BAZIAN STEAL FACTORY
S/S 132/11kV, 1x30/40MVA

EARTHING SYSTEM CALCULATION

Kurdistan Region

Sulaimani

May 2011

Contents:

1. Introduction

The project of earthing system is prepared in accordance with the requirements of the investor and Standard: IEEE 80 –2000 Guide for Safety in Substation Grounding.

Specific resistance is calculated on the basis of measured values of soil resistivity. The earthing system is designed so that the allowable touch and step voltages do not be exceeded.

The calculation is done using the software CDEG MultiGround TM SES - Safe Engineering Services & technologies ltd. Canada whose results are shown in Appendices.

The result shows that the touch and step voltages are within the permissible limits.

2. List of references and symbols

2.1 List of references

[1] IEEE Std 80-2000
IEEE Guide for Safety in AC Substation Grounding

[2] CDEG Software Package, 1998
Current Distribution, Electromagnetic Interference, Grounding and Soil Structure Analysis

2.2 List of symbols

f	Network frequency	Hz
U_n	Nominal system voltage	kV
I_{fs}	Single pole short circuit current	kA
I_{k3}	Symmetrical three phase short-circuit current	kA
I_{k1}	Single phase to earth short-circuit current	kA
I_g	Grid current discharged into grounding system	kA
R_g	Grounding system resistance	Ω
Z_1	Direct impedance	Zpu
Z_o	Homopolar impedance	Zpu
E_{step}	Step voltage	V
E_{touch}	Touch voltage	V
C_s	Reduction factor	
ρ_s	Surface resistivity (gravel area)	Ωm
h_s	Thickness of gravel	m
T_m	Maximum allowable temperature of buried conductor	°C
T_a	Ambient temperature	°C
K_o	Ko = Ao 1/Ao with temperature coefficient of resistivity at 0 ° C	°C
α_r	Thermal resistivity coefficient at the referent temperature	$°C^{-1}$
ρ_r	Resistivity of the grounding conductor at the referent soil temperature (20°C)	μΩ/cm
TCAP	Thermal capacity of copper	$J/cm^3/°C$
A_{min}	Minimal section of the conductor	mm^2

3. Soil resistivity measurements

Document already exists and it is Expected Soill Resistivity Study of Bazian Steal Factory S/S-132/11kV, 1X30/40MVA.

That document should be placed here (suggested).

The measured resistance values at particular site as well as computed output of soil resistivity results are enclosed in Appendices 1 to 4.

4. Earthing Calculation Details to IEEE Std. 80-2000

4.1. Grid Conductor Sizing

Required minimum earth grid conductor size:

$$A_{\min} = I_{fs} \cdot \sqrt{\frac{\frac{t_c \cdot \alpha_r \cdot \rho_r \cdot 10^4}{TCAP}}{\ln \cdot \left(1 + \frac{T_m - T_a}{K_0 + T_a}\right)}} \qquad (Eq.1)$$

Where:

Single pole short circuit current:	I_{fs} = 31,5 kA
Duration of fault current:	t_c = 0,5 s
Thermal resistivity coefficient at the referent temperature (20°C):	α_r = 0,00381 1/ ˚C
Resistivity of the grounding conductor at the referent soil temperature:	ρ_r = 1,78 μΩ·cm
Thermal capacity of copper:	TCAP=3,42J/cm³/˚C
Max allowable temperature for brazed joint:	T_m = 1084 ˚C
Ambient temperature:	T_a = 40 ˚C
K_o=1/A_o at 0°C	K_0 = 235

Therefore:

$$A = 31{,}5 \cdot \sqrt{\frac{\frac{0{,}5 \cdot 0{,}00381 \cdot 1{,}78 \cdot 10^4}{3{,}42}}{\ln \cdot \left(1 + \frac{1084 - 40}{242 + 40}\right)}} = 80{,}4\ mm^2$$

Note:

According to customer's specification earth grid conductor shall not be less than 120 sqmm, therefore the earth grid conductor size to be used is 120 sqmm.

