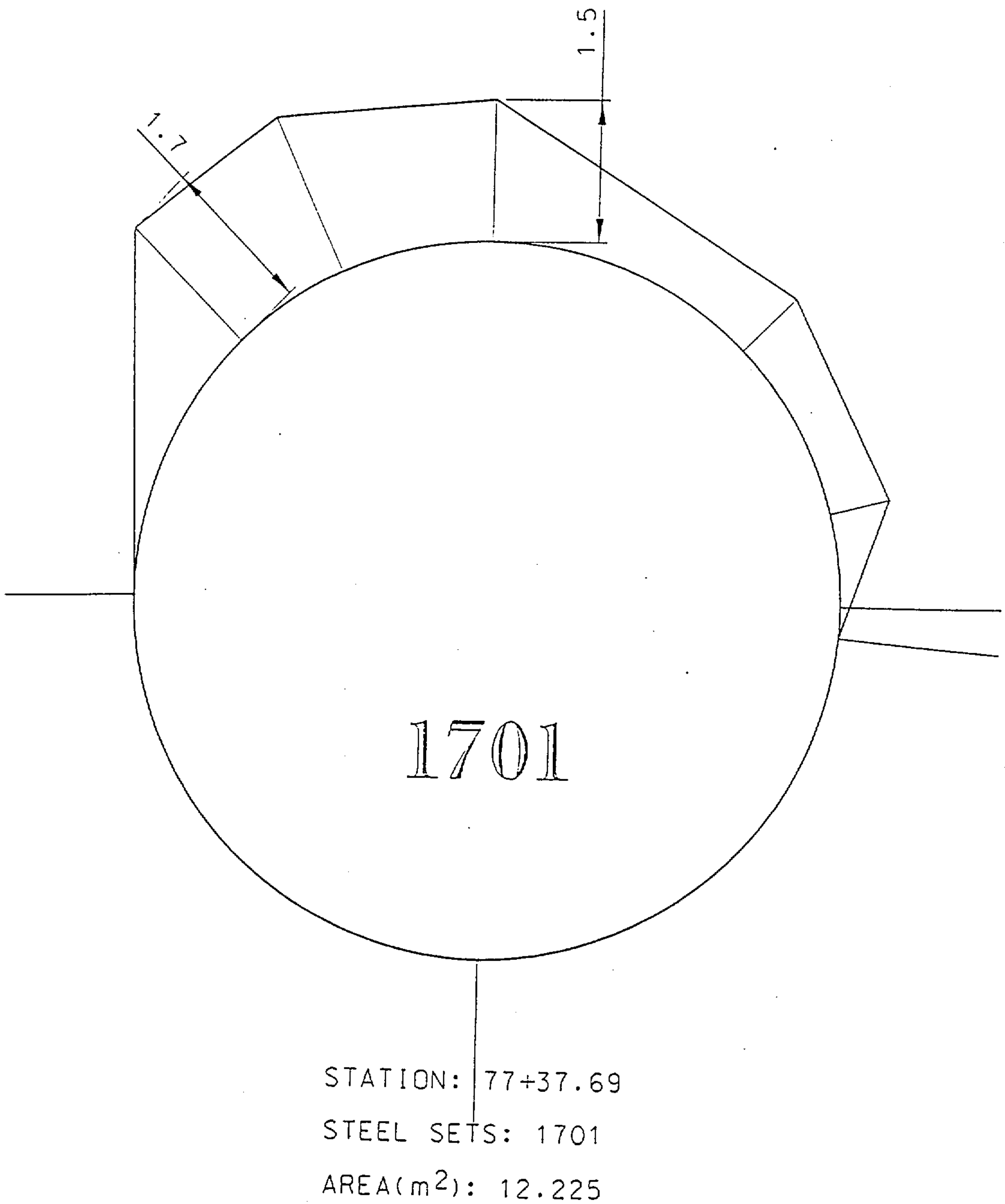


Figure 6-50. Estimates of Voids at Steel Set #1701 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

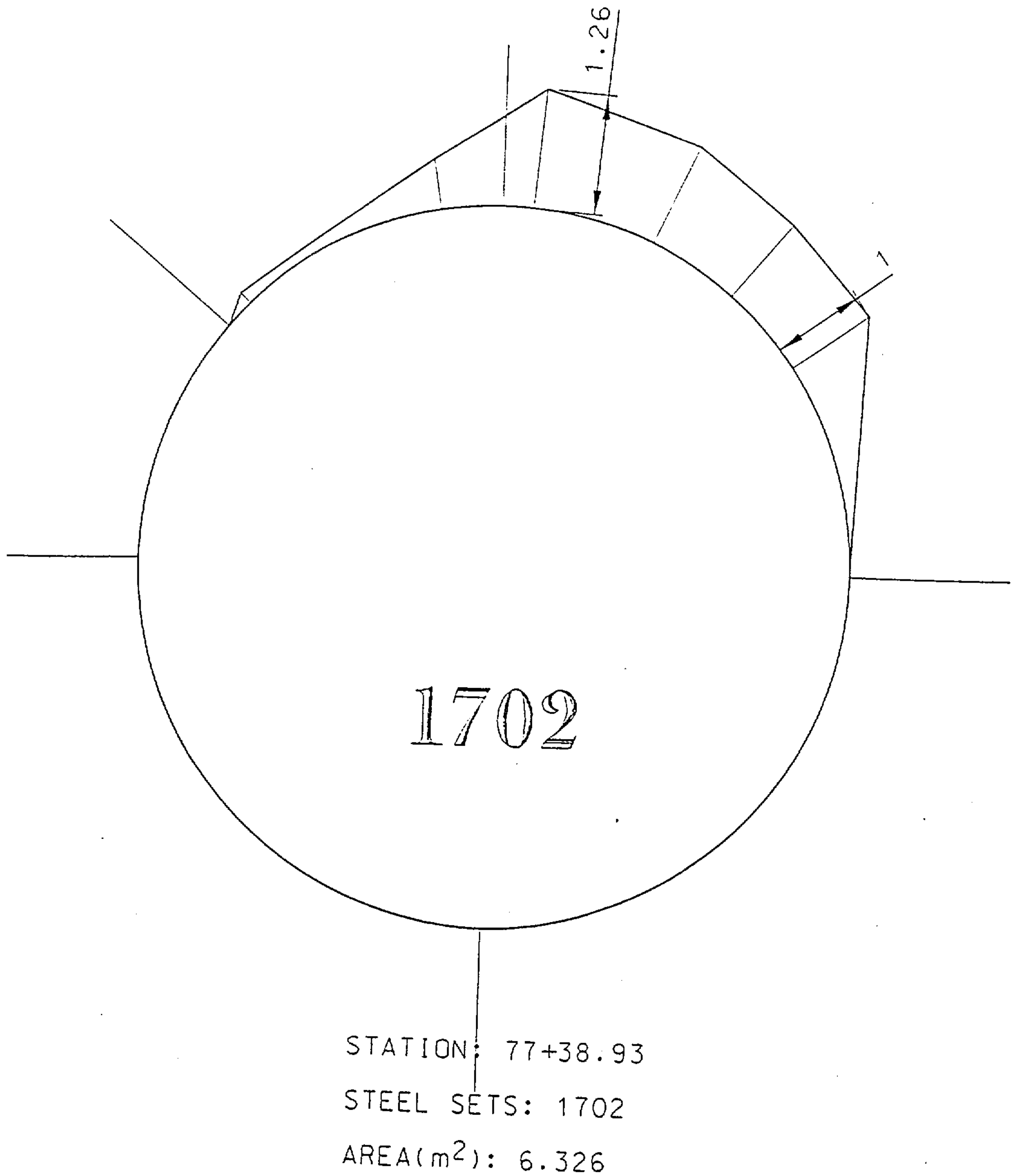


Figure 6-51. Estimates of Voids at Steel Set #1702 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

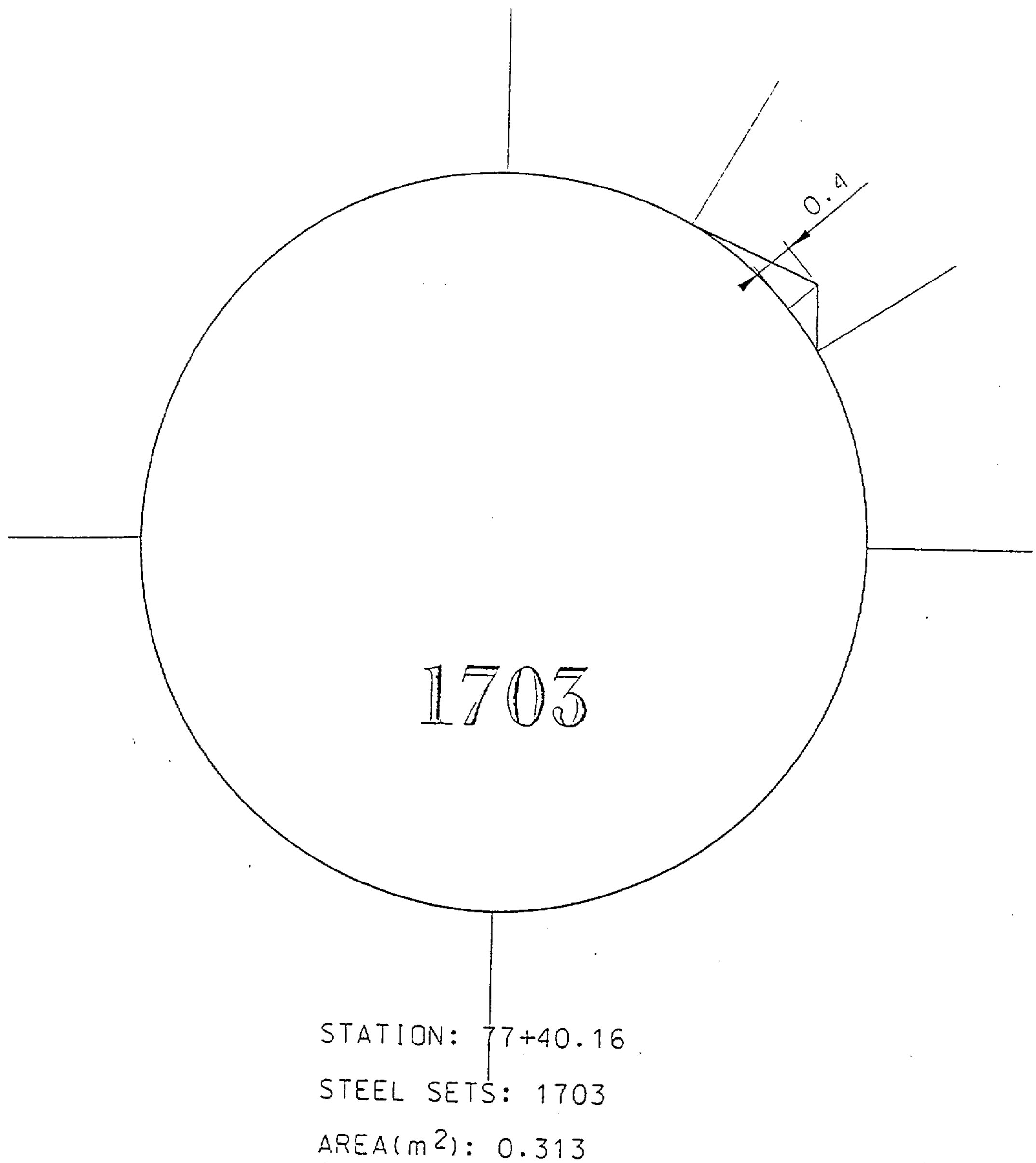


Figure 6-52. Estimates of Voids at Steel Set #1703 Location along the ESF Main Loop Based on Field Survey Data (Reference 8.6)

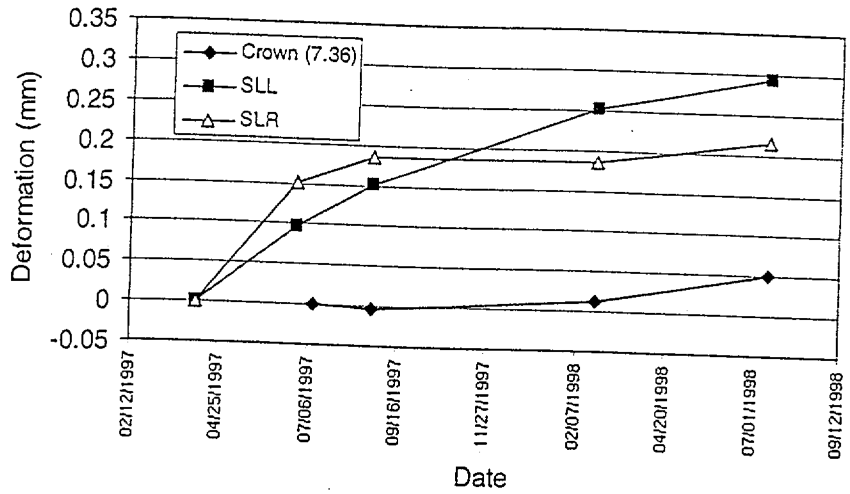


Figure 6-53. Deformation Monitoring Results from Borehole Extensometers at Station 76+96 in ESF Main Loop (Reference 8.16)

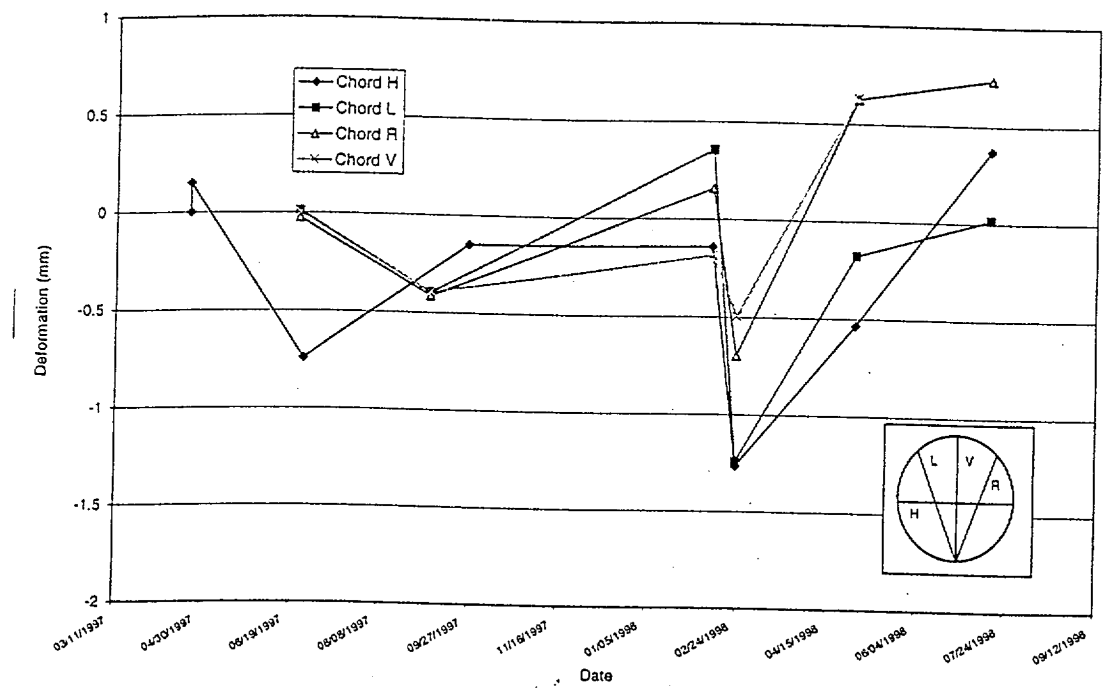


Figure 6-54. Deformation Monitoring Results from Tape Extensometer Measurements at Station 76+96 in ESF Main Loop (Reference 8.16)

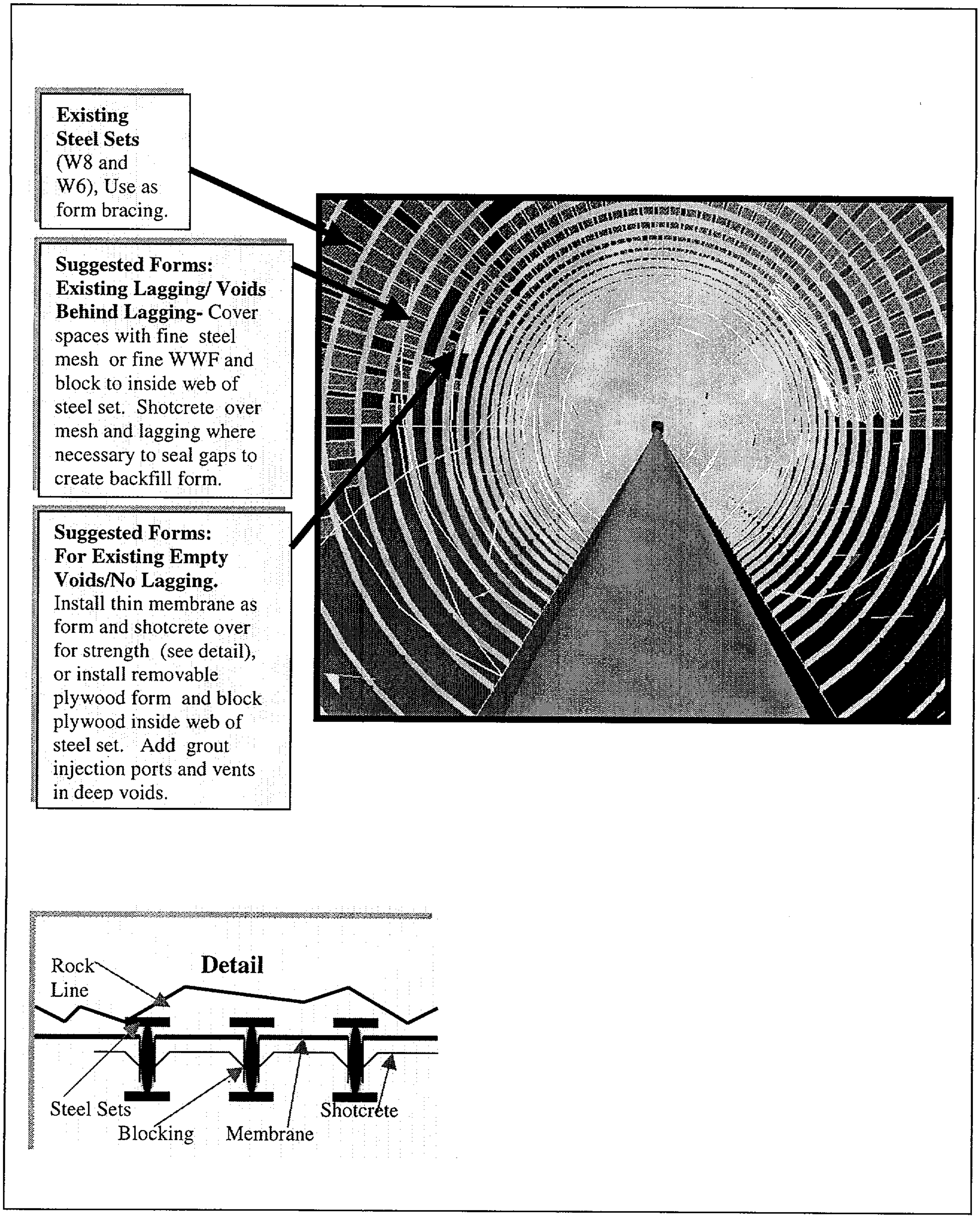
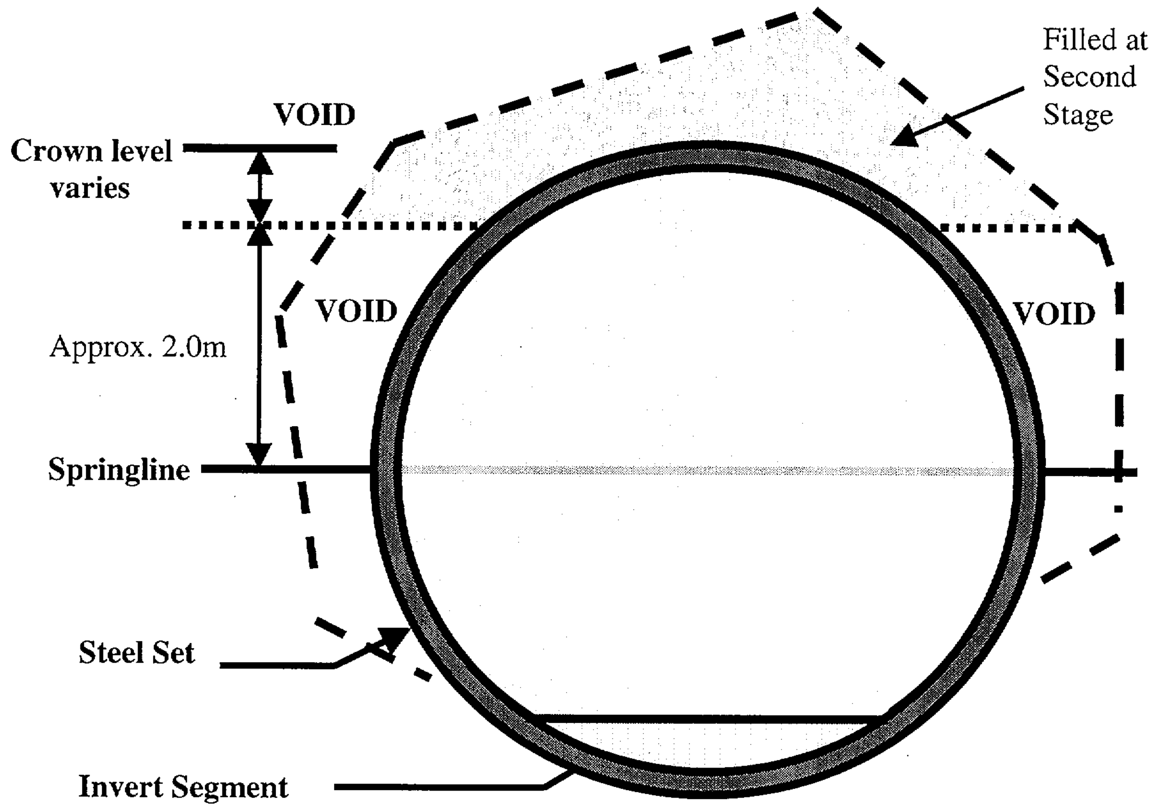


Figure 6-55. Typical Construction Form that May Be Used in 3.01.X Areas for Shotcrete/Concrete Backfill



First Stage (Backfill from Invert Segment up to approximately 2.0 m above the springline) Apply minimum 2 inch **Shotcrete** from Invert Segment up to lowest void, prepare **form** and **backfill** void with concrete/shotcrete. Backfill can be placed in several lifts if necessary to lessen pressure on forms and reduce leakage.

Backfill in Stage 1, should not exceed an elevation above crown level.
(voids in crown to remain visible after completion of Stage 1 for monitoring purposes if Stage 2 is deferred).

Second Stage (Lightweight materials - type to be selected) Install lightweight materials through grout pipes or vent pipes to entirely fill cavities and encase existing wood blocking.

Figure 6-56. Typical Method for 3.01.X Area Shotcrete/Concrete Backfill

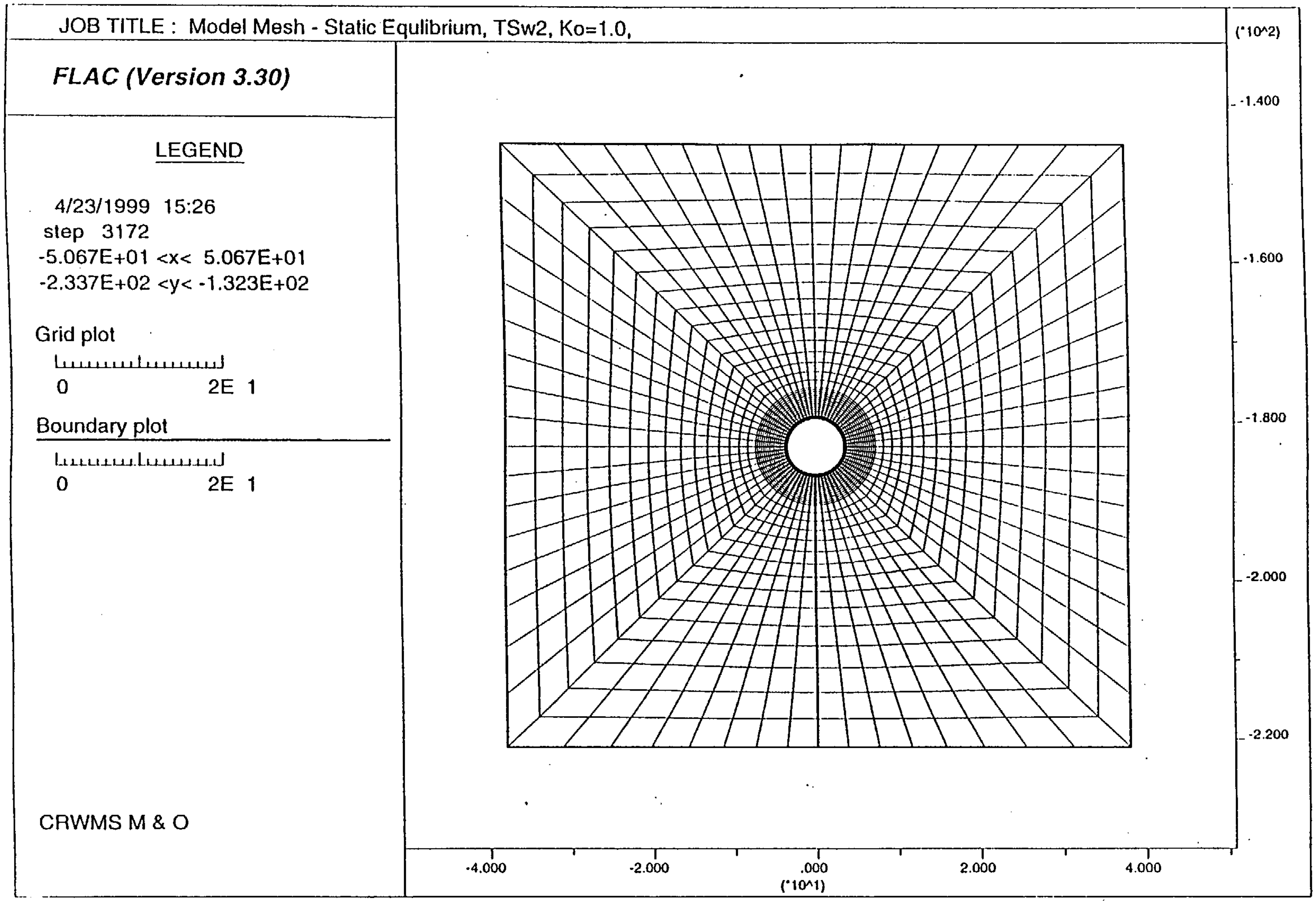


Figure 6-57. Finite Difference Mesh Used in the Analysis of 3.01.X Area. Grid Dimensions Are in Meters.

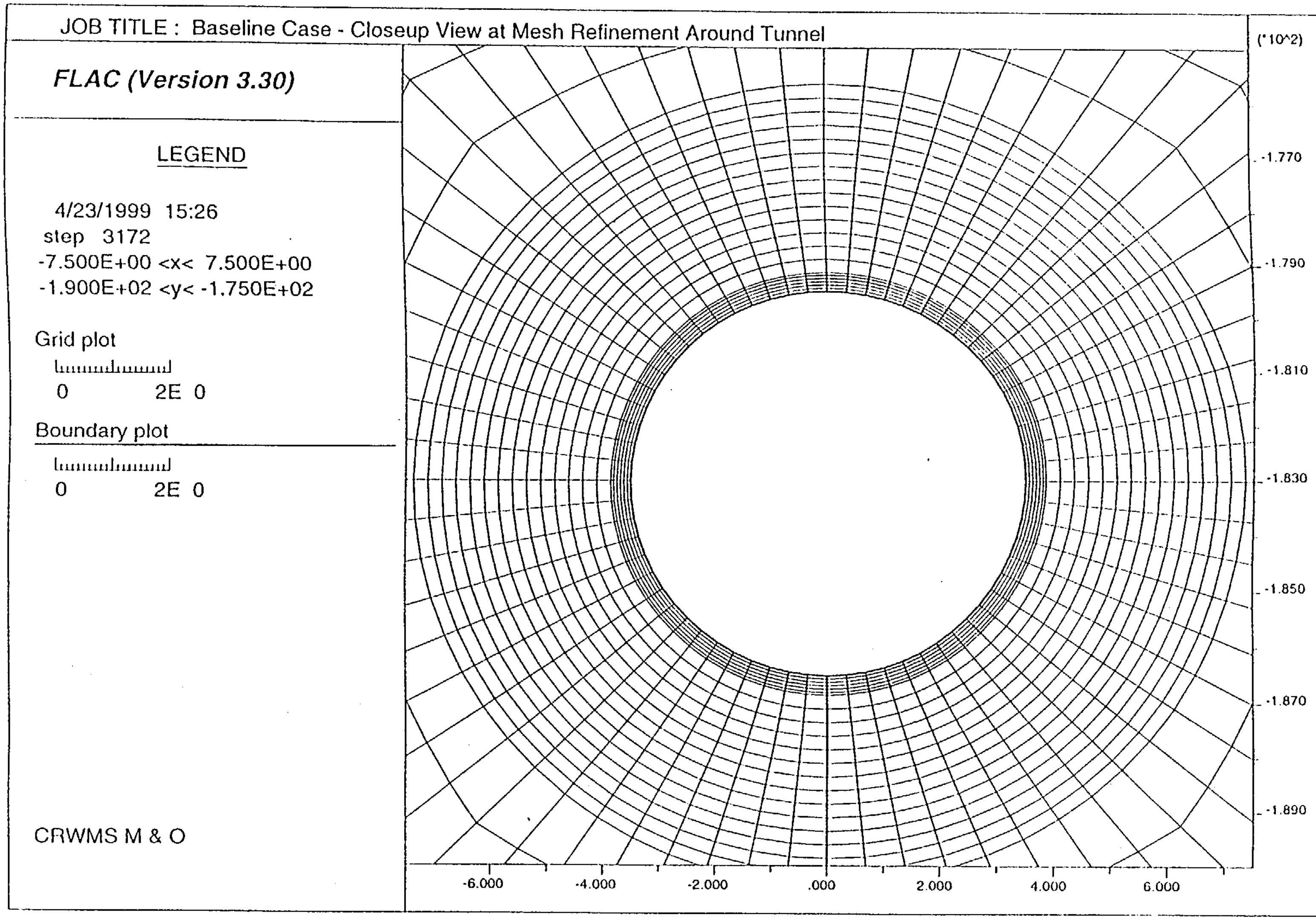


Figure 6-58. Close-up of the Mesh Used in the Analysis of 3.01.X Area. Grid Dimensions Are in Meters.

