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CRWMS/M&O

Non-Q Design Analysis Cover Sheet

Complete only applicable items.

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ECRB Alcove and Niche Ground Support Analysis

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4. Revision No.	5. Description of Revision
00	Initial Issue
01	Analysis was revised to address the elimination of the construction support bay opposite the Alcove and Niche entrance.

1. PURPOSE

The purpose of the analysis is to provide design bases for Enhanced Characterization of the Repository Block (ECRB) alcove and niche ground support drawings. The objective is to evaluate the ESF Alcove Ground Support Analysis (Ref. 5.1) to determine if the calculations technically bound the ECRB alcoves and to address specific differences in the conditions and constraints.

This analysis does not constitute a level-3 deliverable, a level-4 milestone, or a supporting work product. This document is not being prepared in support of the Site Recommendation, EIS, or MGR License Application and should not be cited as a reference in the Site Recommendation, EIS, or MGR License Application.

2. QUALITY ASSURANCE

The Activity Evaluations for the Cross Drift, Alcoves and Niches (Ref. 5.12, 5.13 & 5.14) determined that the work is not subject to the requirements of the QARD. Although Cross Drift, Alcoves and Niches are classified as QA-2 by the Main Access Openings Classification Analysis (Ref. 5.26), this classification doesn't affect ground support because the classification was applied to ensure repository layout criteria are met. There are no QA requirements regarding ground support from the Main Access Opening Classification Analysis (Ref. 5.26), or is the ground support items classified as QA by the Test Support Areas and Ground Support Classification Analyses (Ref. 5.16 & 5.17). There are no QA controls from the applicable DIE (Ref. 5.15) on the Ground Support Design in the ECRB, but there are QA controls on activities associated with the installation of ground support items. However, the DIE controls on activities are not applicable to this analysis and are directly incorporated to the specifications and drawings from the DIE. There are no QA controls generated by this analysis.

3. METHOD

The method to be employed by this analysis is an empirical design and comparative evaluation with the physical conditions, requirements, and constraints from the design of the TS Loop Alcove with the ECRB alcoves and niches. Additional analytical modeling is used where comparative evaluation exceeds the bounds of the existing analyses.

4. DESIGN INPUTS

4.1 DESIGN PARAMETERS

4.1.1 Empirical Design parameters

Alcove/ Niche	Thermal Mechanical Unit	Maximum Alcove/ Niche Size	Tunnel Size	Rock Mass Quality "Q"	Excavation Support Ratio (ESR)
Cross Over Alcove (Alcove #8)	TSw1 *♦	5 m. *♦	5 m. *♦	0.24 **	1 **
Niche #5 and fracture matrix	TSw2 *♦	5 m. *♦	5 m. *♦	0.3 **	1 **
Niche #6 and fracture matrix alcove	TSw2 *♦	5 m. *♦	5 m. *♦	0.3 **	1 **
Crest Alcove Alcove #9	TSw2 *♦	5 m. * ♦	5 m. *♦	0.3 **	1 **

* Criteria Letter (Ref. 5.7) ** ESF Alcove Ground Support Analysis. (Ref. 5.1)
♦ Revised Criteria Letter (Ref. 5.30)

4.1.2 ECRB Alcove and Niches Analytical design parameters

Alcove/ Niche Name	Alcove/ Niche Size	Cross Drift Approximate Station (m)	Thermal Mechanical Unit	Depth of Overburden
Cross Over Alcove (Alcove #8)	1000 mm wider than niche 3 in main drift * 4m***+1m= 5m	Located above Niche #3 in TS Loop * (7 + 73 to 8 + 00) **	TSw1 **	237 m ****

Alcove/ Niche Name	**Alcove/ Niche Size**	**Cross Drift Approximate Station** (m)	**Thermal Mechanical Unit**	**Depth of Overburden**
Niche #5 and fracture matrix alcove	Access Drift 6 m High* by 5m wide.**** Niche at end of drift is 4m by 4 m *	16 + 20 ♦	TSw2 **	288 m ****
Niche #6 and fracture matrix alcove	Access Drift 6 m High* by 5m wide.* Niche at end of drift is 4m by 4 m *	23 + 46 ♦	TSw2**	255 m ****
Crest Alcove Alcove #9	3.7m by 3.7 m min.* Assume 4m. x 4m.	24 + 50 *	TSw2**	226 m ****

* Criteria Letter (Ref. 5.7) ** Cross Drift Excavation Layout Drawings (Ref. 5.3, 5.4 & 5.5) *** Niche drawing (Ref. 5.9) ****Appendix L (Ref. 5.25) ♦ Revised Criteria Letter (Ref. 5.30)

4.1.3 Numerical Modeling Parameters for Attachment A.

4.1.3.1 Intersections Location

The thickness of each thermal mechanical unit above the ECRB tunnel/alcove intersection horizon is required for calculations of vertical stresses. The location of the alcoves and associated rock strata thickness are as listed in Table 1. The alcove/ niche analyzed for approximately ECRB Station 13 +00 (Ref. 5.7) is subject to the highest stresses due to overburden. The maximum depth at this location equal to 287.95 meters (for computational simplicity rounded off to 290 meters) was used to bound the alcove stability analysis. The revised criteria letter (Ref. 5.30) moved the location of the proposed niche to Station 16 + 20, but the 13 +00 location remains the highest stress bounding condition. Therefore the numerical modeling in Appendix A is unaffected and does not require revision.

4.1.3.2 Rock strata

Rock strata parameters needed as input to numerical modeling were extracted from the pertinent Project reports. A list of rock strata parameters used as input is provided in Table 2 along with the source references.

4.1.3.3 In Situ Stresses

Principal in situ stresses are required for calculation of the horizontal-to-vertical stress ratio (K_o). The field stress state was determined based on hydraulic fracturing in situ stress measurements performed in the Thermal Test Facility Alcove located in TSw2 thermal mechanical unit (Reference 5.24). The stresses were determined to be:

σ_h = 1.7 MPa (Minor horizontal stress directed N75°W)

σ_H = 2.9 MPa (Major horizontal stress directed N15°E)

σ_V = 4.7 MPa (Vertical downward stress)

The resulting K_o values are:

$$K_{omin} = \sigma_h/\sigma_V = 1.7/4.7 = 0.362$$

$$K_{omax} = \sigma_H/\sigma_V = 2.9/4.7 = 0.617$$

$$K_{oavg} = [(\sigma_h + \sigma_H)/2] / \sigma_V = [(1.7+2.9)/2] / 4.7 = 0.489$$

For comparison, the Ko values used in the current analysis were equal to 1.0 and 0.5.

4.2 CRITERIA

The following design criteria were developed to respond to the requirements presented in the "Enhanced Characterization of the Repository Block Requirement Document" (Ref. 5.11) that specifically apply to this design analysis. Design criteria that is addressed in ECRB Cross Drift Rockbolts, Shotcrete and Related Items analysis (Ref. 5.8) are considered to bound the ground support design and are not repeated. This issue is addressed in Section 7.3.1.

4.2.1 Design input parameters from References 5.1, 5.21 5.22 5.24 & 5.25 were obtained through the on going site characterization program and used throughout this analysis. (Ref. 5.11, Section VI, 3.7.1.2 A) This issue is addressed in Section 7.3.2.

4.2.2 The seismic loading conditions from Appendix A of the ESFDR were used in the comparative evaluation with the design of the ESF alcove/ niche and in the numerical analysis in attachment A. (Ref. 5.11, Section IV, 3.2.1.2.1.2.A) This issue is addressed in Section 7.3.3

4.2.3 The ground support recommendations from the ESF Alcove Ground Support Analysis (Ref. 5.1) were evaluated for use in excavations made by both mechanical and controlled drill and blast methods and to accommodate constraints on the use of swellex type rockbolts in the test niches. (Ref. 5.11, Section III, 3.7.2.1.2.F & Section IV, 3.7.3.1.D)(DIE Requirement 5g, Ref. 5.15) This issue is addressed in Sections 7.3.4 and 7.4.4.

4.2.4 A tunnel of nominal height 5 meters and the width equal to 15 meters will remain stable for 25 years. Stability can be enhanced by using the rock reinforcement components approved for use in the ESF. (Ref. 5.11, Section IV, 3.7.3.1.G) See Attachment A.

Table 1. Rock Strata Thickness and Vertical Stress at the Test Alcoves Locations

Stratigraphic Unit	ECRB Station Number			
	7+73	13+00	23+75	24+50
TCw Above Sp_L, (m)	237.32	287.95		
TCw Thickness Above Sp_L, (m)	53.58	75.78		
TCw Avg. Sat. Bulk Density, r, (kg/m^3)	2,230	2,230	2,230	2,230
Vert. Stress Above Sp_L Due to TCw, (Pa)	1.1721E+06	1.6578E+06	0	0
PTn Above Sp_L, (m)	183.74	212.17		
PTn Thickness Above Sp_L, (m)	51.07	47.96		
PTn Avg. Sat. Bulk Density, r, (kg/m^3)	1,770	1,770	1,770	1,770
Vert. Stress Above Sp_L Due to PTn, (Pa)	8.8676E+05	8.3276E+05	0	0
TSw1 Above Sp_L, (m)	132.67	164.21	254.66	226.15
TSw1 Thickness Above Sp_L, (m)	132.67	148.61	129.91	85.97
TSw1 Avg. Sat. Bulk Density, r, (kg/m^3)	2,170	2,170	2,170	2,170
Vert. Stress Above Sp_L Due to TSw1, (Pa)	2.8242E+06	3.1636E+06	2.7655E+06	1.8301E+06
TSw2 Above Sp_L, (m)		15.6	124.75	140.18
TSw2 Thickness Above Sp_L, (m)		15.6	124.75	140.18
TSw2 Avg. Sat. Bulk Density, r, (kg/m^3)	2,360	2,360	2,360	2,360
Vert. Stress Above Sp_L Due to TSw2, (Pa)	0	3.6116E+05	2.8882E+06	3.2454E+06
Total Stress At Sp_L, (Pa)	4.8831E+06	**6.0153E+06**	5.6536E+06	5.0755E+06
Total Thickness of Strata Above Sp_L, (m)	237.32	287.95	254.66	226.15
Weighed Average Density=[Sum(H_i*den_i]/Sum_H_i , (kg/m^3)	2,097	2,129	2,263	2,288
Average Stress Gradient, (Pa/m)	2.0576E+04	2.0890E+04	2.2201E+04	2.2443E+04

Notes: 1) Values of the Average Saturated Bulk Density Extracted from Reference 5.22, p.63, Table 21.
2) Vertical Stress = (Strata Thickness * Density * 9.81)
3) Thickness and distance above Spring line (Sp_L) from Reference 5.25, Appendix L.

Table 2. Rock Strata Parameters Used as Input to FLAC Program

	SI Unit	Thermal Mechanical Unit							
		TCw		PTn		TSw1		TSw2	
		Rock Mass Category							
Input E, ν	·	1	3	1	3	1	3	1	3
Young's Modulus, E:	Pa	7.180E+9	1.741E+10	1.214E+10	2.049E+10	7.360E+9	1.550E+10	9.370E+9	1.663E+10
Poisson's Ratio, ν:	(---)	0.21	0.21	0.23	0.23	0.23	0.23	0.21	0.21
Cohesion, c	Pa	1.30E+06	2.53E+06	4.30E+05	6.30E+05	9.30E+05	1.73E+06	1.73E+06	2.80E+06
Internal Friction Angle, ϕ	deg	52.7	56.0	31.7	37.3	42.7	45.7	55.7	57.3
Uniaxial Tensile Strength, σ_{tm}	Pa	8.700E+05	1.570E+06	4.900E+05	6.100E+05	7.900E+05	1.380E+06	1.060E+06	1.630E+06
Avg. Saturated Bulk Density, ρ	kg/m^3	2,230	2,230	1,770	1,770	2,170	2,170	2,360	2,360
Shear Modulus, G: G = E/[2*(1+ν)]	Pa	2.967E+9	7.194E+9	4.935E+9	8.329E+9	2.992E+9	6.301E+9	3.872E+9	6.872E+9
Bulk Modulus, K: K = E/[3*(1-2ν)]	Pa	4.126E+9	1.001E+10	7.494E+9	1.265E+10	4.543E+9	9.568E+9	5.385E+9	9.557E+9

Notes: 1) Average Young's Moduli Determined Using the Two GSI Full-Peripheral and Rmi Scanline Data (Reference 5.21, Table 4, p. 48).
2) Average Poisson's Ratio Values Extracted from Reference 5.24, Table 5-28, p. 5-94.
3) Average Cohesion Values Determined Using the Two GSI Full-Peripheral and Rmi Scanline Data (Reference 5.21, Table 5, p. 49).
4) Average Values of Internal Friction Angle Determined Using the Two GSI Full-Peripheral and Rmi Scanline Data (Reference 5.21, Table 6, p. 50).
5) Average Values of Rock Mass Tensile Strength Determined Using the Two GSI Full-Peripheral and Rmi Scanline Data (Reference 5.21, Table 8, p. 52).
6) Values of Poisson's Ratio Equal to the Mean Poissons Ratio Values Listed in Reference 5.22 p. 5-94 to 5-96, Table 5-28.

4.3 Assumptions

4.3.1 For comparison of proposed ECRB alcove/ niche in situ stresses to existing analyzed in situ stresses, it is assumed that individual densities of the thermomechanical units may be neglected and only the total depth of overburden is required. This assumption does not require further examination because the differences in density and thickness of individual units, which make up the overburden, will not significantly affect the results. The analysis recognizes that changes to the estimates in the order of a few meters will not affect the outcome of the computer analysis results. (Section 4.3.2 Ref. 5.1)

4.3.2 For the purpose of the numerical modeling, the Poisson's ratio for the rock mass is assumed equal to the mean of laboratory test data as shown in Table 2. This assumption is reasonable and is based upon the best available data.

4.3.3 For the purpose of the numerical modeling the Horizontal-to-Vertical stress ratio ($K_o=\sigma_h/\sigma_v$) is assumed to equal 0.5 and represents the in situ state of stress. The Ko value equal to 1.0 was used for comparison only. The bases for this assumption is the K_{oavg} = .498 which is the average of the principle horizontal stresses.

4.3.4 A 45-degree intersection is assumed as the worse case design of the alcove/ niche. Therefore, intersection with an angle that is greater than 45 to 90 degrees are bounded by this analysis. This assumption is based upon the design practice in the ESF Alcove Analysis (Ref. 5.1).

4.4 Codes and Standards

Not Used.

5. References

5.1 CRWMS M&O 1997. *ESF Alcove Ground Support Analysis.* BABEE0000-01717-0200-00001 REV 04. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19970626.0159

5.2 CRWMS M&O 1998. *ECRB Cross Drift Stability Analysis.* BABEE0000-01717-0200-00017 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980428.0010

5.3 CRWMS M&O 1998. *Cross Drift Excavation Layout Profile Sheet 4 of 6.* BABEE0000-01717-2100-40305 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980409.0687

5.4 CRWMS M&O 1998. *Cross Drift Excavation Layout Profile Sheet 5 of 6.* BABEE0000-01717-2100-40306 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980409.0687

5.5 CRWMS M&O 1998. *Cross Drift Excavation Layout Profile Sheet 6 of 6.* BABEE0000-01717-2100-40307 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980409.0687

5.6 CRWMS M&O 1998. *Enhanced Characterization of the Repository Block Requirements Document (ECRB-RD).* BAB000000-01717-5705-00013 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980417.0713

5.7 Los Alamos National Laboratory 1998. *Transmittal of Design and Test-related Information for Design and Construction of the Enhanced Characterization of the Repository Block Cross Over Alcove 8, Niches #5 and #6, F/M Test Beds #2 and #3, and Crest Alcove 9* . Memorandum; Hollins to Snell, CRWMS M&O LA-EES-7-06-98-006 June 5, 1998. Las Vegas, Nevada: J. Hollins. ACC: MOL.19981030.0232

5.8 CRWMS M&O 1998. *ECRB Cross Drift Rockbolts, Shotcrete and Related Items*. BABEE0000-01717-0200-00019 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980325.0531

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5.10 DOE 1997. *Exploratory Studies Facility Design Requirements*. YMP/CM-0019 Revision 2, ICN 1. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19960926.0065 & MOL.19980107.0544.

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5.12 CRWMS M&O 1998. *12666055MC ECRB Cross Drift Design*. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980205.0209.

5.13 CRWMS M&O 1998. *12666055MD ECRB Alcove Design*. Las Vegas, Nevada: R. Snell. ACC: MOL.19980223.0293.

5.14 CRWMS M&O 1998. *12662450M1 ECRB Test Niche Design*. Las Vegas, Nevada: R. Snell. ACC: MOL.19980223.0289.

5.15 CRWMS M&O 1999. *Determination of Importance Evaluation for the ESF Enhanced Characterization of the Repository Block Cross Drift*. BABEAF000-01717-2200-00011 REV 04. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990420.0345

5.16 CRWMS M&O 1996. *QA Classification Analysis of Ground Support Systems (CI: BABEE0000)*. BABEE0000-01717-2200-00001 REV 05. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19970508.0371

5.17 CRWMS M&O 1995. *QA Classification Analysis of Test Support Areas (CI: BABEAF000)*. BABEAF000-01717-2200-00001 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19960212.0219

5.18 Itasca Consulting Group, Inc. 1996. *Fast Lagrangian Analysis of Continua (FLAC) Version 3.30, Computer Software User's Manual, Volumes I, II, III, and IV.* Minneapolis, Minnesota: Itasca Consulting Group, Inc. TIC: 236418, 236419, 236420 and 236421, respectively.

5.19 Barton, N., Lien, R., and Lunde, J. 1974. "Engineering Classification of Rock Masses for the Design of Tunnel Support," *Rock Mechanics*, Vol. 6, No. 4, pp. 189-264. TIC: 219995

5.20 CRWMS M&O 1998, *ESF Design Confirmation - Task 2/ESF Ground Support Confirmation.* BABEE0000-01717-5705-00003 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980727.0308

5.21 CRWMS M&O 1997. *Key ESF Design/Geomechanics Parameters Confirmation.* BABEE0000-01717-5705-00001 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19971021.0552

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5.25 CRWMS M&O 1998. *Cross Drift Geotechnical Predictive Report: Geotechnical Baseline Report.* BABEA0000-01717-5705-00002 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980806.0219

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5.27 CRWMS M&O 1998. *Thermomechanical Analysis for ECRB/Emplacement Drift Interactions.* BCAA00000-01717-0200-00009 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980518.0104

5.28 CRWMS M&O 1999. *Ground Support Walkdown, Maintenance and Repair*. NWI-ESF-022Q/Rev 0/ICN N/A. Las Vegas, Nevada: CRWMS M&O. ACC: MOL. 19990225.0267

5.29 CRWMS M&O 1999. *Cross Drift Alcove and Niche Construction Support Bay*. Design input transmittal No. TFD-SFO-99139.Ta. Las Vegas, NV: CRWMS M&O. ACC: MOL.19990223.0396

5.30 CRWMS M&O 1999. *Transmittal of Design and Test-related Information for Design and Construction of the Enhanced Characterization of the Repository Block Cross Over Alcove 8, Niches #5 and #6*. Design input transmittal No. TFD-NEP-99157.T. Las Vegas, NV: CRWMS M&O. ACC: MOL.19990330.0431

5.31 CRWMS M&O 19xx. *ESF Ground Support Design Analysis*. BABEE0000-01717-0200-00002 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19960409.0355.

5.32 CRWMS M&O 1996. *Dry Process Shotcrete*. Specification Section 03362. BABEE0000-01717-6300-03362 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19961213.0122.

5.33 CRWMS M&O 1996. *Wet Process Shotcrete*. Specification Section 03363. BABEE0000-01717-6300-03363 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19971105.0033.

5.34 CRWMS M&O 1998. *ECRB Cross Drift Rockbolts, Accessories and Associate Ground Support Materials*. Specification Section 02166. BABEE0000-01717-6300-02166 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980409.0678

5.35 CRWMS M&O 1997. *Test, Inspection and Material Dedication Analysis: Shotcrete, Rockbolts and Accessories*. BABEE0000-01717-0200-00006 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19971006.0362.

6. COMPUTER SOFTWARE

Fast Lagrangian Analysis of Continua (FLAC) Version 3.30 (CSCI: 30022 V3.30 [Ref. 5.23]) is used in Attachment A of this analysis. Analysis was performed on a Personnel Computer with a MMX Pentium microprocessor. The software was obtained from the Software Configuration Manager in accordance with the applicable M&O procedures. A complete listing of the input files and output results used in the design analysis are provided in Attachment A. Detailed description of the FLAC and its fields of application are presented in Reference 5.18. FLAC was appropriate for the application used in the analysis. The software was used within the range of validation as specified in the software qualification document.

Microsoft Excel 97 is a commercial spreadsheet program designed to assist in routine and repetitive calculations. The program provides build-in mathematical functions together with user-defined formulae to automate the calculation process and was operated on a Personnel Computer with a MMX Pentium microprocessor. Output formulae are automatically updated as input data are added or changed. *Excel* also includes a graphical package to assist in data presentation.

An *Excel* spreadsheet was developed to produce a standardized set of plots required for comparisons of the rock strata deformations obtained from numerical modeling.

7. Design Analysis

Revision 00 of this analysis was based upon the need for a support bay across from the entrance of each of the alcoves and niches. The support bay was necessary to assemble the mechanical miner to achieve one hundred percent mechanical excavation of the alcoves, in accordance with criteria given by the Test Coordination Office (TCO)(Ref. 5.7).

Revision of the TCO criteria subsequently permits the use of controlled drill and blast methods in the entrance to the alcove and niches. (Ref. 5.30) This change allows the assembly of the mechanical miner in the alcove or niche entrance. The M&O Field Engineer has consequently deleted the design input of the construction support bay. (Ref. 5.29).

The elimination of the construction support bay greatly reduces the possible maximum span of the intersection opening. This in turn reduces the extent and degree of reinforcement necessary to provide a stable opening. For purposes of this analysis, alcoves and niches with the support bay will be termed "four way intersections" and alcoves and niches without the support bay will be termed "three way intersections".

The term niche, alcove and support bay are used in this analysis. Niches are small alcoves that have a special significance in the DIE (Ref. 5.15) due to test interference controls. Support bays are small alcove opposite the niche or alcove that are outside of the test area. Niches, support bays and alcoves are synonymous terms in regards to the ground stability for the underground openings.

7.1 Empirical Design

The empirical design is based upon Rock Quality Index (Q), the span of the opening and a Excavation Support Ratio (ESR). (Ref. 5.19.) The design solution is achieved by selection of rock support categories from a chart. Each category identifies specific recommendation to support the opening.

The ESR varies depending upon the importance of the underground opening. Although the ECRB is classified as a Main Opening (Ref. 5.26), the QA-1 classification evaluation is allocated to Test Support Areas (Ref. 5.17). Since Test Support Areas (Ref. 5.17) do not require permanent ground support the ground support is considered to be temporary (not included into the repository). Therefore, the ESR will be increased to 1.6 which is equivalent to important permanent mine openings from a ESR of 1.0 for power station chambers, major road tunnel. (Ref. 5.1) The Q ground support ESF Alcove Ground Support Analysis (Ref 5.1) used a more conservative ESR of 1.0 because of the QA-1 requirements of main opening classification for the TS Loop.

7.1.1 Tunnel/Alcove Intersection

At intersections of tunnel with alcoves the empirical design method divides the Q parameter by three to compensate for the larger span of the intersection. (Ref. 5.19). The greatest span of either the tunnel or the alcove is used for the span. In this analysis we designate the reduced Q parameter as Q'.