4.2. Calculation od current flowing between ground grid and earth

$$I_{k3} = \frac{1{,}1 \cdot U_n}{\sqrt{3} \cdot |Z_1|} = 31500\,(A) \qquad \text{(Eq.2)}$$

Where:

Symmetrical three phase short-circuit current (r.m.s.)	I_{k3}=31.5 kA
Nominal system voltage	U_n=132 kV
Positive sequence impedance at the fault location	Z_1

$$I_{k1} = \frac{\sqrt{3} \cdot 1{,}1 \cdot U_n}{|Z_1 + Z_2 + Z_0|} = \frac{3 \cdot I_{k3}}{2 + \left| Z_0 / Z_1 \right|} \qquad (Eq.3)$$

Single phase to earth fault current	I_k
Ratio of zero-sequence impedance to positive sequence impedance to network as viewed from fault location in case of solidly earthed neutral	$|Z_0/Z_1|=3$

Therefore,

$$I_{k1} = \frac{3 \times 31500}{2+3} = 18900\,(A)$$

Earth wires of coupled transmission lines or cable sheets connected to the earthing system carry out part of the fault current as result of magnetic coupling. This effect is accounted fir by reduction factor S_F.

$$I_g = S_F \times I_{k1} \qquad (Eq.4)$$

Where:

Grid current discharged into grounding system	I_g
Current division dactor that flows between ground grid and surrounding earth	S_f=0,6
Phase to earth fault current	I_{k1}=18900 (kA)

Therefore, grid current:

$$I_g = 0{,}6 \times 18900 = 11350\ (A)$$

4.3. Tolerable Step and Touch Voltages

4.3.1. Reduction Factor Due to Resistivity of Crush Rock Surface

120 mm thick layer of crushed rock is spread on the earth's surface above ground grid in the switchyard to increase the contact resistance between the soil and the feet

of the personnel in the substation. C_s-reduction factor for derating the nominal value of surface layer resistivity determined as follows:

$$C_s = 1 - 0.09 \cdot \left[\frac{1 - \frac{\rho}{\rho_s}}{2 \cdot h_s + 0.09} \right] \qquad (Eq.5)$$

Where:

Earth resistivity ρ = * Ωm

Crush rock resistivity ρ_s = 3000 Ωm

Thickness of the crushed rock surface layer h_s = 0.12 m

* Value to be obtained from the earth resistivity calculation (See Appendix 3).

4.3.2. Touch and Step Voltage Criteria

The safety of a person depends on preventing the critical amount of shock energy from being absorbed before the fault is cleared and system de-energized. The maximum driving voltage of any accidental circuit should not exceed the limits defined below. For touch and step voltage the limits defined in IEEE Std 80-2000 are:

For a 50 kg body weight:

$$E_{touch} = \frac{1000 + 1.5 \cdot C_s \cdot \rho_s}{\sqrt{t_s}} \cdot 0.116 \qquad (Eq.6)$$

$$E_{step} = \frac{1000 + 6 \cdot C_s \cdot \rho_s}{\sqrt{t_s}} \cdot 0.116 \qquad (Eq.7)$$

For a 70 kg body weight:

$$E_{touch} = \frac{1000 + 1.5 \cdot C_s \cdot \rho_s}{\sqrt{t_s}} \cdot 0.157 \qquad (Eq.6)$$

$$E_{step} = \frac{1000 + 6 \cdot C_s \cdot \rho_s}{\sqrt{t_s}} \cdot 0.157 \qquad (Eq.7)$$

Where:

Shock duration in sec (exposure time) t_s= 0,35 s

Resistivity of the surface material ρ_s = 3000 Ωm

Reduction factor C_s

The safe touch and step voltages to be used for verification of grounding design is calculated using MALT engineering module of CDEGS computer program. In the Appendix 7 the computer printouts are presented.

5. Principal results of the CDEGS software calculations

Configuration of the substation's grounding grid can be seen in Appendix 6.

5.1 Resistance of Electrode System (See Appendix 7)

$$R_g = 0.31847 \quad (\Omega)$$

Conclusion: The resistance of the electrode system is less than 1 Ω, so the system satisfies principal IEEE Std 80-2000 condition.

5.2 Maximaum value od Grand Potential Rise GPR (See Appendices 7 and 15)

$$GPR = I_g \cdot R_g = 3518.7 \quad (V)$$

5.3 Touch voltage (See Appendix 8)

Allowed Touch Voltage E_{touch} = 953.8 (V)

Conclusion: The maximum touch voltages within the switchyard (see Appendix 9), around the transformer (see Appendix 10), entry gates (see Appendix 11), nearby substation fence (see Appendix 12) and capacitor banks (see Appendix 13) are below the safety limit (allowable values).

5.4 Step Voltage (See Appendix 8)

Allowed Touch Voltage E_{step} = 3052,8 (V)

Conclusion: The maximum step voltages in the substation (see Appendix 14) are below the safety limits.