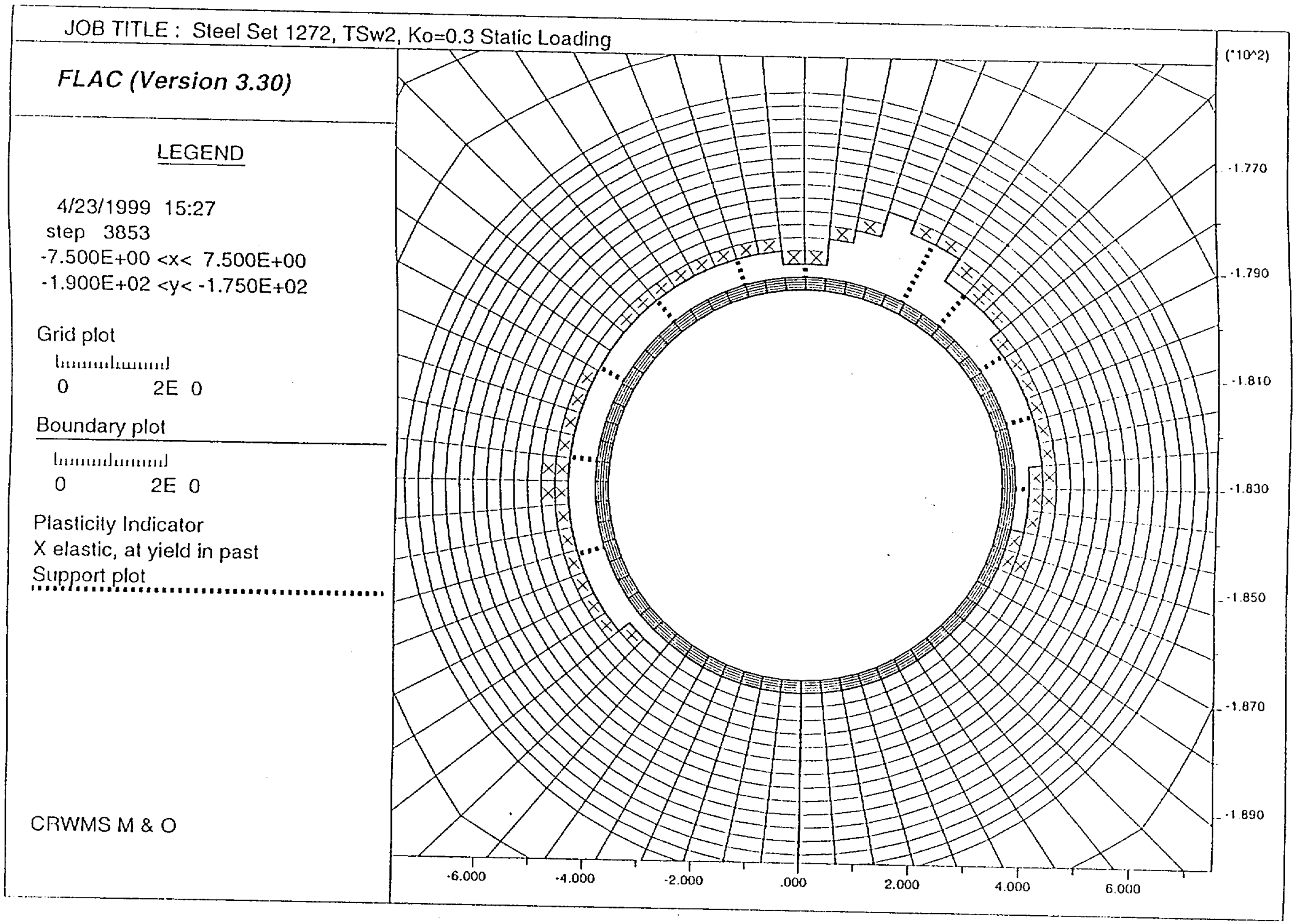


Figure 6-59. Plasticity Indicators at Steel Set #1272 Location, Mohr-Coulomb Plasticity Model, In Situ Loading Condition, K_o=0.3. Grid Dimensions Are in Meters.

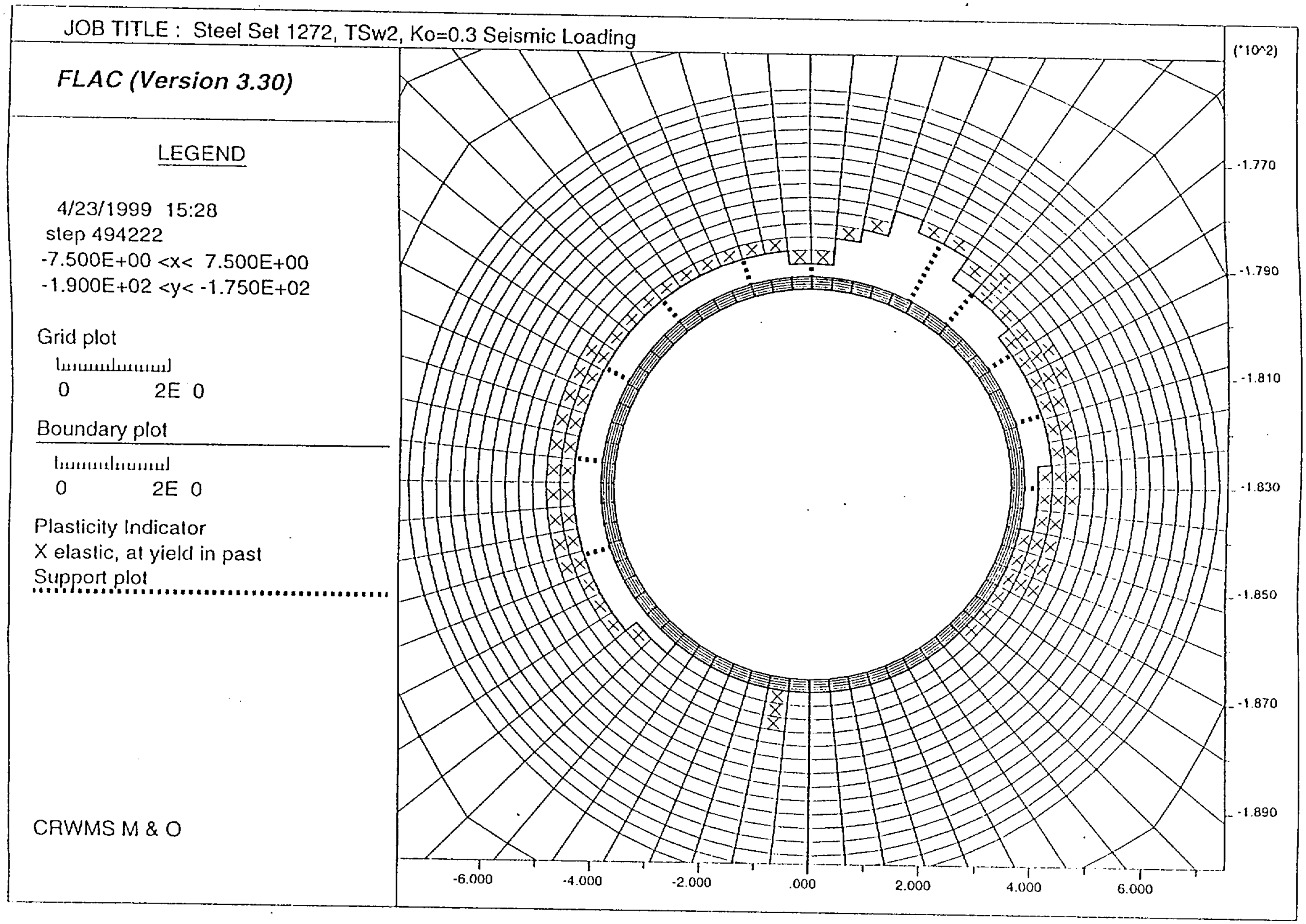


Figure 6-60. Plasticity Indicators at Steel Set #1272 Location, Mohr-Coulomb Plasticity Model, In Situ + Seismic Loading Condition, K_o=0.3. Grid Dimensions Are in Meters.

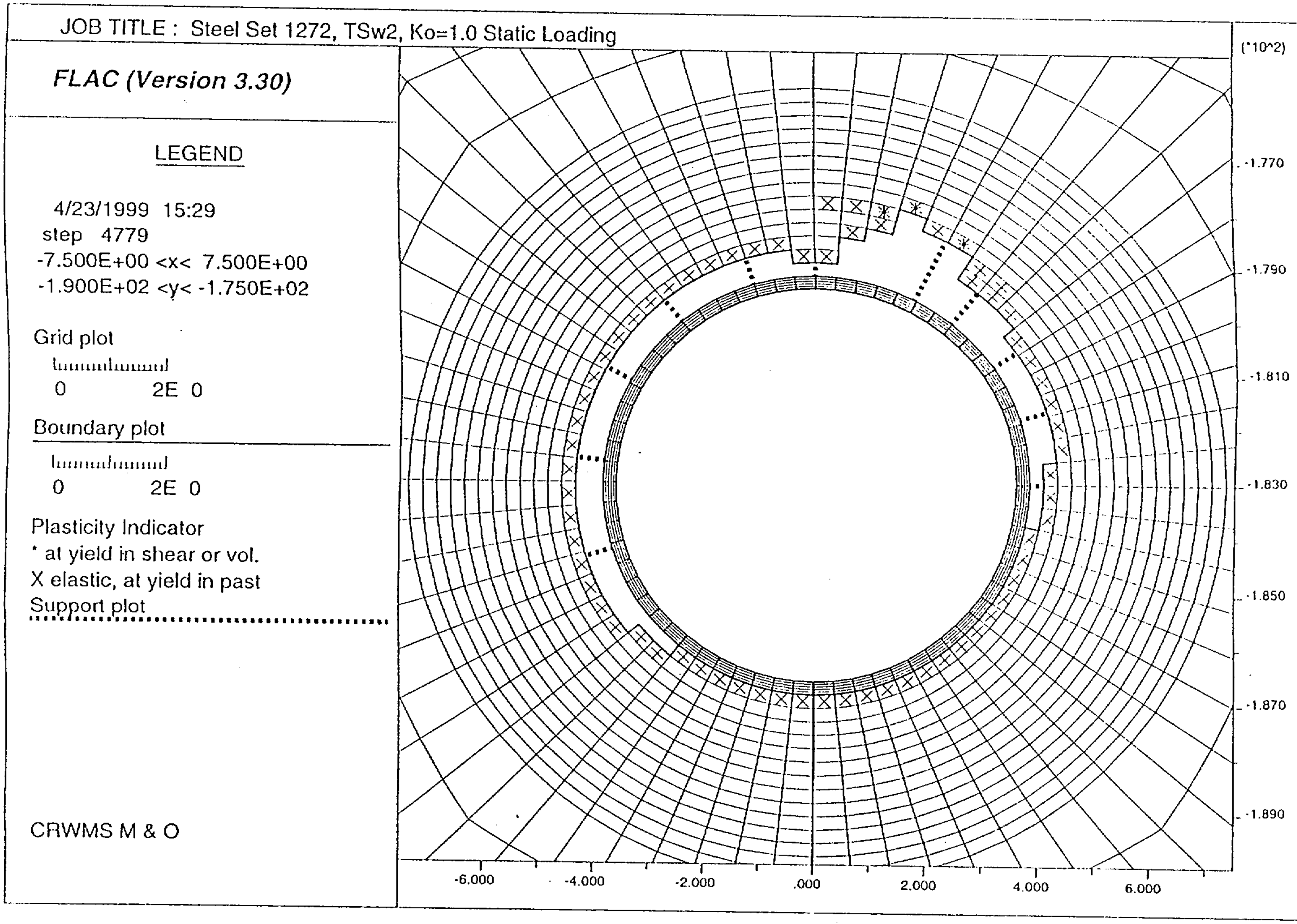


Figure 6-61. Plasticity Indicators at Steel Set #1272 Location, Mohr-Coulomb Plasticity Model, In Situ Loading Condition, K_o=1.0. Grid Dimensions Are in Meters.

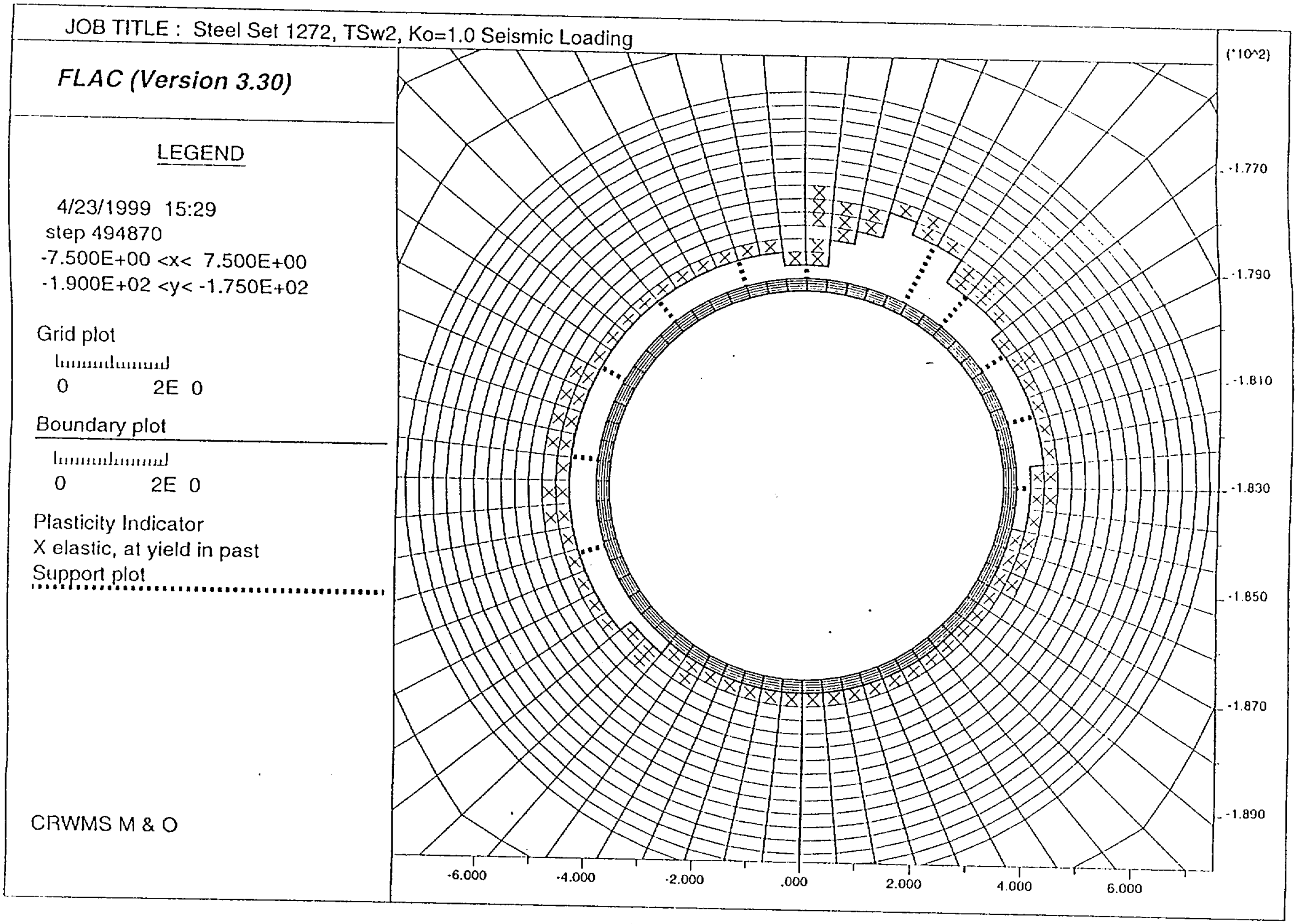


Figure 6-62. Plasticity Indicators at Steel Set #1272 Location, Mohr-Coulomb Plasticity Model, In Situ + Seismic Loading Condition, K_o=1.0. Grid Dimensions Are in Meters.

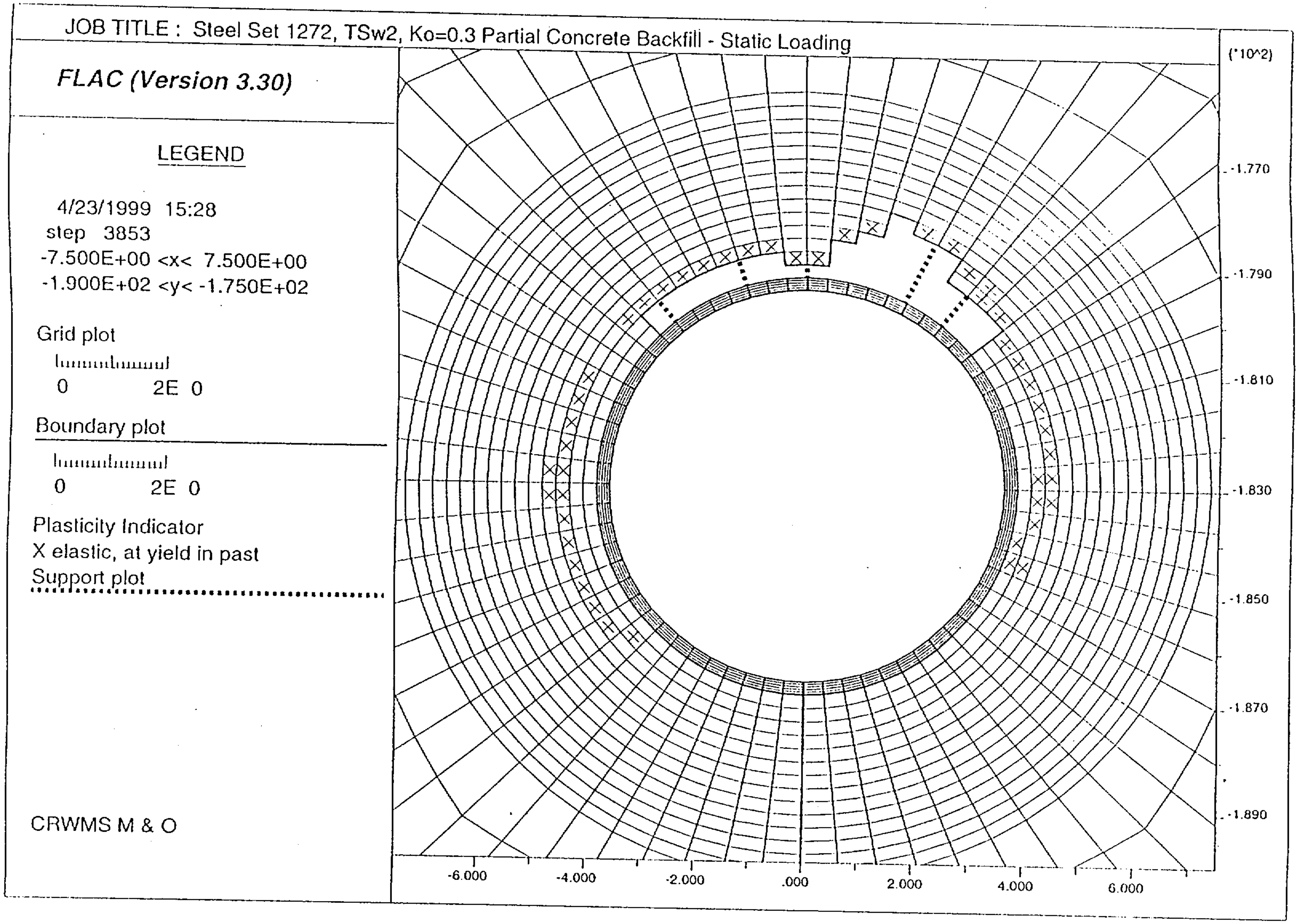


Figure 6-63. Plasticity Indicators at Steel Set #1272 Location, with Concrete or Shotcrete Backfill on the Sides, Mohr-Coulomb Plasticity Model, In Situ Loading Condition, K_o=0.3. Grid Dimensions Are in Meters.

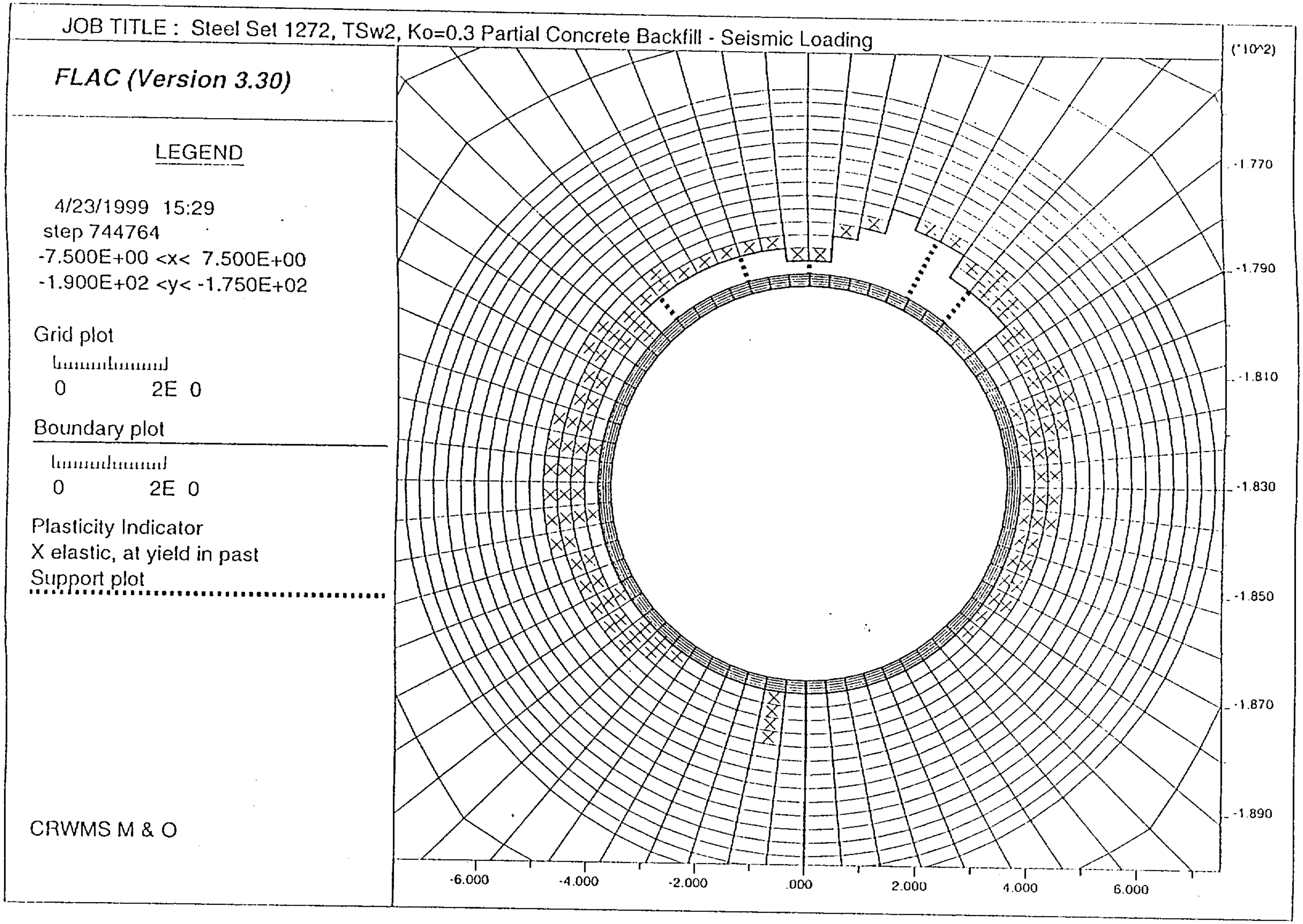


Figure 6-64. Plasticity Indicators at Steel Set #1272 Location, with Concrete or Shotcrete Backfill on the Sides, Mohr-Coulomb Plasticity Model, In Situ + Seismic Loading Condition, K_o=0.3. Grid Dimensions Are in Meters.

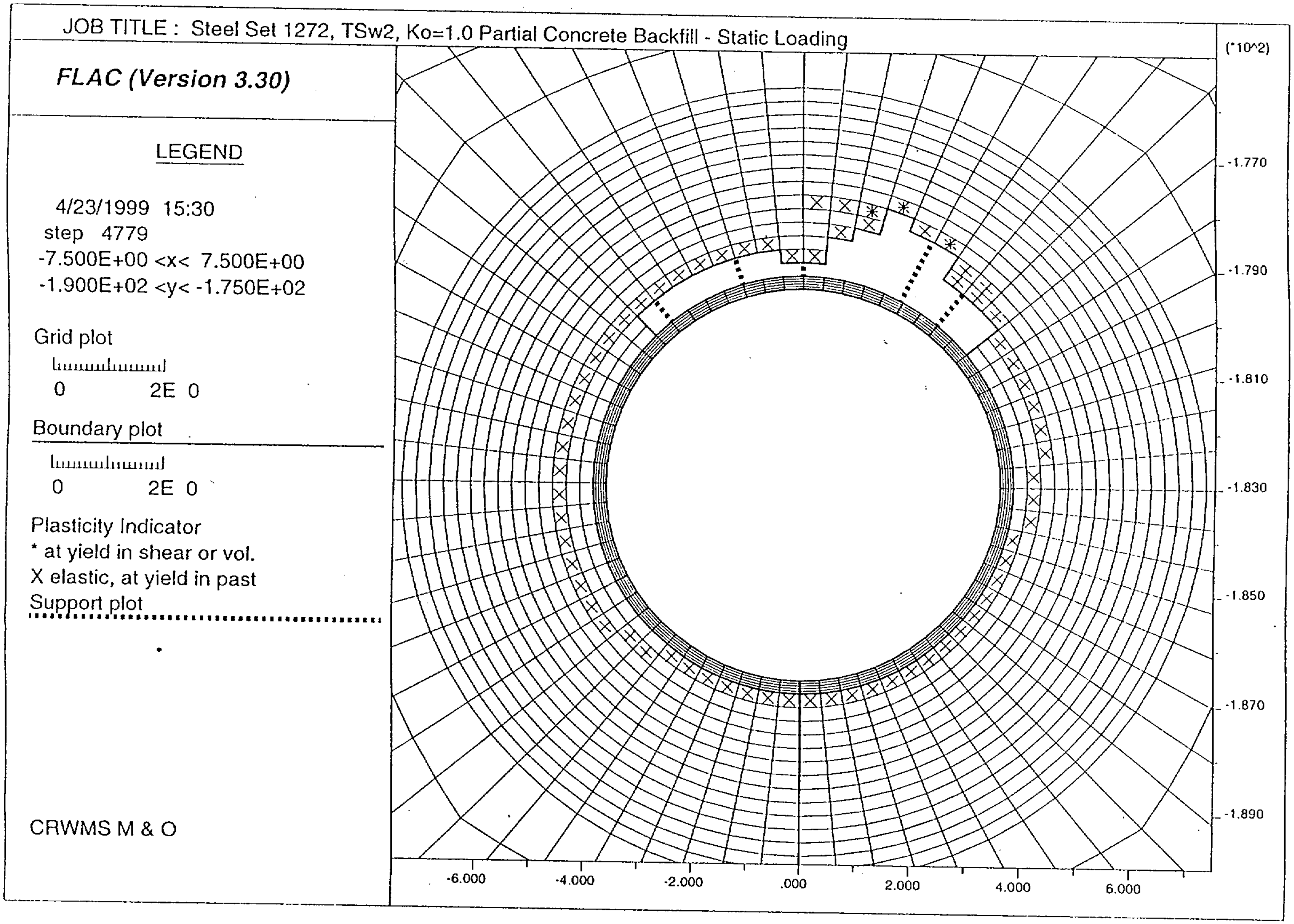


Figure 6-65. Plasticity Indicators at Steel Set #1272 Location, with Concrete or Shotcrete Backfill on the Sides, Mohr-Coulomb Plasticity Model, In Situ Loading Condition, K_o=1.0. Grid Dimensions Are in Meters.

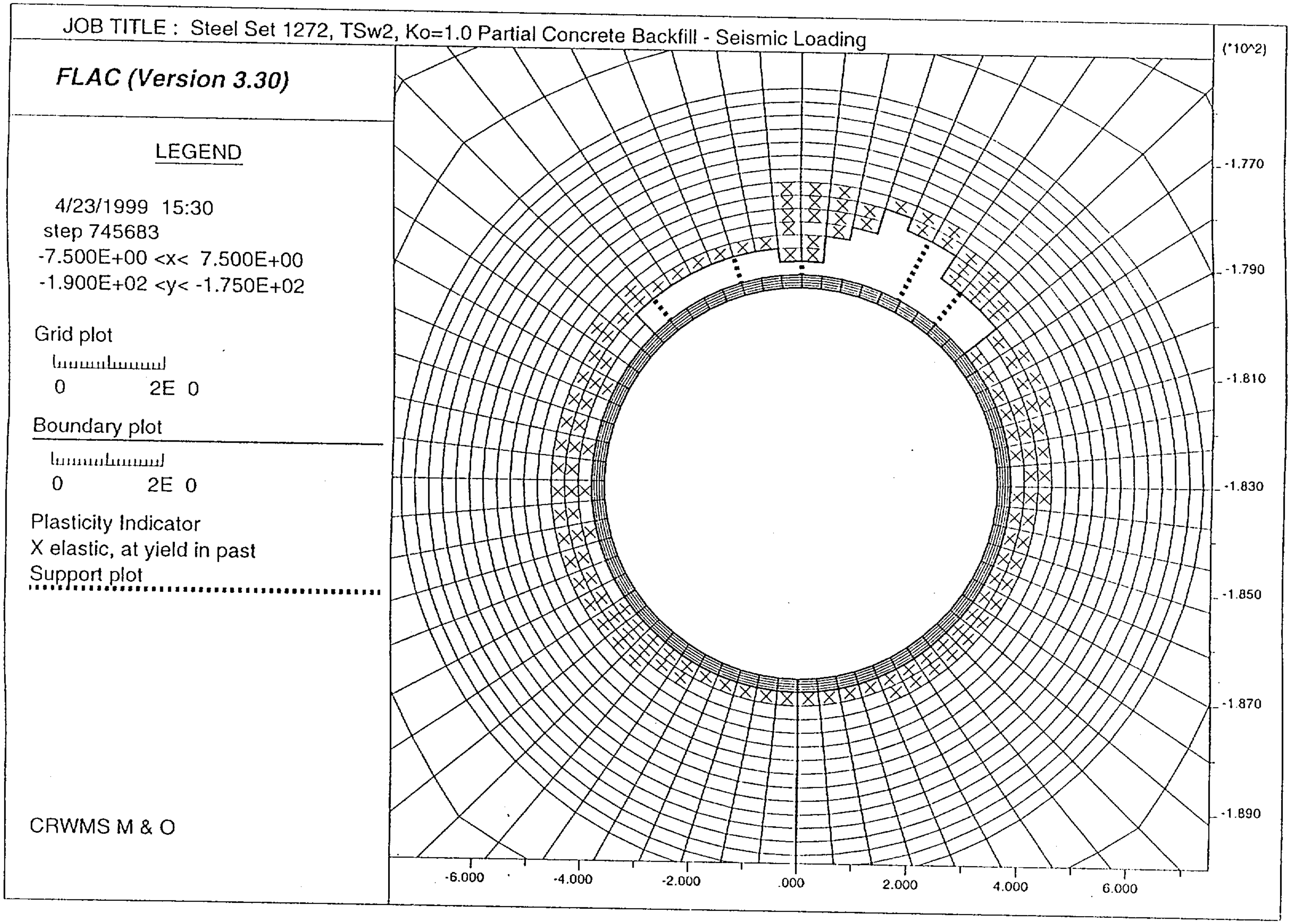


Figure 6-66. Plasticity Indicators at Steel Set #1272 Location, with Concrete or Shotcrete Backfill on the Sides, Mohr-Coulomb Plasticity Model, In Situ + Seismic Loading Condition, K_o=1.0. Grid Dimensions Are in Meters.

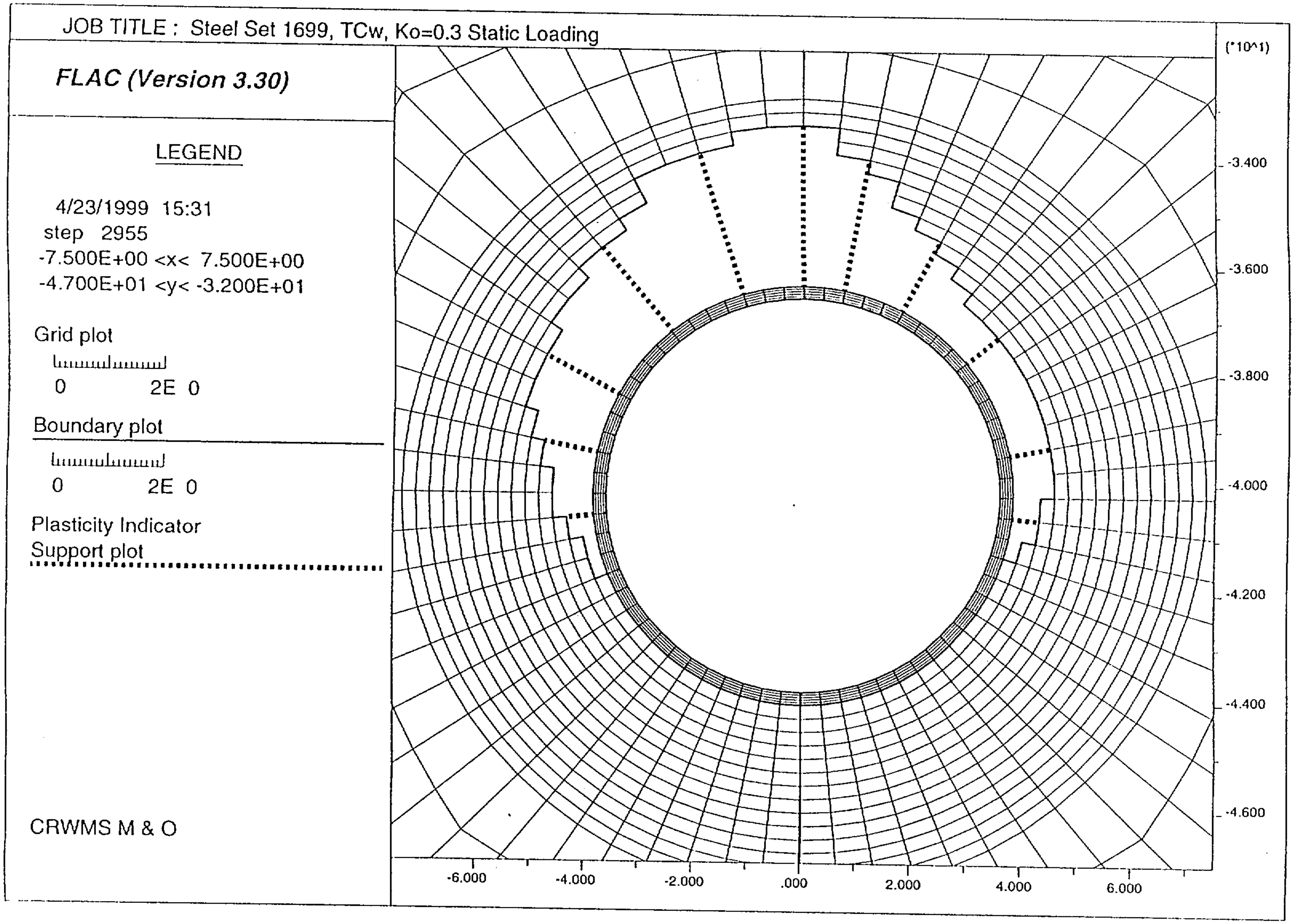


Figure 6-67. Plasticity Indicators at Steel Set #1699 Location, Mohr-Coulomb Plasticity Model, In Situ Loading Condition, K_o=0.3. Grid Dimensions Are in Meters.