TSw2	**TSw1**
Q = .3	Q = .24
Q'= 0.1	Q'= 0.08
Span = 5 m	Span = 5 m
ESR = 1.6	ESR = 1.6

Both the TSw2 and TSw1 intersections fall into the rock support category 34 (Ref. 5.19). The recommendation for this category is rockbolts on 1 m spacing and shotcrete 5 to 7.5 cm. (Ref. 5.19).

7.1.2 Alcoves and Niches

TSw2	**TSw1**
Q = .3	Q = .24
Span = 5 m	Span = 5 m
ESR = 1.6	ESR = 1.6

The TSw2 alcove falls into the rock support category 29 (Ref. 5.19). The recommendation for this category is rockbolts on 1 m spacing and shotcrete 5 cm (Ref. 5.19). The TSW1 alcove falls into the rock support category 30 (Ref. 5.19). The recommendation for this category is rockbolts on 1 m spacing and shotcrete 5 - 7.5 cm (Ref. 5.19).

7.2 Comparison of Design Parameter

	Comparison of Physical Criteria of Alcoves		
		TS Loop	**ECRB**
Opening sizes			
	Tunnel size	7.62m *	5m **
	Alcove size	<6m, <5m , < 3m *	<5m , < 3m ***
Rock type		TCw,TSw1, TSw2, PTn *	TSw1, TSw2, ***
Seismic design criteria		0.37g *	0.30g **
Overburden Thickness	(depth of cover)	Max. 285 m TSw2 * Max. 181 m TSw1 *	Varies ***

* ESF Alcove Ground Support Analysis (Ref. 5.1)

** ECRB Cross Drift Stability Analysis (Ref. 5.2)

*** See design parameters (Section 4.1.1)

7.2.1 Comparison of Opening Sizes.

Both the empirical and analytical methods demonstrate that the smaller the opening the more stable the opening. The ESF Alcove Ground Support Analysis (Ref. 5.1) states: "If a smaller opening is used the analysis is bound by the calculations in this report. The smaller opening would be inherently more stable than the one analyzed here." The FLAC model in that analysis addressed both quasi-static and dynamic seismic loading. The Cross drift is smaller than the TS Loop and the ECRB alcoves and niches are either smaller or equal in size of the alcoves in the ESF Alcove Ground Support Analysis (Ref. 5.1). The maximum size opening evaluated for alcove in the TSw1 is 6m by 4.4 m and for alcoves in the TSw2 is 6 m by 5 m. Therefore, all the ECRB alcoves and niches, including the intersection area are bounded by the ESF Alcove Ground Support Analysis (Ref. 5.1), with the exception of the Cross Over Alcove (Alcove # 8) in TSw1 which is 6 m by 5 m. However the large size alcove is bounded by the TS Loop Tunnel which is 7.62 m diameter and was analysis in the ESF Ground support Analysis. (Ref. 5.31).

7.2.2 Rock Type and Overburden Thickness.

The ESF Alcove Ground Support Analysis (Ref. 5.1) evaluated alcoves in TSw2 to a depth of 285 m. Therefore, the Crest Alcove (Alcove # 9), Niche #5 and Niche #6 are bounded by the analysis. The Cross Over Alcove (Alcove # 8) is in TSw1, with overburden of 240 m, exceeding the bounds of the analysis that calculated a maximum depth of 181 m.

7.2.3 Orientation of the Alcoves.

The ESF Alcove Ground Support Analysis (Ref. 5.1) bounded the alcove and niche centerline layout orientation with respect to the tunnel center in the range between 45^0 to 90^0. ECRB Cross Drift alcove and niche layouts that are within that range will be bounded by the design.

7.3 Comparison of the Design Criteria

7.3.1 The ESF Alcove Ground Support Analysis addressed requirements of the "Determination of Importance Evaluation for the Subsurface Exploratory Studies Facilities" and the "Exploratory Studies Facility Design Requirements"(Ref. 5.1). The applicable requirements for the design of the Alcove and Niches in the ECRB are dictated by ECRB DIE (Ref. 5.15) and the ECRB-DR (Ref. 5.6). Although the requirements are dictated from different documents, the requirements are similar. Many of the similar design criteria that were addressed in the ESF Alcove Ground Support Analysis (Ref. 5.1) have been covered in the ECRB Cross Drift Rockbolts, Shotcrete and Related Items analysis (Ref. 5.8). That analysis completely bounds those criteria for the ground support design and they do not need to be addressed in this analysis.

7.3.2 The ESF Alcove Ground Support Analysis (Ref. 5.1) was consistently revised as various alcoves and niches were designed for construction in the TS Loop. The geotechnical design parameter inputs were derived from drill hole data obtained for the Site Characterization program. The design used category 1 rock mass categories (least favorable ground conditions) for alcoves whose locations had been finalized. This conservatively bounds the ECRB alcove in similar thermal mechanical units. The numerical modeling used in the this analysis in attachment A used current available data from site characterization. (See table 1 & 2).

7.3.3 The ESF Alcove Ground Support Analysis (Ref. 5.1) used the design criteria in the ESFDR YMP/CM-0019 REV 2, Appendix A. The ICN 1 to the ESFDR (Ref. 5.10) did not effect Appendix A. Therefore, the design parameters are identical. The ESF Alcove Ground Support Analysis designed the alcove intersections for a horizontal seismic acceleration of 0.37g (Ref. 5.1 page 6), which is consistent with the QA classification of permanent items in the TS Loop and associated transition zone. The ground support items installed in the ECRB Cross Drift beyond the transition zone are considered to be non-Q and temporary ground support (Ref. 5.8 page 3). The seismic peak ground acceleration for temporary items is 0.30g. (Ref. 5.10 Appendix A). This conservatively bounds the ECRB alcove in similar thermal mechanical units.

7.3.4 The ESF Alcove Ground Support Analysis designed the ground support for both mechanical and drill and blast method. Alcove #2 was excavated using controlled drill and blast while alcoves #3 and #4 were mechanically excavated (Ref. 5.1 page 14). The test interference restriction on drill and blasting will require that the alcoves and niches to be partially mined by mechanical methods. The support bays, opposite the alcoves/ niches, do not have these restrictions, therefore, it may be excavated with drill and blast.

7.4 Evaluation of Ground Support Recommendations.

7.4.1 Tunnel/Alcove Intersection.

The ESF Alcove Ground Support Analysis (Ref. 5.1) used a three dimensional model of the TS loop and alcove intersections for both TSw1 and TSw2 locations. Ground support recommendations are the same for both TSw1 and TSw2. The ESF Alcove Ground Support Analysis (Ref. 5.1) recommended that pattern rockbolts with WWF be installed. The rockbolts were 3 m grouted rockbolts on 1 m by 1m spacing. The ESF Alcove Ground Support Analysis allows the substitution of Super Swellex rockbolts for the grouted rockbolts. However, due to the smaller opening size of the ECRB, the rockbolts may be shortened proportionally from ratio of the TS loop diameter (7.6m) to the ECRB diameter (5m) or 2m in length. This will allow existing 2 m bolts to be incorporated in the 1m by 1 m pattern. However, to be conservative 3 m rockbolts should be used in the area directly in front of the alcove where additional rockbolts are required to be installed to the existing pattern, or to replace damaged rockbolts for excavation activities. In addition, the ESF Alcove Ground Support Analysis recommends unreinforced shotcrete 150 mm nominal 100 mm minimum. The thickness of the shotcrete should be reduced because of the empirical design recommendations of 75 nominal 50 minimum. Shotcrete can not be applied until the Test Coordination Office (TCO) approval is obtained. The shotcrete may be installed over the bolt and bolts and mesh. The shotcrete used in the four way intersection should follow the coverage recommendation of the ESF Alcove Ground

Support Analysis. The analysis recommends that shotcrete be applied from invert to invert for a distance of two alcove widths on either side of the alcove opening. For the three way intersections see section 7.5 in this analysis.

However, the four way intersection created by the addition of the support bay exceeds the bounds of the ESF Alcove Ground Support Analysis (Ref. 5.1). Additional modeling was performed to demonstrate the stability of these underground openings with the result in Attachment A. The recommendations from that work support the empirical design.

7.4.2 Perimeter Support Around the Alcove Excavation.

The ESF Alcove Ground Support Analysis (Ref. 5.1) recommends the installation of rockbolts around the perimeter of the alcove excavation in order to maximize stability during the first crucial rounds of alcove excavation and to provide long term stability to the alcove/main access intersection. The perimeter rockbolts were recommended because of the configuration cause by the relative size of the alcoves to the main access openings. (i.e. significant size brows were formed because the main access opening was 7.6 m with the alcoves being 6 m or less.) In the ECRB Cross drift the tunnel diameter is smaller (5 m.) which will not produce the same pronounced brow. Therefore the adverse conditions that were addressed by the perimeter rockbolts are mitigated or eliminated.

The smaller Cross Drift tunnel diameter doesn't provide sufficient room to effectively install the perimeter bolts. The perimeter rockbolt recommendation should not be carried to the ECRB Cross Drift alcoves and niches. Since perimeter rockbolts were added as supplemental support, and not part of the analytical computer model, the elimination of these rockbolts will not violate the ESF Alcove Ground Support Analysis.

7.4.3 Alcove Ground Support

In alcoves the ESF Alcove Ground Support Analysis (Ref. 5.1) recommends 1 m by 1m pattern super swellex rockbolts with 75 mm x 75 mm Welded Wire Fabric. For alcoves with 3.7 m to 4.5 m openings 2 m minimum length rockbolts were recommended. For spans greater than 4.5 m increase the rockbolt length to 3 m minimum. The bolting pattern will be such that the vertical projection of the collar of the outside bolts is 300 mm nominal from the alcove side walls. For long term stability the alcove should be shotcreted after TCO approval. The analysis preformed in Attachment A bounds the additional depth of alcoves #8 and #9. Alcove #8 may be wider than 5m, due to the actual as built dimensions of Niche #3. This condition is bounded by the TS Loop ground support design, where the 7.6 m tunnel is supported by 3 m swellex rockbolts directly below the end of alcove #8.

7.4.4 Niche Ground Support

The ESF Alcove Ground Support Analysis does not specifically address the test interference requirement in the DIE (Ref. 5.15 requirement 5g) that excludes the use of swellex type rockbolts in the test niches. However, the analysis expressly allows alternative temporary ground support during construction with A/E acceptance. (Ref. 5.1 page 185 & 186) Therefore, SS - 46 Split Set rockbolts, which are a friction type rockbolt, are considered an acceptable alternative to the Super Swellex, where that QA control on activities is applied.

7.5 Deferral of Shotcrete applications.

The installation of shotcrete may interfere with the testing in the ECRB, so it may be desirable to defer the installation of shotcrete. The shotcrete shall be applied after obtaining TCO concurrence. The shotcrete should be installed as soon as practical when testing conditions allow the installation.

Because the ground support has to be designed prior to excavation, the design is based on projected rock conditions. The anticipated worse case rock quality was used to conservatively bound the design. Experience with the ESF alcoves have shown that sections of good quality rock are inherently stable and have not required shotcrete applications. The shotcrete application for the intersections and inside the alcove and niches in the TS main loop is unfinished construction. These areas are regularly check by monthly ground support inspections ("walkdowns") in accordance with the ground support maintenance procedures. (Ref. 5.28). Because the TS loop intersections and alcove have remained stable, shotcrete should not be mandatory unless poor ground conditions or deterioration the opening require its use. Therefore, the empirical design recommendations for shotcrete should be used as remedial criterion on as needed bases, except for the four way intersection where it is required for excavation. The resident A/E (Title III) should direct the application of shotcrete if the conditions warrant and the constructor should have the option to shotcrete the alcove if personnel safety warrant.

7.6 Affects on the ground support in Niche #3 from Alcove #8.

A geotechnical analysis was prepared prior to the excavation of the ECRB Cross Drift to determine the sill thickness (distance between top of proposed repository drifts and invert of cross drift) that is necessary to prevent adverse impacts to repository drifts. (Ref. 5.27) The sill thickness became a QA control in the DIE for the excavation of the ECRB Cross Drift to maintain the sill thickness between 15 m and 20 m. (Ref. 5.15) The DIE requires that the Alcove and Niches be excavated at a minimum of one half percent up grade which will maintain the sill thickness for the alcoves. The excavation of Alcove #8 will not adversely impact the ground support in Niche #3.

7.7 Reinforcement Materials

The reinforcement materials, rockbolts and accessories, Welded Wire Fabric and shotcrete, should be the same type used in the ESF and should be procured and installed in accordance with specification sections 03362, 03363 and 02166. (Ref. 5.32 through 5.34 respectively) The material properties of the reinforcement are addressed in section 4.1.1 of the *Test, Inspection and Material Dedication Analysis: Shotcrete, Rockbolts and Accessories* (Ref. 5.35) The fitness for use of the rockbolts are tested in accordance with specification section 02166.

Five percent of the Swellex rockbolts are tested by proof load testing in the Cross Drift (Ref. 5.34 3.03D2). These test are sufficient, due to the close proximity, to establish the fitness of Swellex in the alcove access drifts, therefore, no further testing is required for the Swellex rockbolts. The Split Set rockbolts require a pull collar, added to the rockbolt prior to installation, to enable pull testing to be performed. Installation of these collars precludes the random proof load testing of these of rockbolts. In lieu of the proof load testing, In-Place Anchorage Testing in accordance with specification section 02166 paragraph 3.03 D1 (Ref 5.34) should be performed for each alcove. These two tests are similar except the Proof Load test only applies a specified load and is non-destructive in nature. The In-Place Anchorage Tests incrementally applies loads until the bolts fail, which is a destructive testing. Each alcove/niche site should have In-Place Anchorage Tests to ensure fitness for use of the Split Set rockbolts for the specific location. The Split Set load capacity should be within the manufactures recommendations. Where the load capacity is below the manufactures recommendation, the A/E should recommend adjustments to the rockbolt borehole size and retest the rockbolts.

8. Conclusions

8.1 Numerical Model Conclusions and Recommendations For Four Way Intersections.

A typical four way intersection between the ECRB Tunnel and the test alcove has been analyzed. The methodology used in this analysis is based on the premise that satisfactory results are demonstrated by verifying that an overall opening with the roof span equal to 15 meters would remain stable. This roof span magnitude is equivalent to the three side-by-side tunnels, each of nominal diameter equal to 5 meters. The rock strata parameters and the alcove location were selected such that the most severe ground and stress conditions were considered. The results of analysis provide the lower (conservative) bound for the strata conditions anticipated in the field. The conclusions, therefore, pertain to any intersection of two tunnels of nominal diameter equal to 5 meters located within the TSw1 and TSw2 thermal mechanical units and the depth as discussed in Attachment A.

The conclusions are as follows:

1. An intersection located in TSw1 thermal mechanical unit represents the more severe case than the same intersection located in TSw2 unit. This is represented by a disturbed zone developing around excavation located in TSw1 unit. (Attachment A, Section A3.3)

2. Even in the most conservative cases represented by the three side-by-side tunnels excavated in TSw1 with the ratio $Ko=\delta_h/\delta_v$ equal to 0.5, the overall tunnel stability can be controlled by conventional methods utilizing rockbolts, wire mesh. (Attachment A, Section A3.3)

3. A conservative approach was used in current analysis. A rock mass of higher quality than used herein (Section 4, Table 1) is expected and in situ stress conditions in the field are expected to be less severe than used in this design.

4. The results indicate that while an overall intersection stability will be preserved while using conventional means of tunnel support modified locally to accommodate testing conditions, the center of the intersection remains most vulnerable to potential loose rock falls from the stress concentration shown in Figure 16 in Attachment A. It is recommended that 3 meters rockbolts and wire mesh be used to reinforce the center of the intersection. A layer of shotcrete of nominal thickness as identified in the main body of analysis should be applied within the intersection and the "nose" pillars created on both sides of ECRB tunnel and alcove intersection. Additional rockbolts should be installed on both sides of the "nose" pillars as shown on the respective ground support drawings.

5. Daily inspection and observation of the local ground conditions is recommended, and if needed, the ground control system must be modified to remedy potentially hazardous situations.

6. The width of the excavated alcove should not exceed 6 meters.

8.2 Ground support recommendations.

8.2.1 Four Way Intersection

The 3 m Super Swellex on 1 m by 1m nominal pattern spacing with 75 mm by 75 mm Welded Wire Fabric (WWF) for a distance of two alcove widths on either side of the alcove opening measured from the alcove rib. In addition unreinforced shotcrete 75 mm nominal 50 mm minimum thickness should be applied. The shotcrete should be applied from invert to invert for a distance of two alcove widths on either side of the alcove opening and one width into the alcove, niche or support bay. Shotcrete shall be applied after obtaining TCO approval or concurrence.

8.2.2 Three Way Intersection

The 2 m minimum Super Swellex on 1 m by 1m nominal pattern spacing with 75 mm by 75 mm Welded Wire Fabric (WWF) for a distance of two alcove widths on either side of the alcove opening measured from the alcove rib. Previous installed 2 m Super Swellex rockbolts may be incorporated into the pattern. At the actual intersection area directly in front of the alcove, 3m Super Swellex should be used to supplement the existing rockbolts in the pattern or to replace rockbolt damaged by excavation activities. If ground conditions warrant the use of shotcrete, unreinforced shotcrete 75 mm nominal 50 mm minimum thickness should be applied, to the extent that the condition warrants. A/E should direct application of shotcrete if ground conditions warrant. Shotcrete should be applied after obtaining TCO approval or concurrence.

8.2.3 Alcove, Niches and Support Bays

In alcoves the ground support should be 1 m by 1m nominal pattern Super Swellex rockbolts 2 m minimum length with 75 mm by 75 mm WWF. For spans (width or height) greater than 4.5 m increase the rockbolt length to 3 m minimum. Adjustments in the pattern should be made to address the geological structure. The bolting pattern will be such that the vertical projection of the collar of the outside bolts are 300 mm nominal from the alcove side walls. If ground conditions warrant the use of shotcrete, unreinforced shotcrete 75 mm nominal 50 mm minimum thickness may be applied. A/E should direct application of shotcrete if ground conditions warrant. Shotcrete should be applied after obtaining TCO approval or concurrence.

8.2.4 Substitution due to restriction on the use of Swellex type rockbolts.

In locations that have test interference restrictions on the use of Swellex rockbolts the ground support should be the same except that the following substitution should be made: SS 46 Split Set rockbolts, of equal length, should be substituted for 2 m Swellex rockbolts and William R7X rockbolts or SS 46 Split Set rockbolts, of equal length, for 3 m Super Swellex rockbolts.

8.2.5 Construction Acceptance Testing

The A/E should check the Split Set rockbolts, for fitness of use, by In-Place Anchorage Tests in accordance with specification section 02166 for each alcove/niche. Proof Load Pull testing is not required.

Attachment A

ECRB Alcove and Niche Ground Support Analysis

Numerical Modeling of the ECRB Tunnel and Test Alcove Intersection

A1.0 Background

The purpose for this attachment is to investigate the impact of excavating the test alcove from the ECRB tunnel on the overall stability of the resulting intersection between the tunnel and the alcove. Four alcoves will be excavated at the predetermined locations. To maximize the intersection roof span to be considered in this analysis a 45 degree intersection is assumed. A typical ECRB/ alcove intersection and associated dimensions are shown in Figure 1. The intersection includes on one side a short maneuvering chamber and on the other side a typical Y-type intersection between two drifts of identical diameters equal to 5 meters each. The current ground control system includes a combination of wire mesh and steel channel secured in place by 2 m swellex rockbolts.

As discussed in the main body of this analysis, empirical methods were used to determine the ground support system enhancements needed to accommodate the intersection. The analyses presented in this Attachment are supplemental to the empirical analysis. Here, the intersection stability was evaluated using numerical methods.

A2.0 Methodology

The intersection of underground openings is a typical three-dimensional problem commonly encountered in underground excavation. The methods for analyzing this problem are limited to relatively simple situations where the roof can be treated as a beam or a plate. If the excavation is constructed in massive rock, however, these simplified methods are no longer appropriate and numerical modeling is used to obtain solution. The two dimensional modeling method is selected to solve the intersection problem. This approach is conservative since it neglects support elements outside of the two dimensional model plane, which is considered in the three dimensional models, and will analyze the maximum span of the opening. The use of three-dimensional modeling is limited because the majority of the problems can be solved using two-dimensional models, which are simpler to construct and the results are easier to interpret.

The ECRB/alcove intersection has been shown in Figure 1 with the dotted lines outlining various combinations of the roof span ranging from 5 to 15 meters. Figures 2 and 3 show the scheme used to determine the equivalent roof span for the intersection. It appears that the equivalent roof span for this intersection ranges from 10 to 15 meters. Conservatively it was concluded that the stability of the equivalent roof span for this intersection equal to three tunnel diameters must be maintained. Furthermore, solution for the tunnel with the 15 meters roof span equal to three 5 meters diameter side-by-side tunnels would be more conservative than an axisymmetric solution.

A two dimensional numerical model shown in Figure 4 was constructed to represent the tunnel dimensions and other input details. The model was numerically adjusted to accommodate the excavation of various widths, while their height and the depth at the springline remained constant (5 meters). Figures 5,6 and 7 show the evolution of the model derived from the circular shape characterized by the width-to-height (W/H) ratio of 1.0 to an elongated ellipse with the W/H equal to 3.0. The W/H=1.0 characterizes a single tunnel, while the W/H=2.0 and 3.0 cases characterize the two and three side-by-side tunnels. Figure 8 shows the model presented in Figure 7 with the excavation shape adjusted to conform more closely to the three side-by-side 5.0 meter diameter tunnels.

The seismic design criteria (Criterion 4.2.2) is satisfied by a quasi-static seismic analysis of the intersection. This analysis consists of applying an additional 0.3g seismic induced loading (total 1.3g) to the intersection model, and evaluating the results.

A3.0 Intersection Stability Analysis

A3.1 Model Geometry

The analysis was performed for the ECRB/alcove intersection located at the depth of 290 m below surface in TSw1 and TSw2 thermal mechanical units. Figures 9 to 12 represent the model geometry and the extent of plastic zone developing around intersection located in TSw1 unit. Similar set of Figures 13 to 16 represent the model geometry and the extent of plastic zone developing around intersection located in TSw2 unit. The four model geometries analyzed in each series represent the following cases:

1) A circular tunnel as shown in Figure 9,
2) An elliptical excavation accommodating the two side-by-side tunnels (Figure 10),
3) An elliptical excavation accommodating the three side-by-side tunnels (Figure 11), and
4) The same intersection roof span as Figure 11, except (the rough) modifications of the tunnel geometry were introduced to accommodate the "three-tunnel" roof span more closely as shown in Figure 12.

The tunnel shapes inscribed within the model are used to illustrate the modeling concept. Figures 13 to 16 represent the identical concept for the tunnel excavated in TSw2 unit. The model boundary conditions shown in Figure 4 were modified to represent Ko value equal to 1.0 and 0.5, respectively. In total, 16 modeling cases were investigated including combinations of one, two and two three-tunnel geometries and the two Ko values (1.0 and 0.5) for the two units TSw1 and TSw2, respectively. The FLAC input file used in numerical modeling of the ECRB/test alcove intersection is listed below.