6. Appendices

Appendix 1: Axis layout of the soil resistivity measurements
Appendix 2: Soil resistivity measurements
Appendix 3: Results of the soil resistivity measurements
Appendix 4: Specific soil resistivity curve
Appendix 5: Cross-section of the grounding conductor
Appendix 6: Configuration of the grounding mesh
Appendix 7: Principal results of the CDEGS software calculations
Appendix 8: Touch and step voltage results
Appendix 9: Touch voltages within the switchyard
Appendix 10: Touch voltages in the transformer area
Appendix 11: Touch voltages around the entry gates
Appendix 12: Touch voltages of the substation fence
Appendix 13: Touch voltages around the capacitor banks
Appendix 14: Step voltage within the substation
Appendix 15: Scalar potentials (3D potential distribution) GPR-Grand Potential Rise
Appendix 16: Maximum touch voltages that appear within the substation (Layout)
Appendix 17: Maximum step voltages that appear within the substation (Layout)

APPENDIX 1: Axis layout of the soil resistivity measurements

Location

The studied area is bounded by latitudes (35° 07' 45" - 35° 07' 47") and longitude (45° 40' 36"- 45° 40' 40"). The elevation of the area is ranging from 600 to 602 m above sea level as shown in Fig (2).

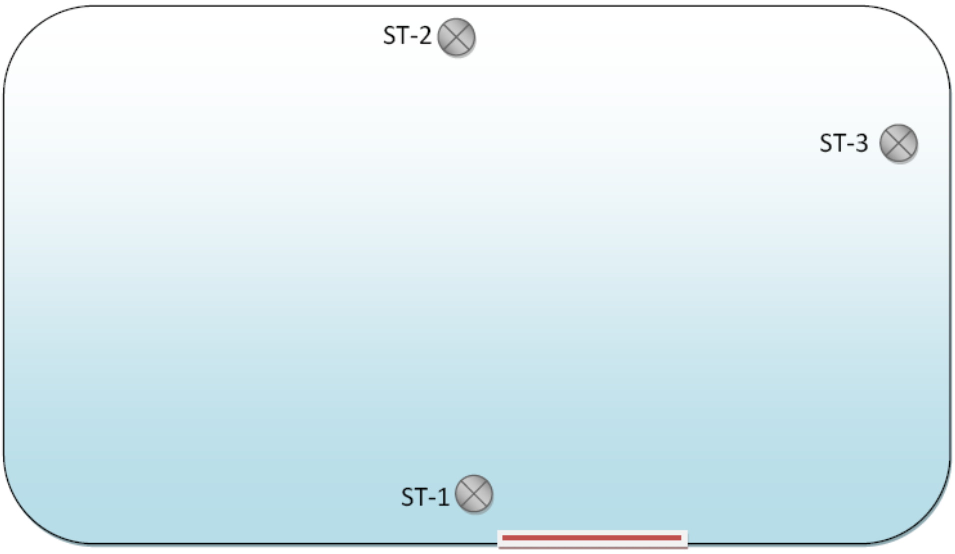

Fig (2) Location map of the investigated area.

APPENDIX 2: Soil resistivity measurements

Project: Bazian Steel Factory S/S 132/11kV, 1x30/40 MVA

Date: April 2011

Coordinate	x	y	z
a	Resistivity St-1 (Ohm.m)	Resistivity St-2 (Ohm.m)	Resistivity St-3 (Ohm.m)
1.0	85.008	79.65257	83.22914
1.5	57.85749	56.45829	57.36814
2.2	52.16137	56.11358	53.68251
3.3	34.15519	38.88249	36.34149
4.6	32.54881	29.17451	29.57931
6.8	33.11597	25.50143	21.98522
10	34.75811	31.05606	23.16537
14.1	39.6214	33.52021	31.48885
Latitude Longitude Elevation	35 07 45.8 45 40 36.4 600	35 07 46.5 45 40 38.8 600	35 07 45.3 45 40 39.1 601