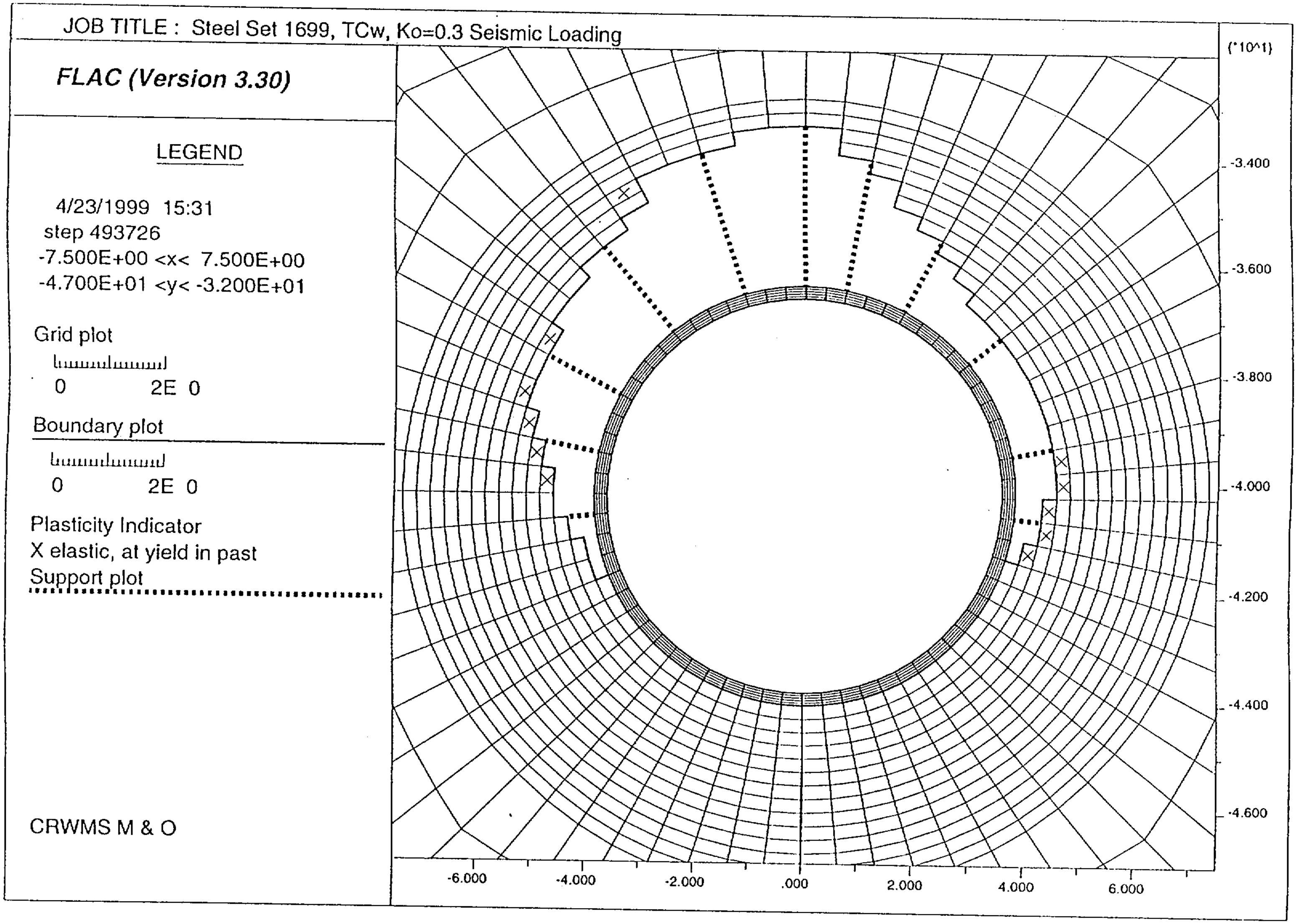


Figure 6-68. Plasticity Indicators at Steel Set #1699 Location, Mohr-Coulomb Plasticity Model, In Situ + Seismic Loading Condition, K_o=0.3. Grid Dimensions Are in Meters.

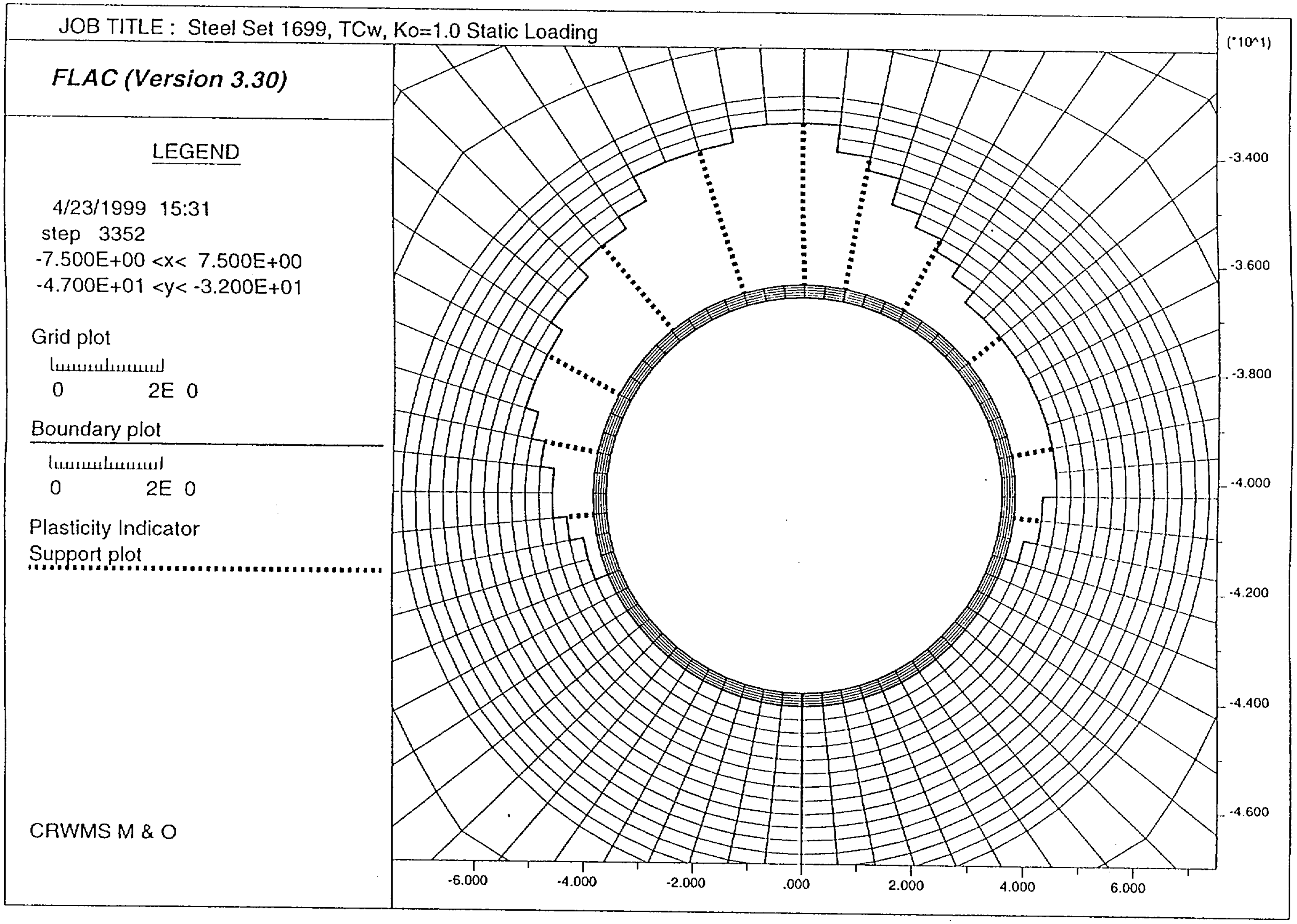


Figure 6-69. Plasticity Indicators at Steel Set #1699 Location, Mohr-Coulomb Plasticity Model, In Situ Loading Condition, K_o=1.0. Grid Dimensions Are in Meters.

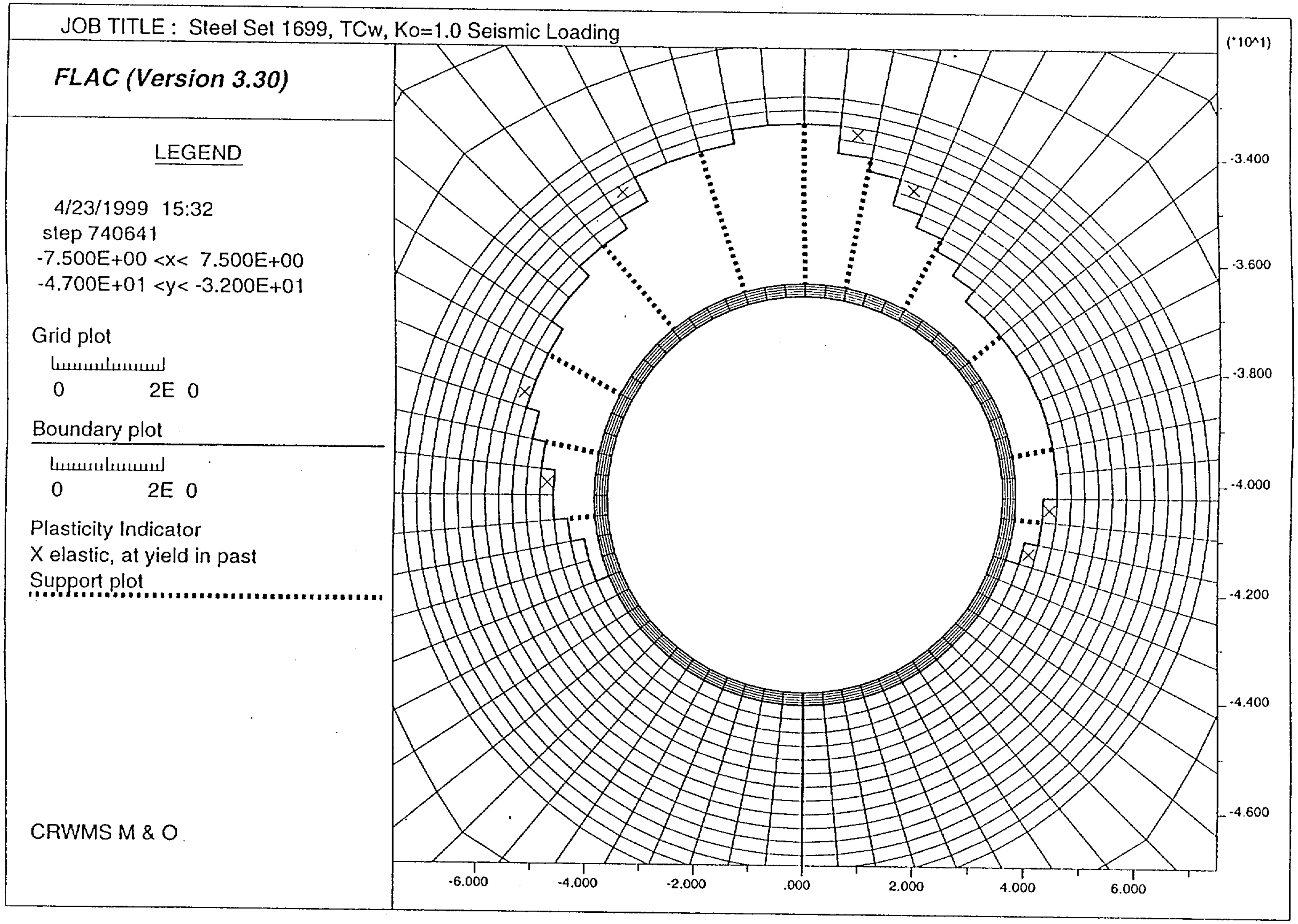


Figure 6-70. Plasticity Indicators at Steel Set #1699 Location, Mohr-Coulomb Plasticity Model, In Situ + Seismic Loading Condition, K_o=1.0. Grid Dimensions Are in Meters.

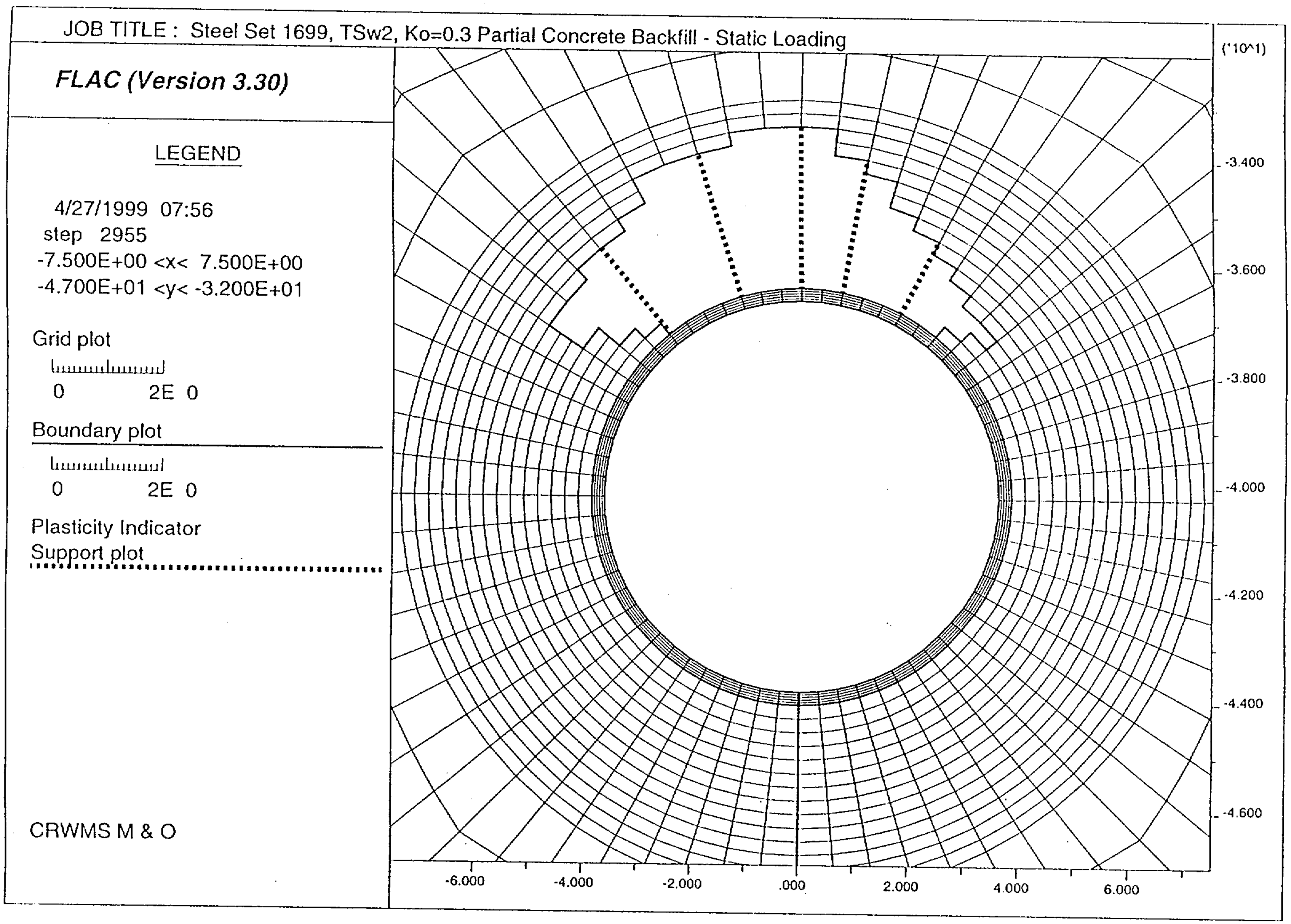


Figure 6-71. Plasticity Indicators at Steel Set #1699 Location, with Concrete or Shotcrete Backfill on the Sides, Mohr-Coulomb Plasticity Model, In Situ Loading Condition, K_o=0.3. Grid Dimensions Are in Meters.

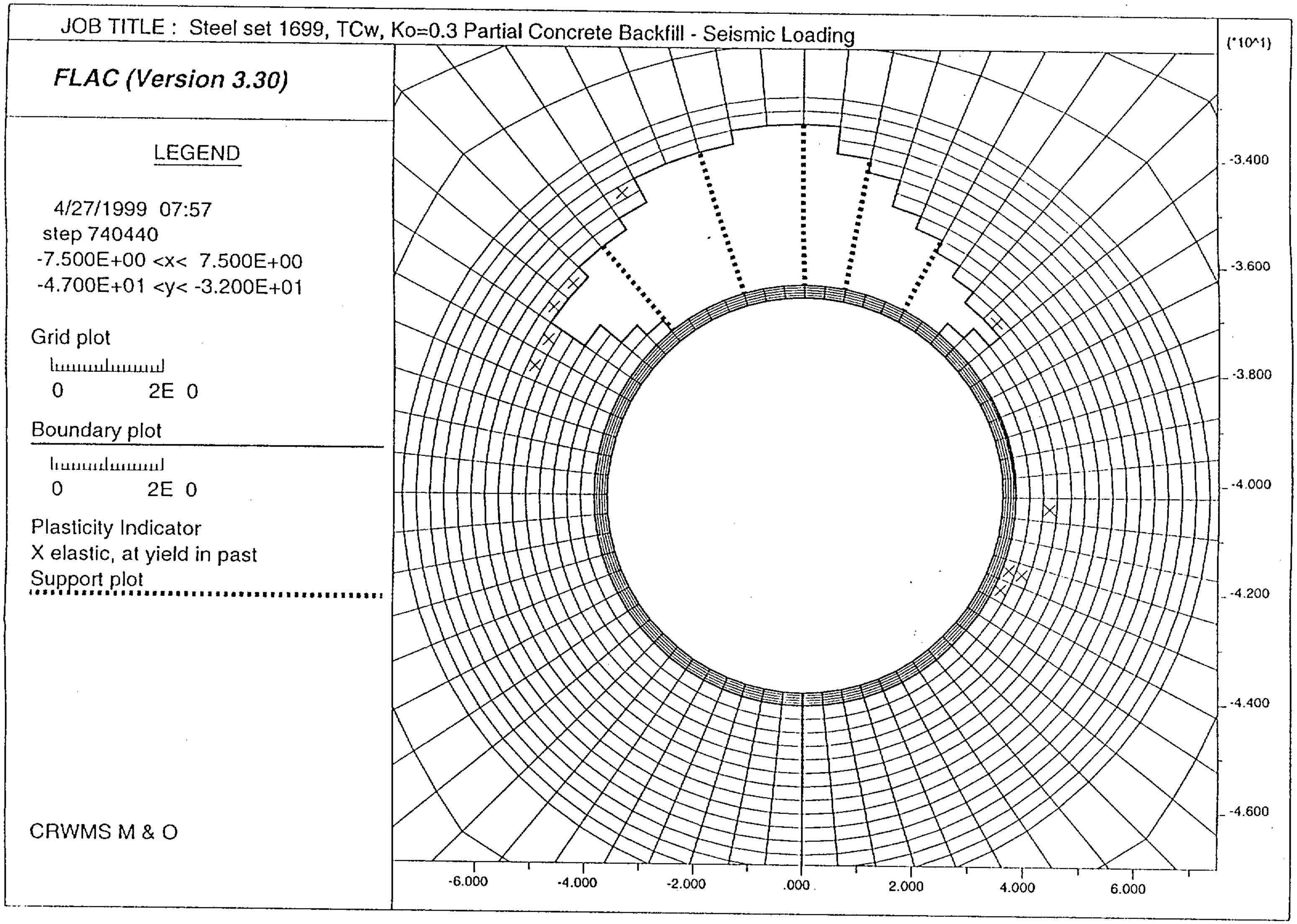


Figure 6-72. Plasticity Indicators at Steel Set #1699 Location, with Concrete or Shotcrete Backfill on the Sides, Mohr-Coulomb Plasticity Model, In Situ + Seismic Loading Condition, K_o=0.3. Grid Dimensions Are in Meters.

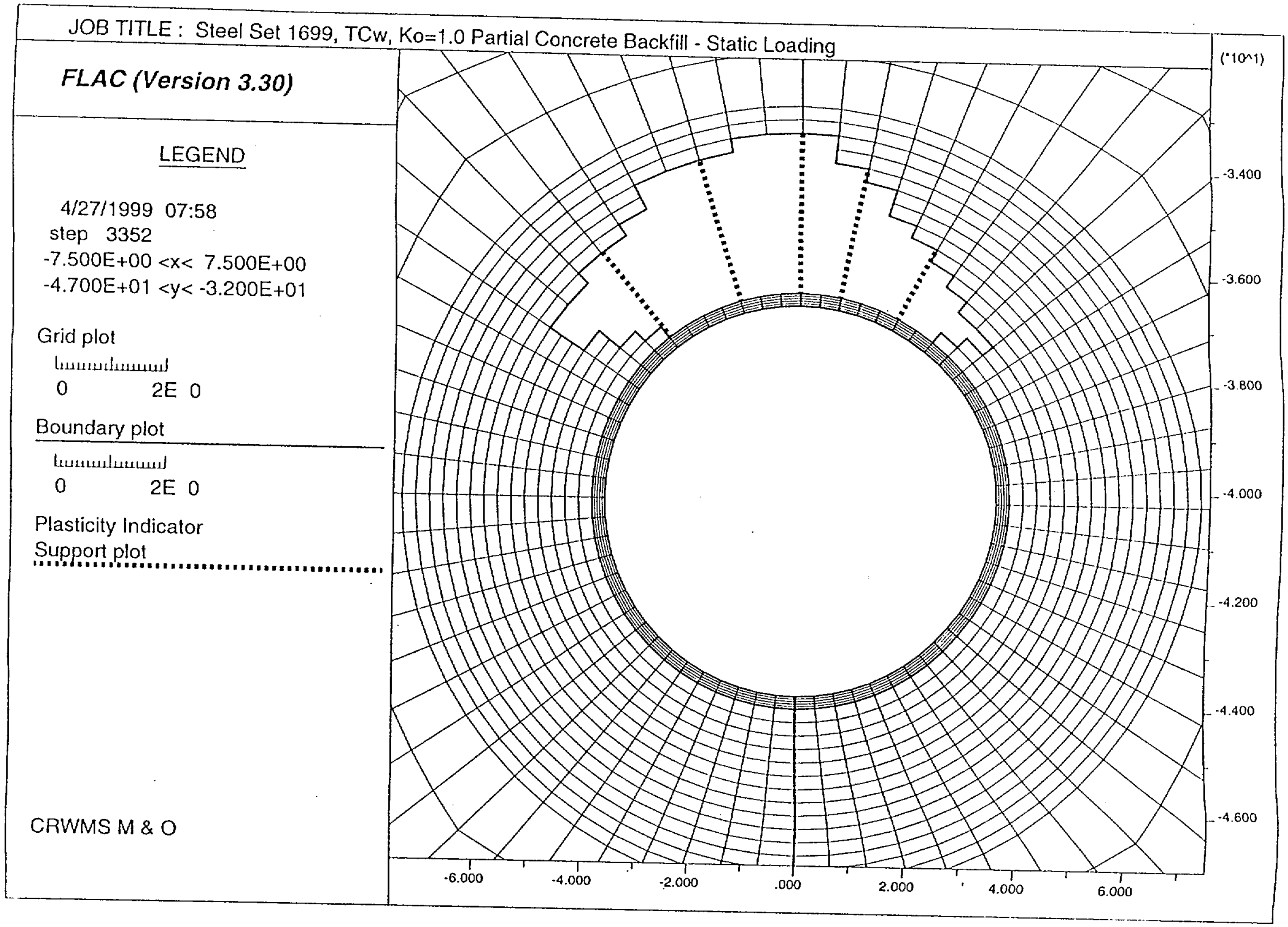


Figure 6-73. Plasticity Indicators at Steel Set #1699 Location, with Concrete or Shotcrete Backfill on the Sides, Mohr-Coulomb Plasticity Model, In Situ Loading Condition, K_o=1.0. Grid Dimensions Are in Meters.

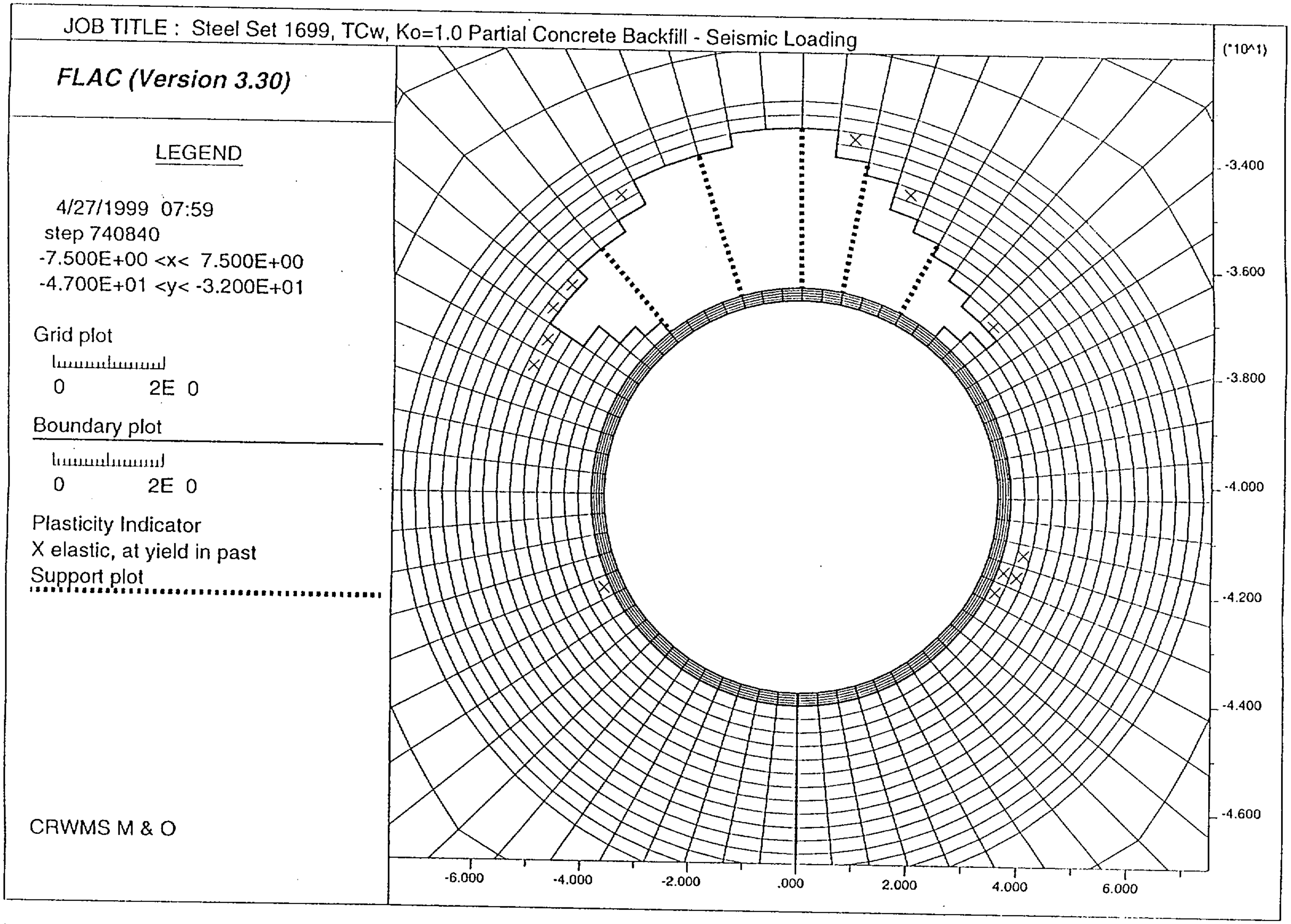


Figure 6-74. Plasticity Indicators at Steel Set #1699 Location, with Concrete or Shotcrete Backfill on the Sides, Mohr-Coulomb Plasticity Model, In Situ + Seismic Loading Condition, K_o=1.0. Grid Dimensions Are in Meters.

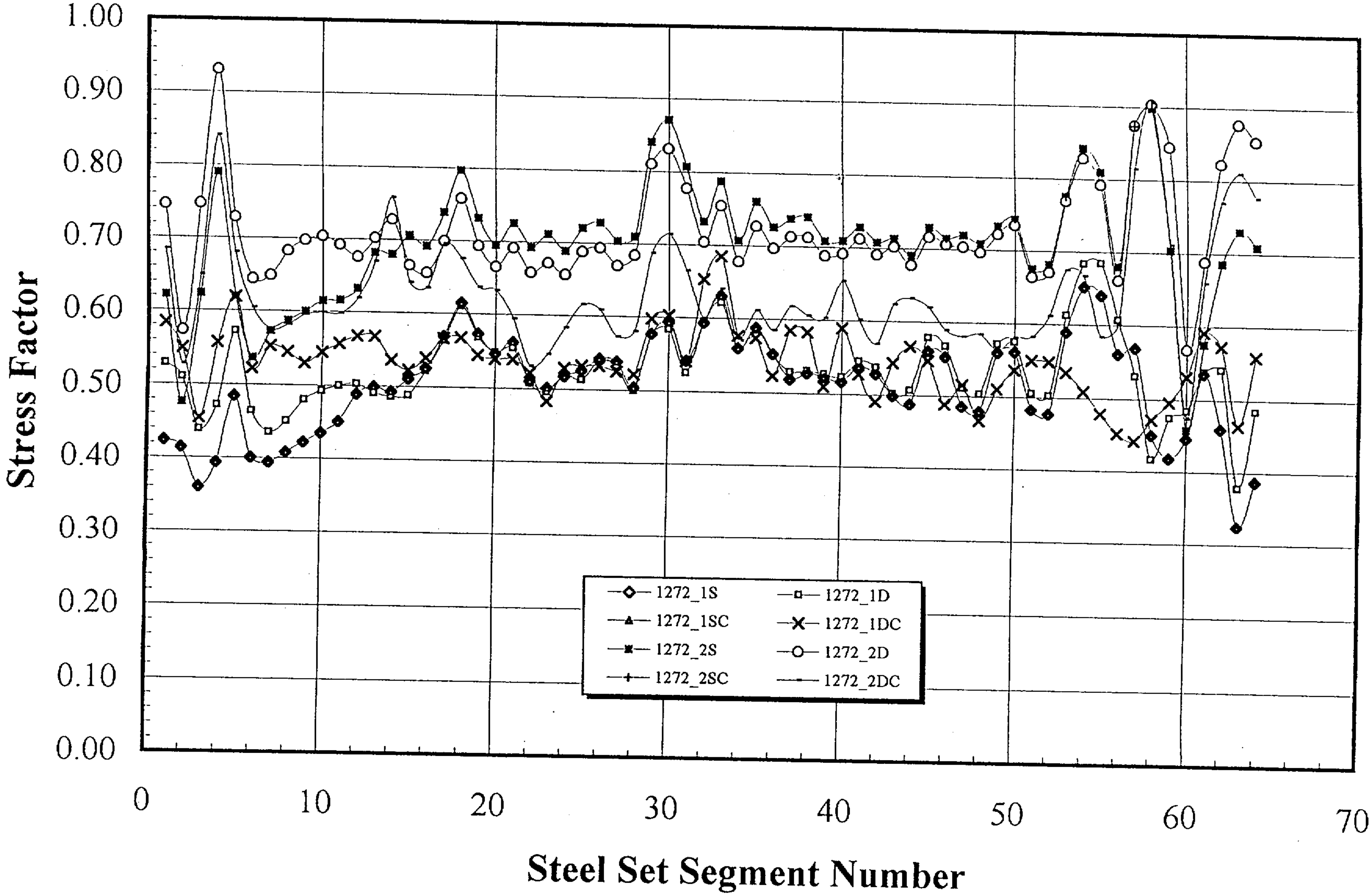


Figure 6-75. Combined Stress Factors for Steel Set #1272, for Both K_o Values and Both Loading Cases, Based on Reference 8.11. Steel Set Segment Numbers Are Shown in Figure 6-77. The Corresponding Input Files Are Represented by Different Symbols as Indicated on the Figure and Are Described in Attachment II.