A3.2 Input File for FLAC Computations

```
* ---------------------------------------------------------------
□
* Model In_T1_11 - Rock: TSw1, Ko=1.0, W/H = 1.0
□
* ===============================================================
* Model established to test the effects of excavation of
* stresses on test alcoves to be developed in TSw1 and TSw2 Units
* ===============================================================
*
gr 35 32
m m
*
* Call the Fish Subroutine to Generate the Model Geometry
* -------------------------------------------------------
call sq_hole.fis
; -.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-
*
```

```
* -----------------------------------------------------------------
* Define the mesh geometry parameters as specified in Fish Subroutine
* -----------------------------------------------------------------
set rmin=2.50     ;Opening radius minus two inner layers & gap
set rmul=10       ;Outer model dimensions multiplier
set ratio=1.1
set z_th1=0.05    ;thickness of one of the five inner layers
set gap=.05       ;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
* -----------------------------------------------------------------
*
sq_hole.fis
*
* -----------------------------------------------------------------
* Add -290 m equal to the local depth at ECRB Station 13+10
* -----------------------------------------------------------------
*
ini y add -290.0
*
* Establish the W/H Ratio by Setting the magnitude of the Multiplier
*
ini x mul 1.0     ;circle, max diam.=5.00 m
*ini x mul 1.5     ;ellipse, max W=1.5xH
*ini x mul 2.0     ;ellipse, max W=2.0xW
*ini x mul 3.0     ;ellipse, max W=3.0xW
* -----------------------------------------------------------------
*
* Fix Boundary Conditions
* -----------------------------------------------------------------
*
fix x   i=1,36 j=1  ;Left Side Below Circle
fix x   i=1,36 j=33 ;Left Side - Above Circle
fix x   i=36 j=9,25 ;Right Side
fix x y i=36 j=1,9  ;Model Bottom
*
* ***********************************************
* Define the properties of the rock mass *******
* ***********************************************
*
* Note: Stress conditions are the same for Models involving both
*       TSw1 and TSw2 rock Mass Category 1 Properties.
*       and represent stresses at the deepest Alcove Location
*       among those considered for ECRB
* Note: The ECRB Station 1310 Chosen to represent the Most Severe Stress
*       Conditions.  Depth at Springline = -287.95 m, for simplicity
*       Depth assumed at -290 m.
* Note: Avg Weighed Density= Sum(H_i*dens_i)/Sum_H_i
*
* --- TSw11111111111111111111111 ---------------------------------
* Rock Property Data for TSw1 --- Rock Category 1 ---
* ---------------------------------------------------------------
* Note: Young's Modulus: E=7.36e9 Pa
*       Poisson's Ratio: niu=0.23
*
*****************************************************************************
*
```

```
prop bu=4.543e9 she=2.992e9 d=2170 c=9.3e5 fric=42.7 ten=7.9e5   ;TSw1
*
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
*
* ---- TSw2222222222222222222222 ---------------------------------
* Rock Property Data for TSw2 --- Rock Category 1 ---
* ----------------------------------------------------------------
* Note: Young's Modulus: E=9.37e9 Pa,
*       Poisson's Ratio: niu=0.21
*
******************************************************************************
*
* prop bu=5.385e9 she=3.872e9 d=2360 c=1.73e6 fric=55.7 ten=1.06e6  ;TSw2
*
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
*
* Apply Pressure on Model Top to Generate the Lithostatic Stress Field
* -------------------------------------------------------------------------
*
apply press=5.436e6               i=36, j=25,33  ;pressure on model top
* -------------------------------------------------------------------------
* Insitu Stress State in the Rock Mass at the Model Base and Up
* -------------------------------------------------------------------------
* Solution for Ko = 1.0 i.e. SigH/SigV = 1.0
*
initial syy -6.594e6 var 0,1.1576e6 j=1,33
initial sxx -6.594e6 var 0,1.1576e6 j=1,33
initial szz -6.594e6 var 0,1.1576e6 j=1,33
* ==========================================================
*
* Solution for Ko = 0.5 i.e. SigH/SigV = 0.5
*
*initial syy -6.594e6 var 0,1.1576e6 j=1,33
*initial sxx -3.297e6 var 0,5.785e5 j=1,33
*initial szz -3.297e6 var 0,5.785e5 j=1,33
* ==========================================================
*
set grav=9.81   ;set gravity
*
his unbal
his ydis i=1 j=33
his ydis i=1 j=16
his ydis i=1 j=1
his xdis i=1 j=16
*
his nstep=30
* ---------------------------------------------------
*
tit
In_T1_11 Circular Opening Excavated & in TSw1, Ko=1.0, W/H=1.0
*
solve
*
save In_T1_11.sav
*
new
*
```

```
call in_T1_12.dat
```

Subroutine SQ_HOLE.FIS Used to Generate Model Geometry

```
; ---------------------------------------------------------------
; FISH Subroutine SQ_HOLE.FIS to create a Half-symmetry hole mesh
; each grid point is defined by its polar coordinates ALFA and RO
; The mesh is circular around the opening and its edges are square
; Modification of the Subroutine Listed in the FLAC User's Manual
; by Marek Mrugala (702) 295-4264
; ---------------------------------------------------------------
; RMAXIT = the maximum distance from the center for each ALFA
; RMIN   = radius of the excavation
; RMUL   = number of radii to the boundary
; RATIO  = grid's ratio
; Z_TH1  = thickness of elements in circular zone #1
; Z_TH2  = thickness of elements in circular zone #2
; N_ZE   = total number of layers in circular zones
; GAP    = thin ring generated for use in definition of the interface
;--------------------------------------------------------------------
def sq_hole.fis
; -.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-
loop j (1,jgp)
   alfa=-0.5*pi + (j-1)*pi/(jgp-1)
;
   if abs(alfa) <= .25*pi then
     rmaxit=rmin*rmul/cos(alfa)
       else
     rmaxit=rmin*rmul/sin(alfa)
   end_if
;
   rmaxit=abs(rmaxit)
;
   a_thick1 = 0.
   a_thick2 = 0.
   a_thick3 = 0.
   n_st     = n_ze+1
;
   loop i (1,igp)
    if i <= n_st then
      if i <= 6 then
        a_thick1=a_thick1+z_th1
        r_int1=rmin+a_thick1
        ro1=r_int1
          x(i,j)=ro1*cos(alfa)
          y(i,j)=ro1*sin(alfa)
      end_if
;
       if i = 7 then
          rmin1=ro1
```

```
          a_thick2=a_thick2+gap
          r_int=rmin1+a_thick2
          ro2=r_int
         x(i,j)=ro2*cos(alfa)
         y(i,j)=ro2*sin(alfa)
       end_if
;
       if i > 7 then
          rmin2=ro2
          a_thick3=a_thick3+z_th2
          r_int=rmin2+a_thick3
          ro3=r_int
         x(i,j)=ro3*cos(alfa)
         y(i,j)=ro3*sin(alfa)
       end_if
    else
;
    ro=ro3+(rmaxit-ro3)*(ratio^(i-n_st)-1)/(ratio^(igp-n_st)-1)
;
         x(i,j)=ro*cos(alfa)
         y(i,j)=ro*sin(alfa)
     end_if
   end_loop
end_loop
end
```

A3.3 Modeling Results

The plastic zone, also referred to as the disturbed zone is created as a result of excavation and associated rearrangement of the in situ stress around the opening. In general, the weaker rock and higher in situ stresses result in more extensive plastic zone. The plastic zone indicator appears in each model grid zone, where the rock strength, as defined by the Coulomb-Mohr yield criterion, was exceeded. (The yielding rock causes stresses to be transferred to the adjacent, undisturbed rock material.) The process continues until the stresses are redistributed and a new state of model equilibrium is attained.

Figures 9 and 13 represent the model geometry and an extent of the plastic zone around identical opening excavated in TSw1 and TSw2, respectively. It is apparent, that the excavation in TSw1 unit will result in generating a more extensive plastic zone compared to TSw2. Figures 11 and 15, representing the largest roof span analyzed with Ko=0.5, show that range of the plastic zone in TSw2 is smaller than one generated within TSw1 unit. In both models, however, small tensile zone generated, mainly in the opening roof can be noted. Comparison of the modeling results obtained for the modified model geometry as shown in Figures 12 and 16 shows that the rockbolts were used to stabilize the roof, especially in its central section.

Changes in stresses result in deformations. Figures 17 to 19 show the vertical displacement calculated at the three monitoring points, namely: 1) the top center, 2) at the tunnel springline, and 3) at the bottom of the opening. The fourth Figure 20 shows the lateral displacement monitored at the tunnel springline. The displacement values plotted are those for W/H ratio ranging from 1.0 to 3M, where "M" indicates the opening with the W/H=3 and modified geometry (e.g. see Figure 12).

Results show that an opening excavated in the TSw1 unit under Ko=0.5 display the largest displacements ranging from 22 mm at the center top (Figure 17) to 14 mm at the opening bottom (Figure 19), approximately. The lateral displacements at the springline do not exceed 5 mm (Figure 20). It should be noted that the negative displacement at the top shown in Figure 17 indicates the rock mass movement toward the opening.

The seismic evaluation was made on the 3 M opening with rockbolt reinforcement. The model uses cable elements to simulate rockbolts. In figures 21 through 26 the rockbolt reinforce 3 diameter elliptical modified (3 M) opening was performed at ambient loading for both TSw1 and TSw2 as a comparative baseline for the reinforced opening. In figures 27 through 32 a Quasi- static seismic loading was added by increasing the gravity to 1.30 g. [Criterion 4.2.2]). Finally in figure 33 and 34 the axial forces on the cable elements are presented for both the TSw1 and TSw2.

The result of the seismic evaluation demonstrate that the displacement increase with the seismic loading but the reinforced opening is stable for both the TSw1 and TSw2. The maximum axial loading on the reinforcing elements is 3.9 E +4 N (7600 lbs.) which is in a strength range that can be easily addressed by Standard Swellex, Super Swellex and Williams rockbolts.

In general, these potential rock instabilities can be controlled using conventional means of rock support, including wire mesh, steel channel, rockbolts and shotcrete.

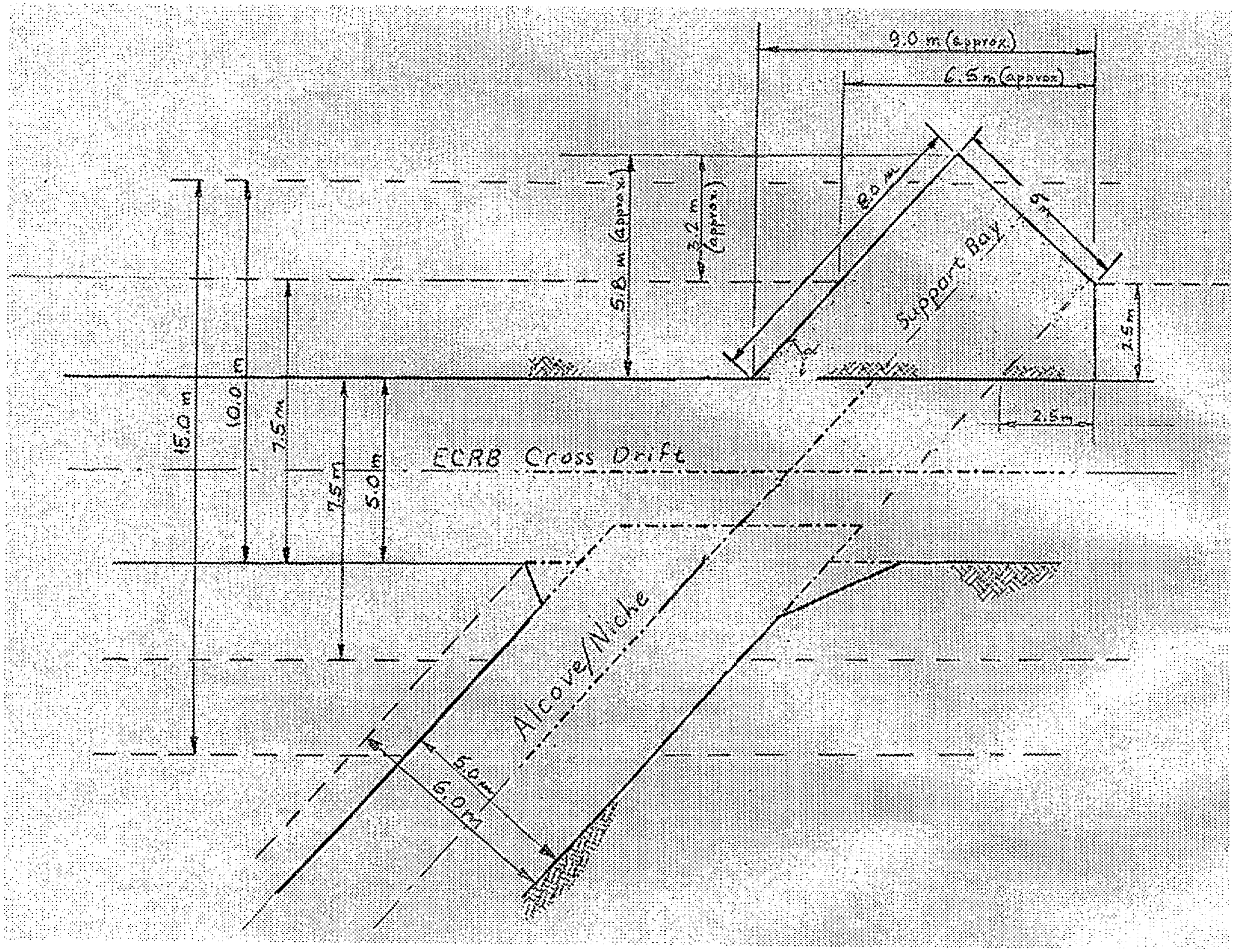

Figure 1. Typical Four-Way ECRB Tunnel/ Test Alcove Intersection.

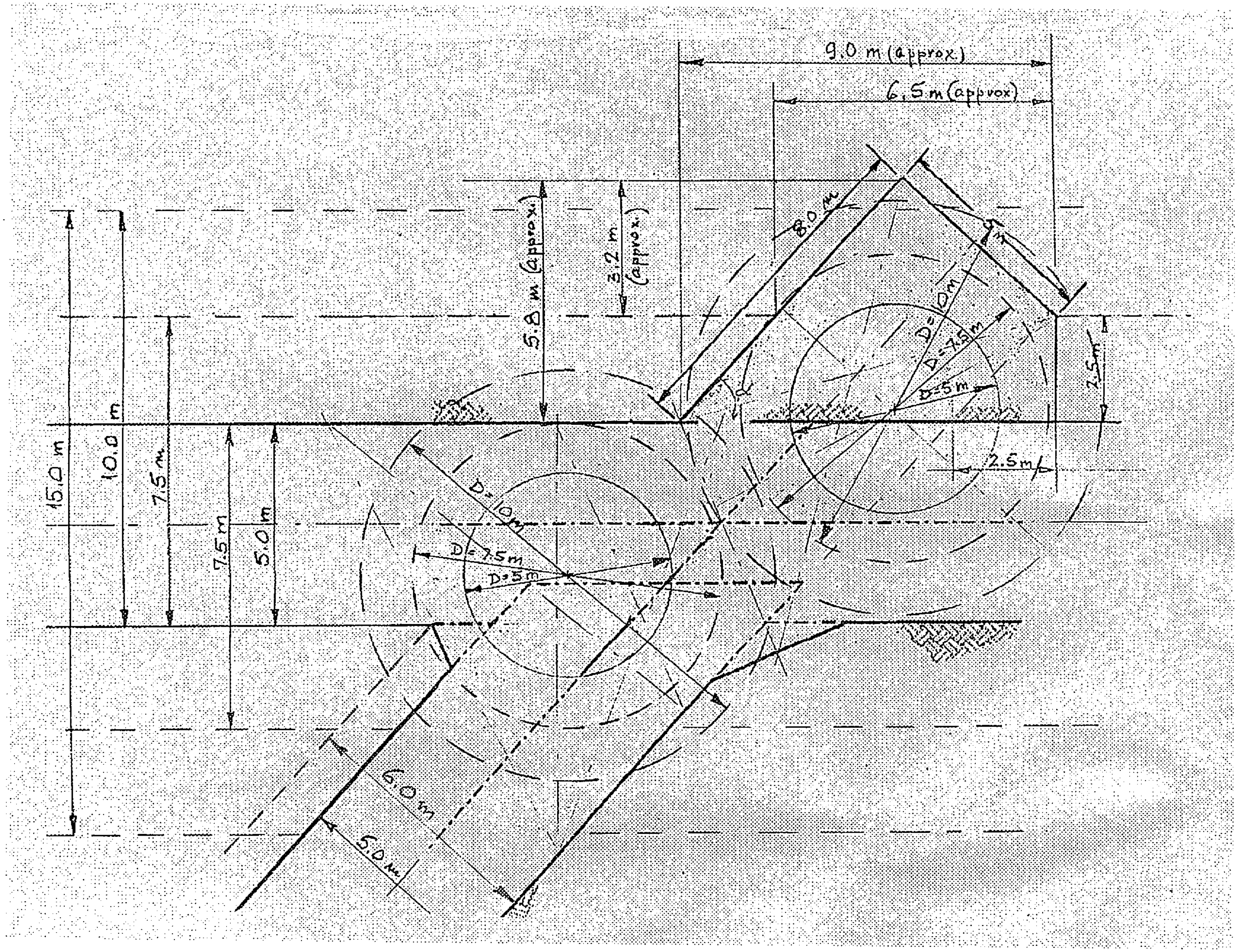

Figure 2. Typical ECRB Tunnel/Test Alcove Intersection with an Overlay of Roof Span Zones Equal to 5.0, 7.5 and 10 meters .

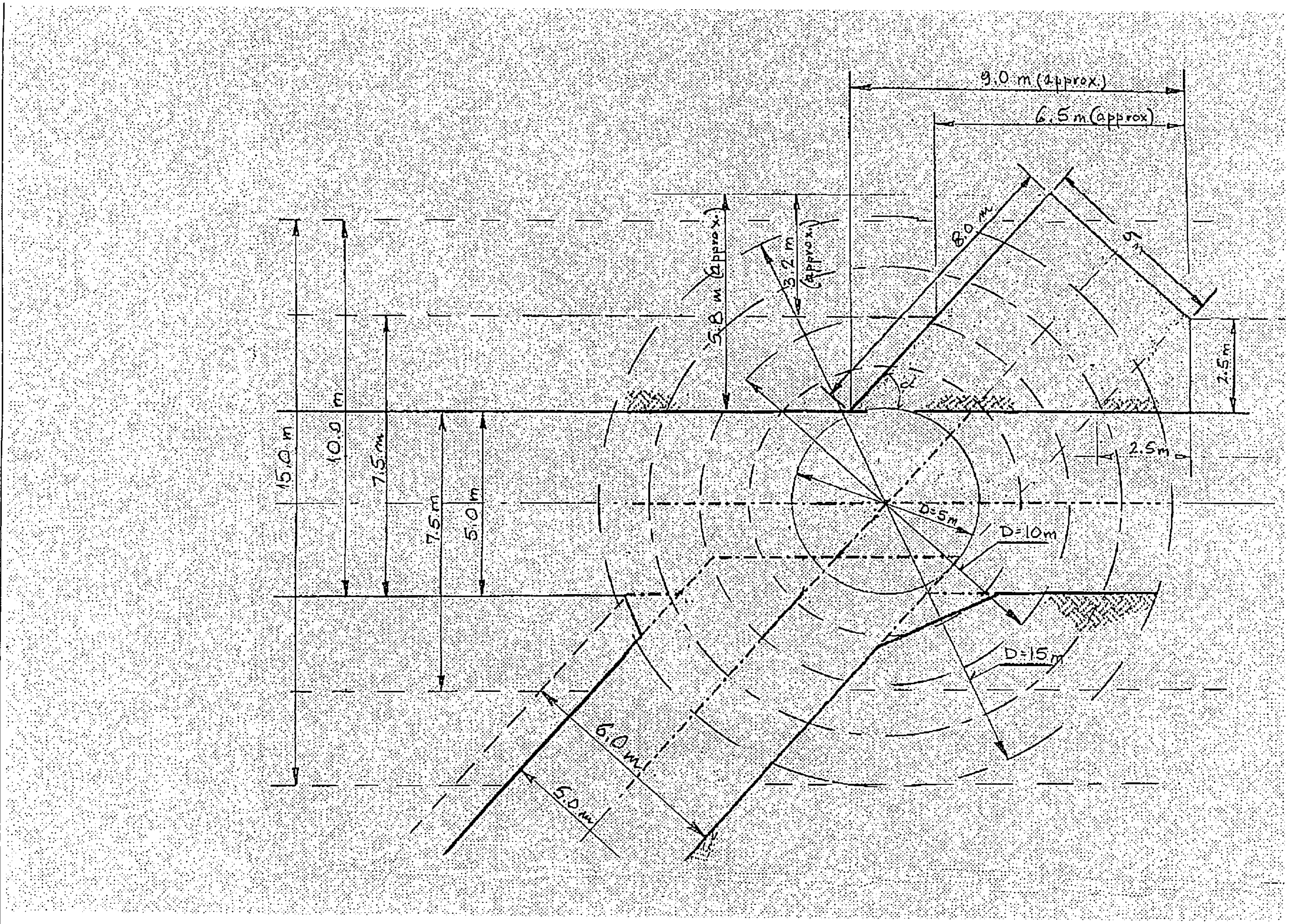

Figure 3. Typical ECRB Tunnel/Test Alcove Intersection with an Overlay of Roof Span Zones Ranging from 5.0 to 15 meters.

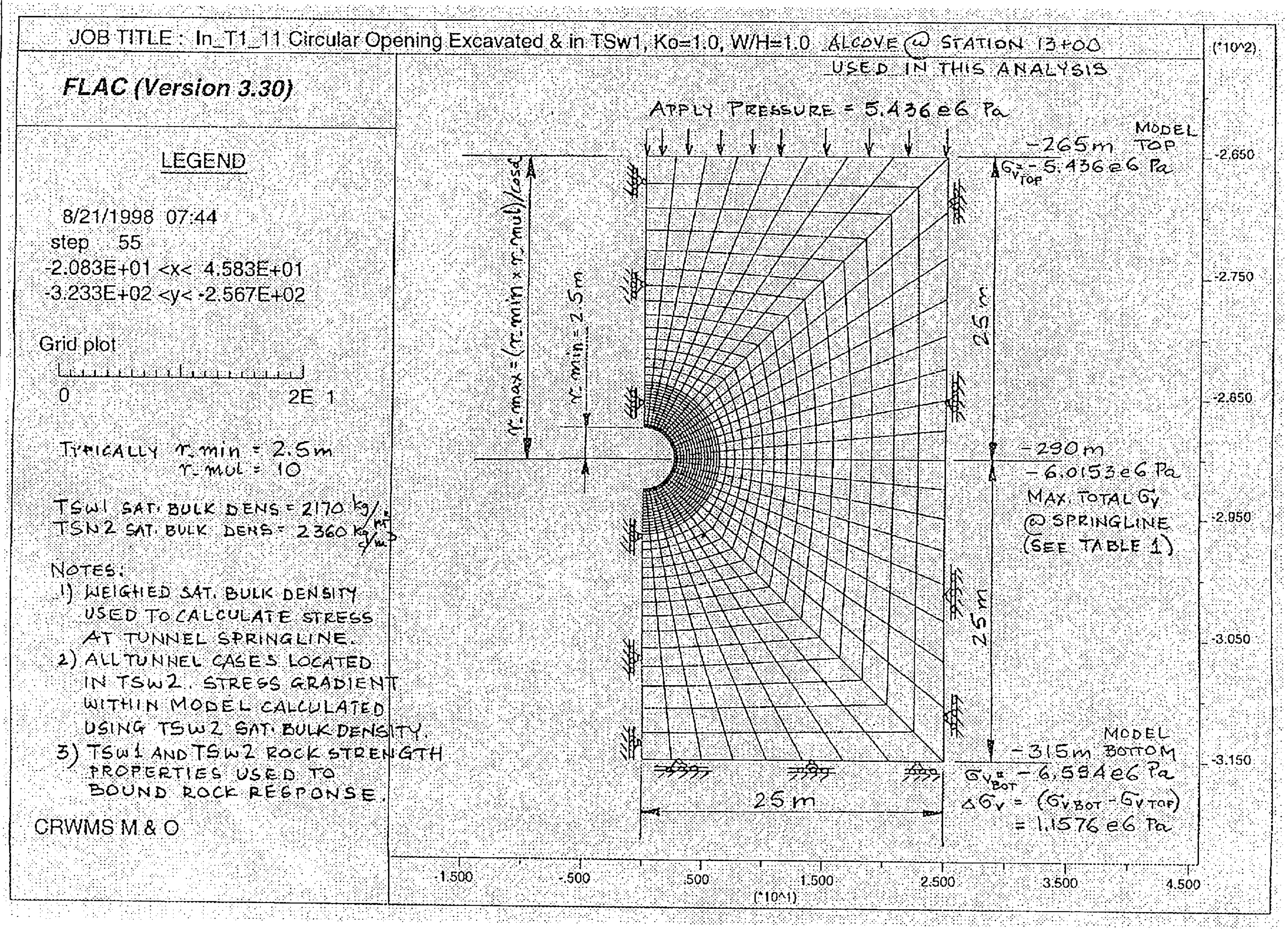

Figure 4. Base Cylindrical-Shape Model Used to Derive Subsequent Models with the Roof Span Width-to-Height (W/H) Ratio Equal 2.0 and 3.0.