APPENDIX 3: Results of the soil resistivity measurements

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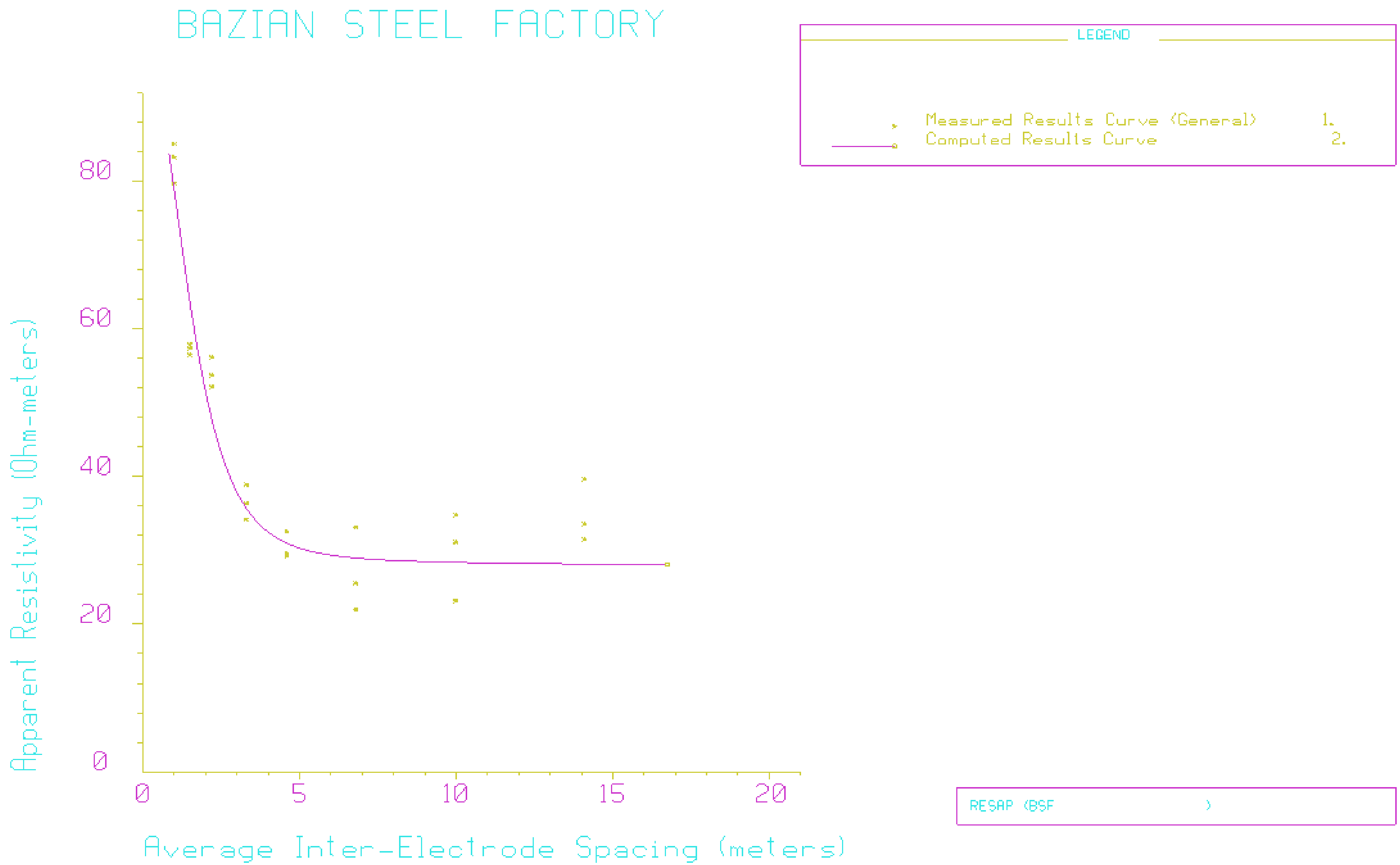
=========< R E S I S T I V I T Y  ( SYSTEM INFORMATION SUMMARY ) >=========