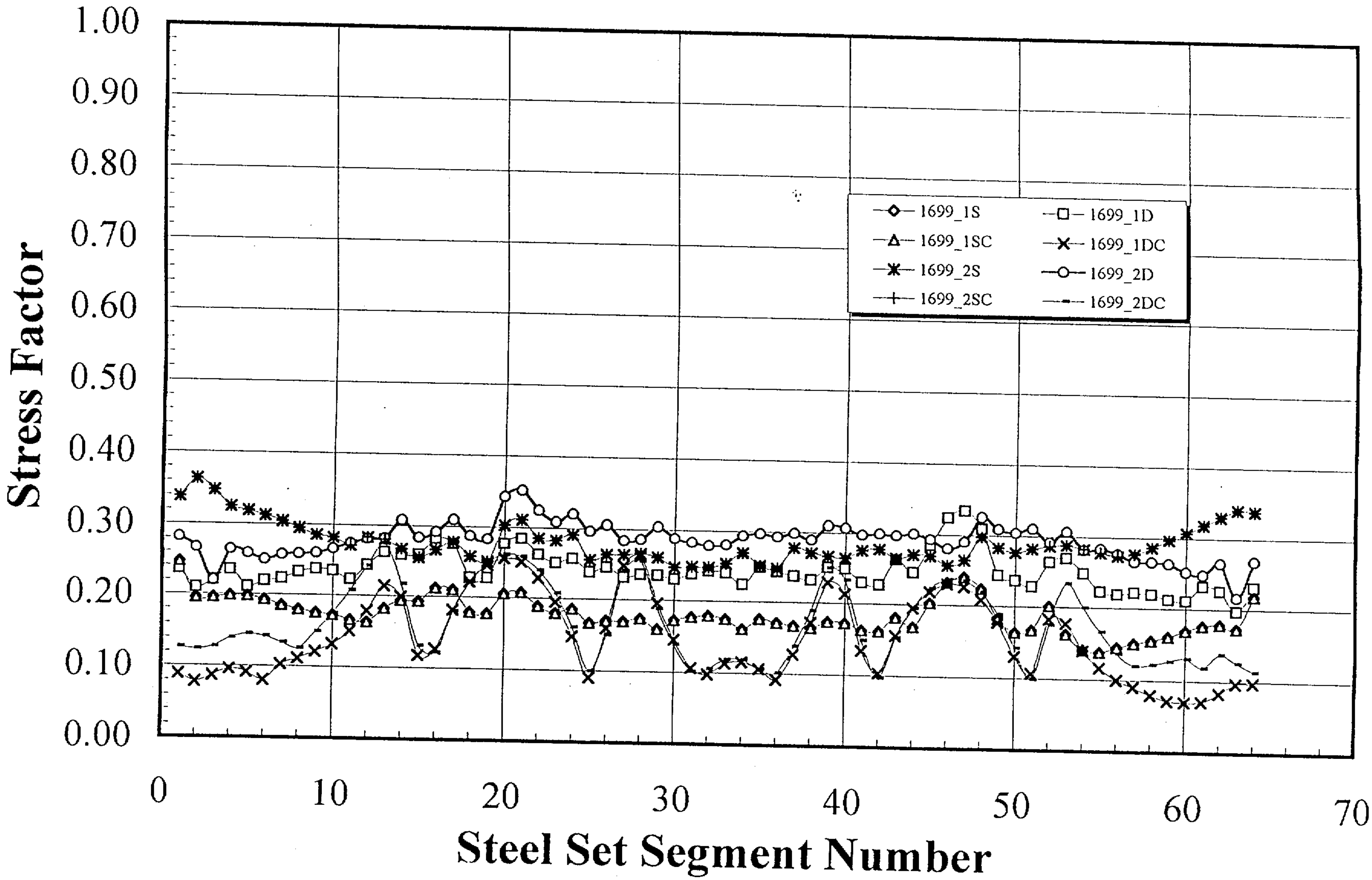


Figure 6-76. Combined Stress Factors for Steel Set #1699, for Both K_o Values and Both Loading Cases, Based on Reference 8.11. Steel Set Segment Numbers Are Shown in Figure 6-77. The Corresponding Input Files Are Represented by Different Symbols as Indicated on the Figure and Are Described in Attachment II.

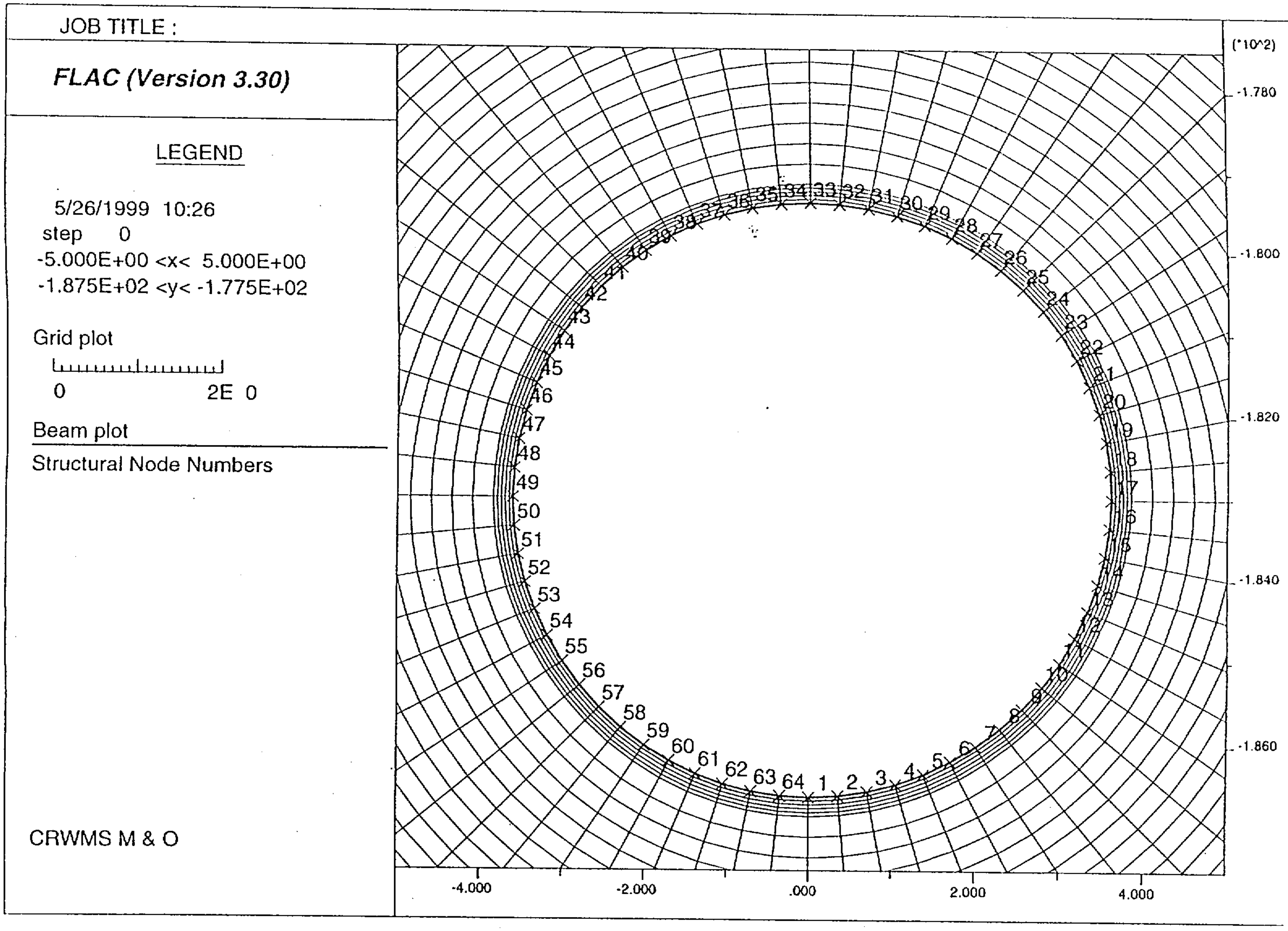


Figure 6-77. Steel Set Segment Numbers Used in the Analysis of Steel Sets #1272 and #1699. Segment Numbers Are the Same for All Cases Analyzed.

ATTACHMENT I

INPUT FILES FOR COMPUTER ANALYSES

I-1 INPUT FILES 1272_1S (Steel Set #1272, Static, K_o=0.3) & 1272_1D (Steel Set #1272, Seismic, K_o=0.3)

```
* ---------------------------------------------------------------
*
*      File: 1272_1s - Tunnel at Depth -183.0 m, Ko=0.3
*
* ---------------------------------------------------------------
* Steel sets represented by a mesh with 5 rows of regular zones;
* properties of the mesh calculated to match mechanical response
* of steel sets.  No structural elements involved.
* The same number of nodes on the side of structural elements
* and on the side of mesh & inner ring used just for generation
* of structural elements.
* ---------------------------------------------------------------
*
configure dynamic
*
gr 35 64
m m
*
Call FSQ_HOLE.fis
*
Call Rng_Down.fis
*
Call Forces.fis
*
* -----------------------------------------
* Define the mesh geometry parameters
* -----------------------------------------
set r_ex=3.80    ;Radius of Excavation
set rmul=10      ;Outer model dimensions multiplier
set ratio=1.1
set z_th1=0.047  ;thickness of one of the five inner layers
set gap=.00      ;Gap to be used in the Interface definition
set z_th2=.25    ;Thickness od circular layers surrounding the opening
set n_ze=20      ;Number of circular layers
set n_rng=5      ;Total number of the inner ring layers
*
set iz_=n_rng    ;Number of Steel Set Ring zones used for Structural Calc's
set jz_=64       ;number of j-zones of the tunnel circumference
set xc_=0.0      ;Tunnel Center "x-coordinate"
set yc_=-183.0   ;Tunnel Center "y-coordinate"
* ------------------------------------------------------------------
*
FSq_Hole.fis
*
* Attach both sides of the mesh
* ==================================================================
*
Attach As from 1,1 to 6,1 Bs from 1,65 to 6,65
Attach As from 7,1 to 36,1 Bs from 7,65 to 36,65
*
* ------------------------------------------------------------------
* Add -183 m equal to the local depth
* ------------------------------------------------------------------
```

```
*
ini y add -183.0
*
* ------------------------------------------------------------------
* Create the Gap Between the Inner Ring and the Rock Mass
*
Rng_Down
*
* ---------------------------------------------------
*
* Create a Void ------------------------------------
*
* ---------------------------------------------------
Call 1272_vo.dat
*
* Fix Boundary Conditions -----------
*
fix x   i=36 j=41,57  ;Left Side
fix x   i=36 j=9,25   ;Right Side
fix x y i=36 j=57,65  ;Model Bottom - Left Side
fix x y i=36 j=1,9    ;Model Bottom - Right Side
*
* ---------------------------------------------------------------
* Define Properties of the rock mass *******
*
* Rock Property Data for TSw2 --- Rock Mass Quality Category 1 ---
* ----------------------------------------------------------------
*
prop bu=4.57e9 she=3.29e09 d=2360 c=1.5e6 fric=43.0 ten=1.27e6    ;TSw2
*
* ----------------------------------------------------------------
* ************* EQUIVALENT LINER SCALING RULES ***************
* ----------------------------------------------------------------
* Applied to the substitution of I-beam steel set with
* the Equivalent continuous liner modeled using a typical
* standard elements, rather than the structural beam properties.
* ============================================================
* A      = Cross-Section Area of the I-beam-type steel set
* I      = Modulus if Inertia of Steel I-beam
* b      = Width of the equivalent continuous liner
*              Note: For 1 m steel set spacing, b=1.0
* h      = Thickness of the equivalent continuous liner
*      h = Sqrt(12*I/A)
* ds     = Density of steel
* de     = Density of the equivalent material
*     de = ds*[A/(b*h)]
* Es     = Young's Modulus of Steel
* Ee     = Young's Modulus of Equivalent Material
*     Ee = Es*A/(b*h)
*     Ee = 12*Es*I/(b*h^3)
*     Ee = 12*E*I/[{Sqrt[12I/(b*A)]^3}*b]
* Ke     = Bulk Modulus of Equivalent Liner Material
*     Ke = Ee/[3*(1-2*niu)]*(1-niu^2)
* Ge     = Shear Modulus of Equivalent Liner Material
*     Ge = Ee/[2*(1+niu)]/(1-niu^2)
*
* ============================================================
```

```
* Elastic Properties of the Equivalent Liner to W6x20 Steel Set
* -------------------------------------------------------------
*
m e i 1 5
* -------------------------------------------------------------
* Es  =                                         = 200e9   GPa
* niu =                                         = 0.3
* ds  =                                         = 7,859   kg/m^3
* A   =                                         = 3.79e-3 m^2
* I   =                                         = 1.72e-5 m^4
* h   = Sqrt(12*1.72e-5/3.79e-3                 = 0.2337  m
* Ee  = 200e9*3.79-3/(1.0*0.2337)               = 3.240e9 Pa
* ..............................................................
* Ke  = {3.240e9/[3*(1-2*0.3)]}*(1-0.3*0.3)     = 2.460e9 Pa
* Ge  = {3.240e9/[2*(1+0.3)]}/(1-0.3*0.3)       = 1.13e9  Pa
* de  = 7859*(5.89e-3/0.3055)                   = 126.41  kg/m^3
* - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
*
prop bu=2.46e9 she=1.13e9 d=126.41 i=1,5   ;prop's of equivalent liner
*
* ---------------------------------------------------------------------------
* Apply Pressure on Model Top to Generate the Lithostatic Stress Field
* ---------------------------------------------------------------------------
apply press=2.973e6          i=36, j=25,41  ;pressure on model top
*
* ---------------------------------------------------------------------------
* Insitu stress state in the rock mass Ko=0.3
* ---------------------------------------------------------------------------
initial syy -4.7123e6 var 0,1.7393e6 j=1,65
initial sxx -1.4137e6 var 0,5.2179e5 j=1,65
initial szz -1.4137e6 var 0,5.2179e5 j=1,65
*
* Reset the Initial stress state in the lining to 0.0
* ---------------------------------------------------------------------------
* prop bu=5.531e6 she=1.630e6 d=15.152 i=1,5   ;1000x reduced prop's of
equivalent liner
*                                             ;10x   reduced density of
equivalent liner
* ---------------------------------------------------------------------------
initial syy 0.  i=1,5
initial sxx 0.  i=1,5
initial szz 0.  i=1,5
*
set large, grav=9.81   ;closing of the gap betwn rk & steel sets
*
* -----------------------------------------------------------
* Specify the Interface Properties
* -----------------------------------------------------------
* Interfaces the Between the Regular and Structural Elements
* -----------------------------------------------------------
int 1 As from 6,65 to 6,1 Bs  from 7,65 to 7,1
int 1 ks=2e9 kn=2e9 fric=15
*
set mech on
*
* Reset initial displacements to zero
* ----------------------------------------
```

```
ini xdis 0. ydis 0.
* -----------------------------------------
* Take histories of velocity and displacement at
* selected points
* -----------------------------------------
*
set force=300  ;set force for convergence=300 kN
*
his unbal
his ydis i=4 j=33
hist xdis i 1 j 1
hist xdis i 1 j 17
hist ydis i 1 j 33
hist xdis i 1 j 49
*
his nstep=20
* -----------------------------------------------------
*
tit
1272_031 TSw2, TSw2 Ko=0.3 Equilibrium After Excavation Completed
*
*pl hold grid apply ye
*pause
*
set dyn=off
*
* solve
*
* save 1272_031.sav
*
* Apply the Cribbing to Support a Void
* ---------------------------------------
*
call 1272_su.dat
*
Tit
1272_032 Equilibrium After 5-Regular Zone Steel Set and Cribbing Applied
*
solve
*
*_section_forces      ;calculate moments, normal & shear forces
*
save 1272_032.sav
*
*
* -----------------------------------------
*       Turn on one seismic load
* -----------------------------------------
*
set dyn on
set large
set st 3000000
*
apply syy=-2.973e6  i=36 j=25,41    *top
*
apply xquiet yquiet i=36 j=25,41    *top
apply xquiet  i=36  j=41,57         *left vertical
```

```
apply xquiet  i=36  j=9,25          *right vertical
*
def p_wave
  freq=freq_set
  dura=dura_set
    p_wave=1.*sin(2.*pi*freq*dytime)
  if dytime > dura_set then
    p_wave=0.0
  end_if
end
*
def s_wave
  freq=freq_set
  dura=dura_set
    s_wave=1.*sin(2.*pi*freq*dytime)
  if dytime > dura_set then
    s_wave=0.0
  end_if
end
*
set freq_set=5 dura_set=1
*
apply yvel  0.23 his p_wave i=36 j=1,9    ;defined in ESF analysis = 23 cm/s
apply yvel  0.23 his p_wave i=36 j=57,65  ;defined in ESF analysis = 23 cm/s
*
apply xvel  0.23 his s_wave i=36 j=1,9    ;defined in ESF analysis = 23 cm/s
apply xvel  0.23 his s_wave i=36 j=57,65  ;defined in ESF analysis = 23 cm/s
*
def run_time
  wave_on=dura_set
  wave_off=2.0*dura_set
end
run_time
 *
set dytime 0
*
ini xdisp 0 ydisp 0
ini xvel=0 yvel=0

his reset
his nstep 200
his unbal
his dytime
*
his ydis i=1 j=33
his ydis i=1 j=1
hist xdis i 1 j 17
hist xdis i 1 j 49
*
* Horizontal velocity monitoring at the base line
his xvel i=36 j=57          * at the left corner
his xvel i=36  j=1          * at the center
his xvel i=36  j=9          * at the right corner
* Horizontal velocity monitoring at the top
his xvel i=36  j=41         * at the left corner
his xvel i=36  j=33         * at the center
his xvel i=36  j=25         * at the right corner
```

```
* Vertical velocity monitoring at the base line
his yvel i=36  j=57         * at the left corner
his yvel i=36  j=1          * at the center
his yvel i=36  j=9          * at the right corner
* Vertical velocity monitoring at the top
his yvel i=36  j=41         * at the left corner
his yvel i=36  j=33         * at the center
his yvel i=36  j=25         * at the right corner
*
* Monitor Closures at the Center
*
def vc_c
  vc_c=ydisp(8,33)-ydisp(8,1)    ;vertical
end
*
def hc_c
  hc_c=xdisp(9,49)-xdisp(8,17)   ;horizontal
end
*
his vc_c
his hc_c
*
*
his sxx i=11 j=1      ;rmass bottom 1 m inside
his sxx i=11 j=17     ;rmass right 1 m inside
his sxx i=11 j=33     ;rmass top 1 m inside
his sxx i=11 j=49     ;rmass left 1 m inside
*
his syy i=11 j=1      ;rmass bottom 1 m inside
his syy i=11 j=17     ;rmass right 1 m inside
his syy i=11 j=33     ;rmass top 1 m inside
his syy i=11 j=49     ;rmass left 1 m inside
*
his ydisp i=8 j=33    ;vert. top
his ydisp i=7 j=1     ;vert bottom
*
his xdisp i=8 j=17    ;hor. right
his xdisp i=9 j=49    ;hor left
*
his ydisp i=1 j=33     ;vert. sset top
his ydisp i=1 j=1      ;vert sset bottom
*
his xdisp i=1 j=17     ;hor. sset right
his xdisp i=1 j=49     ;hor. sset left
*
solve dytime wave_on
sav 1272_3d1.sav
*
*apply xquiet yquiet i=36 j=1,9
*apply xquiet yquiet i=36 j=57,65
*
solve dytime wave_off
sav 1272_3d2.sav
*
ret
```

I-2 INPUT FILES 1272_1SC (Steel Set #1272, Static, Backfilled sides, K_o=0.3) & 1272_1DC (Steel Set #1272, Seismic, Backfilled sides, K_o=0.3)

```
* ----------------------------------------------------------------
*
*      File: 1272_1sc - Tunnel at Depth -183.0 m, Ko=0.3
*
* ----------------------------------------------------------------
* Steel sets represented by a mesh with 5 rows of regular zones;
* properties of the mesh calculated to match mechanical response
* of steel sets.  No structural elements involved.
* The same number of nodes on the side of structural elements
* and on the side of mesh & inner ring used just for generation
* of structural elements.
* ----------------------------------------------------------------
*
configure dynamic
*
gr 35 64
m m
*
Call FSQ_HOLE.fis
*
Call Rng_Down.fis
*
Call Forces.fis
*
* ----------------------------------------
* Define the mesh geometry parameters
* ----------------------------------------
set r_ex=3.80     ;Radius of Excavation
set rmul=10       ;Outer model dimensions multiplier
set ratio=1.1
set z_th1=0.047   ;thickness of one of the five inner layers
set gap=.00       ;Gap to be used in the Interface definition
set z_th2=.25     ;Thickness od circular layers surrounding the opening
set n_ze=20       ;Number of circular layers
set n_rng=5       ;Total number of the inner ring layers
*
set iz_=n_rng     ;Number of Steel Set Ring zones used for Structural Calc's
set jz_=64        ;number of j-zones of the tunnel circumference
set xc_=0.0       ;Tunnel Center "x-coordinate"
set yc_=-183.0    ;Tunnel Center "y-coordinate"
* -------------------------------------------------------------------
*
FSq_Hole.fis
*
* Attach both sides of the mesh
* ===================================================================
*
Attach As from 1,1 to 6,1 Bs from 1,65 to 6,65
Attach As from 7,1 to 36,1 Bs from 7,65 to 36,65
*
* -------------------------------------------------------------------
* Add -183 m equal to the local depth
```

```
* ---------------------------------------------------------------------
*
ini y add -183.0
*
* --------------------------------------------------------------------
* Create the Gap Between the Inner Ring and the Rock Mass
*
Rng_Down
*
* ---------------------------------------------------
*
* Create a Void -------------------------------------
*
* ---------------------------------------------------
Call 1272_vo.dat
*
* ---------------
* Fix Boundary Conditions -----------
*
fix x   i=36 j=41,57  ;Left Side
fix x   i=36 j=9,25   ;Right Side
fix x y i=36 j=57,65  ;Model Bottom - Left Side
fix x y i=36 j=1,9    ;Model Bottom - Right Side
*
* ----------------------------------------------------------------
* Define Properties of the rock mass *******
*
prop bu=4.57e9 she=3.29e09 d=2360 c=1.5e6 fric=43.0 ten=1.27e6    ;TSw2
*
* -----------------------------------------------------------------
* ************* EQUIVALENT LINER SCALING RULES ***************
* -----------------------------------------------------------------
* Applied to the substitution of I-beam steel set with
* the Equivalent continuous liner modeled using a typical
* standard elements, rather than the structural beam properties.
* ==============================================================
* A      = Cross-Section Area of the I-beam-type steel set
* I      = Modulus if Inertia of Steel I-beam
* b      = Width of the equivalent continuous liner
*              Note: For 1 m steel set spacing, b=1.0
* h      = Thickness of the equivalent continuous liner
*      h = Sqrt(12*I/A)
* ds     = Density of steel
* de     = Density of the equivalent material
*     de = ds*[A/(b*h)]
* Es     = Young's Modulus of Steel
* Ee     = Young's Modulus of Equivalent Material
*     Ee = Es*A/(b*h)
*     Ee = 12*Es*I/(b*h^3)
*     Ee = 12*E*I/[{Sqrt[12I/(b*A)]^3}*b]
* Ke     = Bulk Modulus of Equivalent Liner Material
*     Ke = Ee/[3*(1-2*niu)]*(1-niu^2)
* Ge     = Shear Modulus of Equivalent Liner Material
*     Ge = Ee/[2*(1+niu)]/(1-niu^2)
*
* ============================================================
* Elastic Properties of the Equivalent Liner to W6x20 Steel Set
```

```
* ------------------------------------------------------------
*
m e i 1 5
* ------------------------------------------------------------
* Es  =                                          = 200e9   GPa
* niu =                                          = 0.3
* ds  =                                          = 7,859   kg/m^3
* A   =                                          = 3.79e-3 m^2
* I   =                                          = 1.72e-5 m^4
* h   = Sqrt(12*1.72e-5/3.79e-3                  = 0.2337  m
* Ee  = 200e9*3.79-3/(1.0*0.2337)                = 3.240e9 Pa
* ............................................................
* Ke  = {3.240e9/[3*(1-2*0.3)]}*(1-0.3*0.3)  = 2.460e9 Pa
* Ge  = {3.240e9/[2*(1+0.3)]}/(1-0.3*0.3)    = 1.13e9  Pa
* de  = 7859*(5.89e-3/0.3055)                = 126.41  kg/m^3
* - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
*
prop bu=2.46e9 she=1.13e9 d=126.41 i=1,5   ;prop's of equivalent liner
*
* ---------------------------------------------------------------------------
* Apply Pressure on Model Top to Generate the Lithostatic Stress Field
* ---------------------------------------------------------------------------
apply press=2.973e6          i=36, j=25,41  ;pressure on model top
*
* ---------------------------------------------------------------------------
* Insitu stress state in the rock mass Ko=0.3
* ---------------------------------------------------------------------------
initial syy -4.7123e6 var 0,1.7393e6 j=1,65
initial sxx -1.4137e6 var 0,5.2179e5 j=1,65
initial szz -1.4137e6 var 0,5.2179e5 j=1,65
*
* Reset the Initial stress state in the lining to 0.0
* ---------------------------------------------------------------------------
* prop bu=5.531e6 she=1.630e6 d=15.152 i=1,5   ;1000x reduced prop's of
equivalent liner
*                                              ;10x   reduced density of
equivalent liner
* ---------------------------------------------------------------------------
initial syy 0.  i=1,5
initial sxx 0.  i=1,5
initial szz 0.  i=1,5
*
set large, grav=9.81   ;closing of the gap betwn rk & steel sets
*
* -----------------------------------------------------------
* Specify the Interface Properties
* ------------------------------------------------------------
* Interfaces the Between the Regular and Structural Elements
* ------------------------------------------------------------
*
int 1 As from 6,65 to 6,1 Bs  from 7,65 to 7,1
int 1 ks=2e9 kn=2e9 fric=15
*
set mech on
*
* Reset initial displacements to zero
* ----------------------------------------
```

```
ini xdis 0. ydis 0.
* ----------------------------------------
* Take histories of velocity and displacement at
* selected points
* ----------------------------------------
*
set force=300  ;set force for convergence=300 kN
*
his unbal
his ydis i=4 j=33
hist xdis i 1 j 1
hist xdis i 1 j 17
hist ydis i 1 j 33
hist xdis i 1 j 49
*
his nstep=20
* ----------------------------------------------------
*
set dyn=off
*
tit
1272_3B1 TSw2, TSw2 Ko=0.3 Equilibrium After Excavation Completed
*
* solve
*
* save 1272_3B1.sav
* --------------------------------------
* Apply the Cribbing to Support a Void
* --------------------------------------
*
call 1272_su.dat      ;<<<<<<<<<< input structural support data
*
*
Tit
1272_3B2 TSw2, TSw2 Ko=0.3 Equilibrium After Steel Set and Cribbing Applied
*
solve
*
save 1272_3B2.sav      ;SSSSSSS<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
* -------------------------------------------
* Continuation of run with concrete backfill
* -------------------------------------------
struct sup -3.695  -184.2  remove ;node  52
struct sup -3.842  -182.6  remove ;node  48
struct sup -3.405  -181.1  remove ;node  44
*
struct sup  3.861  -183.0  remove ;node  17
struct sup  3.695  -181.8  remove ;node  20
struct sup  3.210  -180.8  remove ;node  23
*
m m i=8 j=18,23
m m i=7 j=15,23
m m i=8 j=41,55
m m i=7 j=41,57
*
* Redefine the Interface Boundaries After Backfill Installation ------
*
```

```
int 1 As from 6,65 to 6,1 Bs  from 7,65 to 7,1
int 1 ks=2e9 kn=2e9 fric=15
*
* Assign a 4000 psi concrete prop's to the backfill elements
*
prop bu=1.38e10 she=1.036e10 co=5.71e6 fri=45 ten=2.8e6 den=2300 i=8 j=18,23
prop bu=1.38e10 she=1.036e10 co=5.71e6 fri=45 ten=2.8e6 den=2300 i=7 j=15,23
prop bu=1.38e10 she=1.036e10 co=5.71e6 fri=45 ten=2.8e6 den=2300 i=8 j=41,55
prop bu=1.38e10 she=1.036e10 co=5.71e6 fri=45 ten=2.8e6 den=2300 i=7 j=41,57
*
Tit
1272_3B3 TSw2 Ko=0.3 Model in Equilibrium After Concrete Backfill Applied
*
sav 1272_3B3.sav          ;SSSSSSSSSSSSSSS<<<<<<<<<<<<<<<<<<<
*
* --------------------------------------------------------------
*       Turn on one seismic load
* -----------------------------------------
*
set dyn on
set large
set st 3000000
*
apply syy=-2.973e6  i=36 j=25,41    *top
*
apply xquiet yquiet i=36 j=25,41    *top
apply xquiet  i=36  j=41,57         *left vertical
apply xquiet  i=36  j=9,25          *right vertical
*
* ------------Define P-Wave ON/OFF Conditions ------------
def p_wave
  freq=freq_set
  dura=dura_set
    p_wave=1.*sin(2.*pi*freq*dytime)
  if dytime > dura_set then
    p_wave=0.0
  end_if
end
*
* ------------Define S-Wave ON/OFF Conditions ------------
def s_wave
  freq=freq_set
  dura=dura_set
    s_wave=1.*sin(2.*pi*freq*dytime)
  if dytime > dura_set then
    s_wave=0.0
  end_if
end
*
* ------------------- Set Frequency and Duration of an Earthquake ---------
set freq_set=5 dura_set=1
* -----------------------------------------
*
apply yvel  0.23 his p_wave i=36 j=1,9    ;defined in ESF analysis = 23 cm/s
apply yvel  0.23 his p_wave i=36 j=57,65  ;defined in ESF analysis = 23 cm/s
*
apply xvel  0.23 his s_wave i=36 j=1,9    ;defined in ESF analysis = 23 cm/s
```

```
apply xvel  0.23 his s_wave i=36 j=57,65  ;defined in ESF analysis = 23 cm/s
*
* --------------------- Set Duration of EQ and Quiet Period Duration ----------
def run_time
  wave_on=dura_set
  wave_off=2.*dura_set
end
* -------------------------------
run_time
 *
set dytime 0
*
ini xdisp 0 ydisp 0
ini xvel=0 yvel=0
* ------------------- Define Histories to be Taken --------------------------
his reset
his nstep 200
his unbal
his dytime
*
his ydis i=1 j=33
his ydis i=1 j=1
hist xdis i 1 j 17
hist xdis i 1 j 49
*
* Horizontal velocity monitoring at the base line
his xvel i=36 j=57         * at the left corner
his xvel i=36  j=1         * at the center
his xvel i=36  j=9         * at the right corner
* Horizontal velocity monitoring at the top
his xvel i=36  j=41        * at the left corner
his xvel i=36  j=33        * at the center
his xvel i=36  j=25        * at the right corner
* Vertical velocity monitoring at the base line
his yvel i=36  j=57        * at the left corner
his yvel i=36  j=1         * at the center
his yvel i=36  j=9         * at the right corner
* Vertical velocity monitoring at the top
his yvel i=36  j=41        * at the left corner
his yvel i=36  j=33        * at the center
his yvel i=36  j=25        * at the right corner
*
* Monitor Closures at the Center
*
def vc_c
  vc_c=ydisp(8,33)-ydisp(8,1)    ;vertical
end
*
def hc_c
  hc_c=xdisp(9,49)-xdisp(8,17)   ;horizontal
end
*
his vc_c
his hc_c
*
*
his sxx i=11 j=1      ;rmass bottom 1 m inside
```

```
his sxx i=11 j=17      ;rmass right 1 m inside
his sxx i=11 j=33      ;rmass top 1 m inside
his sxx i=11 j=49      ;rmass left 1 m inside
*
his syy i=11 j=1       ;rmass bottom 1 m inside
his syy i=11 j=17      ;rmass right 1 m inside
his syy i=11 j=33      ;rmass top 1 m inside
his syy i=11 j=49      ;rmass left 1 m inside
*
his ydisp i=8 j=33     ;vert. top
his ydisp i=7 j=1      ;vert bottom
*
his xdisp i=8 j=17     ;hor. right
his xdisp i=9 j=49     ;hor left
*
his ydisp i=1 j=33      ;vert. sset top
his ydisp i=1 j=1       ;vert sset bottom
*
his xdisp i=1 j=17      ;hor. sset right
his xdisp i=1 j=49      ;hor. sset left
*
* *******************************************************
Tit
12723BD1 TSw2, Ko=0.3 Model Status After 1 Sec EQ Shaking
solve dytime wave_on
*
sav 12723Bd1.sav        ;SSSSSSSSSSSSSSSSSSS<<<<<<<<<<<<<<
* ........................................................
*apply xquiet yquiet i=36 j=1,9
*apply xquiet yquiet i=36 j=57,65
*
Tit
12723Bd2 TSw2, Ko=0.3 Model Status 1 Sec After Earthquake
solve dytime wave_off
*
sav 12723Bd2.sav         ;SSSSSSSSSSSSSSSSSS<<<<<<<<<<<<<<
* ........................................................
Tit
12723Bd3 TSw2 Ko=0.3 Model Status 2 sec After Earthquake
*
solve dytime=3.0
sav 12723Bd3.sav         ;SSSSSSSSSSSSSSSSSS<<<<<<<<<<<<<
* ........................................................
*_section_forces       ;calculate moments, normal & shear forces
*
ret
```