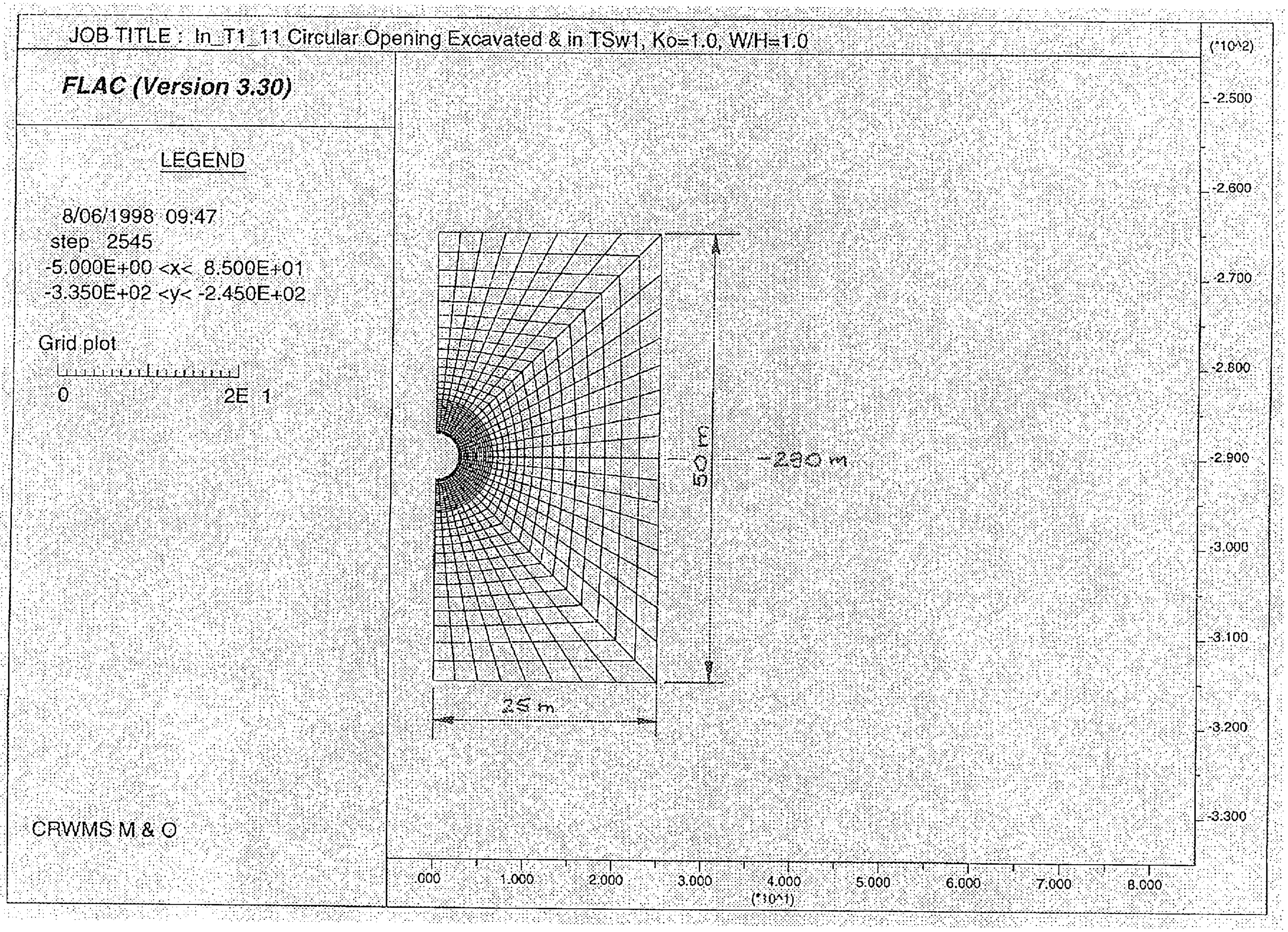

Figure 5. Circular-Shape Model with W/H=1.0.qual 2.0 and 3.0.

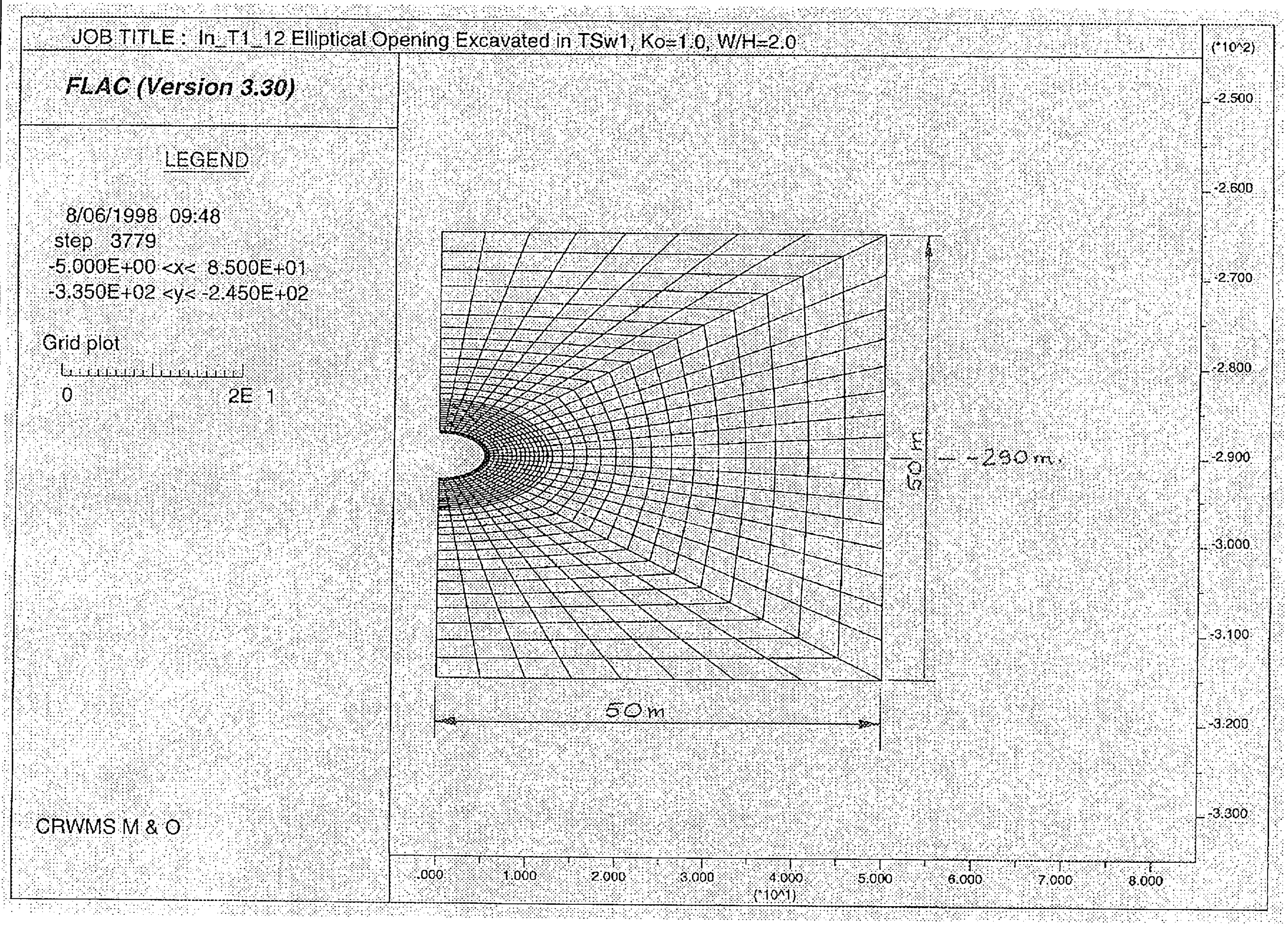

Figure 6. Circular-Shape Model with W/H=2.0.

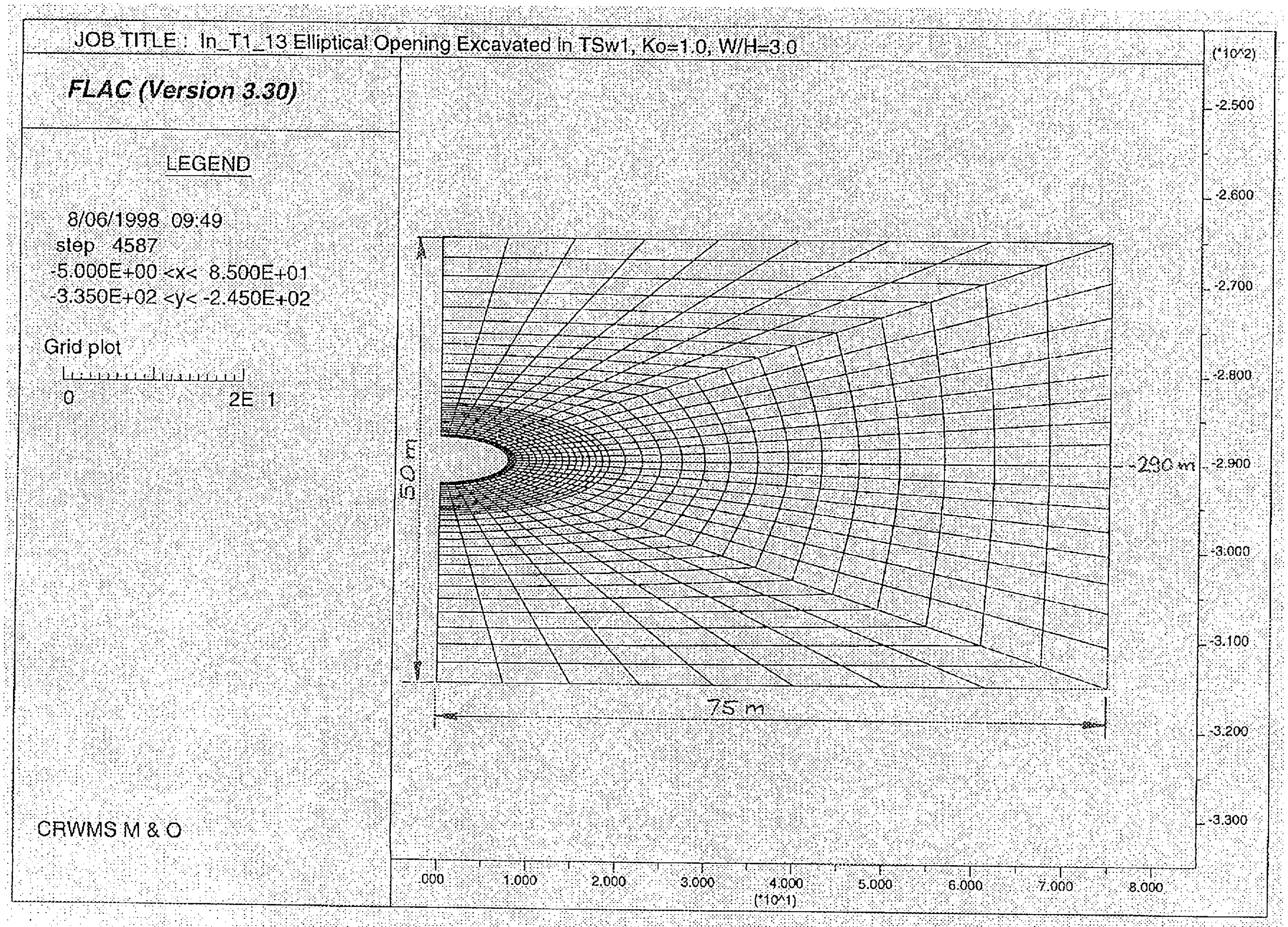

Figure 7. Elliptical-Shape Model with W/H=3.0.

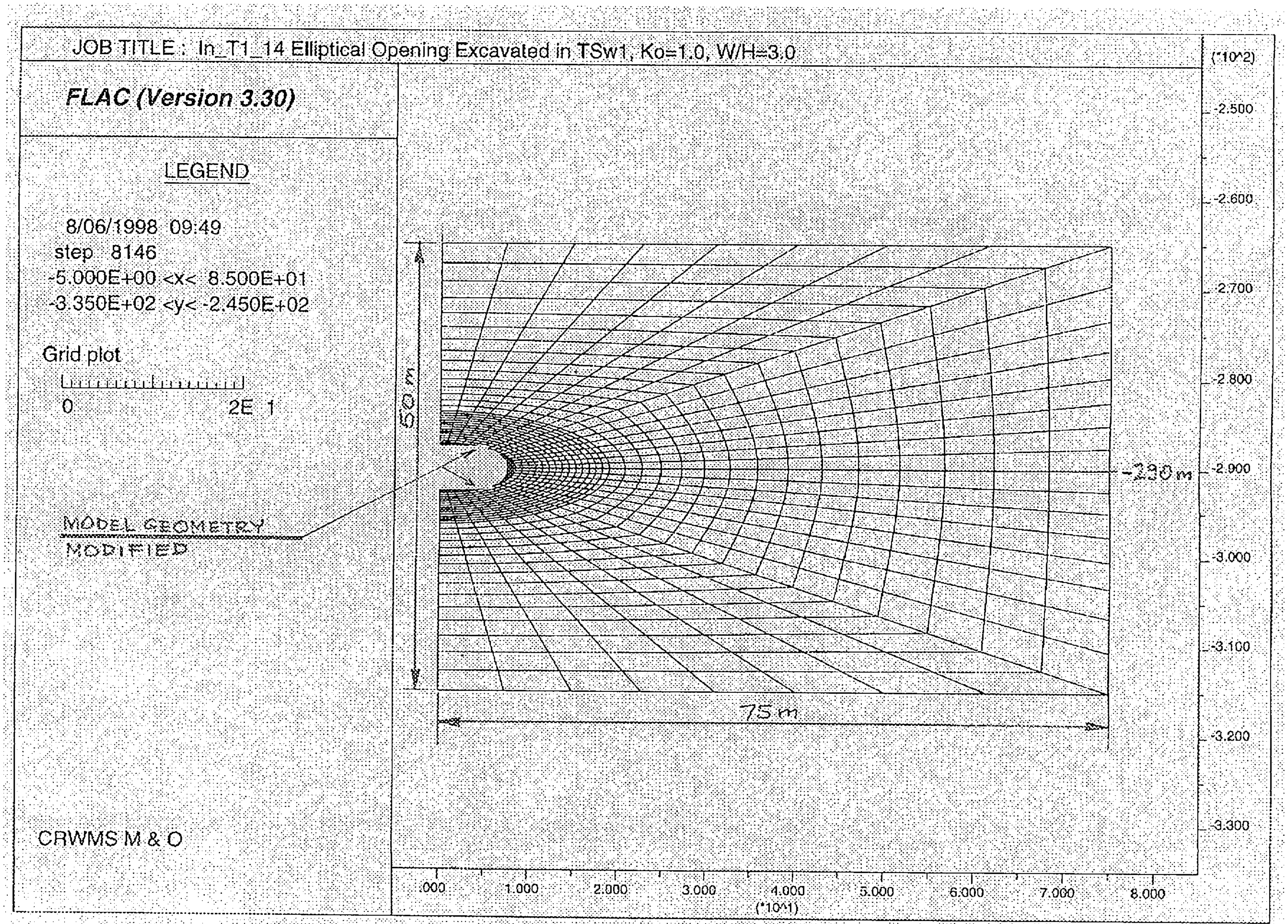

Figure 8. Elliptical-Shape Model with W/H=3.0 and Modified Opening Geometry.

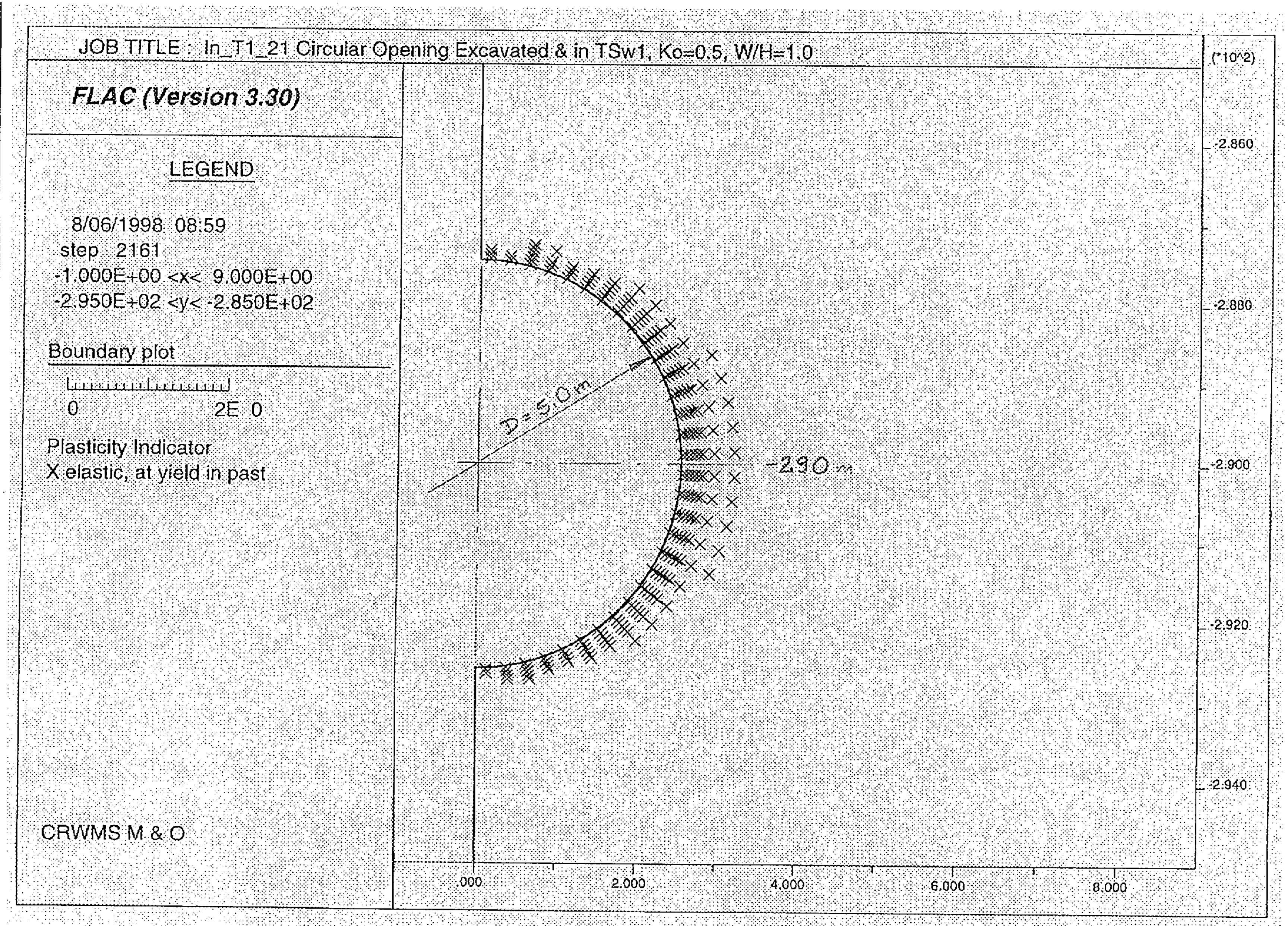

Figure 9. Plastic (Disturbed) Zone Developed Around Circular (W/H=1) Opening excavated in TSw1.

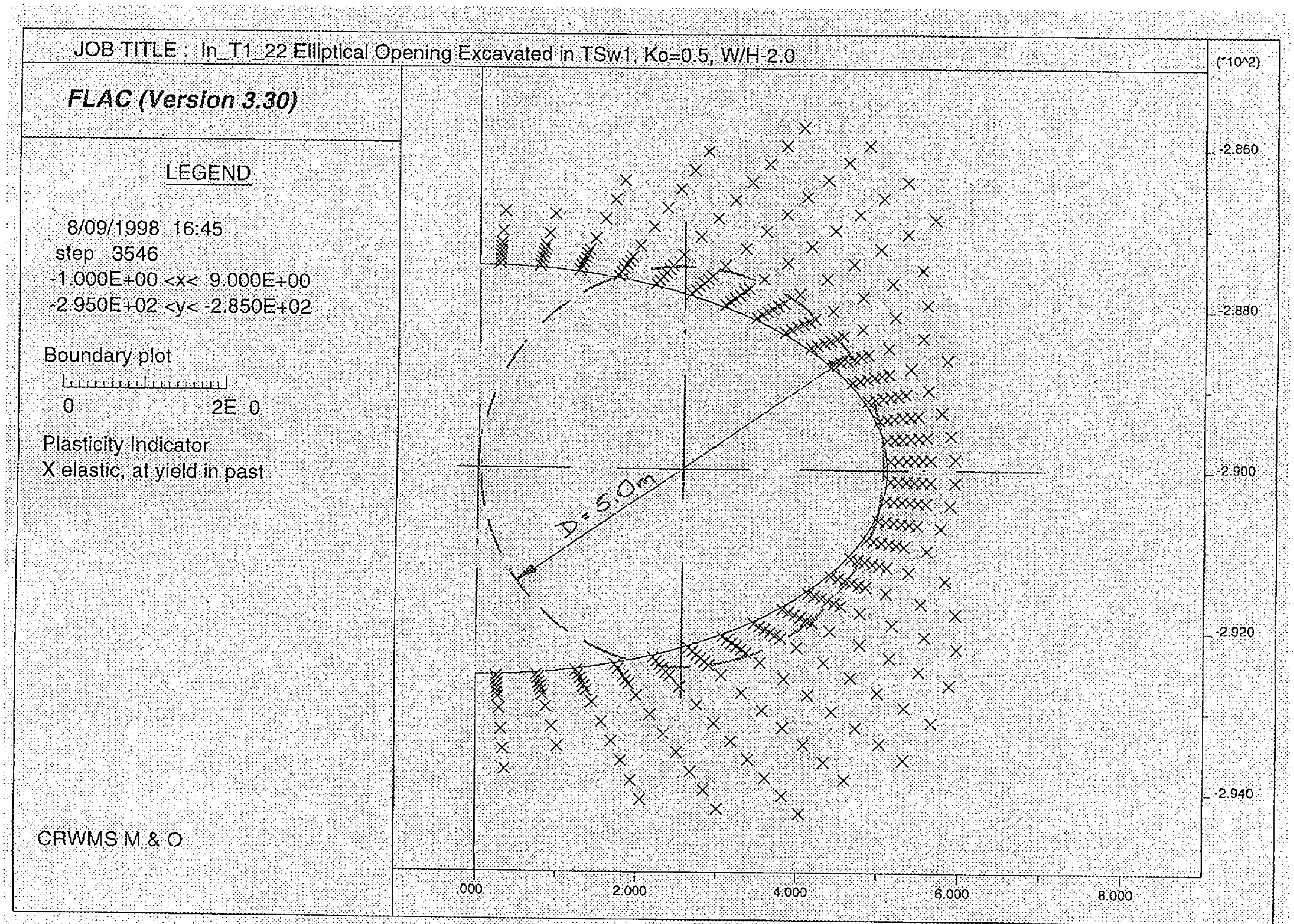

Figure 10. Plastic (Disturbed) Zone Developed Around Elliptical (W/H=2.0) Opening Excavated in TSw1. Horizontal-to-Vertical Stress Ratio, Ko=0.5.