Run ID......................................: BSF
System of Units ............................: Meters
Soil Type Selected..........................: Multi-Layer Horizontal
RMS error between measured and calculated...: 13.741 in percent resistivities
```

Layer Number	<--- LAYER CHARACTERISTICS --> Resistivity (ohm-m)	Thickness (Meters)	Reflection Coefficient (p.u.)	Resistivity Contrast Ratio
1	infinite	infinite	0.0	1.0
2	94.31239	1.084724	-1.0000	0.94312E-18
3	25.34191	0.9349011	-0.57641	0.26870
4	27.93612	infinite	0.48692E-01	1.1024

APPENDIX 4: Specific soil resistivity curve



APPENDIX 5: Cross-section of the grounding conductor

Ampacity Function Report

CDEGS Conductor Ampacity Calculation (per IEEE Standard 80)

Computation Results:

Minimum Conductor Size:
162,3677 MCM
82,2531 sq. mm
0,2015 in (radius)
5,1169 mm (radius)

Input Data:

Symmetrical RMS Current Magnitude: 31,5 kA

Maximum Fault Duration: 0,5 s

Ambient Temperature: 40 °C

Maximum Allowable Temperature: 1084,0000 °C (fusing temperature)

Conductor Type: Copper, commercial hard drawn (97% conductivity)

Decrement Factor: 1,0313
X/R: 10
Frequency: 50 Hz

Material Constants of Conductor:

Name: Copper, commercial hard drawn (97% conductivity)

Reference Temperature for Material Constants: 20,0000 °C

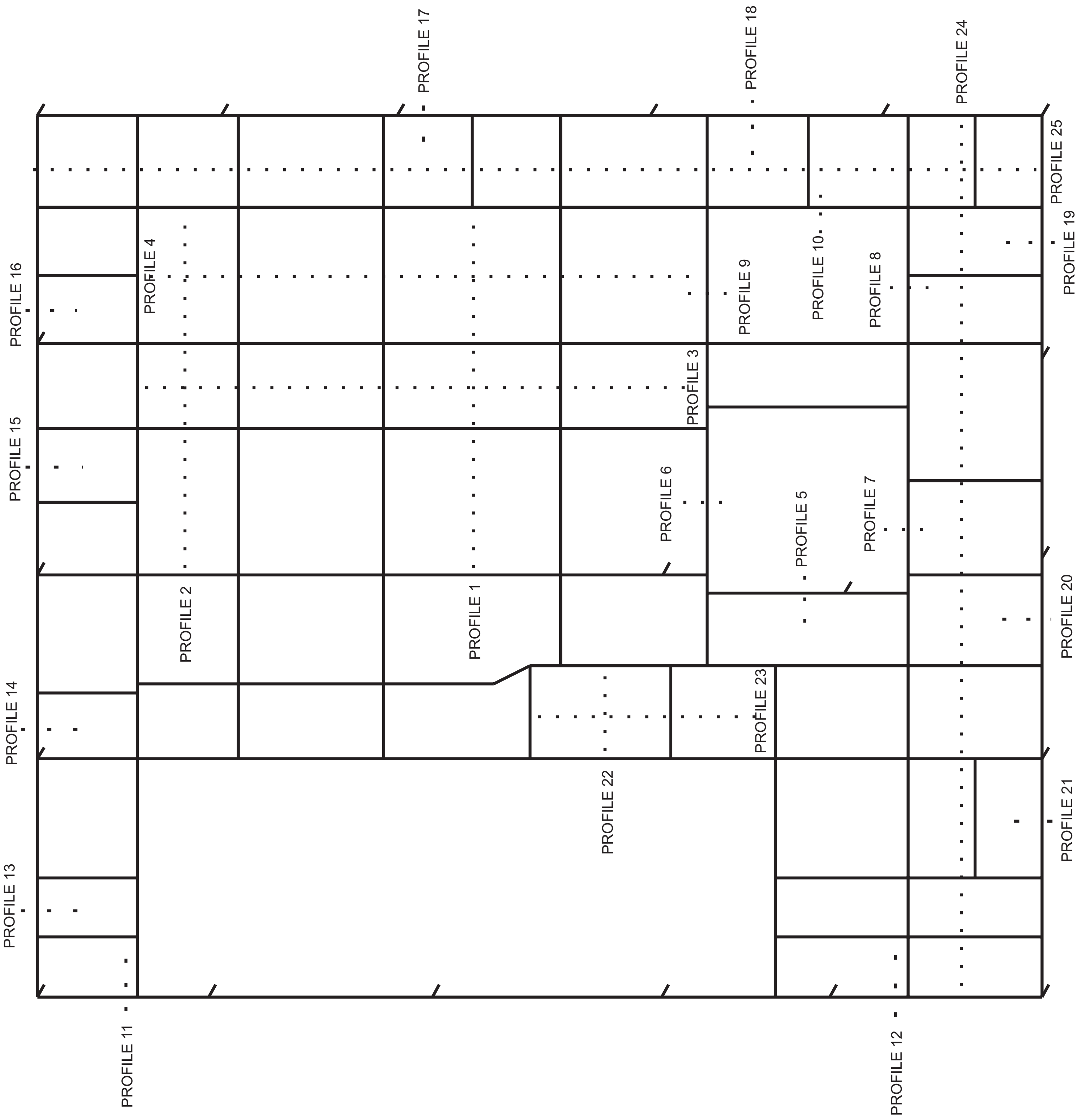
Thermal Coefficient of Resistivity at Reference Temperature: 0,00381 1/°C

Fusing Temperature of Conductor: 1084,0000 °C

Resistivity of Conductor at Reference Temperature: 1,7800 μΩ·cm

Thermal Capacity per Unit Volume: 3,4200 J/cm3 · °C

APPENDIX 6: Configuration of the grounding mesh (Touch and Step Voltages Profiles)



APPENDIX 7: Principal results of the CDEGS software calculations

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===========< G R O U N D I N G ( SYSTEM INFORMATION SUMMARY ) >===========

Run ID.....................................: Bazian Steel Factory