I-3 INPUT FILES 1272_2S (Steel Set #1272, Static, K_o=1.0) 1272_2D (Steel Set #1272, Seismic, K_o=1.0)

```
* -------------------------------------------------------------
*
*       File: 1272_2s - Tunnel at Depth -183.0 m, Ko=1.0
*
* -------------------------------------------------------------
```

```
* Steel sets represented by a mesh with 5 rows of regular zones;
* properties of the mesh calculated to match mechanical response
* of steel sets.  No structural elements involved.
* The same number of nodes on the side of structural elements
* and on the side of mesh & inner ring used just for generation
* of structural elements.
* ----------------------------------------------------------------
*
configure dynamic
*
gr 35 64
m m
*
Call FSQ_HOLE.fis
*
Call Rng_Down.fis
*
Call Forces.fis
*
* ----------------------------------------
* Define the mesh geometry parameters
* ----------------------------------------
set r_ex=3.80     ;Radius of Excavation
set rmul=10       ;Outer model dimensions multiplier
set ratio=1.1
set z_th1=0.047   ;thickness of one of the five inner layers
set gap=.00       ;Gap to be used in the Interface definition
set z_th2=.25     ;Thickness od circular layers surrounding the opening
set n_ze=20       ;Number of circular layers
set n_rng=5       ;Total number of the inner ring layers
*
set iz_=n_rng     ;Number of Steel Set Ring zones used for Structural Calc's
set jz_=64        ;number of j-zones of the tunnel circumference
set xc_=0.0       ;Tunnel Center "x-coordinate"
set yc_=-183.0    ;Tunnel Center "y-coordinate"
* ---------------------------------------------------------------------
*
FSq_Hole.fis
*
* Attach both sides of the mesh
* =====================================================================
*
Attach As from 1,1 to 6,1 Bs from 1,65 to 6,65
Attach As from 7,1 to 36,1 Bs from 7,65 to 36,65
*
* ---------------------------------------------------------------------
* Add -183 m equal to the local depth
* ---------------------------------------------------------------------
*
ini y add -183.0
*
* --------------------------------------------------------------------
* Create the Gap Between the Inner Ring and the Rock Mass
*
Rng_Down
*
* ---------------------------------------------------
```

```
*
* Create a Void -------------------------------------
*
* -----------------------------------------------------
Call 1272_vo.dat
*
*
* Fix Boundary Conditions -----------
*
fix x   i=36 j=41,57  ;Left Side
fix x   i=36 j=9,25   ;Right Side
fix x y i=36 j=57,65  ;Model Bottom - Left Side
fix x y i=36 j=1,9    ;Model Bottom - Right Side
*
* ------------------------------------------------------------------
* Define Properties of the rock mass *******
*
prop bu=4.57e9 she=3.29e09 d=2360 c=1.5e6 fric=43.0 ten=1.27e6    ;TSw2
*.
* -------------------------------------------------------------------
* ************* EQUIVALENT LINER SCALING RULES ***************
* -------------------------------------------------------------------
* Applied to the substitution of I-beam steel set with
* the Equivalent continuous liner modeled using a typical
* standard elements, rather than the structural beam properties.
* ===========================================================
* A       = Cross-Section Area of the I-beam-type steel set
* I       = Modulus if Inertia of Steel I-beam
* b       = Width of the equivalent continuous liner
*                Note: For 1 m steel set spacing, b=1.0
* h       = Thickness of the equivalent continuous liner
*       h = Sqrt(12*I/A)
* ds      = Density of steel
* de      = Density of the equivalent material
*      de = ds*[A/(b*h)]
* Es      = Young's Modulus of Steel
* Ee      = Young's Modulus of Equivalent Material
*      Ee = Es*A/(b*h)
*      Ee = 12*Es*I/(b*h^3)
*      Ee = 12*E*I/[{Sqrt[12I/(b*A)]^3}*b]
* Ke      = Bulk Modulus of Equivalent Liner Material
*      Ke = Ee/[3*(1-2*niu)]*(1-niu^2)
* Ge      = Shear Modulus of Equivalent Liner Material
*      Ge = Ee/[2*(1+niu)]/(1-niu^2)
*
* ===========================================================
* Elastic Properties of the Equivalent Liner to W6x20 Steel Set
* -----------------------------------------------------------
*
m e i 1 5
* -----------------------------------------------------------
* Es  =                                        = 200e9   GPa
* niu =                                        = 0.3
* ds  =                                        = 7,859   kg/m^3
* A   =                                        = 3.79e-3 m^2
* I   =                                        = 1.72e-5 m^4
* h   = Sqrt(12*1.72e-5/3.79e-3                = 0.2337  m
```

```
* Ee  = 200e9*3.79-3/(1.0*0.2337)          = 3.240e9 Pa
* ............................................................
* Ke  = {3.240e9/[3*(1-2*0.3)]}*(1-0.3*0.3)  = 2.460e9 Pa
* Ge  = {3.240e9/[2*(1+0.3)]}/(1-0.3*0.3)    = 1.13e9  Pa
* de  = 7859*(5.89e-3/0.3055)               = 126.41  kg/m^3
* - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
*
prop bu=2.46e9 she=1.13e9 d=126.41 i=1,5   ;prop's of equivalent liner
*
* ------------------------------------------------------------------------
* Apply Pressure on Model Top to Generate the Lithostatic Stress Field
* ------------------------------------------------------------------------
apply press=2.973e6          i=36, j=25,41  ;pressure on model top
*
* ------------------------------------------------------------------------
* Insitu stress state in the rock mass Ko=1.0
* ------------------------------------------------------------------------
initial syy -4.7123e6 var 0,1.7393e6 j=1,65
initial sxx -4.7123e6 var 0,1.7393e6 j=1,65
initial szz -4.7123e6 var 0,1.7393e6 j=1,65
*
* ------------------------------------------------------------------------
* Reset the Initial stress state in the lining to 0.0 - Model #6 Only
* ------------------------------------------------------------------------
* prop bu=5.531e6 she=1.630e6 d=15.152 i=1,5   ;1000x reduced prop's of
equivalent liner
*                                               ;10x   reduced density of
equivalent liner
* ------------------------------------------------------------------------
initial syy 0.  i=1,5
initial sxx 0.  i=1,5
initial szz 0.  i=1,5
*
set large, grav=9.81   ;closing of the gap betwn rk & steel sets
*
* ---------------------------------------------------------
* Specify the Interface Properties
* ----------------------------------------------------------
* Interfaces the Between the Regular and Structural Elements
* ----------------------------------------------------------
int 1 As from 6,65 to 6,1 Bs  from 7,65 to 7,1
int 1 ks=2e9 kn=2e9 fric=15
*
set mech on
*
* Reset initial displacements to zero
* ----------------------------------------
ini xdis 0. ydis 0.
* ----------------------------------------
* Take histories of velocity and displacement at
* selected points
* ----------------------------------------
*
set force=300  ;set force for convergence=300 kN
*
his unbal
his ydis i=4 j=33
```

```
hist xdis i 1 j 1
hist xdis i 1 j 17
hist ydis i 1 j 33
hist xdis i 1 j 49
*
his nstep=20
* ---------------------------------------------------
*
tit
1272_101 TSw2, TSw2 Ko=1.0 Equilibrium After Excavation Completed
*
*pl hold grid apply ye
*
*
set dyn=off
*
* solve
*
* save 1272_101.sav
*
* Apply the Cribbing to Support a Void
* ---------------------------------------
*
call 1272_su.dat
*
* pl hold bo
*
Tit
1272_102 Equilibrium After 5-Regular Zone Steel Set and Cribbing Applied
*
*
solve
*
*_section_forces      ;calculate moments, normal & shear forces
*
save 1272_102.sav
*
* -----------------------------------------
*       Turn on one seismic load
* -----------------------------------------
*
set dyn on
set large
set st 3000000
*
apply syy=-2.973e6  i=36 j=25,41    *top
*
apply xquiet yquiet i=36 j=25,41    *top
apply xquiet  i=36  j=41,57         *left vertical
apply xquiet  i=36  j=9,25          *right vertical
*
def p_wave
  freq=freq_set
  dura=dura_set
    p_wave=1.*sin(2.*pi*freq*dytime)
  if dytime > dura_set then
    p_wave=0.0
```

```
  end_if
end
*
def s_wave
  freq=freq_set
  dura=dura_set
    s_wave=1.*sin(2.*pi*freq*dytime)
  if dytime > dura_set then
    s_wave=0.0
  end_if
end
*
set freq_set=5 dura_set=1
*
apply yvel  0.23 his p_wave i=36 j=1,9    ;defined in ESF analysis = 23 cm/s
apply yvel  0.23 his p_wave i=36 j=57,65  ;defined in ESF analysis = 23 cm/s
*
apply xvel  0.23 his s_wave i=36 j=1,9    ;defined in ESF analysis = 23 cm/s
apply xvel  0.23 his s_wave i=36 j=57,65  ;defined in ESF analysis = 23 cm/s
*
def run_time
  wave_on=dura_set
  wave_off=2.0*dura_set
end
run_time
 *
set dytime 0
*
ini xdisp 0 ydisp 0
ini xvel=0 yvel=0

his reset
his nstep 100
his unbal
his dytime
*
his ydis i=1 j=33
his ydis i=1 j=1
hist xdis i 1 j 17
hist xdis i 1 j 49
*
* Horizontal velocity monitoring at the base line
his xvel i=36 j=57         * at the left corner
his xvel i=36  j=1         * at the center
his xvel i=36  j=9         * at the right corner
* Horizontal velocity monitoring at the top
his xvel i=36  j=41        * at the left corner
his xvel i=36  j=33        * at the center
his xvel i=36  j=25        * at the right corner
* Vertical velocity monitoring at the base line
his yvel i=36  j=57        * at the left corner
his yvel i=36  j=1         * at the center
his yvel i=36  j=9         * at the right corner
* Vertical velocity monitoring at the top
his yvel i=36  j=41        * at the left corner
his yvel i=36  j=33        * at the center
his yvel i=36  j=25        * at the right corner
```

```
*
* Monitor Closures at the Center
*
def vc_c
  vc_c=ydisp(8,33)-ydisp(8,1)    ;vertical
end
*
def hc_c
  hc_c=xdisp(9,49)-xdisp(8,17)   ;horizontal
end
*
his vc_c
his hc_c
*
*
his sxx i=11 j=1       ;rmass bottom 1 m inside
his sxx i=11 j=17      ;rmass right 1 m inside
his sxx i=11 j=33      ;rmass top 1 m inside
his sxx i=11 j=49      ;rmass left 1 m inside
*
his syy i=11 j=1       ;rmass bottom 1 m inside
his syy i=11 j=17      ;rmass right 1 m inside
his syy i=11 j=33      ;rmass top 1 m inside
his syy i=11 j=49      ;rmass left 1 m inside
*
his ydisp i=8 j=33     ;vert. top
his ydisp i=7 j=1      ;vert bottom
*
his xdisp i=8 j=17     ;hor. right
his xdisp i=9 j=49     ;hor left
*
his ydisp i=1 j=33      ;vert. sset top
his ydisp i=1 j=1       ;vert sset bottom
*
his xdisp i=1 j=17      ;hor. sset right
his xdisp i=1 j=49      ;hor. sset left
*
solve dytime wave_on
sav 1272_3d1.sav
*
apply xquiet yquiet i=36 j=1,9
apply xquiet yquiet i=36 j=57,65
*
solve dytime wave_off
sav 1272_3d2.sav
*
ret
```

I-4 INPUT FILES 1272_2SC (Steel Set #1272, Static, backfilled Sides, K_o=1.0) & 1272_2DC (Steel Set #1272, Seismic, backfilled Sides, K_o=1.0)

```
* ----------------------------------------------------------------
*
*      File: 1272_2sc - Tunnel at Depth -183.0 m, Ko=1.0
```

```
*
* ----------------------------------------------------------------
* Steel sets represented by a mesh with 5 rows of regular zones;
* properties of the mesh calculated to match mechanical response
* of steel sets.  No structural elements involved.
* The same number of nodes on the side of structural elements
* and on the side of mesh & inner ring used just for generation
* of structural elements.
* ----------------------------------------------------------------
*
configure dynamic
*
gr 35 64
m m
*
Call FSQ_HOLE.fis
*
Call Rng_Down.fis
*
Call Forces.fis
*
* -----------------------------------------
* Define the mesh geometry parameters
* -----------------------------------------
set r_ex=3.80     ;Radius of Excavation
set rmul=10       ;Outer model dimensions multiplier
set ratio=1.1
set z_th1=0.047   ;thickness of one of the five inner layers
set gap=.00       ;Gap to be used in the Interface definition
set z_th2=.25     ;Thickness od circular layers surrounding the opening
set n_ze=20       ;Number of circular layers
set n_rng=5       ;Total number of the inner ring layers
*
set iz_=n_rng     ;Number of Steel Set Ring zones used for Structural Calc's
set jz_=64        ;number of j-zones of the tunnel circumference
set xc_=0.0       ;Tunnel Center "x-coordinate"
set yc_=-183.0    ;Tunnel Center "y-coordinate"
* -------------------------------------------------------------------
*
FSq_Hole.fis
*
* Attach both sides of the mesh
* ===================================================================
*
Attach As from 1,1 to 6,1 Bs from 1,65 to 6,65
Attach As from 7,1 to 36,1 Bs from 7,65 to 36,65
*
* -------------------------------------------------------------------
* Add -183 m equal to the local depth
* -------------------------------------------------------------------
*
ini y add -183.0
*
* ------------------------------------------------------------------
* Create the Gap Between the Inner Ring and the Rock Mass
*
Rng_Down
```

```
*
* ---------------------------------------------------
*
* Create a Void ------------------------------------
*
* ---------------------------------------------------
Call 1272_vo.dat
*
*
* Fix Boundary Conditions -----------
*
fix x   i=36 j=41,57  ;Left Side
fix x   i=36 j=9,25   ;Right Side
fix x y i=36 j=57,65  ;Model Bottom - Left Side
fix x y i=36 j=1,9    ;Model Bottom - Right Side
*
* ---------------------------------------------------------------
* Define Properties of the rock mass *******
*
* Rock Property Data for TSw2 --- Rock Mass Quality Category 1 ---
* ----------------------------------------------------------------
*
prop bu=4.57e9 she=3.29e09 d=2360 c=1.5e6 fric=43.0 ten=1.27e6    ;TSw2
*
* Linear Scaling
prop bu=2.46e9 she=1.13e9 d=126.41 i=1,5   ;prop's of equivalent liner
*
* -------------------------------------------------------------------------
* Apply Pressure on Model Top to Generate the Lithostatic Stress Field
* -------------------------------------------------------------------------
apply press=2.973e6          i=36, j=25,41  ;pressure on model top
*
* -------------------------------------------------------------------------
* Insitu stress state in the rock mass Ko=1.0
* -------------------------------------------------------------------------
initial syy -4.7123e6 var 0,1.7393e6 j=1,65
initial sxx -4.7123e6 var 0,1.7393e6 j=1,65
initial szz -4.7123e6 var 0,1.7393e6 j=1,65
*
* -------------------------------------------------------------------------
* Reset the Initial stress state in the lining to 0.0
* -------------------------------------------------------------------------
* prop bu=5.531e6 she=1.630e6 d=15.152 i=1,5   ;1000x reduced prop's of
equivalent liner
*                                            ;10x   reduced density of
equivalent liner
* -------------------------------------------------------------------------
initial syy 0.  i=1,5
initial sxx 0.  i=1,5
initial szz 0.  i=1,5
*
set large, grav=9.81   ;closing of the gap betwn rk & steel sets
*
* ---------------------------------------------------------
* Specify the Interface Properties
* ---------------------------------------------------------
* Interfaces the Between the Regular and Structural Elements
```

```
* ---------------------------------------------------------------
int 1 As from 6,65 to 6,1 Bs  from 7,65 to 7,1
int 1 ks=2e9 kn=2e9 fric=15
*
set mech on
*
* Reset initial displacements to zero
* -----------------------------------------
ini xdis 0. ydis 0.
* -----------------------------------------
* Take histories of velocity and displacement at
* selected points
* -----------------------------------------
*
set force=300  ;set force for convergence=300 kN
*
his unbal
his ydis i=4 j=33
hist xdis i 1 j 1
hist xdis i 1 j 17
hist ydis i 1 j 33
hist xdis i 1 j 49
*
his nstep=20
* ---------------------------------------------------
*
set dyn=off
*
tit
1272_B11 TSw2, TSw2 Ko=1.0 Equilibrium After Excavation Completed
*
* solve
*
* save 1272_B11.sav
* ---------------------------------------
* Apply the Cribbing to Support a Void
* ---------------------------------------
*
call 1272_su.dat      ;<<<<<<<<<<< input structural support data
*
pause
*
Tit
1272_1B2 TSw2, TSw2 Ko=1.0 Equilibrium After Steel Set and Cribbing Applied
*
solve
*
save 1272_B12.sav      ;SSSSSSS<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
* --------------------------------------------
* Continuation of run with concrete backfill
* --------------------------------------------
struct sup -3.695  -184.2  remove ;node  52
struct sup -3.842  -182.6  remove ;node  48
struct sup -3.405  -181.1  remove ;node  44
*
struct sup  3.861  -183.0  remove ;node  17
struct sup  3.695  -181.8  remove ;node  20
```

```
struct sup  3.210  -180.8  remove ;node  23
*
m m i=8 j=18,23
m m i=7 j=15,23
m m i=8 j=41,55
m m i=7 j=41,57
*
* Redefine the Interface Boundaries After Backfill Installation ------
*
int 1 As from 6,65 to 6,1 Bs  from 7,65 to 7,1
int 1 ks=2e9 kn=2e9 fric=15
*
* Assign a 4000 psi concrete prop's to the backfill elements
*
prop bu=1.38e10 she=1.036e10 co=5.71e6 fri=45 ten=2.8e6 den=2300 i=8 j=18,23
prop bu=1.38e10 she=1.036e10 co=5.71e6 fri=45 ten=2.8e6 den=2300 i=7 j=15,23
prop bu=1.38e10 she=1.036e10 co=5.71e6 fri=45 ten=2.8e6 den=2300 i=8 j=41,55
prop bu=1.38e10 she=1.036e10 co=5.71e6 fri=45 ten=2.8e6 den=2300 i=7 j=41,57
*
Tit
1272_1B3 TSw2 Ko=1.0 Model in Equilibrium After Concrete Backfill Applied
*
sav 1272_1B3.sav          ;SSSSSSSSSSSSSSS<<<<<<<<<<<<<<<<<<<
*
* --------------------------------------------------------------
*       Turn on one seismic load
* -----------------------------------------
*
set dyn on
set large
set st 3000000
*
apply syy=-2.973e6  i=36 j=25,41    *top
*
apply xquiet yquiet i=36 j=25,41    *top
apply xquiet  i=36  j=41,57         *left vertical
apply xquiet  i=36  j=9,25          *right vertical
*
* ------------Define P-Wave ON/OFF Conditions ------------
def p_wave
  freq=freq_set
  dura=dura_set
    p_wave=1.*sin(2.*pi*freq*dytime)
  if dytime > dura_set then
    p_wave=0.0
  end_if
end
*
* ------------Define S-Wave ON/OFF Conditions ------------
def s_wave
  freq=freq_set
  dura=dura_set
    s_wave=1.*sin(2.*pi*freq*dytime)
  if dytime > dura_set then
    s_wave=0.0
  end_if
end
```

```
*
* ------------------- Set Frequency and Duration of an Earthquake ---------
set freq_set=5 dura_set=1
* -------------------------------------------
*
apply yvel  0.23 his p_wave i=36 j=1,9    ;defined in ESF analysis = 23 cm/s
apply yvel  0.23 his p_wave i=36 j=57,65  ;defined in ESF analysis = 23 cm/s
*
apply xvel  0.23 his s_wave i=36 j=1,9    ;defined in ESF analysis = 23 cm/s
apply xvel  0.23 his s_wave i=36 j=57,65  ;defined in ESF analysis = 23 cm/s
*
* --------------------- Set Duration of EQ and Quiet Period Duration ----------
def run_time
  wave_on=dura_set
  wave_off=2.*dura_set
end
* -------------------------------
run_time
 *
set dytime 0
*
ini xdisp 0 ydisp 0
ini xvel=0 yvel=0
* ------------------- Define Histories to be Taken -------------------------
his reset
his nstep 200
his unbal
his dytime
*
his ydis i=1 j=33
his ydis i=1 j=1
hist xdis i 1 j 17
hist xdis i 1 j 49
*
* Horizontal velocity monitoring at the base line
his xvel i=36 j=57        * at the left corner
his xvel i=36  j=1        * at the center
his xvel i=36  j=9        * at the right corner
* Horizontal velocity monitoring at the top
his xvel i=36  j=41       * at the left corner
his xvel i=36  j=33       * at the center
his xvel i=36  j=25       * at the right corner
* Vertical velocity monitoring at the base line
his yvel i=36  j=57       * at the left corner
his yvel i=36  j=1        * at the center
his yvel i=36  j=9        * at the right corner
* Vertical velocity monitoring at the top
his yvel i=36  j=41       * at the left corner
his yvel i=36  j=33       * at the center
his yvel i=36  j=25       * at the right corner
*
* Monitor Closures at the Center
*
def vc_c
  vc_c=ydisp(8,33)-ydisp(8,1)    ;vertical
end
*
```

```
def hc_c
  hc_c=xdisp(9,49)-xdisp(8,17)    ;horizontal
end
*
his vc_c
his hc_c
*
*
his sxx i=11 j=1       ;rmass bottom 1 m inside
his sxx i=11 j=17      ;rmass right 1 m inside
his sxx i=11 j=33      ;rmass top 1 m inside
his sxx i=11 j=49      ;rmass left 1 m inside
*
his syy i=11 j=1       ;rmass bottom 1 m inside
his syy i=11 j=17      ;rmass right 1 m inside
his syy i=11 j=33      ;rmass top 1 m inside
his syy i=11 j=49      ;rmass left 1 m inside
*
his ydisp i=8 j=33     ;vert. top
his ydisp i=7 j=1      ;vert bottom
*
his xdisp i=8 j=17     ;hor. right
his xdisp i=9 j=49     ;hor left
*
his ydisp i=1 j=33      ;vert. sset top
his ydisp i=1 j=1       ;vert sset bottom
*
his xdisp i=1 j=17      ;hor. sset right
his xdisp i=1 j=49      ;hor. sset left
*
* ********************************************************
Tit
12721BD1 TSw2, Ko=1.0 Model Status After 1 Sec EQ Shaking
solve dytime wave_on
*
sav 12721Bd1.sav        ;SSSSSSSSSSSSSSSSSSS<<<<<<<<<<<<<<
* .........................................................
*apply xquiet yquiet i=36 j=1,9
*apply xquiet yquiet i=36 j=57,65
*
Tit
12721BD2 TSw2, Ko=1.0 Model Status 1 Sec After Earthquake
solve dytime wave_off
*
sav 12721Bd2.sav         ;SSSSSSSSSSSSSSSSSS<<<<<<<<<<<<<<
* .........................................................
Tit
12721Bd3 TSw2 K0=1.0 Model Status 2 sec After Earthquake
*
solve dytime=3.0
sav 12721Bd3.sav         ;SSSSSSSSSSSSSSSSSS<<<<<<<<<<<<<
* .........................................................
*_section_forces      ;calculate moments, normal & shear forces
*
ret
```

I-5 INPUT FILE 1272_SS (Support Elements at Steel Set #1272)

```
* Steel Set 1272 Nodal Point Coordinates * -----------------------
* Structural Support Nodes Coordinates ***************************
*-----------------------------------------------------------------
*
*struct sup  0.000  -186.9  angle=  270.0 seg 2 prop 11 ;node  65
*struct sup -0.378  -186.8  angle=  264.4 seg 2 prop 11 ;node  64
*struct sup -0.753  -186.8  angle=  258.8 seg 2 prop 11 ;node  63
*struct sup -1.121  -186.7  angle=  253.1 seg 2 prop 11 ;node  62
*struct sup -1.478  -186.6  angle=  247.5 seg 2 prop 11 ;node  61
*struct sup -1.820  -186.4  angle=  241.9 seg 2 prop 11 ;node  60
*struct sup -2.145  -186.2  angle=  236.3 seg 2 prop 11 ;node  59
*struct sup -2.449  -186.0  angle=  230.6 seg 2 prop 11 ;node  58
*struct sup -2.730  -185.7  angle=  225.0 seg 2 prop 11 ;node  57
*struct sup -2.985  -185.4  angle=  219.4 seg 2 prop 11 ;node  56
*struct sup -3.210  -185.1  angle=  213.8 seg 2 prop 11 ;node  55
*struct sup -3.405  -184.8  angle=  208.1 seg 2 prop 11 ;node  54
*struct sup -3.567  -184.5  angle=  202.5 seg 2 prop 11 ;node  53
struct sup -3.695  -184.2  angle=  196.9 seg 2 prop 11 ;node  52
*struct sup -3.787  -183.8  angle=  191.3 seg 2 prop 11 ;node  51
*struct sup -3.842  -183.4  angle=  185.6 seg 2 prop 11 ;node  50
*struct sup -3.861  -183.0  angle=  180.0 seg 2 prop 11 ;node  49
struct sup -3.842  -182.6  angle=  174.4 seg 2 prop 11 ;node  48
*struct sup -3.787  -182.2  angle=  168.8 seg 2 prop 11 ;node  47
*struct sup -3.695  -181.9  angle=  163.1 seg 2 prop 11 ;node  46
*struct sup -3.567  -181.5  angle=  157.5 seg 2 prop 11 ;node  45
struct sup -3.405  -181.1  angle=  151.9 seg 2 prop 11 ;node  44
*struct sup -3.210  -180.9  angle=  146.3 seg 2 prop 11 ;node  43
*struct sup -2.985  -180.6  angle=  140.6 seg 2 prop 11 ;node  42
*struct sup -2.730  -180.3  angle=  135.0 seg 2 prop 11 ;node  41
struct sup -2.449  -180.0  angle=  129.4 seg 2 prop 11 ;node  40
*struct sup -2.145  -179.8  angle=  123.8 seg 2 prop 11 ;node  39
*struct sup -1.820  -179.6  angle=  118.1 seg 2 prop 11 ;node  38
*struct sup -1.478  -179.4  angle=  112.5 seg 2 prop 11 ;node  37
struct sup -1.121  -179.3  angle=  106.9 seg 2 prop 11 ;node  36
*struct sup -0.753  -179.2  angle=  101.3 seg 2 prop 11 ;node  35
*struct sup -0.378  -179.2  angle=   95.6 seg 2 prop 11 ;node  34
struct sup  0.000  -179.1  angle=   90.0 seg 2 prop 11 ;node  33
*struct sup  0.378  -179.2  angle=   84.4 seg 2 prop 11 ;node  32
*struct sup  0.753  -179.2  angle=   78.8 seg 2 prop 11 ;node  31
*struct sup  1.121  -179.3  angle=   73.1 seg 2 prop 11 ;node  30
*struct sup  1.478  -179.4  angle=   67.5 seg 2 prop 11 ;node  29
struct sup  1.820  -179.5  angle=   61.9 seg 2 prop 11 ;node  28
*struct sup  2.145  -179.8  angle=   56.3 seg 2 prop 11 ;node  27
struct sup  2.449  -180.0  angle=   50.6 seg 2 prop 11 ;node  26
*struct sup  2.730  -180.3  angle=   45.0 seg 2 prop 11 ;node  25
*struct sup  2.985  -180.6  angle=   39.4 seg 2 prop 11 ;node  24
struct sup  3.210  -180.8  angle=   33.8 seg 2 prop 11 ;node  23
*struct sup  3.405  -181.2  angle=   28.1 seg 2 prop 11 ;node  22
*struct sup  3.567  -181.5  angle=   22.5 seg 2 prop 11 ;node  21
struct sup  3.695  -181.8  angle=   16.9 seg 2 prop 11 ;node  20
*struct sup  3.787  -182.2  angle=   11.3 seg 2 prop 11 ;node  19
*struct sup  3.842  -182.6  angle=    5.6 seg 2 prop 11 ;node  18
struct sup  3.861  -183.0  angle=    0.0 seg 2 prop 11 ;node  17
*struct sup  3.842  -183.4  angle=   -5.6 seg 2 prop 11 ;node  16
*struct sup  3.787  -183.8  angle=  -11.3 seg 2 prop 11 ;node  15
```

```
*struct sup  3.695  -184.1  angle=  -16.9 seg 2 prop 11 ;node  14
*struct sup  3.567  -184.5  angle=  -22.5 seg 2 prop 11 ;node  13
*struct sup  3.405  -184.8  angle=  -28.1 seg 2 prop 11 ;node  12
*struct sup  3.210  -185.1  angle=  -33.8 seg 2 prop 11 ;node  11
*struct sup  2.985  -185.4  angle=  -39.4 seg 2 prop 11 ;node  10
*struct sup  2.730  -185.7  angle=  -45.0 seg 2 prop 11 ;node   9
*struct sup  2.449  -186.0  angle=  -50.6 seg 2 prop 11 ;node   8
*struct sup  2.145  -186.2  angle=  -56.3 seg 2 prop 11 ;node   7
*struct sup  1.820  -186.4  angle=  -61.9 seg 2 prop 11 ;node   6
*struct sup  1.478  -186.6  angle=  -67.5 seg 2 prop 11 ;node   5
*struct sup  1.121  -186.7  angle=  -73.1 seg 2 prop 11 ;node   4
*struct sup  0.753  -186.8  angle=  -78.8 seg 2 prop 11 ;node   3
*struct sup  0.378  -186.8  angle=  -84.4 seg 2 prop 11 ;node   2
*struct sup  0.000  -186.9  angle=  -90.0 seg 2 prop 11 ;node   1
*
* Force/Displacement relation for support
* stru prop 11 kn=1.0e7
stru prop 11 kn=1.0e8
*
```

I-6 INPUT FILE 1272_VD (Voids at Steel Set #1272)

```
*m n j=10 i=7
*m n j=11 i=7
*m n j=12 i=7
*m n j=13 i=7
*m n j=14 i=7
m n j=15 i=7
m n j=16 i=7
m n j=17 i=7
m n j=18 i=7,8
m n j=19 i=7,8
m n j=20 i=7,8
m n j=21 i=7,8
m n j=22 i=7,8
m n j=23 i=7,8
m n j=24 i=7,9
m n j=25 i=7,9
m n j=26 i=7,9
m n j=27 i=7,11
m n j=28 i=7,11
m n j=29 i=7,12
m n j=30 i=7,10
m n j=31 i=7,9
m n j=32 i=7,7
m n j=33 i=7,7
m n j=34 i=7,8
m n j=35 i=7,8
m n j=36 i=7,8
m n j=37 i=7,8
m n j=38 i=7,8
m n j=39 i=7,8
m n j=40 i=7,8
m n j=41 i=7,8
m n j=42 i=7,8
m n j=43 i=7,8
```

```
m n j=44 i=7,8
m n j=45 i=7,8
m n j=46 i=7,8
m n j=47 i=7,8
m n j=48 i=7,8
m n j=49 i=7,8
m n j=50 i=7,8
m n j=51 i=7,8
m n j=52 i=7,8
m n j=53 i=7,8
m n j=54 i=7,8
m n j=55 i=7,8
m n j=56 i=7
m n j=57 i=7
```