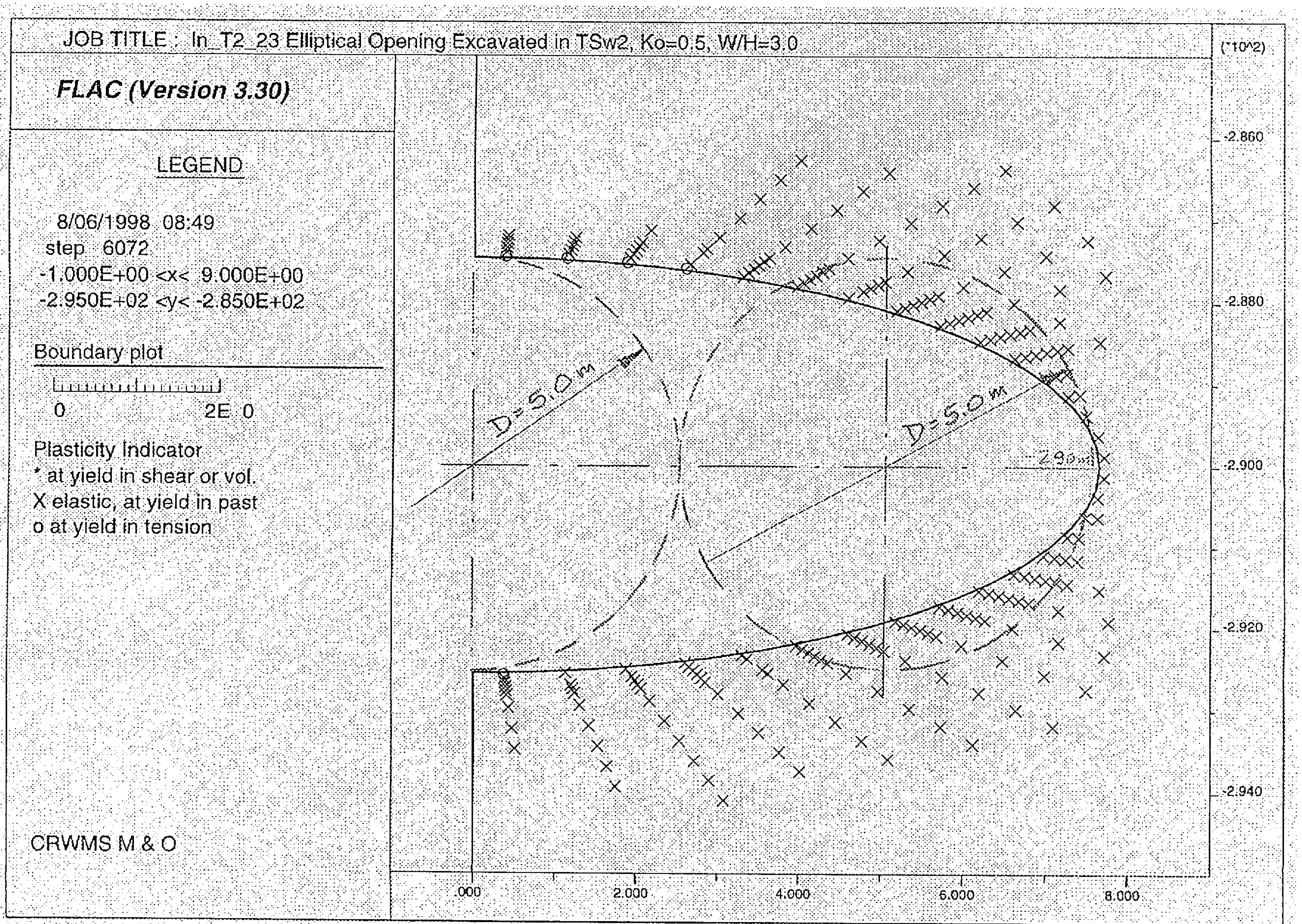

Figure 11. Plastic (Disturbed) Zone Developed Around Elliptical (W/H=3.0) Opening Excavated in TSw1. Horizontal-to-Vertical Stress Ratio, Ko=0.5.

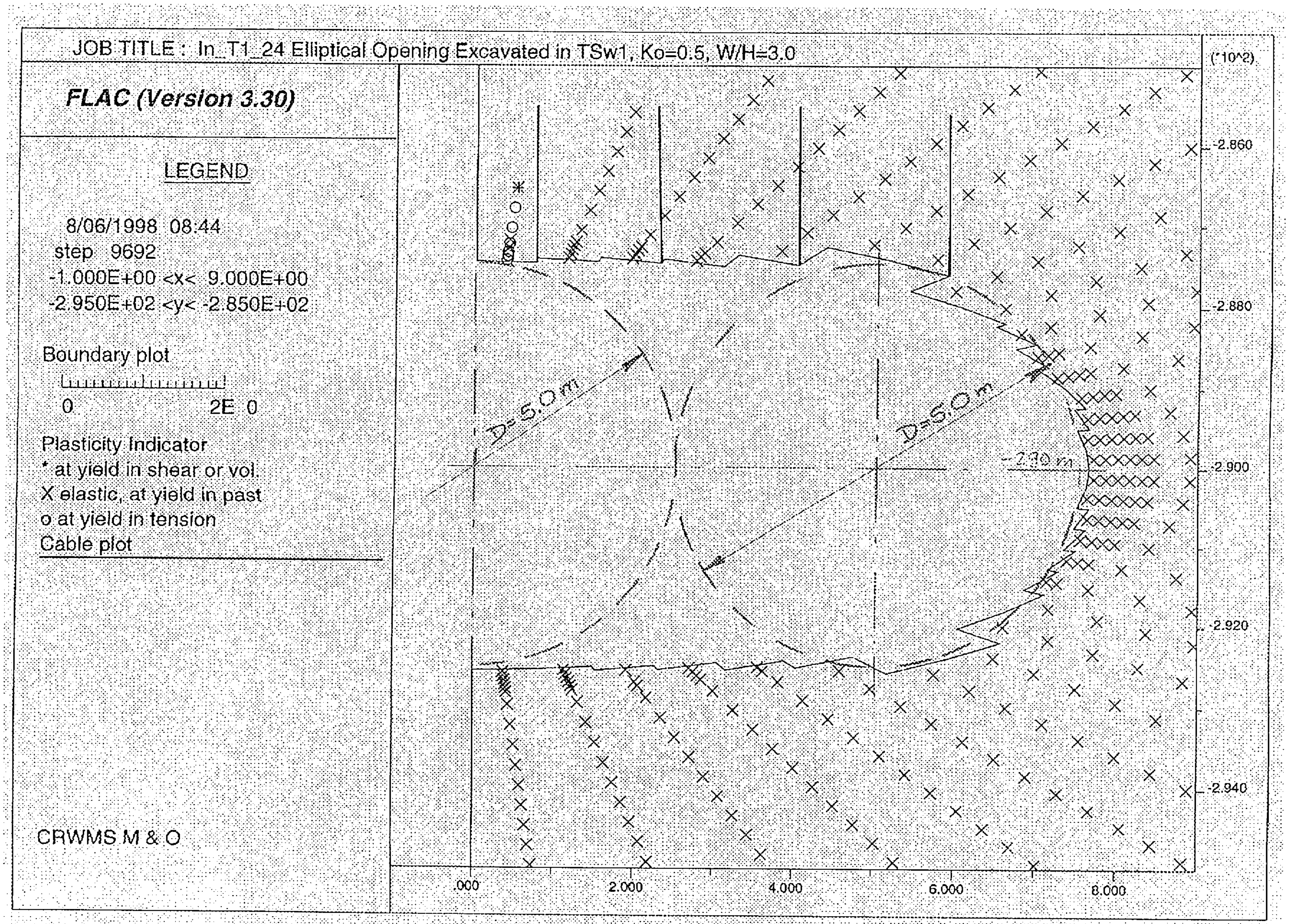

Figure 12. Plastic (Disturbed) Zone Developed Around Elliptical (W/H=3.0) Opening Excavated in TSw1. Horizontal-to-Vertical Stress Ratio, Ko=0.5, Opening Geometry Modified.

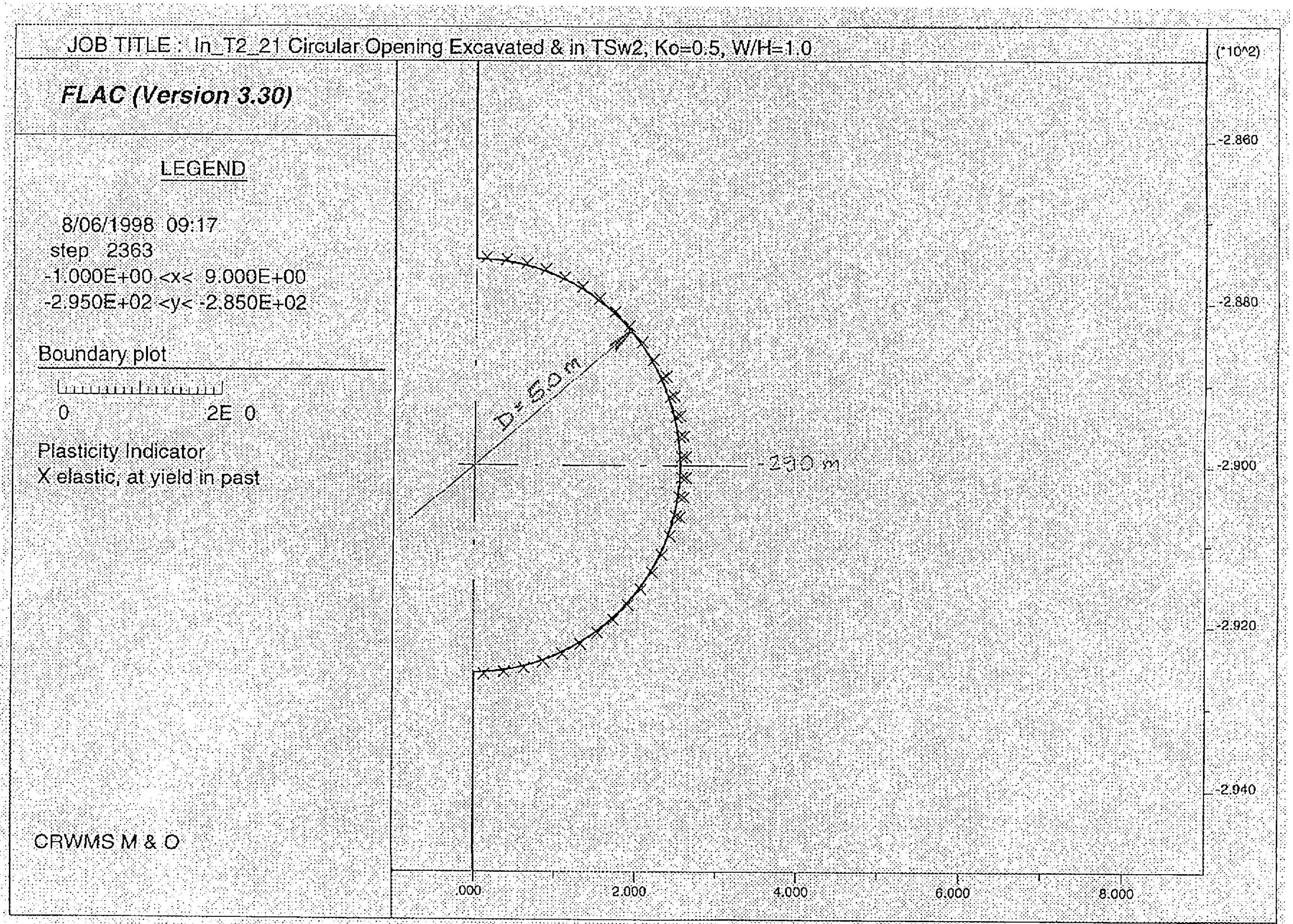

Figure 13. Plastic (Disturbed) Zone Developed Around Circular (W/H=1.0) Opening Excavated in TSw2.

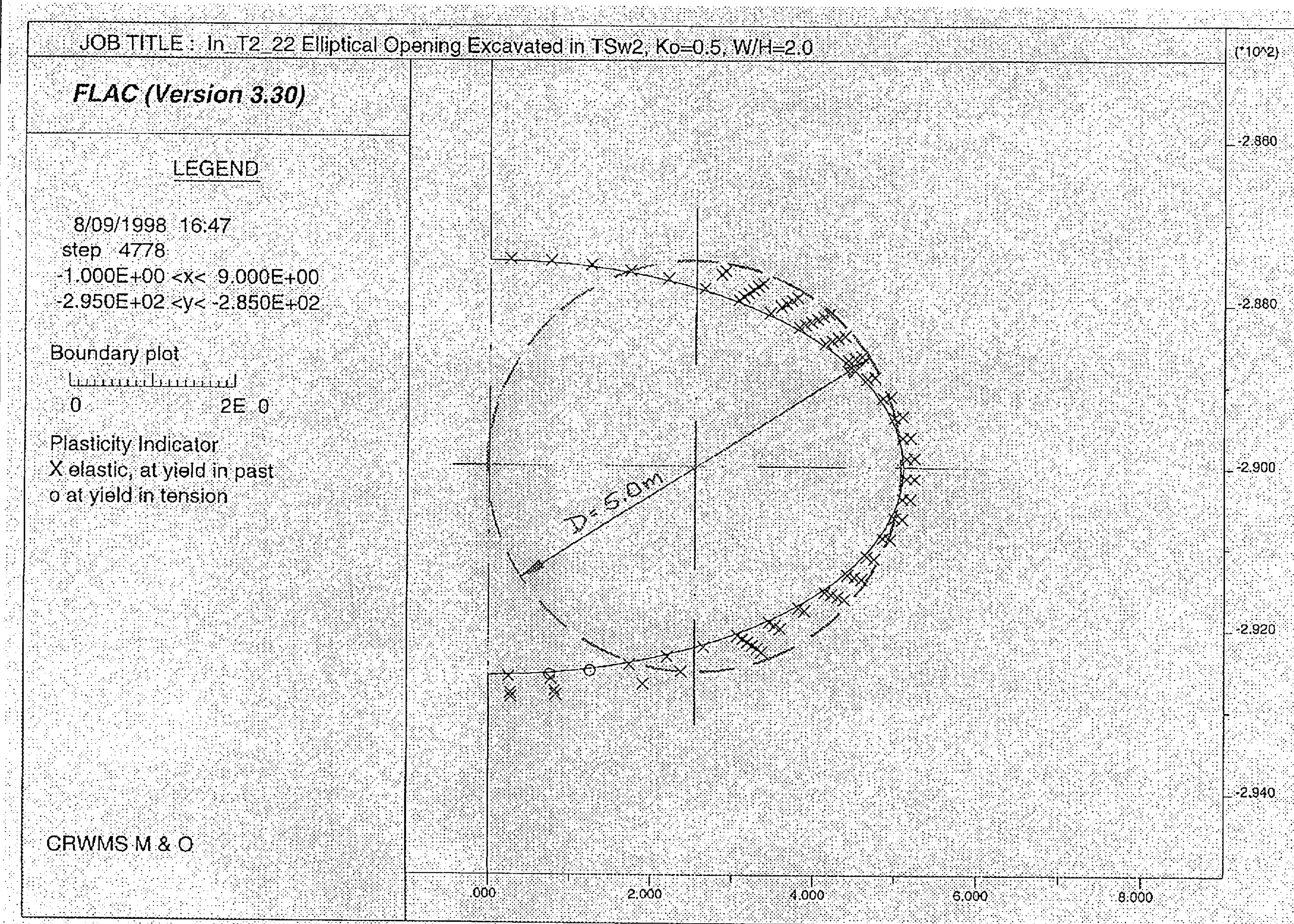

Figure 14. Plastic (Disturbed) Zone Developed Around Elliptical (W/H=2.0) Opening Excavated in TSw2. Horizontal-to-Vertical Stress Ratio, Ko=0.5.

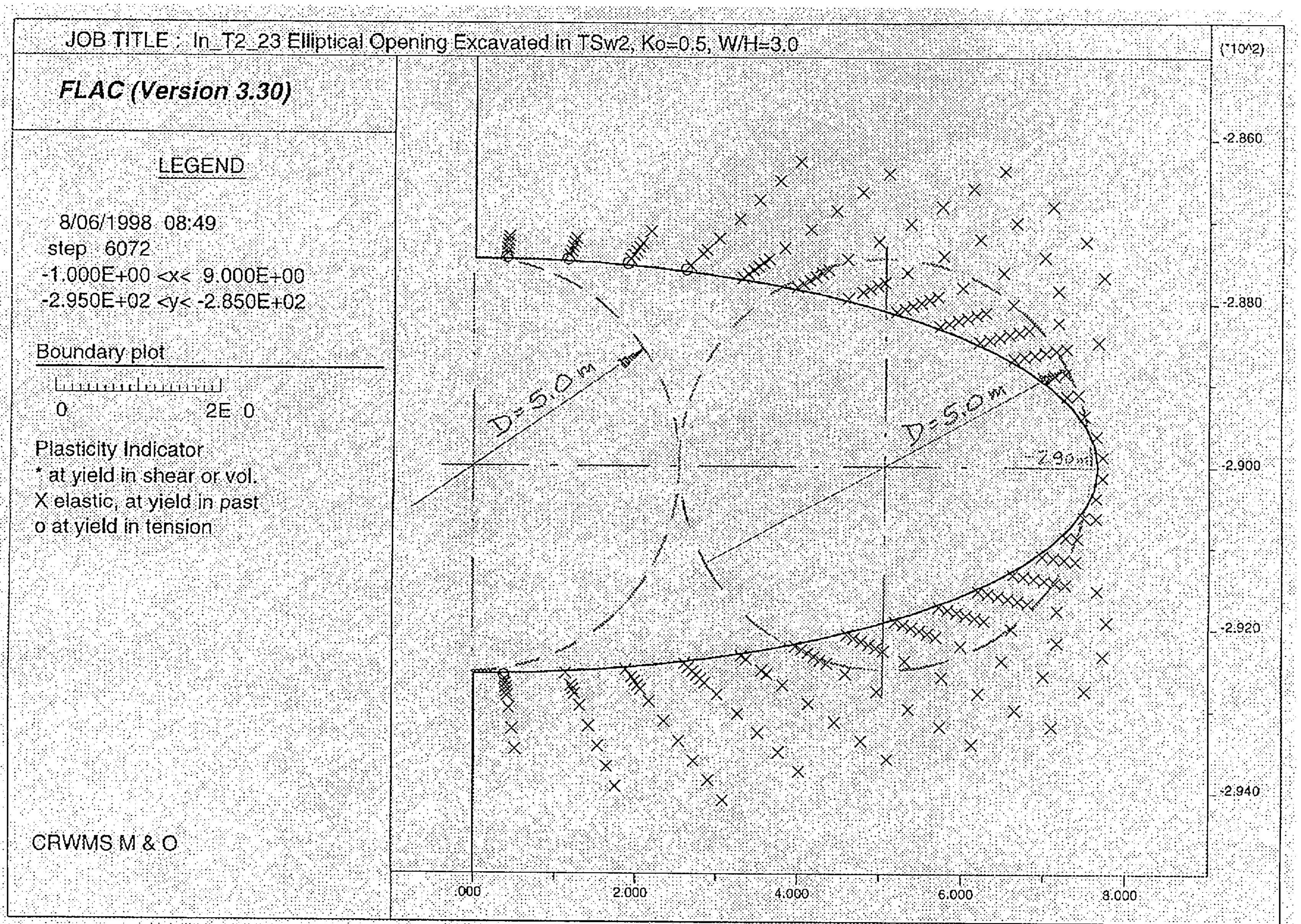

Figure 15. Plastic (Disturbed) Zone Developed Around Elliptical (W/H=3.0) Opening Excavated in TSw2. Horizontal-to-Vertical Stress Ratio, Ko=0.5.

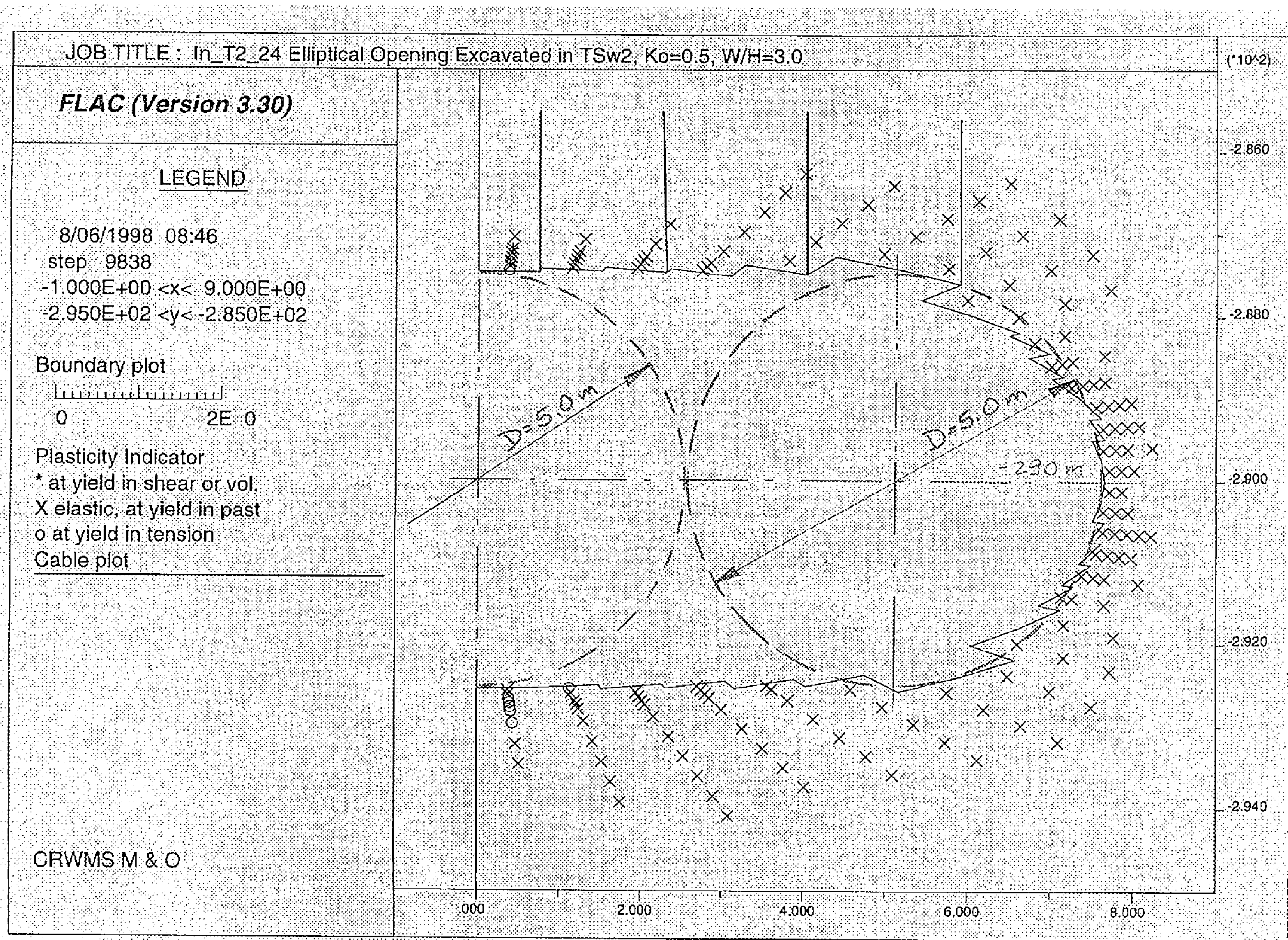

Figure 16. Plastic (Disturbed) Zone Developed Around Elliptical (W/H=3.0) Opening Excavated in TSw2. Horizontal-to-Vertical Stress Ratio, Ko=0.5, Opening Geometry Modified.