System of Units ...........................: Metric
Earth Potential Calculations...............: Multiple Electrode Case
Mutual Resistance Calculations.............: NO
Type of Electrodes Considered..............: Both Main + Buried Electrode
Soil Type Selected.........................: Multi-Layer Horizontal
SPLITS/FCDIST Scaling Factor...............: 11.350


    MULTI-LAYER EARTH CHARACTERISTICS USED BY PROGRAM
    -------------------------------------------------

    Common layer height                        :  0.183602     METERS


    LAYER  TYPE  REFLECTION    RESISTIVITY     HEIGHT
     No.         COEFFICIENT   (ohm-meter)     METERS
    ----- ------ ------------- ------------- -------------
      1   Air     0.00000      0.100000E+21  0.100000E+11
      2   Soil  -0.999990       94.3124       1.10161
      3   Soil  -0.576415       25.3419      0.918011
      4   Soil   0.486921E-01   27.9361      0.100000E+11


CONFIGURATION OF MAIN ELECTRODE
===============================

Original Electrical Current Flowing In Electrode..:   1000.0     amperes
Current Scaling Factor (SPLITS/FCDIST/specified)..:   11.350
Adjusted Electrical Current Flowing In Electrode..:   11350.     amperes
Number of Conductors in Electrode.................:   37
Resistance of Electrode System....................:   0.31847     ohms


SUBDIVISION
===========
Grand Total of Conductors After Subdivision.:  1858


EARTH POTENTIAL COMPUTATIONS < Returns & Buried Structures >
============================

Number of Return Grounds................:     0
Number of Buried Structures.............:     1


MODULE NAME : BURIED STRUCTURES
================================

Number of Buried Structures.............:     1
Structure   No. of    Start    End
Number   Conductors < Conductor No >
--------- ---------- ------- --------
     1         20     1859    1878
```