I-7 INPUT FILES 1699_1S (Steel Set #1699, Static, K_o=0.3) & 1699_1D (Steel Set #1699, Seismic, K_o=0.3)

```
* -----------------------------------------------------------------
*  1699_1s - Tunnel Located in TSw2 at Depth -40.22 m.
*  Rock: TCw, Ko=0.3
* -----------------------------------------------------------------
* Steel sets represented by a mesh with 5 rows of regular zones;
* properties of the mesh calculated to match mechanical response
* of steel sets.  No structural elements involved.
* The same number of nodes on the side of structural elements
* and on the side of mesh & inner ring used just for generation
* of structural elements.
* -----------------------------------------------------------------
*
configure dynamic
*
gr 35 64
m m
*
Call FSQ_HOLE.fis
*
Call Rng_Down.fis
*
Call Forces.fis
*
* -----------------------------------------
* Define the mesh geometry parameters
* -----------------------------------------
set r_ex=3.80     ;Radius of Excavation
set rmul=10       ;Outer model dimensions multiplier
set ratio=1.1
set z_th1=0.047   ;thickness of one of the five inner layers
set gap=.00       ;Gap to be used in the Interface definition
set z_th2=.25     ;Thickness od circular layers surrounding the opening
set n_ze=20       ;Number of circular layers
set n_rng=5       ;Total number of the inner ring layers
*
set iz_=n_rng     ;Number of Steel Set Ring zones used for Structural Calc's
set jz_=64        ;number of j-zones of the tunnel circumference
```

```
set xc_=0.0       ;Tunnel Center "x-coordinate"
set yc_=-40.22    ;Tunnel Center "y-coordinate"
* --------------------------------------------------------------------
*
FSq_Hole.fis
*
* Attach both sides of the mesh
* ====================================================================
*
Attach As from 1,1 to 6,1 Bs from 1,65 to 6,65
Attach As from 7,1 to 36,1 Bs from 7,65 to 36,65
*
* --------------------------------------------------------------------
* Add -186 m equal to the local depth and TCw density=2115 kg/m^3
* --------------------------------------------------------------------
*
ini y add -40.22
*
* -------------------------------------------------------------------
* Create the Gap Between the Inner Ring and the Rock Mass
*
Rng_Down
*
* -------------------------------------------------
*
* Create a Void -------------------------------------
*
* -------------------------------------------------
Call 1699_vo.dat
*
ca win1
*
* Fix Boundary Conditions -----------
*
fix x   i=36 j=41,57  ;Left Side
fix x   i=36 j=9,25   ;Right Side
fix x y i=36 j=57,65  ;Model Bottom - Left Side
fix x y i=36 j=1,9    ;Model Bottom - Right Side
*
* ---------------------------------------------------------------
* Define Properties of the rock mass *******
*
* ---------------------------------------------------------------
* Rock Property Data for TCw --- Rock Mass Quality Category 1 ---
* ---------------------------------------------------------------
*
prop bu=2.95e9 she=2.21e9 d=2230 c=9.0e5 fric=53 ten=6e5        ;TCw
*
* ---------------------------------------------------------------
* ************* EQUIVALENT LINER SCALING RULES ***************
* ---------------------------------------------------------------
* Applied to the substitution of I-beam steel set with
* the Equivalent continuous liner modeled using a typical
* standard elements, rather than the structural beam properties.
* =============================================================
* A       = Cross-Section Area of the I-beam-type steel set
* I       = Modulus if Inertia of Steel I-beam
```

```
* b       = Width of the equivalent continuous liner
*               Note: For 1 m steel set spacing, b=1.0
* h       = Thickness of the equivalent continuous liner
*       h = Sqrt(12*I/A)
* ds      = Density of steel
* de      = Density of the equivalent material
*      de = ds*[A/(b*h)]
* Es      = Young's Modulus of Steel
* Ee      = Young's Modulus of Equivalent Material
*      Ee = Es*A/(b*h)
*      Ee = 12*Es*I/(b*h^3)
*      Ee = 12*E*I/[{Sqrt[12I/(b*A)]^3}*b]
* Ke      = Bulk Modulus of Equivalent Liner Material
*      Ke = Ee/[3*(1-2*niu)]*(1-niu^2)
* Ge      = Shear Modulus of Equivalent Liner Material
*      Ge = Ee/[2*(1+niu)]/(1-niu^2)
*
* ============================================================
* Elastic Properties of the Equivalent Liner to W6x20 Steel Set
* ------------------------------------------------------------
*
m e i 1 5
* ------------------------------------------------------------
* Es  =                                       = 200e9    GPa
* niu =                                       = 0.3
* ds  =                                       = 7,859    kg/m^3
* A   =                                       = 3.79e-3  m^2
* I   =                                       = 1.72e-5  m^4
* h   = Sqrt(12*1.72e-5/3.79e-3               = 0.2337   m
* Ee  = 200e9*3.79-3/(1.0*0.2337)             = 3.240e9  Pa
* ..............................................................
* Ke  = {3.240e9/[3*(1-2*0.3)]}*(1-0.3*0.3)   = 2.460e9  Pa
* Ge  = {3.240e9/[2*(1+0.3)]}/(1-0.3*0.3)     = 1.13e9   Pa
* de  = 7859*(5.89e-3/0.3055)                 = 126.41   kg/m^3
* - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
*
prop bu=2.46e9 she=1.13e9 d=126.41 i=1,5   ;prop's of equivalent liner
*
* ---------------------------------------------------------------------------
* Apply Pressure on Model Top to Generate the Lithostatic Stress Field
* ---------------------------------------------------------------------------
apply press=4.726e4    i=36, j=25,41  ;pressure on model top
*
* ---------------------------------------------------------------------------
* Insitu stress state in the rock mass Ko=0.3
* ---------------------------------------------------------------------------
initial syy -1.711e6 var 0,1.6639e6 j=1,65
initial sxx -513300  var 0,499170   j=1,65
initial szz -513300  var 0,499170   j=1,65
*
* ---------------------------------------------------------------------------
* Reset the Initial stress state in the lining to 0.0
* ---------------------------------------------------------------------------
*
initial syy 0.  i=1,5
initial sxx 0.  i=1,5
initial szz 0.  i=1,5
```

```
*
set large, grav=9.81   ;closing of the gap betwn rk & steel sets
*
* ---------------------------------------------------------
* Specify the Interface Properties
* ----------------------------------------------------------
* Interfaces the Between the Regular and Structural Elements
* ----------------------------------------------------------
int 1 As from 6,65 to 6,1 Bs  from 7,65 to 7,1
int 1 ks=2e9 kn=2e9 fric=15
*
set mech on
*
* Reset initial displacements to zero
* ----------------------------------------
 ini xdis 0. ydis 0.
* ----------------------------------------
* Take histories of velocity and displacement at
* selected points
* ----------------------------------------
*
set force=300  ;set force for convergence=300 kN
*
his unbal
his ydis i=4 j=33
hist xdis i 1 j 1
hist xdis i 1 j 17
hist ydis i 1 j 33
hist xdis i 1 j 49
*
his nstep=20
* ---------------------------------------------------
*
tit
1699_K03 Equilibrium After Excavation Completed
*
*
set dyn=off
*
*step 100
*
*save 1699_031.sav
*
* Apply the Cribbing to Support a Void
* ---------------------------------------
*
call 1699_su.dat
*
*
*
Tit
1699_032 Equilibrium After 5-Regular Zone Steel Set and Cribbing Applied
*
solve
*
*_section_forces      ;calculate moments, normal & shear forces
*
```

```
save 1699_032.sav
*
* ----------------------------------------
*       Turn on one seismic load
* ----------------------------------------
*
set dyn on
set large
set st 3000000
*
apply syy=-4.726e4  i=36 j=25,41     *top
*
* Use Viscous Boundaries ****
*
*apply xquiet yquiet i=36 j=25,41    *top
*apply xquiet  i=36  j=41,57         *left vertical
*apply xquiet  i=36  j=9,25          *right vertical
*
* Use mass damping to prevent system oscillations
*
set dy_damp=rayl 2 25.0 mass
*
def p_wave
  freq=freq_set
  dura=dura_set
    p_wave=1.*sin(2.*pi*freq*dytime)
  if dytime > dura_set then
    p_wave=0.0
  end_if
end
*
def s_wave
  freq=freq_set
  dura=dura_set
    s_wave=1.*sin(2.*pi*freq*dytime)
  if dytime > dura_set then
    s_wave=0.0
  end_if
end
*
set freq_set=5 dura_set=1.0
*
apply yvel  0.23 his p_wave i=36 j=1,9    ;defined in ESF analysis = 23 cm/s
apply yvel  0.23 his p_wave i=36 j=57,65  ;defined in ESF analysis = 23 cm/s
*
apply xvel  0.23 his s_wave i=36 j=1,9    ;defined in ESF analysis = 23 cm/s
apply xvel  0.23 his s_wave i=36 j=57,65  ;defined in ESF analysis = 23 cm/s
*
def run_time
  wave_on=dura_set
  wave_off=2.0*dura_set
end
run_time
 *
set dytime 0
*
ini xdisp 0 ydisp 0
```

```
ini xvel=0 yvel=0

his reset
his nstep 150
*
his unbal
his dytime
*
his ydis i=1 j=33
his ydis i=1 j=1
hist xdis i 1 j 17
hist xdis i 1 j 49
*
* Horizontal velocity monitoring at the base line
his xvel i=36 j=57          * at the left corner
his xvel i=36  j=1          * at the center
his xvel i=36  j=9          * at the right corner
* Horizontal velocity monitoring at the top
his xvel i=36  j=41         * at the left corner
his xvel i=36  j=33         * at the center
his xvel i=36  j=25         * at the right corner
* Vertical velocity monitoring at the base line
his yvel i=36  j=57         * at the left corner
his yvel i=36  j=1          * at the center
his yvel i=36  j=9          * at the right corner
* Vertical velocity monitoring at the top
his yvel i=36  j=41         * at the left corner
his yvel i=36  j=33         * at the center
his yvel i=36  j=25         * at the right corner
*
* Monitor Closures at the Center
*
def vc_c
  vc_c=ydisp(19,33)-ydisp(7,1)    ;vertical
end
*
def hc_c
  hc_c=xdisp(10,49)-xdisp(9,17)   ;horizontal
end
*
his vc_c
his hc_c
*
*
his sxx i=12 j=49   ;left side
his sxx i=12 j=17   ;right side
his syy i=25 j=33   ;top
his syy i=20 j=33   ;top
his syy i=30 j=33   ;top
his syy i=1  j=10   ;bottom
*
*his sxx i=72 j=60
*his syy i=72 j=40
*his syy i=72 j=44
*his syy i=72 j=50
*his syy i=72 j=55
*his syy i=72 j=60
```

```
*his syy i=77 j=36
**
his ydisp i=19 j=33  ;top
his ydisp i=36 j=33  ;top closest to surface
his ydisp i=7  j=1    ;bottom
his xdisp i=9  j=17   ;right
his xdisp i=10 j=49    ;right
his xdisp i=1 j=33     ;steel set crown
* -------------------------------------------------------------
*
Tit
1699_3d1 Model Status at the End of Shaking Before Equilibrium
*
solve dytime wave_on
*
sav 1699_3d1.sav
*
*apply xquiet yquiet i=36 j=1,9
*apply xquiet yquiet i=36 j=57,65
*
Tit
1699_3d2 Model in Equilibrium After 5 Hz, 1 sec Duration Earthquake
*
solve dytime wave_off
*
sav 1699_3d2.sav
*
ret
```

I-8 INPUT FILES 1699_1SC (Steel Set #1699, Static, Backfilled Sides, K_o=0.3) & 1699_1DC (Steel Set #1699, Seismic, Backfilled Sides, K_o=0.3)

```
* -------------------------------------------------------------
*  1699_1sc - Tunnel Located in TSw2 at Depth -40.22 m.
*  Rock: TCw, Ko=.3
* -------------------------------------------------------------
* Steel sets represented by a mesh with 5 rows of regular zones;
* properties of the mesh calculated to match mechanical response
* of steel sets.  No structural elements involved.
* The same number of nodes on the side of structural elements
* and on the side of mesh & inner ring used just for generation
* of structural elements.
* -------------------------------------------------------------
*
configure dynamic
*
gr 35 64
m m
*
Call FSQ_HOLE.fis
*
Call Rng_Down.fis
*
Call Forces.fis
```

```
*
* ------------------------------------------
* Define the mesh geometry parameters
* ------------------------------------------
set r_ex=3.80     ;Radius of Excavation
set rmul=10       ;Outer model dimensions multiplier
set ratio=1.1
set z_th1=0.047   ;thickness of one of the five inner layers
set gap=.00       ;Gap to be used in the Interface definition
set z_th2=.25     ;Thickness od circular layers surrounding the opening
set n_ze=20       ;Number of circular layers
set n_rng=5       ;Total number of the inner ring layers
*
set iz_=n_rng     ;Number of Steel Set Ring zones used for Structural Calc's
set jz_=64        ;number of j-zones of the tunnel circumference
set xc_=0.0       ;Tunnel Center "x-coordinate"
set yc_=-40.22    ;Tunnel Center "y-coordinate"
* ----------------------------------------------------------------------
*
FSq_Hole.fis
*
* Attach both sides of the mesh
* ======================================================================
*
Attach As from 1,1 to 6,1 Bs from 1,65 to 6,65
Attach As from 7,1 to 36,1 Bs from 7,65 to 36,65
*
* ----------------------------------------------------------------------
* Add -186 m equal to the local depth and TCw density=2115 kg/m^3
* ----------------------------------------------------------------------
*
ini y add -40.22
*
* ---------------------------------------------------------------------
* Create the Gap Between the Inner Ring and the Rock Mass
*
Rng_Down
*
* ----------------------------------------------------
*
* Create a Void -----------------------------------
*
* ----------------------------------------------------
Call 1699_vo.dat
*
*
* Fix Boundary Conditions -----------
*
fix x   i=36 j=41,57  ;Left Side
fix x   i=36 j=9,25   ;Right Side
fix x y i=36 j=57,65  ;Model Bottom - Left Side
fix x y i=36 j=1,9    ;Model Bottom - Right Side
*
* ----------------------------------------------------------------
* Define Properties of the rock mass *******
*
* ----------------------------------------------------------------
```

```
* Rock Property Data for TCw --- Rock Mass Quality Category 1 ---
* -----------------------------------------------------------------
*
prop bu=2.95e9 she=2.21e9 d=2230 c=9.0e5 fric=53 ten=6e5         ;TCw
*
* ------------------------------------------------------------------
* ************* EQUIVALENT LINER SCALING RULES ***************
* ------------------------------------------------------------------
* Applied to the substitution of I-beam steel set with
* the Equivalent continuous liner modeled using a typical
* standard elements, rather than the structural beam properties.
* ===============================================================
* A       = Cross-Section Area of the I-beam-type steel set
* I       = Modulus if Inertia of Steel I-beam
* b       = Width of the equivalent continuous liner
*               Note: For 1 m steel set spacing, b=1.0
* h       = Thickness of the equivalent continuous liner
*       h = Sqrt(12*I/A)
* ds      = Density of steel
* de      = Density of the equivalent material
*      de = ds*[A/(b*h)]
* Es      = Young's Modulus of Steel
* Ee      = Young's Modulus of Equivalent Material
*      Ee = Es*A/(b*h)
*      Ee = 12*Es*I/(b*h^3)
*      Ee = 12*E*I/[{Sqrt[12I/(b*A)]^3}*b]
* Ke      = Bulk Modulus of Equivalent Liner Material
*      Ke = Ee/[3*(1-2*niu)]*(1-niu^2)
* Ge      = Shear Modulus of Equivalent Liner Material
*      Ge = Ee/[2*(1+niu)]/(1-niu^2)
*
* ==============================================================
* Elastic Properties of the Equivalent Liner to W6x20 Steel Set
* -------------------------------------------------------------
*
m e i 1 5
* -------------------------------------------------------------
* Es  =                                     = 200e9   GPa
* niu =                                     = 0.3
* ds  =                                     = 7,859   kg/m^3
* A   =                                     = 3.79e-3 m^2
* I   =                                     = 1.72e-5 m^4
* h   = Sqrt(12*1.72e-5/3.79e-3             = 0.2337  m
* Ee  = 200e9*3.79-3/(1.0*0.2337)           = 3.240e9 Pa
* .............................................................
* Ke  = {3.240e9/[3*(1-2*0.3)]}*(1-0.3*0.3)  = 2.460e9 Pa
* Ge  = {3.240e9/[2*(1+0.3)]}/(1-0.3*0.3)    = 1.13e9  Pa
* de  = 7859*(5.89e-3/0.3055)                = 126.41  kg/m^3
* - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
*
prop bu=2.46e9 she=1.13e9 d=126.41 i=1,5    ;prop's of equivalent liner
*
* ---------------------------------------------------------------------------
* Apply Pressure on Model Top to Generate the Lithostatic Stress Field
* ---------------------------------------------------------------------------
apply press=4.726e4     i=36, j=25,41   ;pressure on model top
*
```

```
* ---------------------------------------------------------------------------
* Insitu stress state in the rock mass Ko=0.3
* ---------------------------------------------------------------------------
initial syy -1.711e6 var 0,1.6639e6 j=1,65
initial sxx -513300  var 0,499170   j=1,65
initial szz -513300  var 0,499170   j=1,65
*
* ---------------------------------------------------------------------------
* Reset the Initial stress state in the lining to 0.0
initial syy 0.  i=1,5
initial sxx 0.  i=1,5
initial szz 0.  i=1,5
*
set large, grav=9.81   ;closing of the gap betwn rk & steel sets
*
* -----------------------------------------------------------
* Specify the Interface Properties
* ------------------------------------------------------------
* Interfaces the Between the Regular and Structural Elements
* ------------------------------------------------------------
int 1 As from 6,65 to 6,1 Bs  from 7,65 to 7,1
int 1 ks=2e9 kn=2e9 fric=15
*
set mech on
*
* Reset initial displacements to zero
* ----------------------------------------
ini xdis 0. ydis 0.
* ----------------------------------------
* Take histories of velocity and displacement at
* selected points
* ----------------------------------------
*
set force=300  ;set force for convergence=300 kN
*
his unbal
his ydis i=4 j=33
hist xdis i 1 j 1
hist xdis i 1 j 17
hist ydis i 1 j 33
hist xdis i 1 j 49
*
his nstep=20
* ---------------------------------------------------
*
set dyn=off
*
tit
1699_3b1 TCw, Ko=1.0 Equilibrium After Excavation Completed
*
*save 1699_3b1.sav
*
* --------------------------------------
* Apply the Cribbing to Support a Void
* --------------------------------------
*
call 1699_su.dat         ;<<<<<<<<<<<<<<<<<<<<
```

```
*
pause
*
Tit
1699_302 Equilibrium After 5-Regular Zone Steel Set and Cribbing Applied
*
solve
*
save 1699_3b2.sav     ;<<<<<<<<<<<<<<<<<<<
*
struct sup -3.83  -40.60 remove ;no 50
struct sup -3.775 -39.47 remove ;no 47
struct sup -3.395 -38.41 remove ;no 44
*
struct sup  2.978 -37.78 remove ;no 24
struct sup  3.778 -39.47 remove ;no 19
struct sup  3.830 -40.60 remove ;no 16
*
* Backfill the portion of the void
*
m m i=7 j=14,25
m m i=8 j=15,24
m m i=9 j=17,23
*
m m i=7 j=40,52
m m i=8 j=41,50
m m i=9 j=42,49
m m i=10 j=42,47
m m i=11 j=43,46
m m i=12 j=43,45
*
* Assign a 4000 psi concrete prop's to the backfill elements
*
prop bu=1.38e10 she=1.036e10 co=5.71e6 fri=45 ten=2.8e6 den=2300  i=7 j=14,25
prop bu=1.38e10 she=1.036e10 co=5.71e6 fri=45 ten=2.8e6 den=2300  i=8 j=15,24
prop bu=1.38e10 she=1.036e10 co=5.71e6 fri=45 ten=2.8e6 den=2300  i=9 j=17,23
*
prop bu=1.38e10 she=1.036e10 co=5.71e6 fri=45 ten=2.8e6 den=2300  i=7 j=40,52
prop bu=1.38e10 she=1.036e10 co=5.71e6 fri=45 ten=2.8e6 den=2300  i=8 j=41,50
prop bu=1.38e10 she=1.036e10 co=5.71e6 fri=45 ten=2.8e6 den=2300  i=9 j=42,49
prop bu=1.38e10 she=1.036e10 co=5.71e6 fri=45 ten=2.8e6 den=2300  i=10 j=42,47
prop bu=1.38e10 she=1.036e10 co=5.71e6 fri=45 ten=2.8e6 den=2300  i=11 j=43,46
prop bu=1.38e10 she=1.036e10 co=5.71e6 fri=45 ten=2.8e6 den=2300  i=12 j=43,45
*
Tit
1699_3B3 TSw2 Ko=0.3 Model in Equilibrium After Concrete Backfill Applied
*
sav 1699_3B3.sav         ;SSSSSSSSSSSSSSS<<<<<<<<<<<<<<<<<<
*
* ------------------------------------------------------------
*       Turn on one seismic load
* -----------------------------------------
*
set dyn on
set large
set st 3000000
*
```

```
apply syy=-4.726e4  i=36 j=25,41    *top
*
*apply xquiet yquiet i=36 j=25,41    *top
*apply xquiet  i=36  j=41,57         *left vertical
*apply xquiet  i=36  j=9,25          *right vertical
*
* Use mass damping to prevent system oscillations
*
set dy_damp=rayl 2 25.0 mass
*
* ------------Define P-Wave ON/OFF Conditions ------------
def p_wave
  freq=freq_set
  dura=dura_set
    p_wave=1.*sin(2.*pi*freq*dytime)
  if dytime > dura_set then
    p_wave=0.0
  end_if
end
*
* ------------Define S-Wave ON/OFF Conditions ------------
def s_wave
  freq=freq_set
  dura=dura_set
    s_wave=1.*sin(2.*pi*freq*dytime)
  if dytime > dura_set then
    s_wave=0.0
  end_if
end
*
* ------------------- Set Frequency and Duration of an Earthquake ---------
set freq_set=5 dura_set=1
* -----------------------------------------
*
apply yvel  0.23 his p_wave i=36 j=1,9    ;defined in ESF analysis = 23 cm/s
apply yvel  0.23 his p_wave i=36 j=57,65  ;defined in ESF analysis = 23 cm/s
*
apply xvel  0.23 his s_wave i=36 j=1,9    ;defined in ESF analysis = 23 cm/s
apply xvel  0.23 his s_wave i=36 j=57,65  ;defined in ESF analysis = 23 cm/s
*
* --------------------- Set Duration of EQ and Quiet Period Duration ----------
def run_time
  wave_on=dura_set
  wave_off=2.*dura_set
end
* -------------------------------
run_time
 *
set dytime 0
*
ini xdisp 0 ydisp 0
ini xvel=0 yvel=0
* ------------------- Define Histories to be Taken --------------------------
his reset
his nstep 200
his unbal
his dytime
```

```
*
his ydis i=1 j=33
his ydis i=1 j=1
hist xdis i 1 j 17
hist xdis i 1 j 49
*
* Horizontal velocity monitoring at the base line
his xvel i=36 j=57         * at the left corner
his xvel i=36  j=1         * at the center
his xvel i=36  j=9         * at the right corner
* Horizontal velocity monitoring at the top
his xvel i=36  j=41        * at the left corner
his xvel i=36  j=33        * at the center
his xvel i=36  j=25        * at the right corner
* Vertical velocity monitoring at the base line
his yvel i=36  j=57        * at the left corner
his yvel i=36  j=1         * at the center
his yvel i=36  j=9         * at the right corner
* Vertical velocity monitoring at the top
his yvel i=36  j=41        * at the left corner
his yvel i=36  j=33        * at the center
his yvel i=36  j=25        * at the right corner
*
* Monitor Closures at the Center
*
def vc_c
  vc_c=ydisp(8,33)-ydisp(8,1)    ;vertical
end
*
def hc_c
  hc_c=xdisp(1,49)-xdisp(1,17)   ;horizontal
end
*
his vc_c
his hc_c
*
*
his sxx i=11 j=1      ;rmass bottom 1 m inside
his sxx i=11 j=17     ;rmass right 1 m inside
his sxx i=11 j=33     ;rmass top 1 m inside
his sxx i=11 j=49     ;rmass left 1 m inside
*
his syy i=11 j=1      ;rmass bottom 1 m inside
his syy i=11 j=17     ;rmass right 1 m inside
his syy i=11 j=33     ;rmass top 1 m inside
his syy i=11 j=49     ;rmass left 1 m inside
*
his ydisp i=8 j=33    ;vert. top
his ydisp i=7 j=1     ;vert bottom
*
his xdisp i=8 j=17    ;hor. right
his xdisp i=9 j=49    ;hor left
*
his ydisp i=1 j=33     ;vert. sset top
his ydisp i=1 j=1      ;vert sset bottom
*
his xdisp i=1 j=17     ;hor. sset right
```

```
his xdisp i=1 j=49     ;hor. sset left
*
* ******************************************************
Tit
16993BD1 TSw2, Ko=0.3 Model Status After 1 Sec EQ Shaking
*
solve dytime wave_on
*
sav 16993Bd1.sav        ;SSSSSSSSSSSSSSSSSS<<<<<<<<<<<<<<
* .......................................................
*apply xquiet yquiet i=36 j=1,9
*apply xquiet yquiet i=36 j=57,65
*
Tit
16993BD2 TSw2, Ko=0.3 Model Status 1 Sec After Earthquake
*
solve dytime wave_off
*
sav 16993Bd2.sav         ;SSSSSSSSSSSSSSSSSS<<<<<<<<<<<<<<
* .......................................................
Tit
16993Bd3 TSw2 K0=1.0 Model Status 2 sec After Earthquake
*
solve dytime=3.0
sav 16993Bd3.sav         ;SSSSSSSSSSSSSSSSSS<<<<<<<<<<<<<
* .......................................................
*_section_forces      ;calculate moments, normal & shear forces
*
ret
```

I-9 INPUT FILES 1699_2S (Steel Set #1699, Static, K_o=1.0) & 1699_2D (Steel Set #1699, Seismic, K_o=1.0)

```
* ---------------------------------------------------------------
*  1699_2s - Tunnel Located in TSw2 at Depth -40.22 m.
*  Rock: TCw, Ko=1.0
* ---------------------------------------------------------------
* Steel sets represented by a mesh with 5 rows of regular zones;
* properties of the mesh calculated to match mechanical response
* of steel sets.  No structural elements involved.
* The same number of nodes on the side of structural elements
* and on the side of mesh & inner ring used just for generation
* of structural elements.
* ---------------------------------------------------------------
*
configure dynamic
*
gr 35 64
m m
*
Call FSQ_HOLE.fis
*
Call Rng_Down.fis
*
Call Forces.fis
```

```
*
* ------------------------------------------
* Define the mesh geometry parameters
* ------------------------------------------
set r_ex=3.80     ;Radius of Excavation
set rmul=10       ;Outer model dimensions multiplier
set ratio=1.1
set z_th1=0.047   ;thickness of one of the five inner layers
set gap=.00       ;Gap to be used in the Interface definition
set z_th2=.25     ;Thickness od circular layers surrounding the opening
set n_ze=20       ;Number of circular layers
set n_rng=5       ;Total number of the inner ring layers
*
set iz_=n_rng     ;Number of Steel Set Ring zones used for Structural Calc's
set jz_=64        ;number of j-zones of the tunnel circumference
set xc_=0.0       ;Tunnel Center "x-coordinate"
set yc_=-40.22    ;Tunnel Center "y-coordinate"
* ---------------------------------------------------------------------
*
FSq_Hole.fis
*
* Attach both sides of the mesh
* =====================================================================
*
Attach As from 1,1 to 6,1 Bs from 1,65 to 6,65
Attach As from 7,1 to 36,1 Bs from 7,65 to 36,65
*
* ---------------------------------------------------------------------
* Add -186 m equal to the local depth and TCw density=2115 kg/m^3
* ---------------------------------------------------------------------
*
ini y add -40.22
*
* --------------------------------------------------------------------
* Create the Gap Between the Inner Ring and the Rock Mass
*
Rng_Down
*
* ----------------------------------------------------
*
* Create a Void -----------------------------------
*
* ----------------------------------------------------
Call 1699_vo.dat
*
* Fix Boundary Conditions -----------
*
fix x   i=36 j=41,57  ;Left Side
fix x   i=36 j=9,25   ;Right Side
fix x y i=36 j=57,65  ;Model Bottom - Left Side
fix x y i=36 j=1,9    ;Model Bottom - Right Side
*
* ---------------------------------------------------------------
* Define Properties of the rock mass *******
*
* ---------------------------------------------------------------
* Rock Property Data for TCw --- Rock Mass Quality Category 1 ---
```

```
* ------------------------------------------------------------------
*
prop bu=2.95e9 she=2.21e9 d=2230 c=9.0e5 fric=53 ten=6e5        ;TCw
*
* ------------------------------------------------------------------
* ************* EQUIVALENT LINER SCALING RULES ***************
* ------------------------------------------------------------------
* Applied to the substitution of I-beam steel set with
* the Equivalent continuous liner modeled using a typical
* standard elements, rather than the structural beam properties.
* ===============================================================
* A       = Cross-Section Area of the I-beam-type steel set
* I       = Modulus if Inertia of Steel I-beam
* b       = Width of the equivalent continuous liner
*               Note: For 1 m steel set spacing, b=1.0
* h       = Thickness of the equivalent continuous liner
*       h = Sqrt(12*I/A)
* ds      = Density of steel
* de      = Density of the equivalent material
*      de = ds*[A/(b*h)]
* Es      = Young's Modulus of Steel
* Ee      = Young's Modulus of Equivalent Material
*      Ee = Es*A/(b*h)
*      Ee = 12*Es*I/(b*h^3)
*      Ee = 12*E*I/[{Sqrt[12I/(b*A)]^3}*b]
* Ke      = Bulk Modulus of Equivalent Liner Material
*      Ke = Ee/[3*(1-2*niu)]*(1-niu^2)
* Ge      = Shear Modulus of Equivalent Liner Material
*      Ge = Ee/[2*(1+niu)]/(1-niu^2)
*
* ============================================================
* Elastic Properties of the Equivalent Liner to W6x20 Steel Set
* ------------------------------------------------------------
*
m e i 1 5
* ------------------------------------------------------------
* Es  =                                     = 200e9   GPa
* niu =                                     = 0.3
* ds  =                                     = 7,859   kg/m^3
* A   =                                     = 3.79e-3 m^2
* I   =                                     = 1.72e-5 m^4
* h   = Sqrt(12*1.72e-5/3.79e-3             = 0.2337  m
* Ee  = 200e9*3.79-3/(1.0*0.2337)           = 3.240e9 Pa
* ...........................................................
* Ke  = {3.240e9/[3*(1-2*0.3)]}*(1-0.3*0.3) = 2.460e9 Pa
* Ge  = {3.240e9/[2*(1+0.3)]}/(1-0.3*0.3)   = 1.13e9  Pa
* de  = 7859*(5.89e-3/0.3055)               = 126.41  kg/m^3
* - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
*
prop bu=2.46e9 she=1.13e9 d=126.41 i=1,5   ;prop's of equivalent liner
*
* ------------------------------------------------------------------------
* Apply Pressure on Model Top to Generate the Lithostatic Stress Field
* ------------------------------------------------------------------------
apply press=4.726e4    i=36, j=25,41  ;pressure on model top
*
* ------------------------------------------------------------------------
```

```
* Insitu stress state in the rock mass Ko=1.0
* ---------------------------------------------------------------------------
initial syy -1.711e6 var 0,1.6639e6 j=1,65
initial sxx -1.711e6 var 0,1.6639e6 j=1,65
initial szz -1.711e6 var 0,1.6639e6 j=1,65
*
* ---------------------------------------------------------------------------
* Reset the Initial stress state in the lining to 0.0
* ---------------------------------------------------------------------------
*
initial syy 0.  i=1,5
initial sxx 0.  i=1,5
initial szz 0.  i=1,5
*
set large, grav=9.81   ;closing of the gap betwn rk & steel sets
*
* ----------------------------------------------------------
* Specify the Interface Properties
* -----------------------------------------------------------
* Interfaces the Between the Regular and Structural Elements
* -----------------------------------------------------------
int 1 As from 6,65 to 6,1 Bs  from 7,65 to 7,1
int 1 ks=2e9 kn=2e9 fric=15
*
set mech on
*
* Reset initial displacements to zero
* ----------------------------------------
ini xdis 0. ydis 0.
* ----------------------------------------
* Take histories of velocity and displacement at
* selected points
* ----------------------------------------
*
set force=300  ;set force for convergence=300 kN
*
his unbal
his ydis i=4 j=33
hist xdis i 1 j 1
hist xdis i 1 j 17
hist ydis i 1 j 33
hist xdis i 1 j 49
*
his nstep=20
* --------------------------------------------------
*
tit
1699_K10 Equilibrium After Excavation Completed
*
* pl hold grid
*
set dyn=off
*
*save 1699_101.sav
*
* Apply the Cribbing to Support a Void
* ---------------------------------------
```

```
*
call 1699_su.dat
*
Tit
1699_102 Equilibrium After 5-Regular Zone Steel Set and Cribbing Applied
*
solve
*
*_section_forces       ;calculate moments, normal & shear forces
*
save 1699_102.sav
*
* -----------------------------------------
*       Turn on one seismic load
* -----------------------------------------
*
set dyn on
set large
set st 3000000
*
apply syy=-4.726e4  i=36 j=25,41     *top
*
* Use Viscous Boundaries ****
*
*apply xquiet yquiet i=36 j=25,41    *top
*apply xquiet  i=36  j=41,57         *left vertical
*apply xquiet  i=36  j=9,25          *right vertical
*
* Use mass damping to prevent system oscillations
*
set dy_damp=rayl 2 25.0 mass
*
def p_wave
  freq=freq_set
  dura=dura_set
    p_wave=1.*sin(2.*pi*freq*dytime)
  if dytime > dura_set then
    p_wave=0.0
  end_if
end
*
def s_wave
  freq=freq_set
  dura=dura_set
    s_wave=1.*sin(2.*pi*freq*dytime)
  if dytime > dura_set then
    s_wave=0.0
  end_if
end
*
set freq_set=5 dura_set=1.0
*
apply yvel  0.23 his p_wave i=36 j=1,9    ;defined in ESF analysis = 23 cm/s
apply yvel  0.23 his p_wave i=36 j=57,65  ;defined in ESF analysis = 23 cm/s
*
apply xvel  0.23 his s_wave i=36 j=1,9    ;defined in ESF analysis = 23 cm/s
apply xvel  0.23 his s_wave i=36 j=57,65  ;defined in ESF analysis = 23 cm/s
```

```
*
def run_time
  wave_on=dura_set
  wave_off=3.0*dura_set
end
run_time
 *
set dytime 0
*
ini xdisp 0 ydisp 0
ini xvel=0 yvel=0

his reset
his nstep 150
*
his unbal
his dytime
*
his ydis i=1 j=33
his ydis i=1 j=1
hist xdis i 1 j 17
hist xdis i 1 j 49
*
* Horizontal velocity monitoring at the base line
his xvel i=36 j=57        * at the left corner
his xvel i=36  j=1        * at the center
his xvel i=36  j=9        * at the right corner
* Horizontal velocity monitoring at the top
his xvel i=36  j=41       * at the left corner
his xvel i=36  j=33       * at the center
his xvel i=36  j=25       * at the right corner
* Vertical velocity monitoring at the base line
his yvel i=36  j=57       * at the left corner
his yvel i=36  j=1        * at the center
his yvel i=36  j=9        * at the right corner
* Vertical velocity monitoring at the top
his yvel i=36  j=41       * at the left corner
his yvel i=36  j=33       * at the center
his yvel i=36  j=25       * at the right corner
*
* Monitor Closures at the Center
*
def vc_c
  vc_c=ydisp(19,33)-ydisp(7,1)    ;vertical
end
*
def hc_c
  hc_c=xdisp(10,49)-xdisp(9,17)   ;horizontal
end
*
his vc_c
his hc_c
*
*
his sxx i=12 j=49   ;left side
his sxx i=12 j=17   ;right side
his syy i=25 j=33   ;top
```

```
his syy i=20 j=33   ;top
his syy i=30 j=33   ;top
his syy i=1  j=10   ;bottom
*
*his sxx i=72 j=60
*his syy i=72 j=40
*his syy i=72 j=44
*his syy i=72 j=50
*his syy i=72 j=55
*his syy i=72 j=60
*his syy i=77 j=36
**
his ydisp i=19 j=33  ;top
his ydisp i=36 j=33  ;top closest to surface
his ydisp i=7  j=1    ;bottom
his xdisp i=9  j=17   ;right
his xdisp i=10 j=49    ;right
his xdisp i=1 j=33     ;steel set crown
*
*step 100
*
Tit
1699_1d1 Model Status at the End of Shaking Before Equilibrium
*
solve dytime wave_on
*
sav 1699_1d1.sav
*
*apply xquiet yquiet i=36 j=1,9
*apply xquiet yquiet i=36 j=57,65
*
Tit
1699_1d2 Model in Equilibrium After 5 Hz, 1 sec Duration Earthquake
*
solve dytime wave_off
*
sav 1699_1d2.sav
*
ret
```