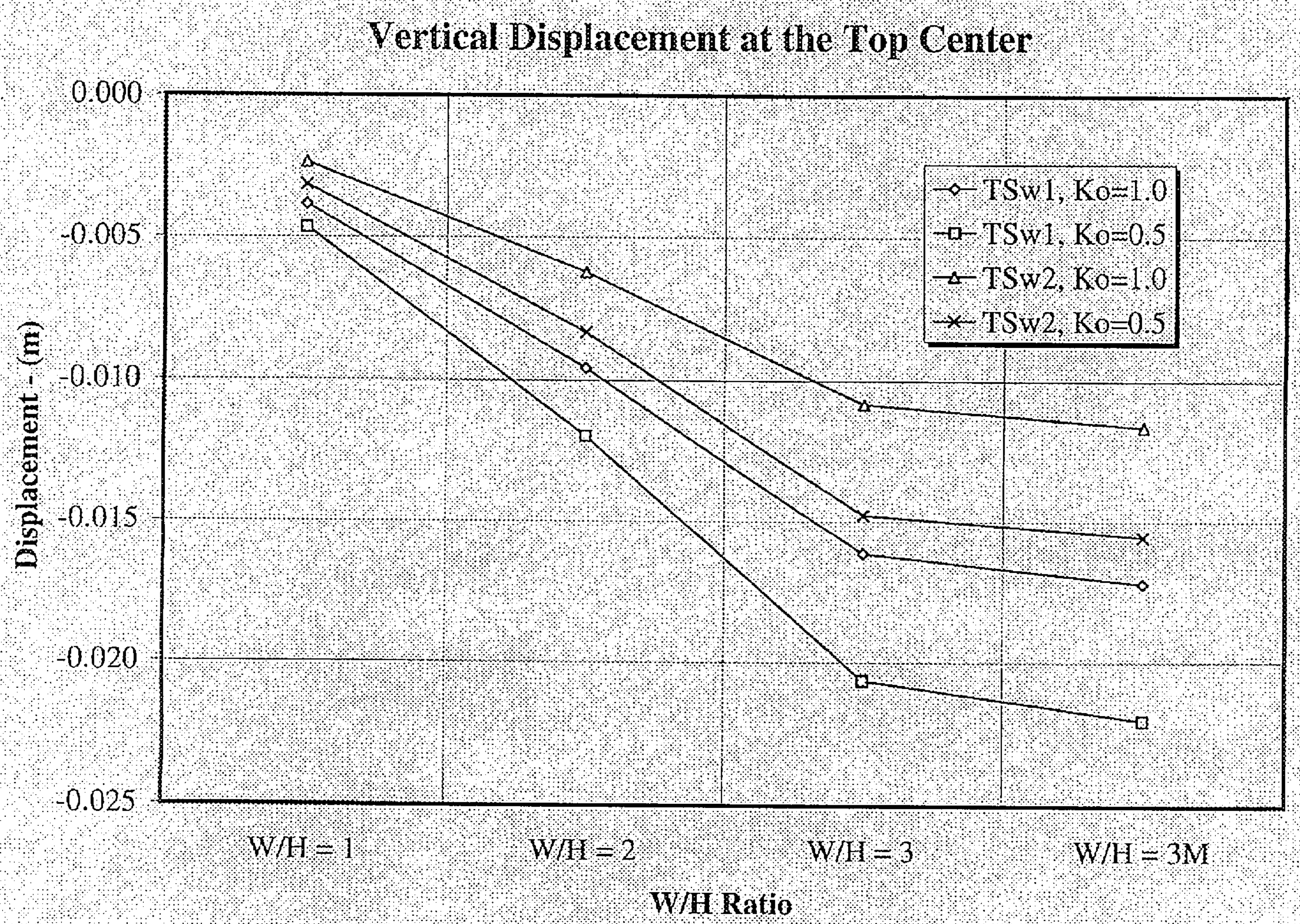

Figure 17. Vertical Displacement at the Top Center of the Opening for Various W/H Ratio.

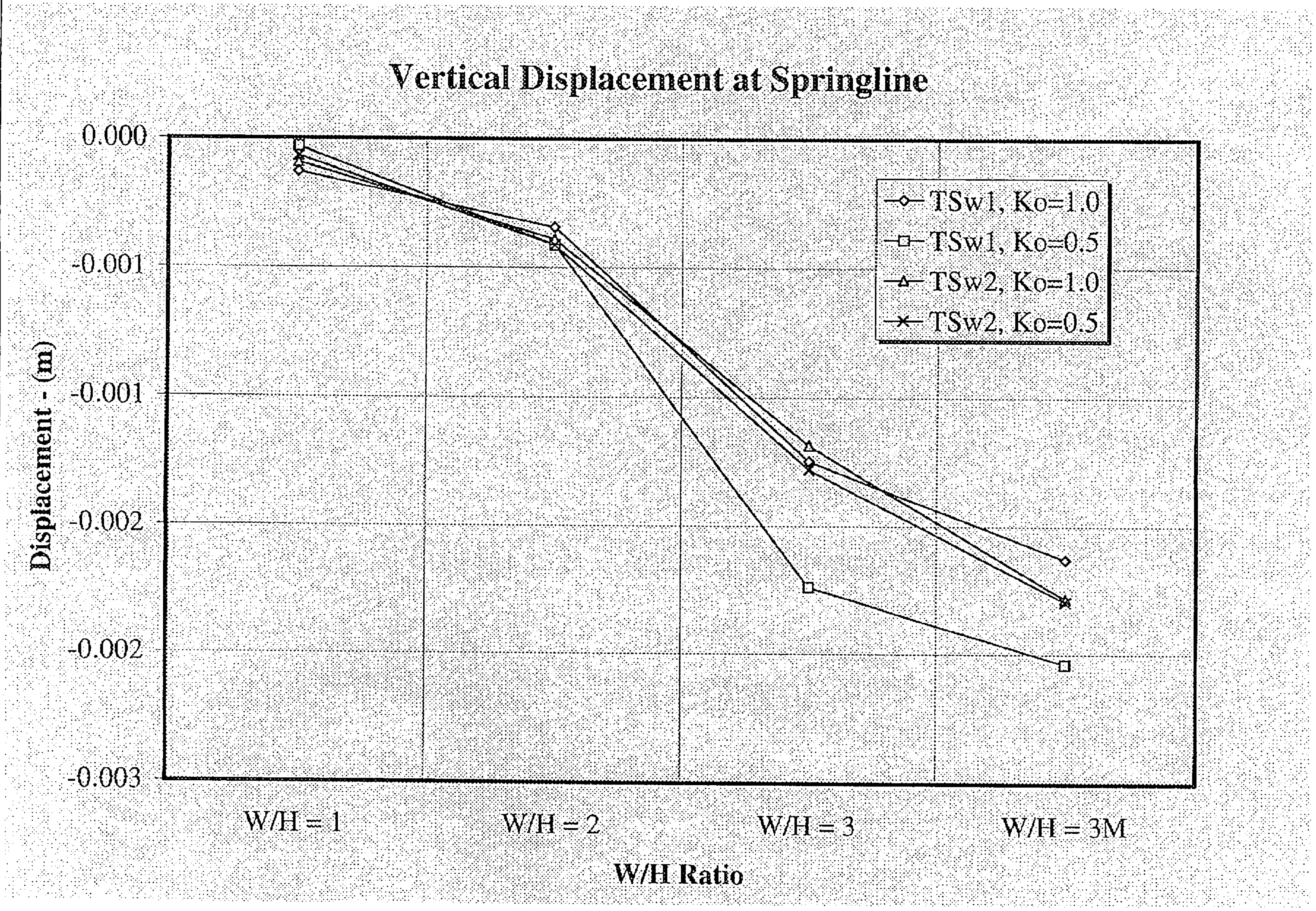

Figure 18. Vertical Displacement at the Springline of the Opening for Various W/H Ratio.

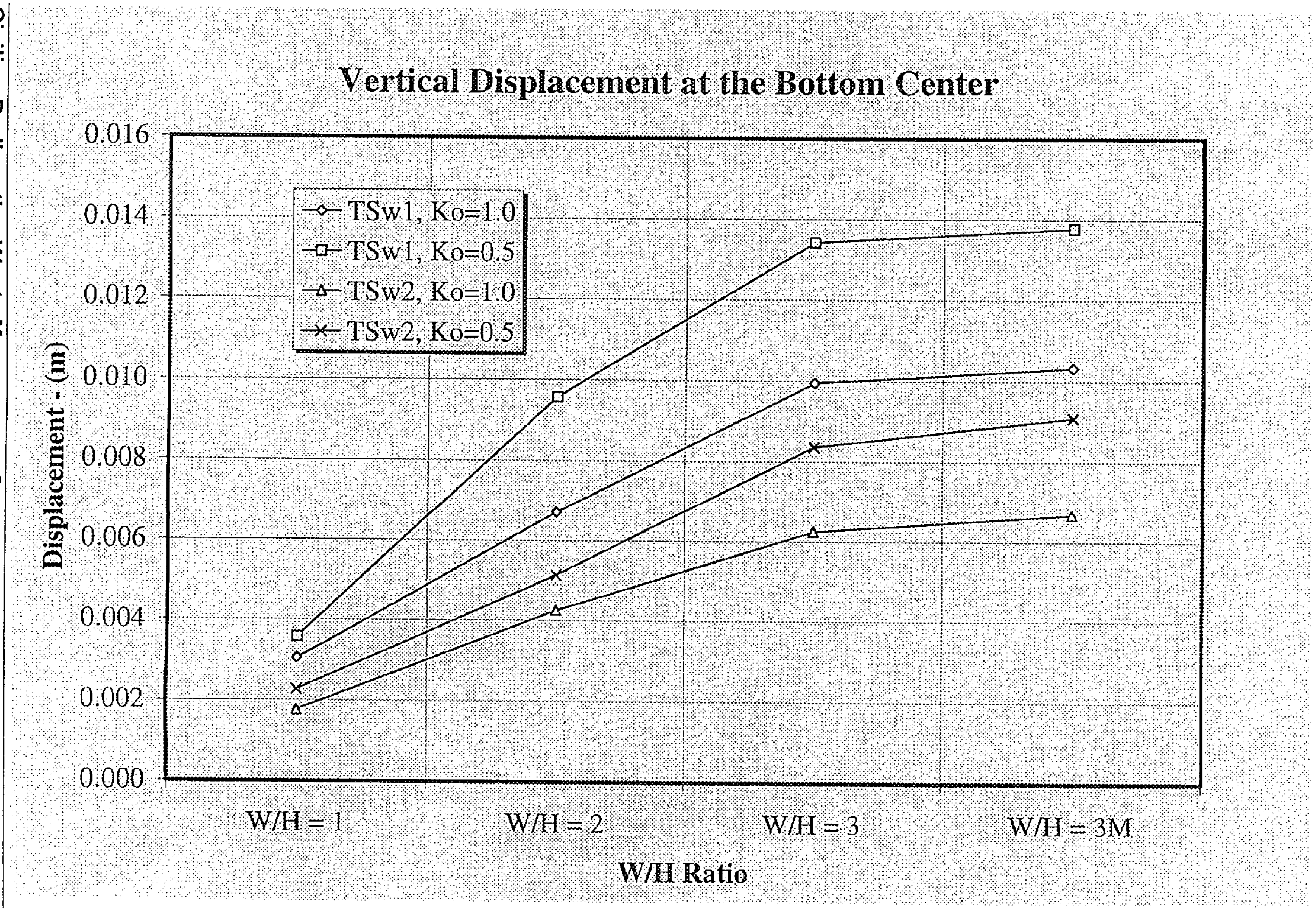

Figure 19. Vertical Displacement at the Springline of the Opening for Various W/H Ratio.

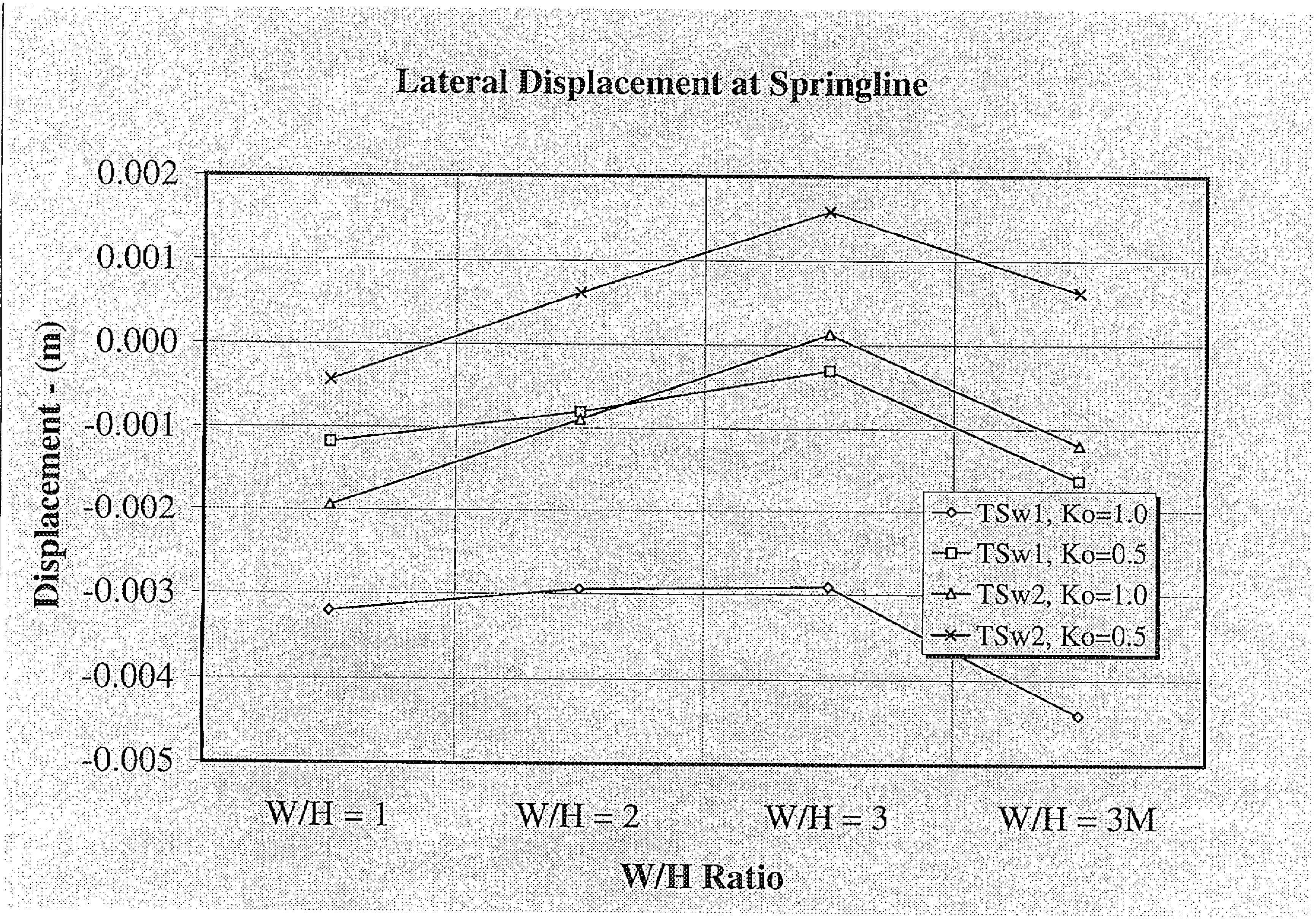

Figure 20. Horizontal Displacement at the Bottom Center of the Opening for Various W/H Ratio.

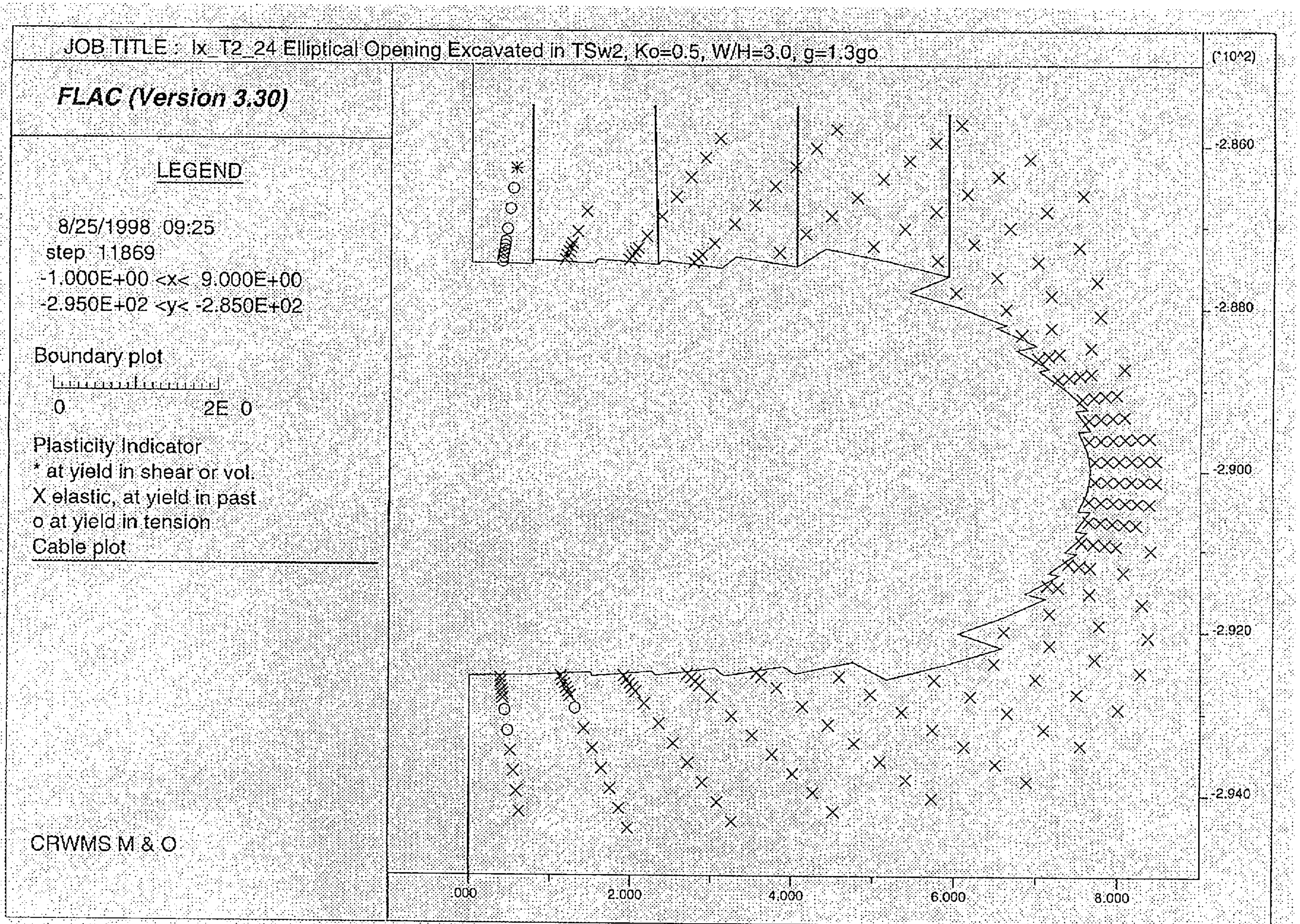

Figure 21. TSw1 Plasticity Diagram for 3 M Opening with Rockbolt Reinforcement. (Close up view)

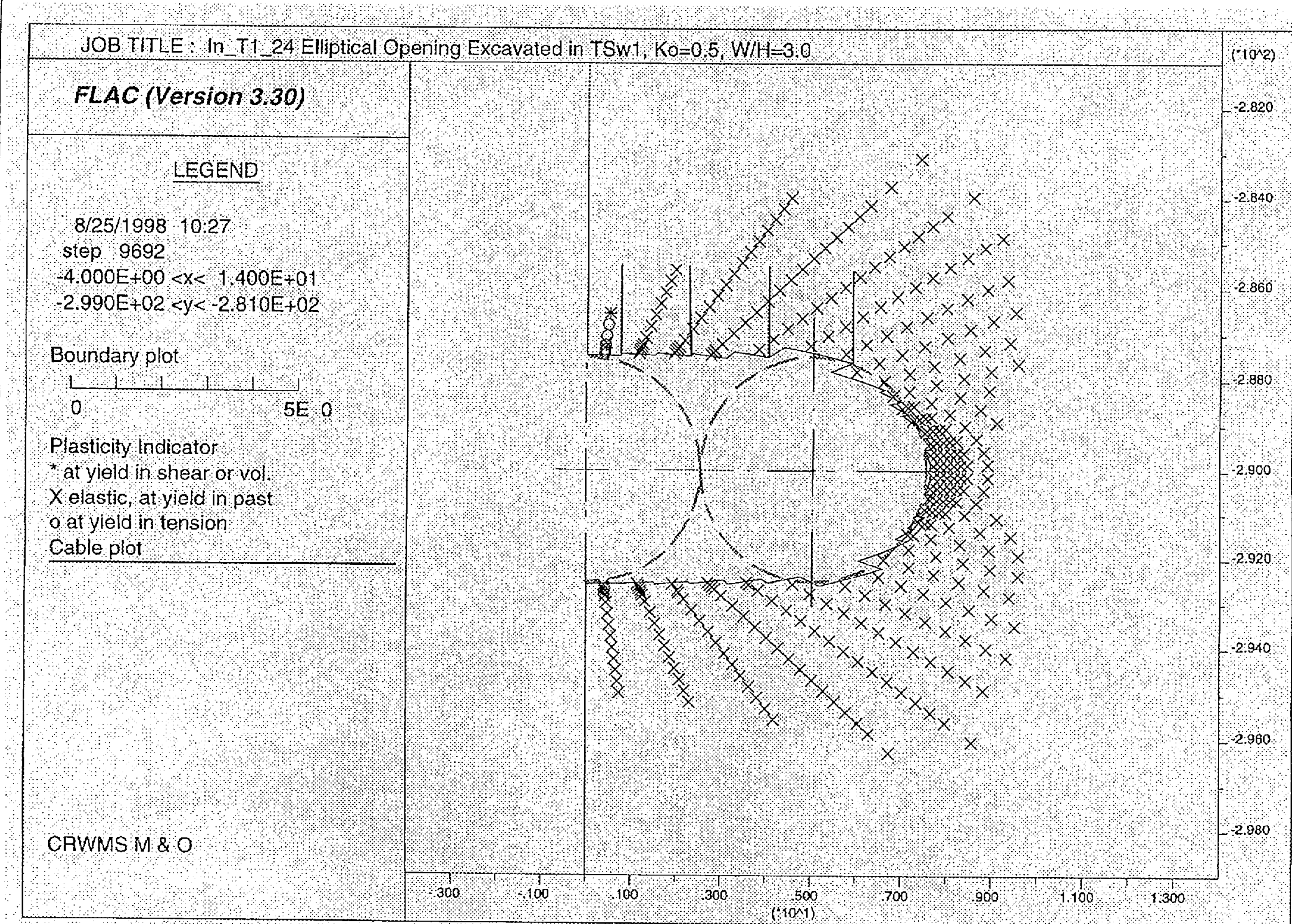

Figure 22. TSw1 Plasticity Diagram for 3 M opening with Rockbolt Reinforcement. (Full view)