EARTH POTENTIAL COMPUTATIONS

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Main Electrode Potential Rise (GPR).....:       3518.7     volts
Return Electrode Potential Rise (GPR)...:       0.0000     volts
(based on two representative points)

Buried Metallic Structure No.1 Potential Rise (GPR).....:  2394.8 volts

TOTAL BURIED LENGTH OF MAIN ELECTRODE:           872.344 METERS
TOTAL BURIED LENGTH OF RETURN ELECTRODE:           0.000 METERS
TOTAL BURIED LENGTH OF METALLIC STRUCTURES:       30.000 METERS
TOTAL BURIED LENGTH OF GROUNDING NETWORK:        902.344 METERS
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APPENDIX 8: Touch and step voltages results

>> Safety Calculations Table

System Frequency..........................(Hertz).: 50.000
System X/R..: 10.000
Surface Layer Thickness....................(m)...: 0.12000
Number of Surface Layer Resistivities...............: 10
Starting Surface Layer Resistivity..........(ohm-m).: NONE
Incremental Surface Layer Resistivity.......(ohm-m).: 500.00
Equivalent Sub-Surface Layer Resistivity....(ohm-m).: 94.312

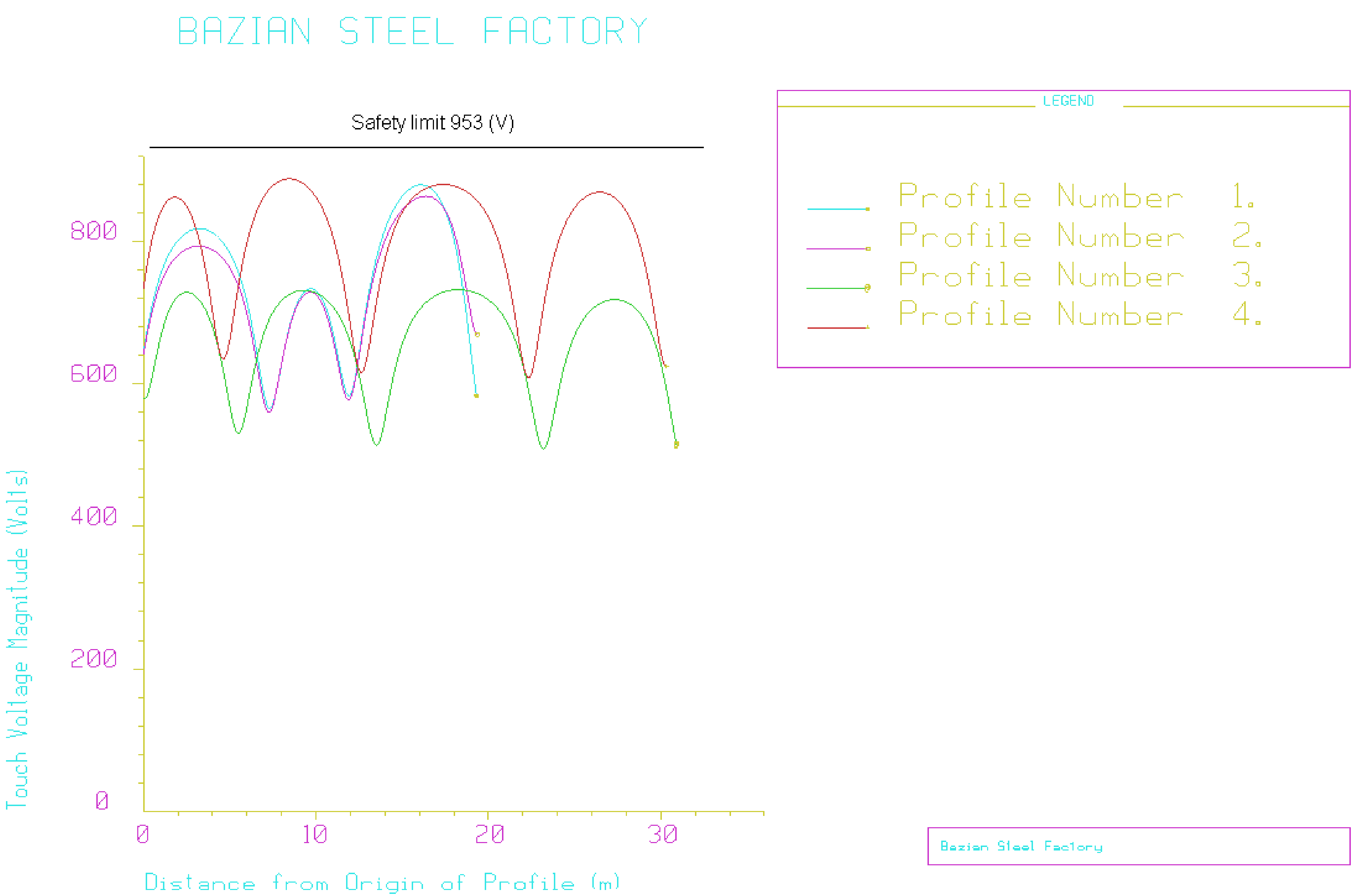
Body Resistance Calculation..........: IEEE 80
Fibrillation Current Calculation.....: IEEE 80 (70kg)
Foot Resistance Calculation..........: IEEE (Std.80) Series Expansion Cs
User Defined Extra Foot Resistance: 0.0000 ohms

Fault Clearing Time (sec)	0.125	0.350	0.500
Decrement Factor	1.120	1.044	1.000
Fibrillation Current (amps)	0.396	0.254	0.222
Body Resistance (ohms)	1000.00	1000.00	1000.00