I-10 INPUT FILES 1699_2SC (Steel Set #1699, Static, Backfilled Sides, K_o=1.0) & 1699_2DC (Steel Set #1699, Seismic, Backfilled Sides, K_o=1.0)

```
* ---------------------------------------------------------------
*  1699_2sc - Tunnel Located in TSw2 at Depth -40.22 m.
*  Rock: TCw, Ko=1.0
* ---------------------------------------------------------------
* Steel sets represented by a mesh with 5 rows of regular zones;
* properties of the mesh calculated to match mechanical response
* of steel sets.  No structural elements involved.
* The same number of nodes on the side of structural elements
* and on the side of mesh & inner ring used just for generation
* of structural elements.
* ---------------------------------------------------------------
```

```
*
configure dynamic
*
gr 35 64
m m
*
Call FSQ_HOLE.fis
*
Call Rng_Down.fis
*
Call Forces.fis
*
* -----------------------------------------
* Define the mesh geometry parameters
* -----------------------------------------
set r_ex=3.80     ;Radius of Excavation
set rmul=10       ;Outer model dimensions multiplier
set ratio=1.1
set z_th1=0.047   ;thickness of one of the five inner layers
set gap=.00       ;Gap to be used in the Interface definition
set z_th2=.25     ;Thickness od circular layers surrounding the opening
set n_ze=20       ;Number of circular layers
set n_rng=5       ;Total number of the inner ring layers
*
set iz_=n_rng     ;Number of Steel Set Ring zones used for Structural Calc's
set jz_=64        ;number of j-zones of the tunnel circumference
set xc_=0.0       ;Tunnel Center "x-coordinate"
set yc_=-40.22    ;Tunnel Center "y-coordinate"
* -------------------------------------------------------------------
*
FSq_Hole.fis
*
* Attach both sides of the mesh
* ===================================================================
*
Attach As from 1,1 to 6,1 Bs from 1,65 to 6,65
Attach As from 7,1 to 36,1 Bs from 7,65 to 36,65
*
* -------------------------------------------------------------------
* Add -186 m equal to the local depth and TCw density=2115 kg/m^3
* -------------------------------------------------------------------
*
ini y add -40.22
*
* ------------------------------------------------------------------
* Create the Gap Between the Inner Ring and the Rock Mass
*
Rng_Down
*  .
* --------------------------------------------------
*
* Create a Void --------------------------------------
*
* --------------------------------------------------
Call 1699_vo.dat
*
*
```

```
* Fix Boundary Conditions -----------
*
fix x   i=36 j=41,57  ;Left Side
fix x   i=36 j=9,25   ;Right Side
fix x y i=36 j=57,65  ;Model Bottom - Left Side
fix x y i=36 j=1,9    ;Model Bottom - Right Side
*
* -----------------------------------------------------------------
* Define Properties of the rock mass *******
*
* -----------------------------------------------------------------
* Rock Property Data for TCw --- Rock Mass Quality Category 1 ---
* -----------------------------------------------------------------
*
prop bu=2.95e9 she=2.21e9 d=2230 c=9.0e5 fric=53 ten=6e5        ;TCw
*
* ------------------------------------------------------------------
* ************* EQUIVALENT LINER SCALING RULES ***************
* ------------------------------------------------------------------
* Applied to the substitution of I-beam steel set with
* the Equivalent continuous liner modeled using a typical
* standard elements, rather than the structural beam properties.
* ===============================================================
* A       = Cross-Section Area of the I-beam-type steel set
* I       = Modulus if Inertia of Steel I-beam
* b       = Width of the equivalent continuous liner
*              Note: For 1 m steel set spacing, b=1.0
* h       = Thickness of the equivalent continuous liner
*       h = Sqrt(12*I/A)
* ds      = Density of steel
* de      = Density of the equivalent material
*      de = ds*[A/(b*h)]
* Es      = Young's Modulus of Steel
* Ee      = Young's Modulus of Equivalent Material
*      Ee = Es*A/(b*h)
*      Ee = 12*Es*I/(b*h^3)
*      Ee = 12*E*I/[{Sqrt[12I/(b*A)]^3}*b]
* Ke      = Bulk Modulus of Equivalent Liner Material
*      Ke = Ee/[3*(1-2*niu)]*(1-niu^2)
* Ge      = Shear Modulus of Equivalent Liner Material
*      Ge = Ee/[2*(1+niu)]/(1-niu^2)
*
* ==============================================================
* Elastic Properties of the Equivalent Liner to W6x20 Steel Set
* --------------------------------------------------------------
*
m e i 1 5
* --------------------------------------------------------------
* Es  =                                        = 200e9   GPa
* niu =                                        = 0.3
* ds  =                                        = 7,859   kg/m^3
* A   =                                        = 3.79e-3 m^2
* I   =                                        = 1.72e-5 m^4
* h   = Sqrt(12*1.72e-5/3.79e-3                = 0.2337  m
* Ee  = 200e9*3.79-3/(1.0*0.2337)              = 3.240e9 Pa
* ...............................................................
* Ke  = {3.240e9/[3*(1-2*0.3)]}*(1-0.3*0.3)    = 2.460e9 Pa
```

```
* Ge  = {3.240e9/[2*(1+0.3)]}/(1-0.3*0.3)      = 1.13e9  Pa
* de  = 7859*(5.89e-3/0.3055)                  = 126.41  kg/m^3
* - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
*
prop bu=2.46e9 she=1.13e9 d=126.41 i=1,5   ;prop's of equivalent liner
*
* --------------------------------------------------------------------------
* Apply Pressure on Model Top to Generate the Lithostatic Stress Field
* --------------------------------------------------------------------------
apply press=4.726e4    i=36, j=25,41  ;pressure on model top
*
* --------------------------------------------------------------------------
* Insitu stress state in the rock mass Ko=1.0
* --------------------------------------------------------------------------
initial syy -1.711e6 var 0,1.6639e6 j=1,65
initial sxx -1.711e6 var 0,1.6639e6 j=1,65
initial szz -1.711e6 var 0,1.6639e6 j=1,65
*
* --------------------------------------------------------------------------
* Reset the Initial stress state in the lining to 0.0
* --------------------------------------------------------------------------
*
initial syy 0.  i=1,5
initial sxx 0.  i=1,5
initial szz 0.  i=1,5
*
set large, grav=9.81   ;closing of the gap betwn rk & steel sets
*
* ------------------------------------------------------------
* Specify the Interface Properties
* -------------------------------------------------------------
* Interfaces the Between the Regular and Structural Elements
* -------------------------------------------------------------
int 1 As from 6,65 to 6,1 Bs  from 7,65 to 7,1
int 1 ks=2e9 kn=2e9 fric=15
*
set mech on
*
* Reset initial displacements to zero
* ----------------------------------------
ini xdis 0. ydis 0.
* ----------------------------------------
* Take histories of velocity and displacement at
* selected points
* ----------------------------------------
*
set force=300  ;set force for convergence=300 kN
*
his unbal
his ydis i=4 j=33
hist xdis i 1 j 1
hist xdis i 1 j 17
hist ydis i 1 j 33
hist xdis i 1 j 49
*
his nstep=20
* ---------------------------------------------------
```

```
*
set dyn=off
*
tit
1699_1b1 TCw, Ko=1.0 Equilibrium After Excavation Completed
*
*save 1699_1b1.sav
*
* ---------------------------------------
* Apply the Cribbing to Support a Void
* ---------------------------------------
*
call 1699_su.dat         ;<<<<<<<<<<<<<<<<<<<<
*
*
Tit
1699_102 Equilibrium After 5-Regular Zone Steel Set and Cribbing Applied
*
solve
*
save 1699_1b2.sav     ;<<<<<<<<<<<<<<<<<<<
*
struct sup -3.83  -40.60 remove ;no 50
struct sup -3.775 -39.47 remove ;no 47
struct sup -3.395 -38.41 remove ;no 44
*
struct sup  2.978 -37.78 remove ;no 24
struct sup  3.778 -39.47 remove ;no 19
struct sup  3.830 -40.60 remove ;no 16
*
* Backfill the portion of the void
*
m m i=7 j=14,25
m m i=8 j=15,24
m m i=9 j=17,23
*
m m i=7 j=40,52
m m i=8 j=41,50
m m i=9 j=42,49
m m i=10 j=42,47
m m i=11 j=43,46
m m i=12 j=43,45
*
* Assign a 4000 psi concrete prop's to the backfill elements
*
prop bu=1.38e10 she=1.036e10 co=5.71e6 fri=45 ten=2.8e6 den=2300  i=7 j=14,25
prop bu=1.38e10 she=1.036e10 co=5.71e6 fri=45 ten=2.8e6 den=2300  i=8 j=15,24
prop bu=1.38e10 she=1.036e10 co=5.71e6 fri=45 ten=2.8e6 den=2300  i=9 j=17,23
*
prop bu=1.38e10 she=1.036e10 co=5.71e6 fri=45 ten=2.8e6 den=2300  i=7 j=40,52
prop bu=1.38e10 she=1.036e10 co=5.71e6 fri=45 ten=2.8e6 den=2300  i=8 j=41,50
prop bu=1.38e10 she=1.036e10 co=5.71e6 fri=45 ten=2.8e6 den=2300  i=9 j=42,49
prop bu=1.38e10 she=1.036e10 co=5.71e6 fri=45 ten=2.8e6 den=2300  i=10 j=42,47
prop bu=1.38e10 she=1.036e10 co=5.71e6 fri=45 ten=2.8e6 den=2300  i=11 j=43,46
prop bu=1.38e10 she=1.036e10 co=5.71e6 fri=45 ten=2.8e6 den=2300  i=12 j=43,45
*
*
```

```
Tit
1699_1B3 TSw2 Ko=1.0 Model in Equilibrium After Concrete Backfill Applied
*
sav 1699_1B3.sav          ;SSSSSSSSSSSSSSS<<<<<<<<<<<<<<<<<<<
*
* -----------------------------------------------------------------
*       Turn on one seismic load
* -----------------------------------------
*
set dyn on
set large
set st 3000000
*
apply syy=-4.726e4  i=36 j=25,41    *top
*
*apply xquiet yquiet i=36 j=25,41    *top
*apply xquiet  i=36  j=41,57         *left vertical
*apply xquiet  i=36  j=9,25          *right vertical
*
* Use mass damping to prevent system oscillations
*
set dy_damp=rayl 2 25.0 mass
*
* ------------Define P-Wave ON/OFF Conditions ------------
def p_wave
  freq=freq_set
  dura=dura_set
    p_wave=1.*sin(2.*pi*freq*dytime)
  if dytime > dura_set then
    p_wave=0.0
  end_if
end
*
* ------------Define S-Wave ON/OFF Conditions ------------
def s_wave
  freq=freq_set
  dura=dura_set
    s_wave=1.*sin(2.*pi*freq*dytime)
  if dytime > dura_set then
    s_wave=0.0
  end_if
end
*
* ------------------- Set Frequency and Duration of an Earthquake ---------
set freq_set=5 dura_set=1
* -----------------------------------------
*
apply yvel  0.23 his p_wave i=36 j=1,9    ;defined in ESF analysis = 23 cm/s
apply yvel  0.23 his p_wave i=36 j=57,65  ;defined in ESF analysis = 23 cm/s
*
apply xvel  0.23 his s_wave i=36 j=1,9    ;defined in ESF analysis = 23 cm/s
apply xvel  0.23 his s_wave i=36 j=57,65  ;defined in ESF analysis = 23 cm/s
*
* --------------------- Set Duration of EQ and Quiet Period Duration ----------
def run_time
  wave_on=dura_set
  wave_off=2.*dura_set
```

```
end
* --------------------------------
run_time
 *
set dytime 0
*
ini xdisp 0 ydisp 0
ini xvel=0 yvel=0
* ------------------- Define Histories to be Taken --------------------------
his reset
his nstep 200
his unbal
his dytime
*
his ydis i=1 j=33
his ydis i=1 j=1
hist xdis i 1 j 17
hist xdis i 1 j 49
*
* Horizontal velocity monitoring at the base line
his xvel i=36 j=57          * at the left corner
his xvel i=36  j=1          * at the center
his xvel i=36  j=9          * at the right corner
* Horizontal velocity monitoring at the top
his xvel i=36  j=41         * at the left corner
his xvel i=36  j=33         * at the center
his xvel i=36  j=25         * at the right corner
* Vertical velocity monitoring at the base line
his yvel i=36  j=57         * at the left corner
his yvel i=36  j=1          * at the center
his yvel i=36  j=9          * at the right corner
* Vertical velocity monitoring at the top
his yvel i=36  j=41         * at the left corner
his yvel i=36  j=33         * at the center
his yvel i=36  j=25         * at the right corner
*
* Monitor Closures at the Center
*
def vc_c
  vc_c=ydisp(8,33)-ydisp(8,1)    ;vertical
end
*
def hc_c
  hc_c=xdisp(1,49)-xdisp(1,17)   ;horizontal
end
*
his vc_c
his hc_c
*
*
his sxx i=11 j=1       ;rmass bottom 1 m inside
his sxx i=11 j=17      ;rmass right 1 m inside
his sxx i=11 j=33      ;rmass top 1 m inside
his sxx i=11 j=49      ;rmass left 1 m inside
*
his syy i=11 j=1       ;rmass bottom 1 m inside
his syy i=11 j=17      ;rmass right 1 m inside
```

```
his syy i=11 j=33      ;rmass top 1 m inside
his syy i=11 j=49      ;rmass left 1 m inside
*
his ydisp i=8 j=33     ;vert. top
his ydisp i=7 j=1      ;vert bottom
*
his xdisp i=8 j=17     ;hor. right
his xdisp i=9 j=49     ;hor left
*
his ydisp i=1 j=33      ;vert. sset top
his ydisp i=1 j=1       ;vert sset bottom
*
his xdisp i=1 j=17      ;hor. sset right
his xdisp i=1 j=49      ;hor. sset left
*
* ********************************************************
Tit
16991BD1 TSw2, Ko=1.0 Model Status After 1 Sec EQ Shaking
solve dytime wave_on
*
sav 16991Bd1.sav        ;SSSSSSSSSSSSSSSSSSS<<<<<<<<<<<<<<
* .........................................................
*apply xquiet yquiet i=36 j=1,9
*apply xquiet yquiet i=36 j=57,65
*
Tit
16991BD2 TSw2, Ko=1.0 Model Status 1 Sec After Earthquake
*
solve dytime wave_off
*
sav 16991Bd2.sav         ;SSSSSSSSSSSSSSSSSS<<<<<<<<<<<<<<
* .........................................................
Tit
16991Bd3 TSw2 Ko=1.0 Model Status 2 sec After Earthquake
*
solve dytime=3.0
sav 16991Bd3.sav         ;SSSSSSSSSSSSSSSSSS<<<<<<<<<<<<<
* .........................................................
*_section_forces      ;calculate moments, normal & shear forces
*
ret
```

I-11 INPUT FILE 1699_SS (Support Element at Steel Set #1699)

```
* Steel Set 1699 Nodal Point Coordinates * ------------------------
* Structural Support Nodes Coordinates ***************************
*-----------------------------------------------------------------
*
*struct support  0.000-44.07 angle  270.0 seg 2 prop   ;no 65
*struct support -0.377-44.05 angle  264.4 seg 2 prop 11 ;no 64
*struct support -0.751-43.99 angle  258.8 seg 2 prop 11 ;no 63
*struct support -1.117-43.90 angle  253.1 seg 2 prop 11 ;no 62
*struct support -1.472-43.77 angle  247.5 seg 2 prop 11 ;no 61
*struct support -1.813-43.61 angle  241.9 seg 2 prop 11 ;no 60
*struct support -2.137-43.42 angle  236.3 seg 2 prop 11 ;no 59
*struct support -2.441-43.19 angle  230.6 seg 2 prop 11 ;no 58
```

```
*struct support -2.720-42.94 angle  225.0 seg 2 prop 11 ;no 57
*struct support -2.974-42.66 angle  219.4 seg 2 prop 11 ;no 56
*struct support -3.199-42.36 angle  213.8 seg 2 prop 11 ;no 55
*struct support -3.393-42.03 angle  208.1 seg 2 prop 11 ;no 54
*struct support -3.554-41.69 angle  202.5 seg 2 prop 11 ;no 53
*struct support -3.681-41.34 angle  196.9 seg 2 prop 11 ;no 52
*struct support -3.773-40.97 angle  191.3 seg 2 prop 11 ;no 51
struct support -3.83 -40.60 angle  185.6 seg 2 prop 11 ;no 50
*struct support -3.847-40.22 angle  180.0 seg 2 prop 11 ;no 49
*struct support -3.828-39.84 angle  174.4 seg 2 prop 11 ;no 48
struct support -3.775 -39.47 angle  168.8 seg 2 prop 11 ;no 47
*struct support -3.681-39.10 angle  163.1 seg 2 prop 11 ;no 46
*struct support -3.554-38.75 angle  157.5 seg 2 prop 11 ;no 45
struct support -3.395 -38.41 angle  151.9 seg 2 prop 11 ;no 44
*struct support -3.199-38.08 angle  146.3 seg 2 prop 11 ;no 43
*struct support -2.974-37.78 angle  140.6 seg 2 prop 11 ;no 42
*struct support -2.720-37.50 angle  135.0 seg 2 prop 11 ;no 41
struct support -2.443 -37.20 angle  129.4 seg 2 prop 11 ;no 40
*struct support -2.137-37.02 angle  123.8 seg 2 prop 11 ;no 39
*struct support -1.813-36.83 angle  118.1 seg 2 prop 11 ;no 38
*struct support -1.472-36.67 angle  112.5 seg 2 prop 11 ;no 37
struct support -1.119 -36.50 angle  106.9 seg 2 prop 11 ;no 36
*struct support -0.751-36.45 angle  101.3 seg 2 prop 11 ;no 35
*struct support -0.377-36.39 angle   95.6 seg 2 prop 11 ;no 34
struct support  0.000 -36.36 angle   90.0 seg 2 prop 11 ;no 33
*struct support  0.377-36.39 angle   84.4 seg 2 prop 11 ;no 32
struct support  0.753 -36.40 angle   78.8 seg 2 prop 11 ;no 31
*struct support  1.117-36.54 angle   73.1 seg 2 prop 11 ;no 30
*struct support  1.472-36.67 angle   67.5 seg 2 prop 11 ;no 29
struct support  1.815 -36.80 angle   61.9 seg 2 prop 11 ;no 28
*struct support  2.137-37.02 angle   56.3 seg 2 prop 11 ;no 27
*struct support  2.441-37.25 angle   50.6 seg 2 prop 11 ;no 26
*struct support  2.720-37.50 angle   45.0 seg 2 prop 11 ;no 25
struct support  2.978 -37.78 angle   39.4 seg 2 prop 11 ;no 24
*struct support  3.199-38.08 angle   33.8 seg 2 prop 11 ;no 23
*struct support  3.393-38.41 angle   28.1 seg 2 prop 11 ;no 22
*struct support  3.554-38.75 angle   22.5 seg 2 prop 11 ;no 21
*struct support  3.681-39.10 angle   16.9 seg 2 prop 11 ;no 20
struct support  3.778 -39.47 angle   11.3 seg 2 prop 11 ;no 19
*struct support  3.828-39.84 angle    5.6 seg 2 prop 11 ;no 18
*struct support  3.847-40.22 angle    0.0 seg 2 prop 11 ;no 17
struct support  3.830 -40.60 angle   -5.6 seg 2 prop 11 ;no 16
*struct support  3.773-40.97 angle  -11.3 seg 2 prop 11 ;no 15
*struct support  3.681-41.34 angle  -16.9 seg 2 prop 11 ;no 14
*struct support  3.554-41.69 angle  -22.5 seg 2 prop 11 ;no 13
*struct support  3.393-42.03 angle  -28.1 seg 2 prop 11 ;no 12
*struct support  3.199-42.36 angle  -33.8 seg 2 prop 11 ;no 11
*struct support  2.974-42.66 angle  -39.4 seg 2 prop 11 ;no 10
*struct support  2.720-42.94 angle  -45.0 seg 2 prop 11 ;no  9
*struct support  2.441-43.19 angle  -50.6 seg 2 prop 11 ;no  8
*struct support  2.137-43.42 angle  -56.3 seg 2 prop 11 ;no  7
*struct support  1.813-43.61 angle  -61.9 seg 2 prop 11 ;no  6
*struct support  1.472-43.77 angle  -67.5 seg 2 prop 11 ;no  5
*struct support  1.117-43.90 angle  -73.1 seg 2 prop 11 ;no  4
*struct support  0.751-43.99 angle  -78.8 seg 2 prop 11 ;no  3
*struct support  0.377-44.05 angle  -84.4 seg 2 prop 11 ;no  2
*struct support  0.000-44.07 angle  -90.0 seg 2 prop 11 ;no  1
```

```
*
* Force/Displacement relation for support
* stru prop 11 kn=1.0e7
stru prop 11 kn=1.0e8
*
```

I-12 INPUT FILE 1699_VD (Voids at Steel Set #1699)

```
*m n j=10 i=
*m n j=11 i=7
*m n j=12 i=7
*m n j=13 i=7
m n j=14 i=7
m n j=15 i=7,8
m n j=16 i=7,8
m n j=17 i=7,9
m n j=18 i=7,9
m n j=19 i=7,9
m n j=20 i=7,9
m n j=21 i=7,9
m n j=22 i=7,9
m n j=23 i=7,9
m n j=24 i=7,9
m n j=25 i=7,9
m n j=26 i=7,10
m n j=27 i=7,11
m n j=28 i=7,12
m n j=29 i=7,13
m n j=30 i=7,15
m n j=31 i=7,16
m n j=32 i=7,18
m n j=33 i=7,18
m n j=34 i=7,18
m n j=35 i=7,17
m n j=36 i=7,17
m n j=37 i=7,17
m n j=38 i=7,15
m n j=39 i=7,14
m n j=40 i=7,14
m n j=41 i=7,13
m n j=42 i=7,13
m n j=43 i=7,12
m n j=44 i=7,12
m n j=45 i=7,12
m n j=46 i=7,11
m n j=47 i=7,10
m n j=48 i=7,9
m n j=49 i=7,9
m n j=50 i=7,8
m n j=51 i=7
m n j=52 i=7
*m n j=53 i=7
*m n j=54 i=7
*m n j=55 i=7
*m n j=56 i=7
*m n j=57 i=7
```

ATTACHMENT II

STRESS FACTORS

Note: For description of Input Files see Attachment I, and for Element Numbers see Figure 6-77

1272_1S = Steel Set #1272, Static, K_o=0.3

1272_1D = Steel Set #1272, Seismic, K_o=0.3

1272_1SC = Steel Set #1272, Static, Backfilled Sides, K_o=0.3

1272_1DC = Steel Set #1272, Seismic, Backfilled Sides, K_o=0.3

1272_2S = Steel Set #1272, Static, K_o=1.0

1272_2D = Steel Set #1272, Seismic, K_o=1.0

1272_2SC = Steel Set #1272, Static, Backfilled Sides, K_o=1.0

1272_2DC = Steel Set #1272, Seismic, Backfilled Sides, K_o=1.0

1699_1S = Steel Set #1699, Static, K_o=0.3

1699_1D = Steel Set #1699, Seismic, K_o=0.3

1699_1SC = Steel Set #1699, Static, Backfilled Sides, K_o=0.3

1699_1DC = Steel Set #1699, Seismic, Backfilled Sides, K_o=0.3

1699_2S = Steel Set #1699, Static, K_o=1.0

1699_2D = Steel Set #1699, Seismic, K_o=1.0

1699_2SC = Steel Set #1699, Static, Backfilled Sides, K_o=1.0

1699_2DC = Steel Set #1699, Seismic, Backfilled Sides, K_o=1.0

Steel Set 1272 - Stress Factor Due to Bending: BMF=(M/Sx)/Fb

Segment	1272_1S	1272_1D	1272_1SC	1272_1DC	1272_2S	1272_2D	1272_2SC	1272_2DC
1	-0.104	-0.142	-0.104	-0.160	-0.185	-0.220	-0.185	-0.222
2	-0.093	-0.123	-0.093	-0.141	-0.041	-0.051	-0.041	-0.056
3	-0.039	-0.055	-0.039	-0.063	0.191	0.228	0.191	0.211
4	0.073	0.085	0.073	0.092	0.266	0.312	0.266	0.300
5	0.113	0.133	0.113	0.158	0.087	0.102	0.087	0.107
6	0.021	0.027	0.021	0.048	-0.002	0.019	-0.002	0.026
7	-0.013	0.005	-0.013	-0.001	-0.031	-0.010	-0.031	-0.004
8	-0.014	0.006	-0.014	-0.003	-0.029	-0.026	-0.029	-0.008
9	-0.014	-0.013	-0.014	-0.026	-0.025	-0.031	-0.025	-0.007
10	-0.013	-0.025	-0.013	-0.038	-0.023	-0.029	-0.023	-0.007
11	-0.012	-0.021	-0.012	-0.017	-0.011	-0.018	-0.011	-0.006
12	-0.028	-0.022	-0.028	-0.024	0.011	0.005	0.011	0.022
13	-0.037	-0.015	-0.037	-0.023	0.051	0.037	0.051	0.072
14	0.025	0.015	0.025	0.008	0.067	0.079	0.067	0.157
15	0.022	-0.003	0.022	0.002	0.032	0.028	0.032	0.077
16	-0.035	-0.035	-0.035	-0.050	-0.016	-0.016	-0.016	-0.081
17	-0.078	-0.074	-0.078	-0.070	-0.063	-0.061	-0.063	-0.138
18	-0.123	-0.121	-0.123	-0.060	-0.120	-0.114	-0.120	-0.114
19	-0.080	-0.077	-0.080	-0.044	-0.057	-0.053	-0.057	-0.096
20	-0.054	-0.055	-0.054	-0.051	-0.021	-0.025	-0.021	-0.090
21	-0.067	-0.065	-0.067	-0.063	-0.047	-0.046	-0.047	-0.052
22	-0.015	-0.013	-0.015	-0.049	0.016	0.015	0.016	0.002
23	0.006	0.001	0.006	-0.006	0.036	0.032	0.036	0.036
24	-0.020	-0.026	-0.020	0.021	-0.012	-0.014	-0.012	0.038
25	0.030	0.024	0.030	0.031	0.045	0.041	0.045	0.063
26	0.047	0.048	0.047	0.029	0.053	0.047	0.053	0.056
27	0.042	0.037	0.042	0.014	0.028	0.024	0.028	0.022
28	0.008	0.003	0.008	-0.025	-0.034	-0.036	-0.034	-0.035
29	-0.078	-0.080	-0.078	-0.109	-0.160	-0.157	-0.160	-0.134
30	-0.095	-0.091	-0.095	-0.111	-0.191	-0.182	-0.191	-0.153
31	-0.043	-0.032	-0.043	-0.036	-0.128	-0.126	-0.128	-0.101
32	0.098	0.106	0.098	0.143	0.056	0.056	0.056	0.048
33	0.136	0.138	0.136	0.182	0.112	0.108	0.112	0.089
34	0.067	0.069	0.067	0.071	0.031	0.030	0.031	0.024
35	0.096	0.097	0.096	0.062	0.086	0.083	0.086	0.067
36	0.062	0.060	0.062	-0.004	0.052	0.048	0.052	0.039
37	-0.027	-0.029	-0.027	-0.104	-0.063	-0.060	-0.063	-0.050
38	-0.036	-0.039	-0.036	-0.101	-0.066	-0.060	-0.066	-0.046
39	0.033	0.035	0.033	-0.028	0.037	0.037	0.037	0.050
40	0.028	0.029	0.028	0.139	0.038	0.038	0.038	0.078
41	-0.048	-0.048	-0.048	0.151	-0.057	-0.056	-0.057	0.028
42	-0.040	-0.041	-0.040	0.037	-0.037	-0.036	-0.037	-0.001
43	0.016	0.012	0.016	-0.041	0.051	0.052	0.051	-0.060
44	-0.006	-0.010	-0.006	-0.099	0.027	0.028	0.027	-0.079
45	-0.078	-0.080	-0.078	-0.116	-0.066	-0.068	-0.066	-0.041
46	-0.071	-0.069	-0.071	-0.100	-0.052	-0.056	-0.052	-0.011
47	0.006	0.014	0.006	-0.063	0.060	0.055	0.060	-0.022
48	0.000	0.005	0.000	-0.003	0.049	0.048	0.049	0.016
49	-0.080	-0.076	-0.080	0.002	-0.072	-0.071	-0.072	0.001
50	-0.082	-0.075	-0.082	-0.028	-0.082	-0.081	-0.082	-0.049
51	-0.005	0.010	-0.005	-0.044	0.015	0.012	0.015	-0.017
52	-0.001	0.004	-0.001	-0.066	0.023	0.021	0.023	-0.058
53	-0.107	-0.116	-0.107	-0.086	-0.109	-0.110	-0.109	-0.135
54	-0.168	-0.188	-0.168	-0.097	-0.176	-0.171	-0.176	-0.131
55	-0.156	-0.187	-0.156	-0.087	-0.145	-0.136	-0.145	-0.064
56	-0.078	-0.115	-0.078	-0.065	-0.017	-0.007	-0.017	0.065
57	0.089	0.038	0.089	0.000	0.215	0.222	0.215	0.292
58	0.098	0.093	0.098	0.050	0.383	0.397	0.383	0.428
59	0.066	0.141	0.066	0.078	0.275	0.329	0.275	0.276
60	0.093	0.153	0.093	0.132	0.026	0.042	0.026	-0.021
61	0.184	0.204	0.184	0.212	-0.141	-0.161	-0.141	-0.206
62	0.145	0.161	0.145	0.168	-0.250	-0.292	-0.250	-0.324
63	0.008	0.001	0.008	-0.017	-0.293	-0.346	-0.293	-0.365
64	-0.068	-0.098	-0.068	-0.124	-0.272	-0.326	-0.272	-0.331