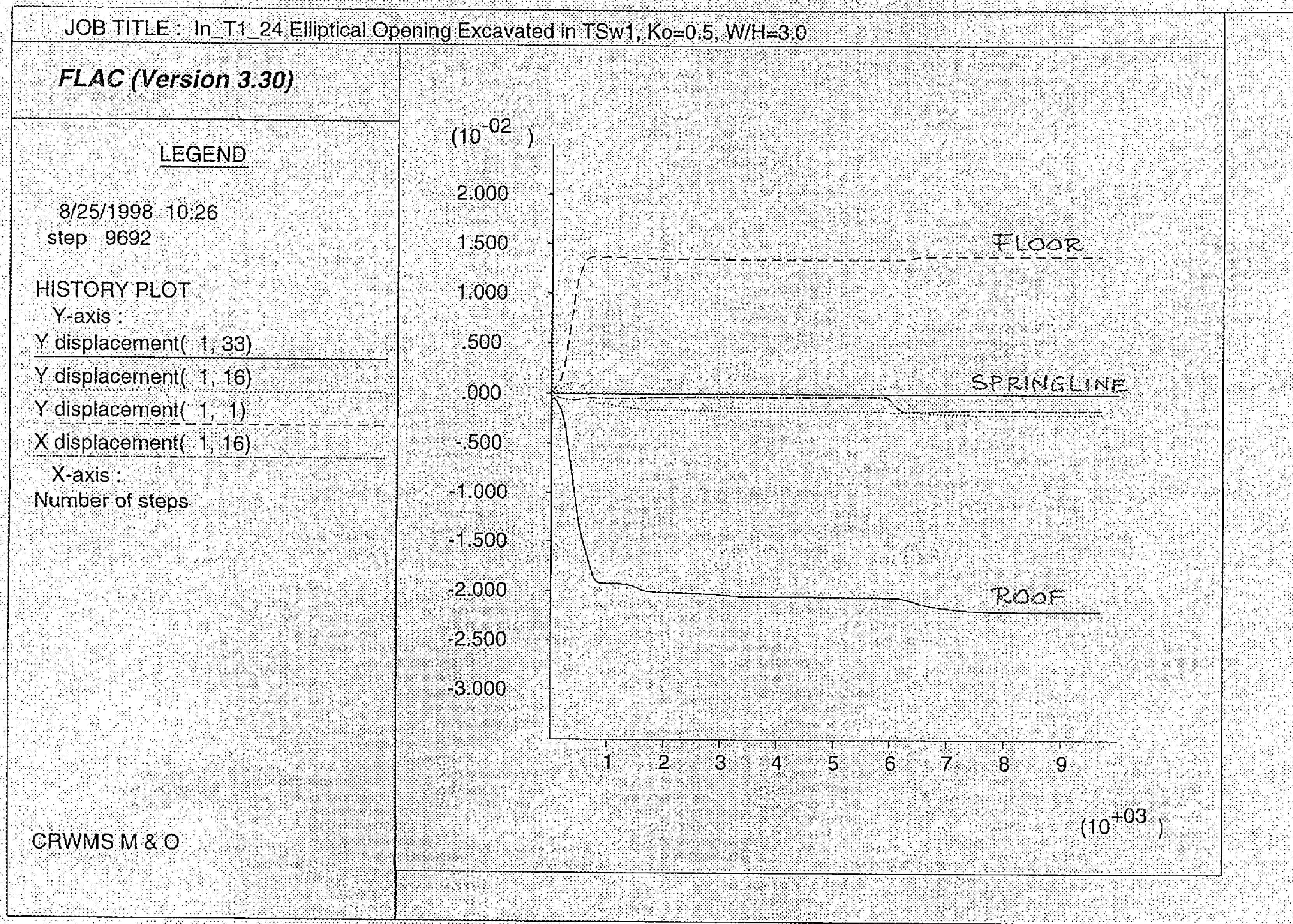

Figure 23. TSw1 Displacement Curve (deformation vs. model recalculation iterations)

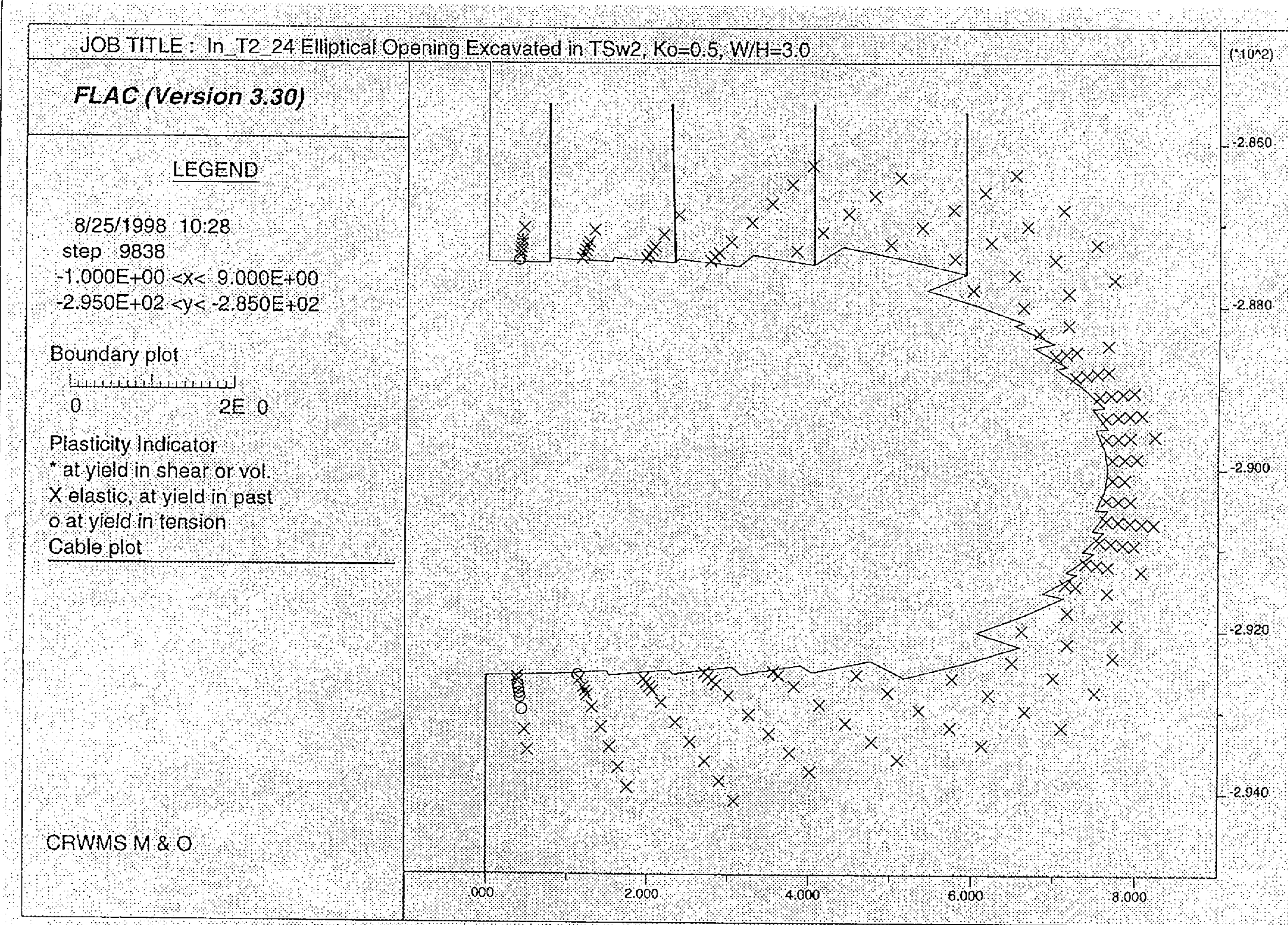

Figure 24. TSw2 Plasticity diagram for 3 M opening with rockbolt reinforcement. (Close up view)

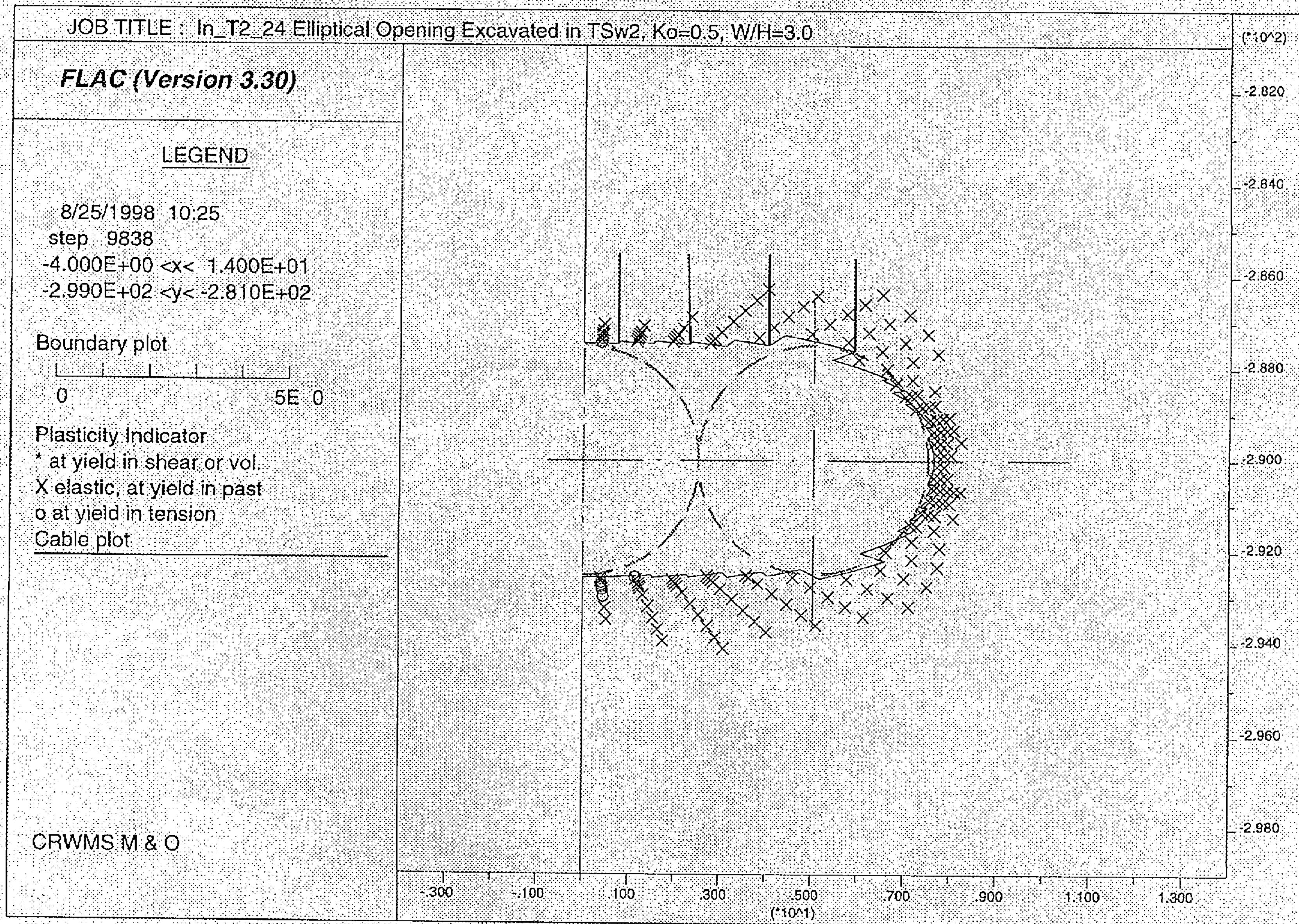

Figure 25. TSw2 Plasticity diagram for 3 M opening with rockbolt reinforcement. (Full view)

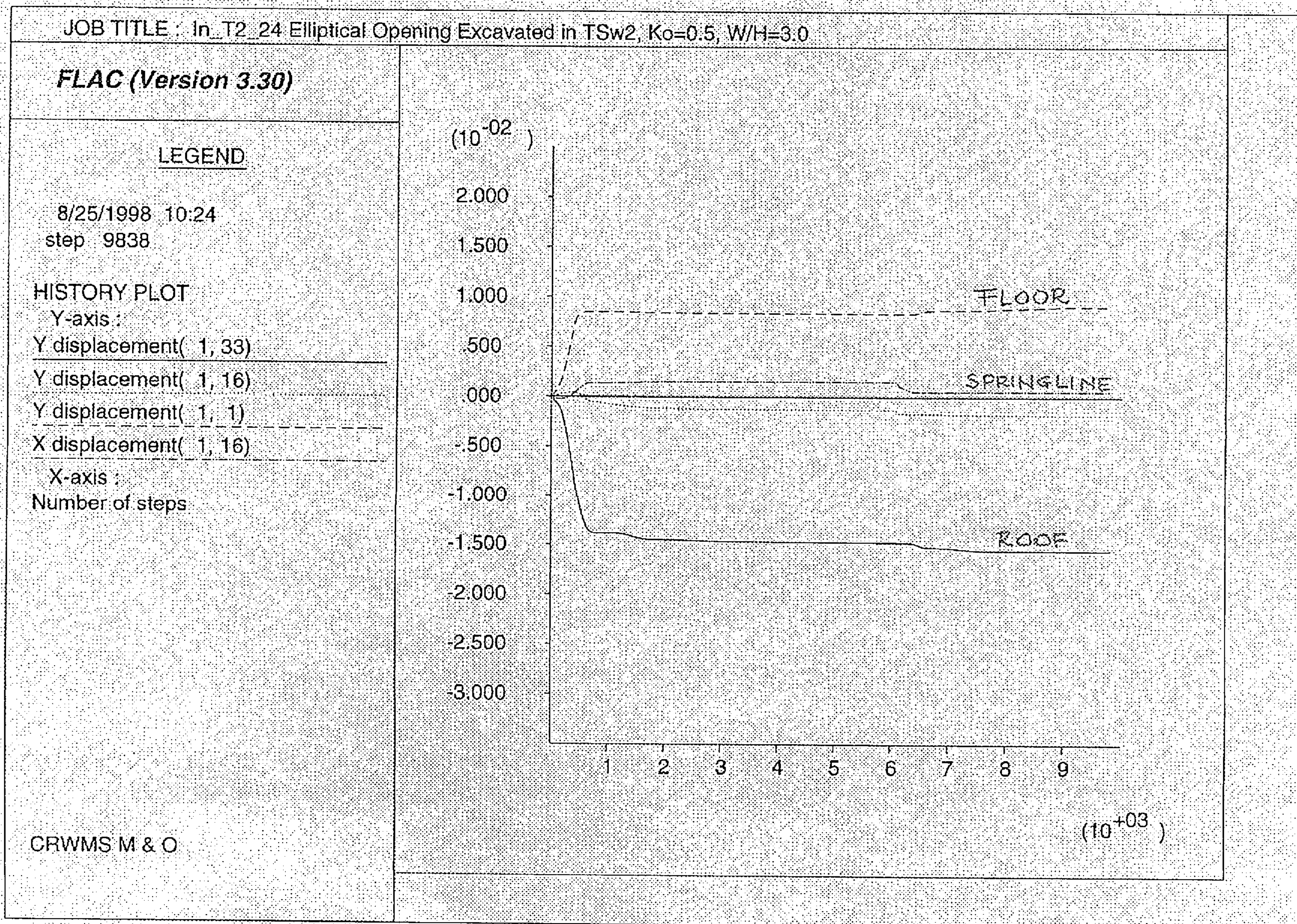

Figure 26. TSw2 Displacement curve (deformation vs. model recalculation iterations)

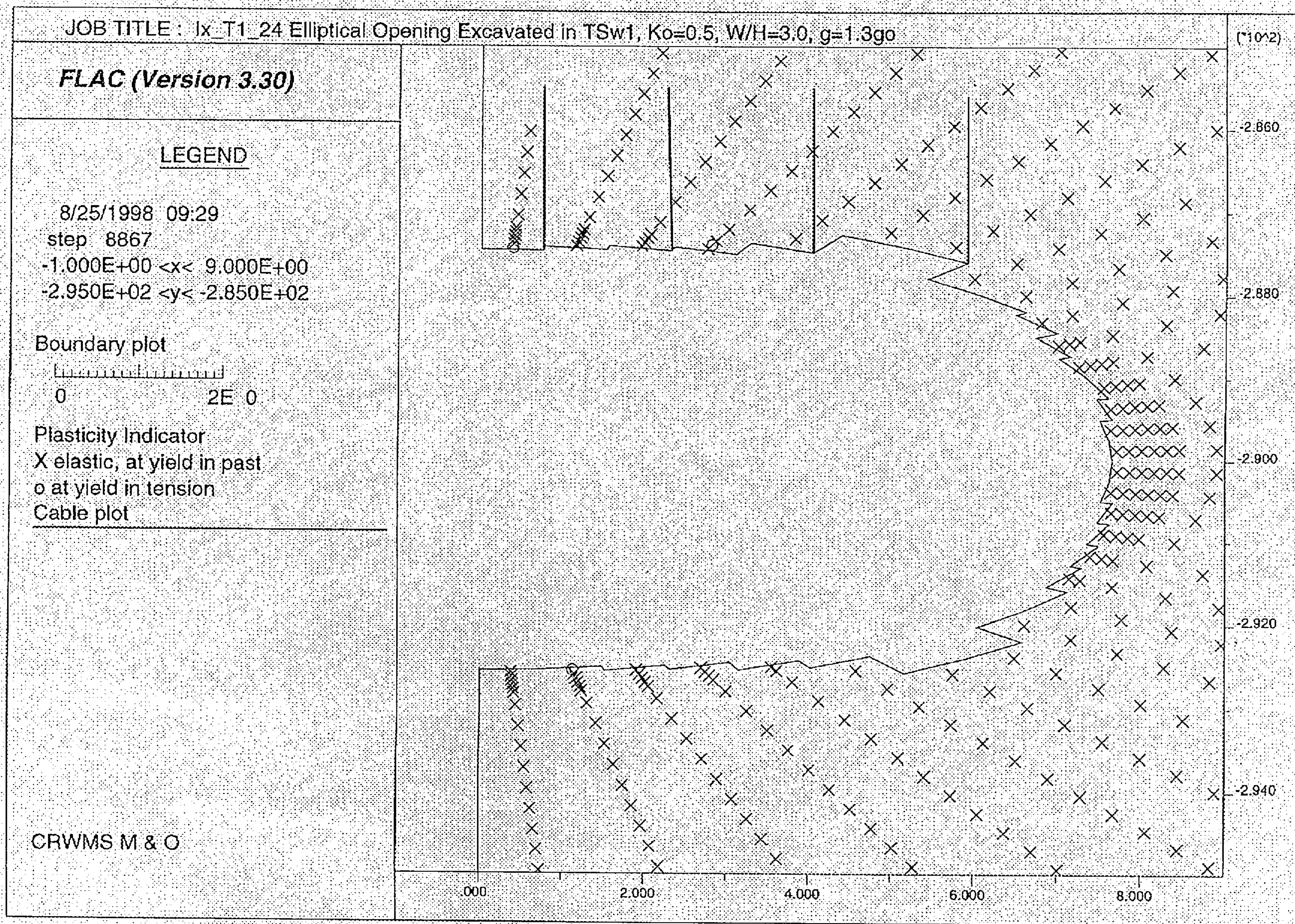

Figure 27. TSw1 Seismic load Plasticity diagram for 3 M opening with rockbolt reinforcement. (Close up view)

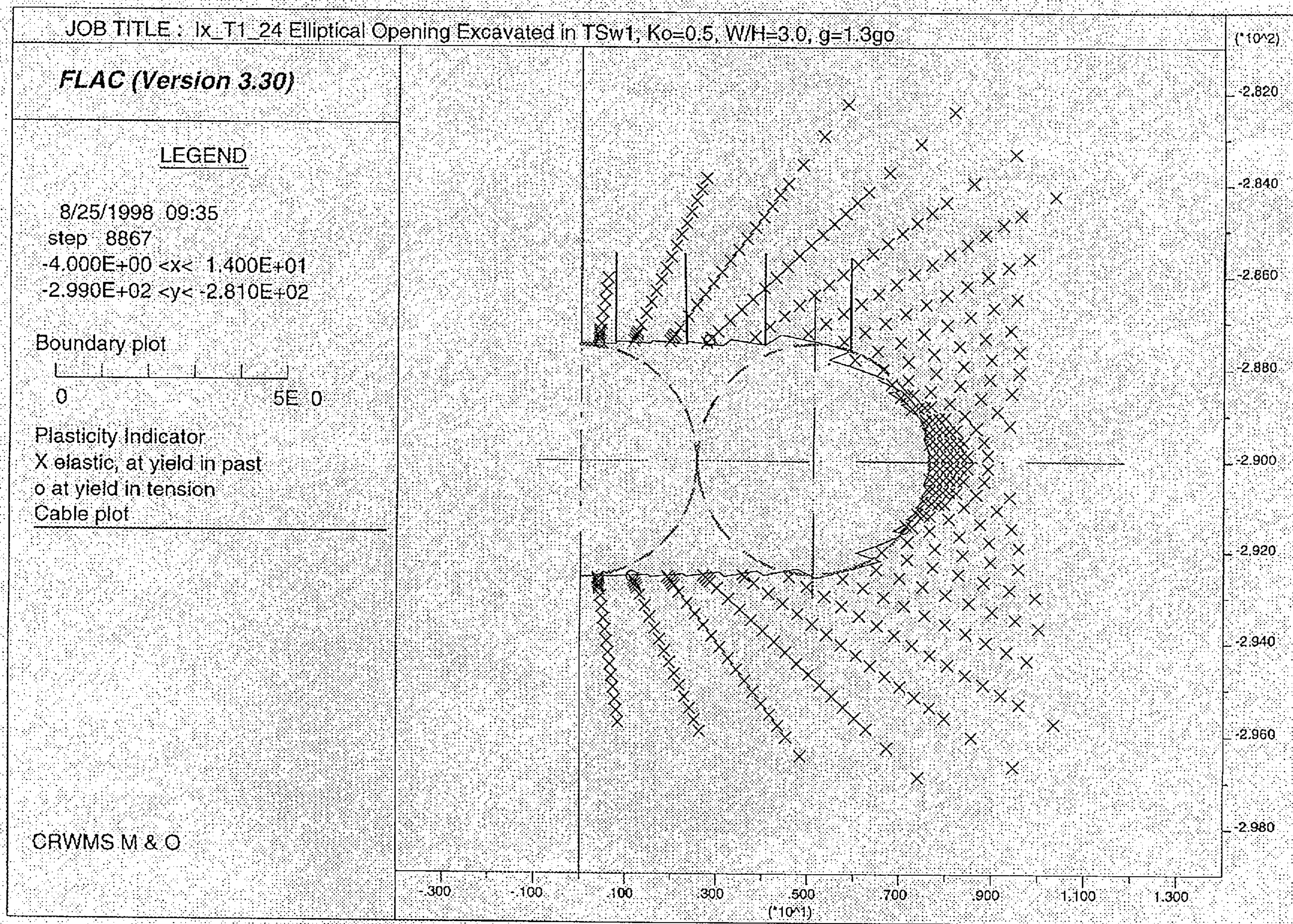

Figure 28. TSw1 Seismic induced Plasticity diagram for 3 M opening with rockbolt reinforcement. (Full view)

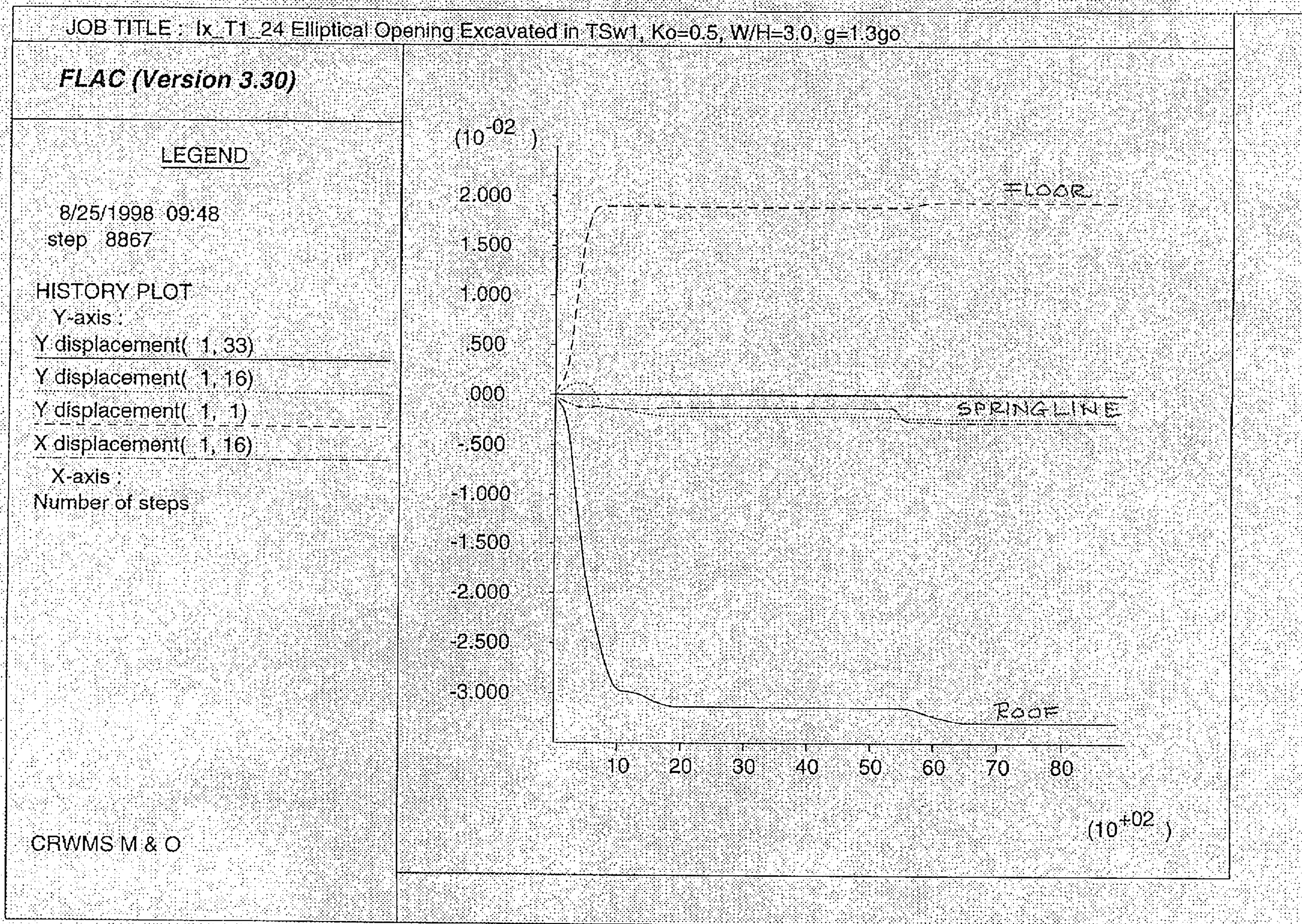

Figure 29. TSw1 Seismic Displacement Curve (deformation vs. model recalculation iterations.)

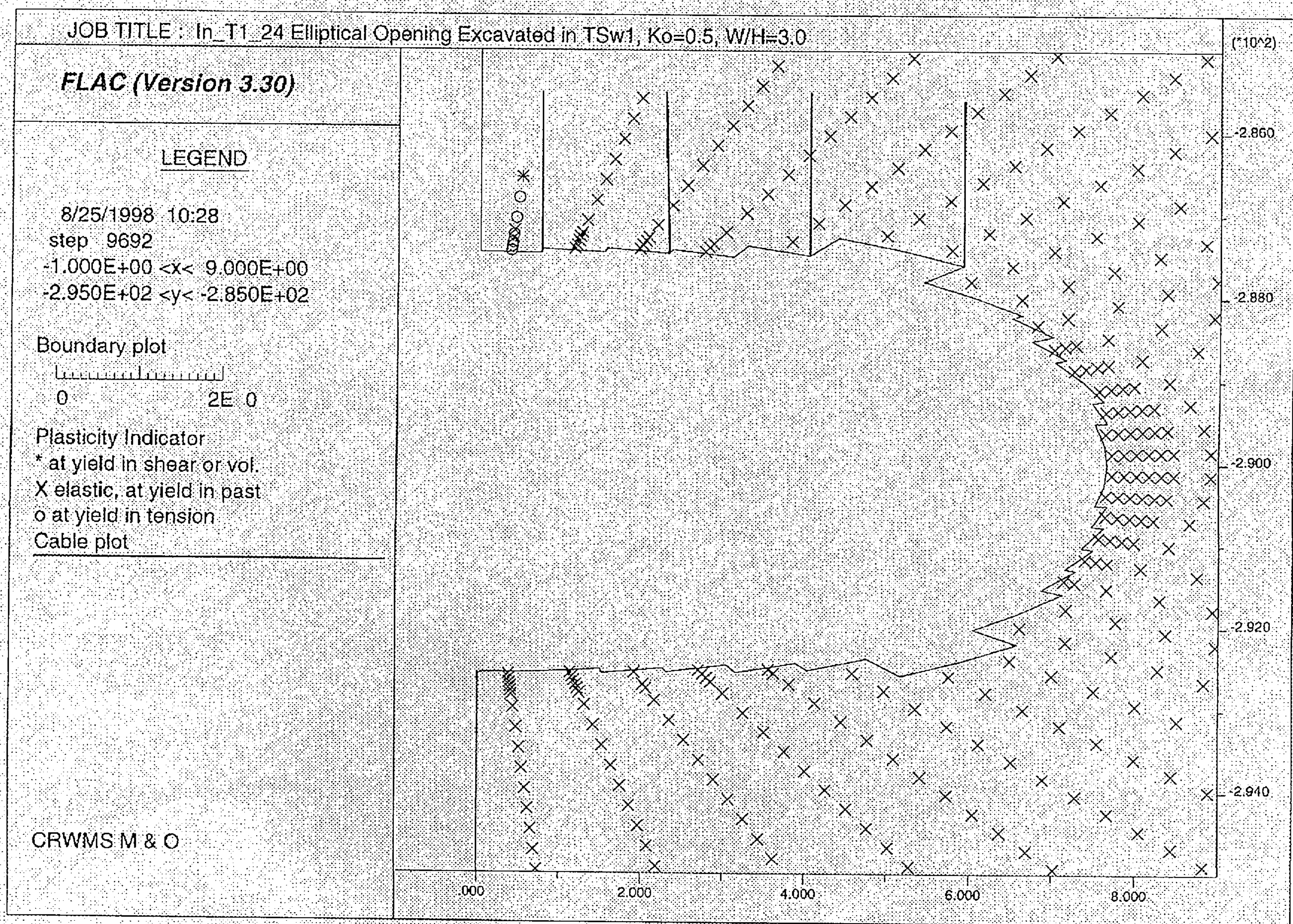

Figure 30. TSw2 Seismic load Plasticity diagram for 3 M opening with rockbolt reinforcement. (Close up view)

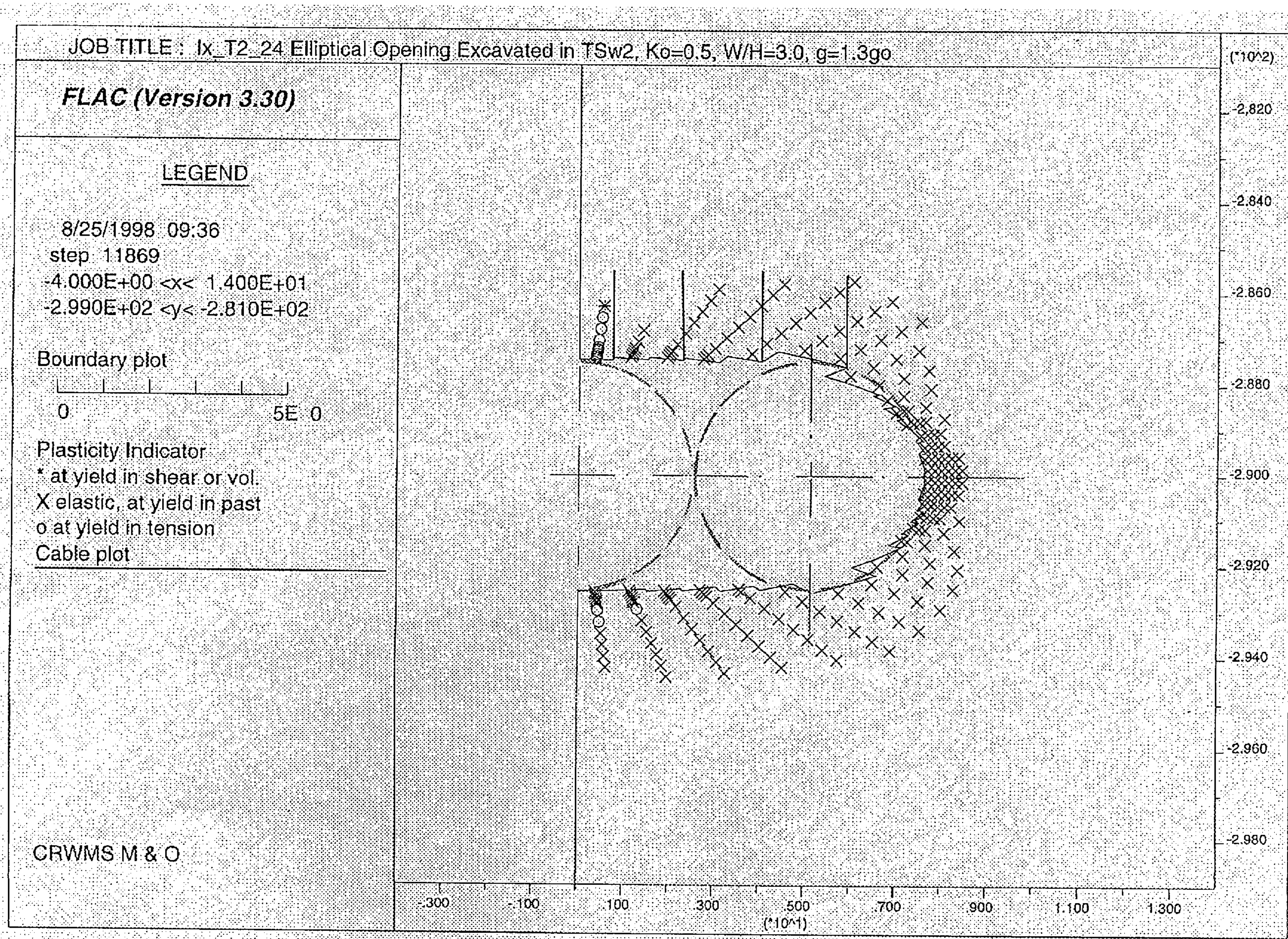

Figure 31. TSw2 Seismic induced Plasticity diagram for 3 M opening with rockbolt reinforcement.
(Full view)

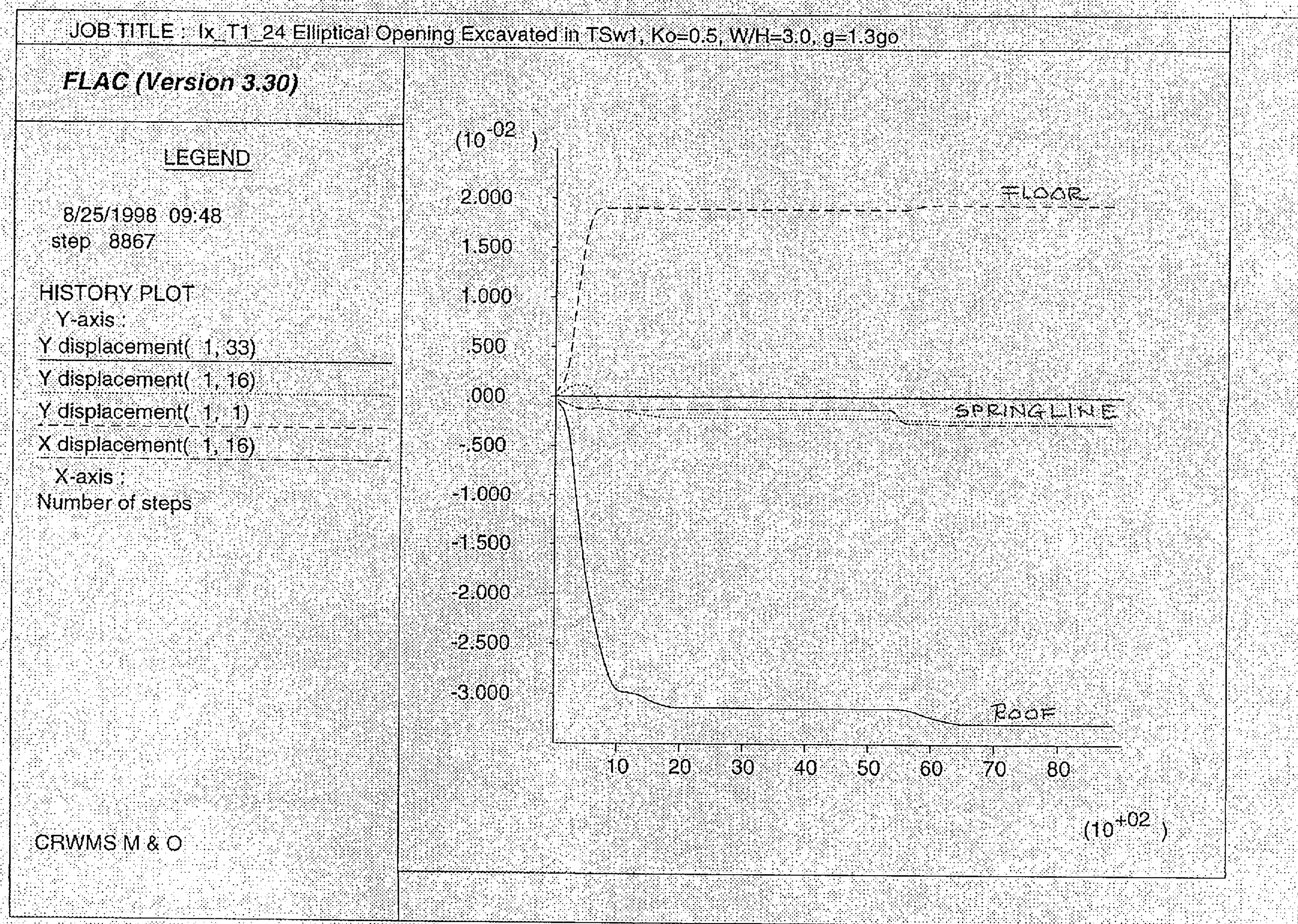

Figure 32. TSw2 Seismic inducted displacement curve (deformation vs. model recalculation iterations)

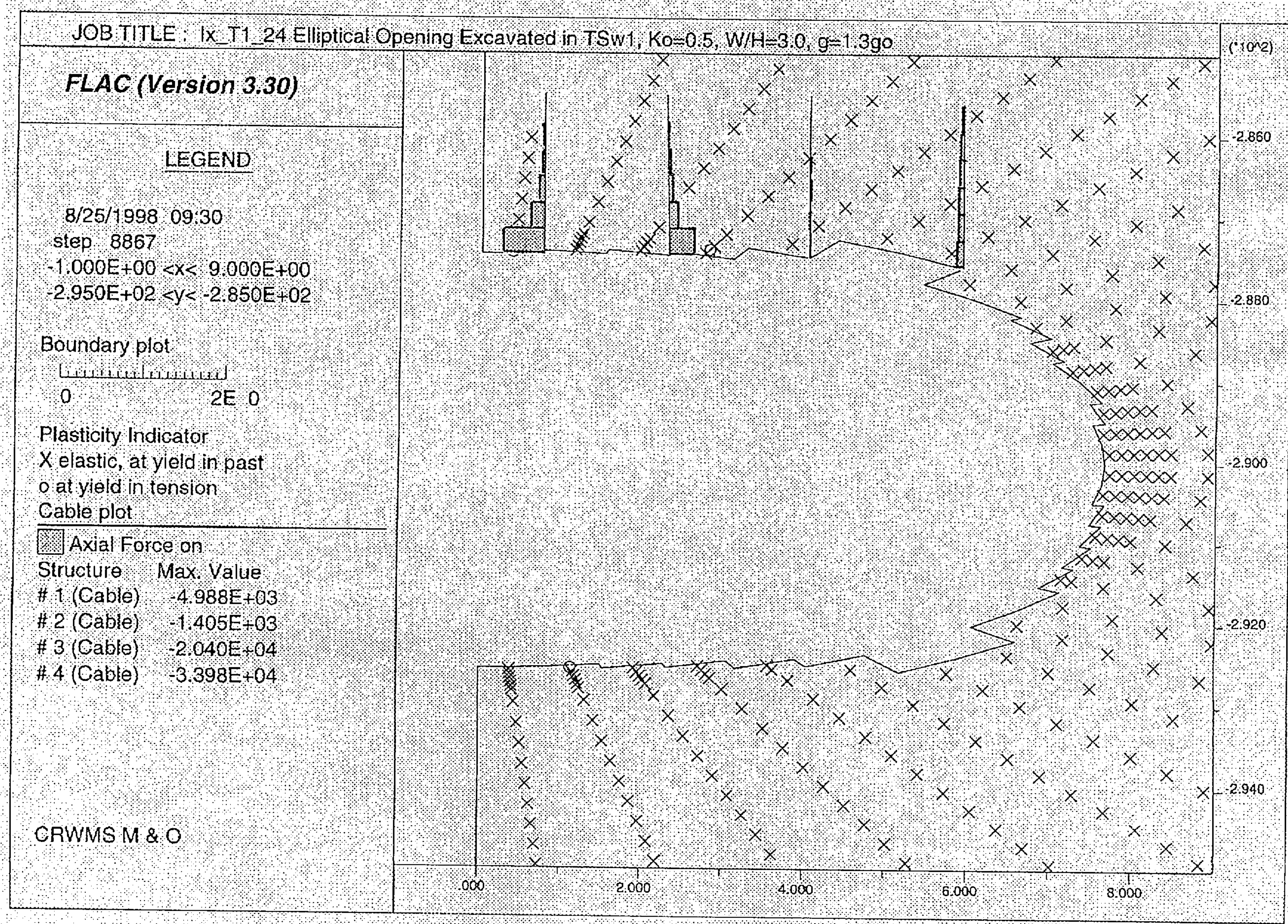

Figure 33. Axial force (Newtons) on Rockbolts for 3 M opening in TSw1 with seismic inducted loading.

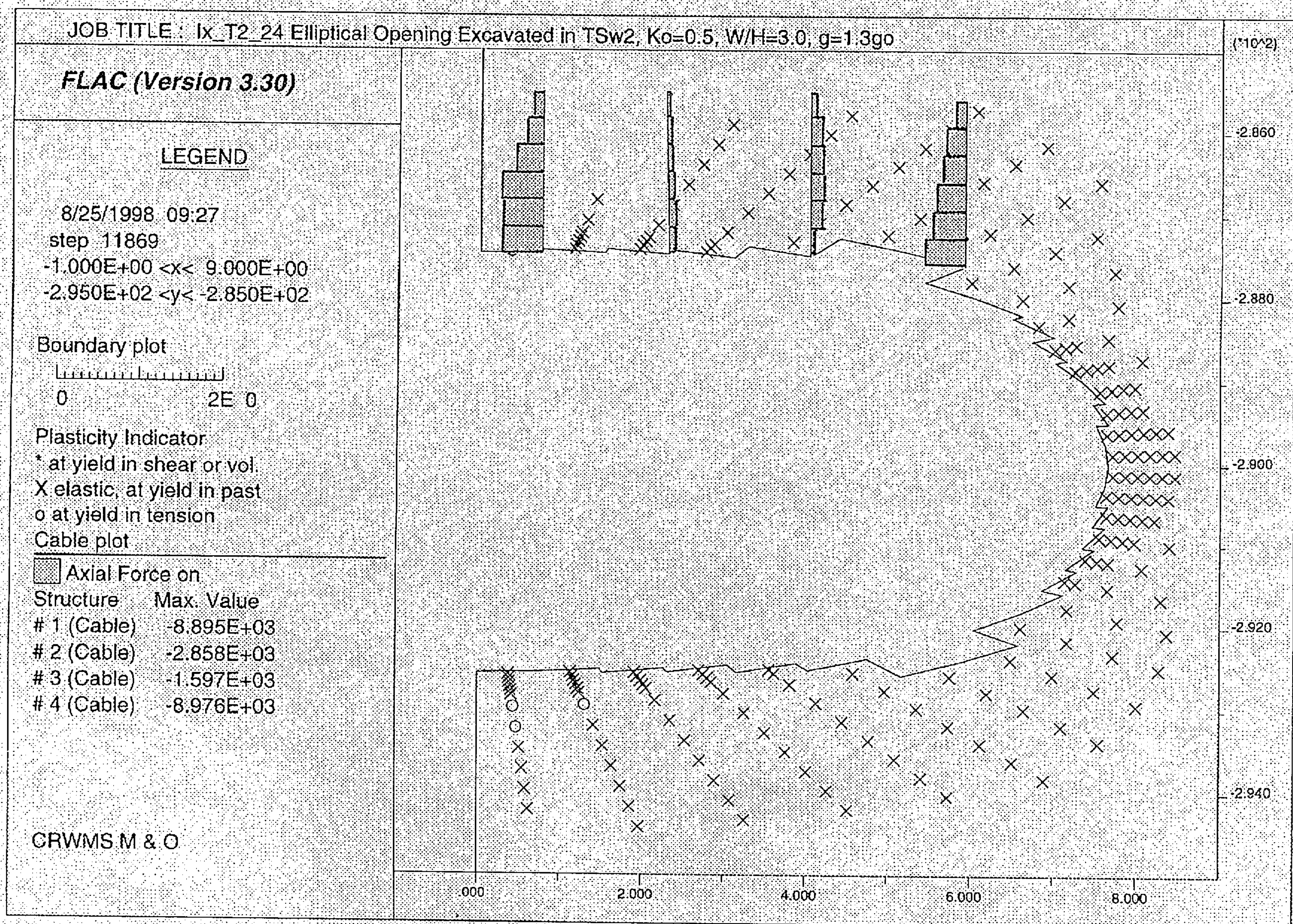

Figure 34. Axial force (Newtons) on Rockbolts for 3 M opening in TSw2 with seismic inducted loading.