Steel Set 1272 - Stress Factor Due to Compressive Axial Load: AFF=(F_Axi/A)/Fa

Segment	1272_1S	1272_1D	1272_1SC	1272_1DC	1272_2S	1272_2D	1272_2SC	1272_2DC
1	-0.320	-0.385	-0.320	-0.432	-0.437	-0.525	-0.437	-0.470
2	-0.321	-0.386	-0.321	-0.431	-0.435	-0.523	-0.435	-0.465
3	-0.321	-0.384	-0.321	-0.431	-0.433	-0.519	-0.433	-0.461
4	-0.320	-0.387	-0.320	-0.430	-0.524	-0.619	-0.524	-0.558
5	-0.372	-0.440	-0.372	-0.499	-0.532	-0.626	-0.532	-0.558
6	-0.379	-0.437	-0.379	-0.499	-0.535	-0.625	-0.535	-0.561
7	-0.381	-0.430	-0.381	-0.502	-0.543	-0.639	-0.543	-0.565
8	-0.394	-0.445	-0.394	-0.507	-0.558	-0.657	-0.558	-0.578
9	-0.408	-0.467	-0.408	-0.528	-0.575	-0.667	-0.575	-0.582
10	-0.422	-0.467	-0.422	-0.532	-0.591	-0.675	-0.591	-0.597
11	-0.439	-0.479	-0.439	-0.538	-0.605	-0.674	-0.605	-0.599
12	-0.461	-0.480	-0.461	-0.541	-0.622	-0.671	-0.622	-0.604
13	-0.462	-0.475	-0.462	-0.542	-0.631	-0.665	-0.631	-0.606
14	-0.467	-0.471	-0.467	-0.543	-0.613	-0.649	-0.613	-0.601
15	-0.488	-0.485	-0.488	-0.541	-0.674	-0.638	-0.674	-0.550
16	-0.490	-0.487	-0.490	-0.543	-0.675	-0.639	-0.675	-0.555
17	-0.491	-0.490	-0.491	-0.541	-0.676	-0.638	-0.676	-0.551
18	-0.492	-0.491	-0.492	-0.531	-0.677	-0.644	-0.677	-0.551
19	-0.493	-0.491	-0.493	-0.517	-0.675	-0.641	-0.675	-0.538
20	-0.492	-0.494	-0.492	-0.500	-0.674	-0.640	-0.674	-0.534
21	-0.496	-0.490	-0.496	-0.498	-0.678	-0.645	-0.678	-0.530
22	-0.495	-0.494	-0.495	-0.497	-0.676	-0.643	-0.676	-0.525
23	-0.495	-0.495	-0.495	-0.495	-0.675	-0.640	-0.675	-0.510
24	-0.497	-0.492	-0.497	-0.549	-0.677	-0.642	-0.677	-0.537
25	-0.496	-0.490	-0.496	-0.550	-0.676	-0.647	-0.676	-0.539
26	-0.495	-0.491	-0.495	-0.550	-0.675	-0.647	-0.675	-0.541
27	-0.496	-0.496	-0.496	-0.551	-0.676	-0.646	-0.676	-0.543
28	-0.496	-0.497	-0.496	-0.552	-0.676	-0.648	-0.676	-0.545
29	-0.499	-0.496	-0.499	-0.557	-0.681	-0.653	-0.681	-0.547
30	-0.500	-0.493	-0.500	-0.560	-0.681	-0.650	-0.681	-0.549
31	-0.498	-0.493	-0.498	-0.559	-0.679	-0.651	-0.679	-0.549
32	-0.496	-0.490	-0.496	-0.557	-0.676	-0.649	-0.676	-0.548
33	-0.494	-0.483	-0.494	-0.559	-0.676	-0.646	-0.676	-0.551
34	-0.493	-0.491	-0.493	-0.562	-0.676	-0.648	-0.676	-0.554
35	-0.492	-0.489	-0.492	-0.563	-0.675	-0.644	-0.675	-0.551
36	-0.491	-0.491	-0.491	-0.566	-0.675	-0.649	-0.675	-0.550
37	-0.492	-0.499	-0.492	-0.566	-0.675	-0.653	-0.675	-0.554
38	-0.492	-0.491	-0.492	-0.562	-0.675	-0.652	-0.675	-0.553
39	-0.489	-0.492	-0.489	-0.560	-0.672	-0.651	-0.672	-0.552
40	-0.488	-0.494	-0.488	-0.558	-0.670	-0.654	-0.670	-0.551
41	-0.489	-0.497	-0.489	-0.493	-0.672	-0.656	-0.672	-0.538
42	-0.488	-0.497	-0.488	-0.496	-0.671	-0.655	-0.671	-0.552
43	-0.482	-0.489	-0.482	-0.495	-0.663	-0.650	-0.663	-0.554
44	-0.482	-0.496	-0.482	-0.493	-0.663	-0.649	-0.663	-0.555
45	-0.483	-0.499	-0.483	-0.494	-0.664	-0.649	-0.664	-0.554
46	-0.482	-0.499	-0.482	-0.490	-0.663	-0.650	-0.663	-0.573
47	-0.479	-0.497	-0.479	-0.484	-0.660	-0.648	-0.660	-0.569
48	-0.479	-0.499	-0.479	-0.478	-0.660	-0.648	-0.660	-0.570
49	-0.479	-0.495	-0.479	-0.456	-0.661	-0.651	-0.661	-0.564
50	-0.479	-0.500	-0.479	-0.451	-0.661	-0.654	-0.661	-0.564
51	-0.477	-0.496	-0.477	-0.448	-0.660	-0.652	-0.660	-0.562
52	-0.476	-0.499	-0.476	-0.435	-0.659	-0.650	-0.659	-0.527
53	-0.483	-0.497	-0.483	-0.427	-0.666	-0.659	-0.666	-0.528
54	-0.484	-0.496	-0.484	-0.424	-0.666	-0.658	-0.666	-0.526
55	-0.484	-0.497	-0.484	-0.420	-0.665	-0.655	-0.665	-0.525
56	-0.483	-0.493	-0.483	-0.414	-0.663	-0.654	-0.663	-0.525
57	-0.480	-0.493	-0.480	-0.414	-0.659	-0.653	-0.659	-0.519
58	-0.352	-0.323	-0.352	-0.400	-0.516	-0.507	-0.516	-0.483
59	-0.353	-0.333	-0.353	-0.400	-0.428	-0.517	-0.428	-0.467
60	-0.352	-0.331	-0.352	-0.401	-0.432	-0.525	-0.432	-0.473
61	-0.351	-0.334	-0.351	-0.397	-0.434	-0.527	-0.434	-0.472
62	-0.315	-0.380	-0.315	-0.428	-0.436	-0.530	-0.436	-0.472
63	-0.317	-0.377	-0.317	-0.431	-0.437	-0.531	-0.437	-0.472
64	-0.319	-0.387	-0.319	-0.432	-0.437	-0.528	-0.437	-0.471

Steel Set 1272 - Combined Stress Factor = BMF + AAF

Segment	1272_1S	1272_1D	1272_1SC	1272_1DC	1272_2S	1272_2D	1272_2SC	1272_2DC
1	0.424	0.528	0.424	0.592	0.622	0.745	0.622	0.692
2	0.414	0.509	0.414	0.572	0.476	0.573	0.476	0.520
3	0.360	0.439	0.360	0.493	0.623	0.747	0.623	0.673
4	0.393	0.472	0.393	0.522	0.790	0.931	0.790	0.857
5	0.485	0.572	0.485	0.656	0.620	0.728	0.620	0.665
6	0.400	0.464	0.400	0.547	0.536	0.644	0.536	0.587
7	0.394	0.435	0.394	0.503	0.573	0.649	0.573	0.569
8	0.408	0.451	0.408	0.511	0.587	0.683	0.587	0.587
9	0.423	0.480	0.423	0.554	0.600	0.697	0.600	0.589
10	0.435	0.492	0.435	0.570	0.615	0.704	0.615	0.604
11	0.451	0.499	0.451	0.555	0.617	0.692	0.617	0.605
12	0.489	0.502	0.489	0.565	0.633	0.676	0.633	0.625
13	0.499	0.490	0.499	0.565	0.682	0.702	0.682	0.677
14	0.493	0.486	0.493	0.552	0.680	0.727	0.680	0.758
15	0.511	0.488	0.511	0.542	0.706	0.665	0.706	0.627
16	0.525	0.522	0.525	0.592	0.692	0.656	0.692	0.635
17	0.569	0.563	0.569	0.611	0.739	0.699	0.739	0.690
18	0.615	0.611	0.615	0.591	0.797	0.758	0.797	0.666
19	0.573	0.569	0.573	0.560	0.732	0.694	0.732	0.634
20	0.546	0.549	0.546	0.551	0.695	0.665	0.695	0.625
21	0.563	0.555	0.563	0.560	0.725	0.691	0.725	0.583
22	0.510	0.508	0.510	0.546	0.693	0.658	0.693	0.527
23	0.501	0.496	0.501	0.502	0.711	0.671	0.711	0.546
24	0.517	0.519	0.517	0.570	0.689	0.656	0.689	0.576
25	0.526	0.513	0.526	0.581	0.721	0.688	0.721	0.602
26	0.542	0.539	0.542	0.579	0.728	0.694	0.728	0.597
27	0.538	0.533	0.538	0.565	0.703	0.669	0.703	0.565
28	0.504	0.500	0.504	0.578	0.710	0.684	0.710	0.579
29	0.578	0.577	0.578	0.666	0.841	0.811	0.841	0.681
30	0.594	0.584	0.594	0.672	0.871	0.832	0.871	0.702
31	0.542	0.525	0.542	0.595	0.808	0.777	0.808	0.650
32	0.594	0.595	0.594	0.701	0.732	0.704	0.732	0.595
33	0.630	0.621	0.630	0.741	0.788	0.755	0.788	0.640
34	0.560	0.559	0.560	0.632	0.707	0.678	0.707	0.578
35	0.588	0.586	0.588	0.625	0.761	0.727	0.761	0.618
36	0.553	0.551	0.553	0.570	0.726	0.697	0.726	0.589
37	0.519	0.529	0.519	0.670	0.738	0.713	0.738	0.604
38	0.528	0.531	0.528	0.663	0.741	0.712	0.741	0.599
39	0.523	0.526	0.523	0.588	0.709	0.688	0.709	0.602
40	0.517	0.523	0.517	0.697	0.709	0.691	0.709	0.630
41	0.537	0.545	0.537	0.643	0.728	0.712	0.728	0.566
42	0.528	0.537	0.528	0.533	0.707	0.691	0.707	0.553
43	0.499	0.501	0.499	0.536	0.714	0.702	0.714	0.615
44	0.488	0.507	0.488	0.592	0.691	0.677	0.691	0.634
45	0.561	0.579	0.561	0.610	0.730	0.717	0.730	0.595
46	0.553	0.568	0.553	0.590	0.715	0.707	0.715	0.584
47	0.485	0.511	0.485	0.547	0.720	0.704	0.720	0.591
48	0.479	0.503	0.479	0.481	0.709	0.696	0.709	0.586
49	0.560	0.572	0.560	0.458	0.733	0.722	0.733	0.565
50	0.561	0.575	0.561	0.479	0.743	0.735	0.743	0.613
51	0.482	0.506	0.482	0.491	0.675	0.664	0.675	0.579
52	0.477	0.503	0.477	0.501	0.682	0.671	0.682	0.585
53	0.590	0.613	0.590	0.514	0.776	0.769	0.776	0.663
54	0.652	0.684	0.652	0.521	0.843	0.829	0.843	0.657
55	0.640	0.684	0.640	0.506	0.810	0.792	0.810	0.589
56	0.561	0.607	0.561	0.479	0.680	0.661	0.680	0.589
57	0.569	0.531	0.569	0.415	0.874	0.874	0.874	0.810
58	0.450	0.417	0.450	0.450	0.899	0.904	0.899	0.912
59	0.418	0.474	0.418	0.477	0.703	0.846	0.703	0.743
60	0.446	0.484	0.446	0.532	0.458	0.568	0.458	0.493
61	0.535	0.538	0.535	0.610	0.575	0.688	0.575	0.679
62	0.460	0.541	0.460	0.596	0.686	0.823	0.686	0.796
63	0.325	0.378	0.325	0.448	0.730	0.877	0.730	0.837
64	0.387	0.484	0.387	0.556	0.709	0.854	0.709	0.802

Steel Set 1699 - Stress Factor Due to Bending: BMF=(M/Sx)/Fb

Segment	1699_1S	1699_1D	1699_1SC	1699_1DC	1699_2S	1699_2D	1699_2SC	1699_2DC
1	0.058	-0.044	-0.025	-0.026	0.010	-0.065	0.014	-0.016
2	0.007	-0.019	-0.018	-0.009	-0.035	-0.049	0.000	-0.002
3	-0.007	0.025	0.018	-0.002	-0.020	0.004	-0.015	-0.012
4	-0.009	0.029	0.033	-0.014	-0.002	0.037	-0.006	-0.013
5	-0.010	-0.002	0.005	-0.011	-0.006	0.022	-0.008	-0.009
6	-0.007	-0.008	-0.005	0.003	-0.008	0.005	-0.008	0.002
7	-0.005	-0.005	-0.005	0.019	-0.008	-0.010	-0.008	0.014
8	-0.005	-0.009	-0.006	0.025	-0.007	-0.007	-0.008	0.028
9	-0.007	-0.009	-0.007	0.033	-0.006	-0.002	-0.008	0.043
10	-0.009	-0.008	-0.011	0.044	-0.013	-0.003	-0.013	0.059
11	-0.007	0.000	-0.011	0.064	0.002	0.010	0.006	0.081
12	0.007	0.024	0.004	0.091	0.025	0.025	0.026	0.112
13	0.032	0.052	0.038	0.130	0.032	0.035	0.031	0.156
14	0.024	0.032	0.025	0.109	0.016	0.028	0.016	0.133
15	-0.025	-0.031	-0.023	0.027	-0.003	0.003	-0.004	0.043
16	-0.044	-0.055	-0.043	-0.036	-0.016	-0.012	-0.016	-0.027
17	-0.043	-0.048	-0.042	-0.089	-0.028	-0.029	-0.028	-0.086
18	-0.013	-0.001	-0.014	-0.126	0.008	0.008	0.007	-0.129
19	-0.013	-0.002	-0.015	-0.150	-0.001	-0.003	-0.001	-0.157
20	-0.043	-0.050	-0.044	-0.159	-0.053	-0.063	-0.053	-0.170
21	-0.045	-0.058	-0.046	-0.155	-0.061	-0.072	-0.060	-0.168
22	-0.027	-0.036	-0.028	-0.135	-0.036	-0.045	-0.035	-0.149
23	0.019	0.026	0.018	-0.102	0.034	0.031	0.034	-0.116
24	0.025	0.033	0.026	-0.056	0.043	0.042	0.043	-0.070
25	-0.007	-0.013	-0.005	0.003	-0.008	-0.018	-0.007	-0.009
26	-0.011	-0.021	-0.009	0.071	-0.015	-0.028	-0.015	0.062
27	0.011	0.008	0.011	0.161	0.016	0.006	0.016	0.156
28	0.016	0.012	0.015	0.172	0.018	0.008	0.018	0.170
29	0.001	-0.011	0.001	0.107	-0.013	-0.026	-0.013	0.101
30	0.014	0.006	0.014	0.058	0.000	-0.010	0.000	0.050
31	0.020	0.014	0.019	0.018	0.002	-0.005	0.002	0.009
32	0.022	0.019	0.021	-0.009	-0.001	-0.001	-0.001	-0.017
33	0.018	0.017	0.017	-0.024	-0.007	-0.003	-0.008	-0.031
34	0.004	0.001	0.004	-0.027	-0.023	-0.016	-0.023	-0.032
35	0.019	0.026	0.018	-0.017	0.005	0.020	0.005	-0.019
36	0.013	0.020	0.013	0.005	0.002	0.016	0.001	0.007
37	-0.010	-0.013	-0.010	0.039	-0.031	-0.021	-0.030	0.047
38	-0.007	-0.008	-0.007	0.084	-0.023	-0.012	-0.023	0.098
39	0.017	0.027	0.017	0.142	0.019	0.034	0.019	0.161
40	0.016	0.026	0.016	0.125	0.016	0.031	0.016	0.147
41	-0.006	-0.006	-0.006	0.047	-0.026	-0.021	-0.026	0.060
42	-0.004	-0.003	-0.004	-0.015	-0.027	-0.022	-0.027	-0.007
43	0.024	0.040	0.024	-0.066	0.013	0.020	0.013	-0.061
44	0.011	0.022	0.011	-0.103	0.018	0.023	0.018	-0.102
45	-0.044	-0.059	-0.044	-0.127	-0.015	-0.015	-0.015	-0.129
46	-0.072	-0.098	-0.072	-0.136	0.001	-0.002	0.001	-0.141
47	-0.079	-0.107	-0.079	-0.131	-0.007	-0.011	-0.007	-0.139
48	-0.063	-0.083	-0.064	-0.115	-0.039	-0.047	-0.039	-0.121
49	-0.021	-0.018	-0.021	-0.085	-0.022	-0.030	-0.022	-0.089
50	0.002	0.011	0.002	-0.040	-0.016	-0.025	-0.016	-0.041
51	0.005	0.003	0.005	0.017	-0.020	-0.031	-0.020	0.018
52	0.039	0.037	0.040	0.091	0.024	0.012	0.023	0.098
53	0.030	0.052	0.031	0.104	0.046	0.045	0.044	0.112
54	0.006	0.031	0.007	0.066	0.023	0.018	0.024	0.074
55	-0.001	0.007	-0.001	0.043	-0.017	-0.020	-0.012	0.051
56	-0.004	-0.005	-0.006	0.028	-0.012	-0.012	-0.012	0.035
57	-0.005	-0.009	-0.006	0.017	0.002	-0.006	0.000	0.030
58	-0.005	-0.009	-0.005	0.009	-0.003	-0.010	-0.004	0.028
59	-0.005	-0.005	-0.006	0.003	-0.007	-0.012	-0.005	0.005
60	-0.009	0.007	-0.006	-0.001	-0.009	-0.006	-0.001	-0.026
61	-0.012	0.028	0.004	-0.001	-0.011	0.007	0.006	-0.046
62	-0.010	0.030	0.038	-0.011	-0.013	0.031	-0.015	-0.056
63	0.004	-0.007	0.035	-0.027	-0.016	0.001	-0.043	-0.053
64	0.051	-0.041	-0.011	-0.032	0.015	-0.051	-0.018	-0.041

Steel Set 1699 - Stress Factor Due to Compressive Axial Load: AFF=(F_Axi/A)/Fa

Segment	1699_1S	1699_1D	1699_1SC	1699_1DC	1699_2S	1699_2D	1699_2SC	1699_2DC
1	-0.188	-0.191	-0.161	-0.066	-0.327	-0.217	-0.316	-0.069
2	-0.189	-0.191	-0.161	-0.066	-0.328	-0.216	-0.323	-0.078
3	-0.189	-0.195	-0.160	-0.075	-0.328	-0.215	-0.323	-0.080
4	-0.190	-0.206	-0.178	-0.075	-0.322	-0.227	-0.323	-0.081
5	-0.188	-0.209	-0.178	-0.075	-0.313	-0.236	-0.313	-0.082
6	-0.186	-0.212	-0.178	-0.074	-0.305	-0.244	-0.304	-0.084
7	-0.181	-0.218	-0.178	-0.079	-0.296	-0.247	-0.295	-0.086
8	-0.175	-0.223	-0.178	-0.081	-0.288	-0.251	-0.287	-0.088
9	-0.169	-0.228	-0.177	-0.083	-0.279	-0.258	-0.278	-0.090
10	-0.163	-0.227	-0.173	-0.084	-0.270	-0.263	-0.269	-0.090
11	-0.159	-0.223	-0.169	-0.083	-0.269	-0.264	-0.268	-0.089
12	-0.156	-0.219	-0.168	-0.082	-0.258	-0.256	-0.255	-0.088
13	-0.150	-0.210	-0.165	-0.079	-0.248	-0.247	-0.246	-0.085
14	-0.170	-0.226	-0.157	-0.086	-0.251	-0.280	-0.249	-0.092
15	-0.169	-0.227	-0.157	-0.087	-0.251	-0.280	-0.249	-0.094
16	-0.168	-0.227	-0.157	-0.088	-0.251	-0.280	-0.249	-0.095
17	-0.167	-0.227	-0.156	-0.089	-0.250	-0.280	-0.249	-0.095
18	-0.166	-0.226	-0.155	-0.089	-0.249	-0.279	-0.247	-0.096
19	-0.164	-0.226	-0.154	-0.089	-0.249	-0.279	-0.247	-0.096
20	-0.163	-0.226	-0.155	-0.089	-0.250	-0.280	-0.248	-0.096
21	-0.163	-0.226	-0.155	-0.089	-0.250	-0.280	-0.248	-0.096
22	-0.162	-0.226	-0.154	-0.088	-0.249	-0.279	-0.247	-0.095
23	-0.161	-0.224	-0.153	-0.088	-0.248	-0.278	-0.246	-0.096
24	-0.161	-0.224	-0.152	-0.087	-0.247	-0.277	-0.246	-0.094
25	-0.160	-0.225	-0.152	-0.086	-0.248	-0.278	-0.246	-0.093
26	-0.160	-0.225	-0.153	-0.084	-0.248	-0.278	-0.246	-0.091
27	-0.159	-0.224	-0.152	-0.083	-0.247	-0.278	-0.246	-0.089
28	-0.159	-0.224	-0.152	-0.082	-0.247	-0.277	-0.245	-0.089
29	-0.159	-0.224	-0.153	-0.084	-0.247	-0.278	-0.245	-0.090
30	-0.158	-0.224	-0.153	-0.085	-0.247	-0.278	-0.245	-0.091
31	-0.158	-0.224	-0.153	-0.085	-0.246	-0.278	-0.245	-0.092
32	-0.158	-0.224	-0.154	-0.086	-0.246	-0.278	-0.245	-0.092
33	-0.158	-0.224	-0.154	-0.086	-0.246	-0.278	-0.245	-0.093
34	-0.158	-0.224	-0.154	-0.086	-0.246	-0.278	-0.245	-0.093
35	-0.157	-0.223	-0.154	-0.086	-0.246	-0.277	-0.244	-0.092
36	-0.158	-0.223	-0.154	-0.086	-0.246	-0.277	-0.245	-0.092
37	-0.158	-0.224	-0.155	-0.085	-0.246	-0.278	-0.245	-0.091
38	-0.158	-0.224	-0.155	-0.084	-0.247	-0.278	-0.245	-0.091
39	-0.157	-0.223	-0.154	-0.083	-0.247	-0.276	-0.244	-0.089
40	-0.157	-0.223	-0.154	-0.083	-0.248	-0.276	-0.244	-0.089
41	-0.157	-0.224	-0.154	-0.085	-0.249	-0.278	-0.245	-0.091
42	-0.157	-0.224	-0.156	-0.086	-0.251	-0.278	-0.246	-0.092
43	-0.157	-0.223	-0.156	-0.087	-0.252	-0.277	-0.246	-0.093
44	-0.158	-0.224	-0.156	-0.088	-0.252	-0.277	-0.247	-0.094
45	-0.159	-0.226	-0.158	-0.088	-0.254	-0.278	-0.249	-0.095
46	-0.160	-0.227	-0.159	-0.089	-0.255	-0.278	-0.250	-0.095
47	-0.161	-0.227	-0.160	-0.089	-0.256	-0.279	-0.251	-0.096
48	-0.161	-0.227	-0.160	-0.089	-0.259	-0.279	-0.254	-0.095
49	-0.161	-0.226	-0.161	-0.089	-0.260	-0.279	-0.255	-0.095
50	-0.162	-0.226	-0.162	-0.088	-0.260	-0.279	-0.256	-0.094
51	-0.163	-0.226	-0.163	-0.087	-0.262	-0.280	-0.257	-0.094
52	-0.163	-0.226	-0.163	-0.086	-0.262	-0.279	-0.258	-0.092
53	-0.132	-0.216	-0.130	-0.068	-0.241	-0.262	-0.236	-0.074
54	-0.134	-0.217	-0.132	-0.070	-0.260	-0.262	-0.253	-0.075
55	-0.137	-0.217	-0.136	-0.070	-0.261	-0.263	-0.257	-0.076
56	-0.142	-0.215	-0.140	-0.071	-0.261	-0.263	-0.257	-0.077
57	-0.146	-0.214	-0.144	-0.070	-0.274	-0.259	-0.269	-0.077
58	-0.151	-0.211	-0.148	-0.068	-0.283	-0.255	-0.277	-0.074
59	-0.156	-0.208	-0.151	-0.067	-0.291	-0.251	-0.285	-0.068
60	-0.161	-0.205	-0.152	-0.066	-0.299	-0.245	-0.292	-0.069
61	-0.165	-0.204	-0.153	-0.064	-0.308	-0.241	-0.301	-0.069
62	-0.169	-0.196	-0.153	-0.066	-0.317	-0.234	-0.315	-0.069
63	-0.169	-0.190	-0.160	-0.066	-0.324	-0.216	-0.315	-0.069
64	-0.169	-0.191	-0.161	-0.066	-0.324	-0.216	-0.315	-0.069

Steel Set 1699 - Combined Stress Factor = BMF + AFF

Segment	1699_1S	1699_1D	1699_1SC	1699_1DC	1699_2S	1699_2D	1699_2SC	1699_2DC
1	0.246	0.235	0.186	0.093	0.338	0.282	0.329	0.085
2	0.196	0.210	0.179	0.075	0.363	0.266	0.323	0.080
3	0.196	0.220	0.178	0.077	0.347	0.219	0.338	0.092
4	0.199	0.234	0.211	0.088	0.324	0.264	0.329	0.094
5	0.198	0.211	0.183	0.086	0.319	0.258	0.321	0.091
6	0.193	0.219	0.182	0.077	0.312	0.249	0.313	0.086
7	0.186	0.223	0.183	0.098	0.304	0.257	0.304	0.100
8	0.180	0.232	0.184	0.106	0.295	0.258	0.294	0.116
9	0.176	0.237	0.185	0.116	0.285	0.260	0.285	0.134
10	0.172	0.234	0.184	0.128	0.283	0.266	0.282	0.150
11	0.166	0.223	0.180	0.147	0.271	0.275	0.273	0.170
12	0.164	0.243	0.172	0.173	0.283	0.281	0.281	0.200
13	0.182	0.262	0.203	0.209	0.280	0.282	0.277	0.241
14	0.194	0.258	0.182	0.195	0.267	0.308	0.265	0.225
15	0.193	0.259	0.180	0.114	0.254	0.283	0.253	0.137
16	0.212	0.282	0.200	0.124	0.266	0.292	0.265	0.122
17	0.210	0.275	0.199	0.178	0.278	0.309	0.276	0.181
18	0.179	0.227	0.170	0.215	0.257	0.287	0.255	0.225
19	0.177	0.227	0.169	0.240	0.250	0.283	0.249	0.253
20	0.206	0.276	0.198	0.249	0.303	0.343	0.301	0.266
21	0.208	0.285	0.200	0.244	0.311	0.352	0.308	0.264
22	0.189	0.262	0.181	0.223	0.285	0.324	0.283	0.244
23	0.180	0.250	0.171	0.190	0.282	0.309	0.281	0.211
24	0.186	0.257	0.178	0.143	0.290	0.320	0.289	0.164
25	0.167	0.238	0.157	0.088	0.255	0.296	0.254	0.102
26	0.170	0.245	0.161	0.156	0.263	0.306	0.262	0.154
27	0.170	0.232	0.164	0.243	0.263	0.284	0.262	0.245
28	0.174	0.236	0.167	0.255	0.265	0.286	0.263	0.259
29	0.160	0.235	0.154	0.191	0.260	0.304	0.258	0.191
30	0.173	0.230	0.167	0.143	0.247	0.288	0.245	0.141
31	0.178	0.238	0.173	0.103	0.248	0.283	0.246	0.101
32	0.179	0.243	0.175	0.095	0.247	0.279	0.246	0.110
33	0.175	0.240	0.171	0.110	0.253	0.280	0.252	0.124
34	0.162	0.225	0.158	0.113	0.269	0.294	0.268	0.125
35	0.176	0.249	0.172	0.103	0.251	0.297	0.249	0.111
36	0.171	0.243	0.167	0.090	0.248	0.293	0.246	0.100
37	0.168	0.238	0.164	0.124	0.277	0.298	0.275	0.139
38	0.165	0.233	0.162	0.168	0.270	0.289	0.268	0.189
39	0.174	0.250	0.170	0.224	0.266	0.310	0.263	0.250
40	0.173	0.249	0.170	0.208	0.264	0.307	0.260	0.236
41	0.163	0.230	0.160	0.131	0.275	0.298	0.271	0.151
42	0.162	0.227	0.159	0.101	0.278	0.300	0.273	0.099
43	0.182	0.263	0.180	0.153	0.265	0.298	0.258	0.155
44	0.169	0.246	0.167	0.190	0.270	0.301	0.265	0.196
45	0.203	0.285	0.202	0.215	0.269	0.293	0.264	0.224
46	0.232	0.325	0.231	0.224	0.256	0.280	0.252	0.236
47	0.240	0.334	0.239	0.220	0.264	0.290	0.259	0.235
48	0.225	0.309	0.224	0.204	0.298	0.326	0.293	0.217
49	0.183	0.244	0.182	0.173	0.282	0.310	0.278	0.184
50	0.164	0.237	0.164	0.128	0.276	0.304	0.272	0.136
51	0.167	0.229	0.168	0.104	0.282	0.311	0.277	0.112
52	0.202	0.263	0.203	0.177	0.285	0.291	0.281	0.191
53	0.163	0.269	0.160	0.173	0.288	0.307	0.280	0.187
54	0.141	0.248	0.139	0.136	0.282	0.280	0.277	0.149
55	0.138	0.223	0.137	0.113	0.278	0.283	0.268	0.127
56	0.146	0.220	0.146	0.098	0.273	0.276	0.269	0.112
57	0.151	0.223	0.151	0.087	0.276	0.265	0.269	0.107
58	0.156	0.220	0.154	0.077	0.286	0.265	0.281	0.102
59	0.161	0.213	0.157	0.069	0.297	0.263	0.289	0.073
60	0.169	0.212	0.158	0.066	0.308	0.252	0.293	0.095
61	0.177	0.232	0.157	0.065	0.319	0.248	0.307	0.115
62	0.179	0.226	0.191	0.077	0.331	0.265	0.330	0.125
63	0.173	0.197	0.195	0.094	0.340	0.216	0.359	0.122
64	0.219	0.232	0.172	0.098	0.339	0.267	0.333	0.110