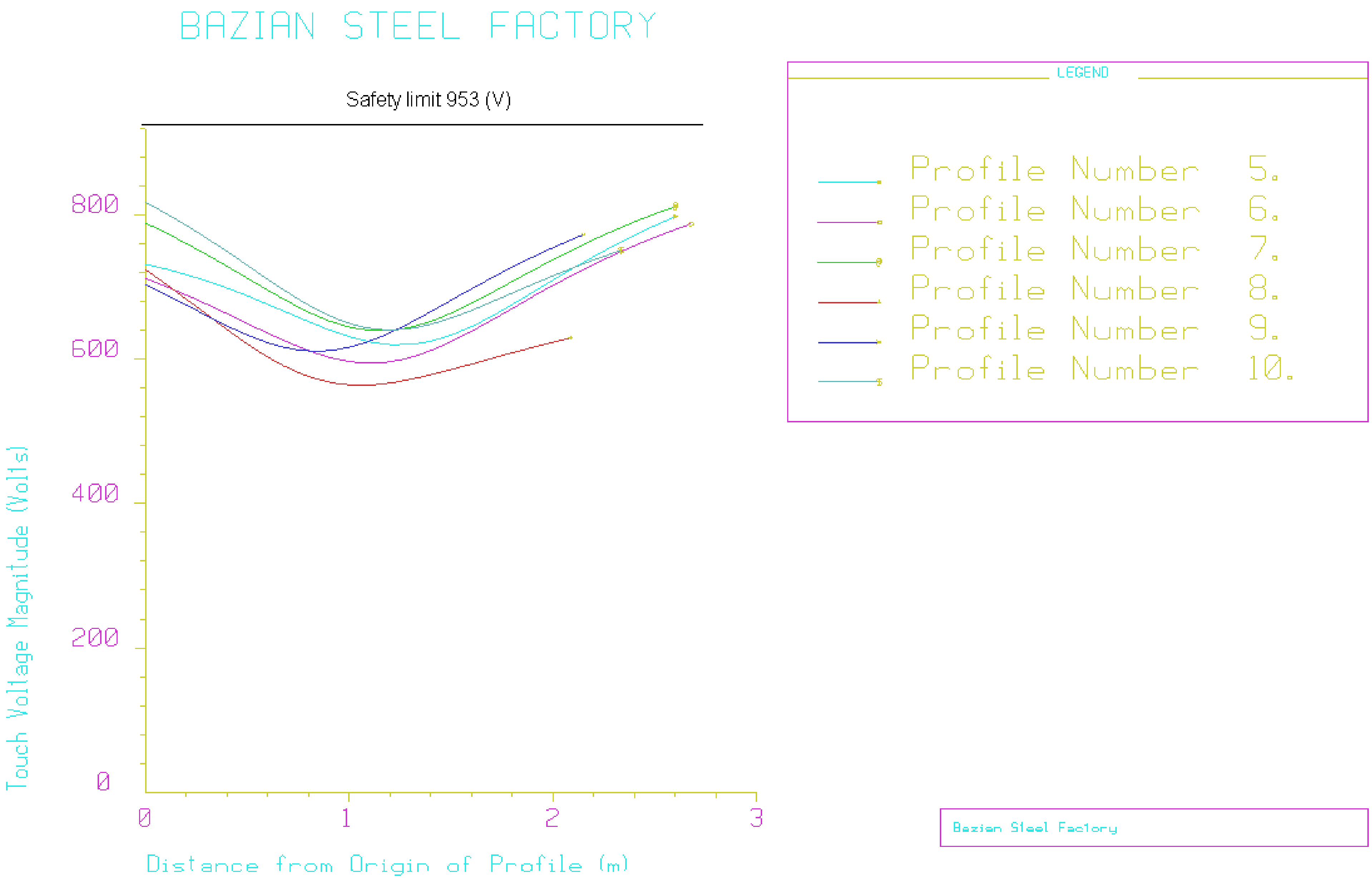
SURFACE LAYER RESIST-IVITY (OHM-M)	FAULT CLEARING TIME 0.125 sec. STEP VOLTAGE (VOLTS)	0.125 sec. TOUCH VOLTAGE (VOLTS)	0.350 sec. STEP VOLTAGE (VOLTS)	0.350 sec. TOUCH VOLTAGE (VOLTS)	0.500 sec. STEP VOLTAGE (VOLTS)	0.500 sec. TOUCH VOLTAGE (VOLTS)	FOOT RESIST-ANCE: 1 FOOT (OHMS)
NONE	630.2	454.9	403.8	291.5	352.9	254.8	294.7
500.0	1232.3	605.4	789.8	388.0	690.2	339.1	1054.2
1000.0	1942.1	782.9	1244.6	501.7	1087.6	438.4	1949.3
1500.0	2648.4	959.4	1697.3	614.9	1483.2	537.3	2840.1
2000.0	3353.8	1135.8	2149.3	727.9	1878.2	636.1	3729.7
2500.0	4058.8	1312.0	2601.1	840.8	2273.1	734.8	4618.8
3000.0	4763.6	1488.3	***3052.8**	***953.8**	2667.8	833.5	5507.7
3500.0	5468.4	1664.5	3504.5	1066.7	3062.5	932.1	6396.5
4000.0	6173.2	1840.6	3956.2	1179.6	3457.2	1030.8	7285.4
4500.0	6878.0	2016.9	4407.9	1292.5	3851.9	1129.5	8174.3

* NOTE * Safety limit

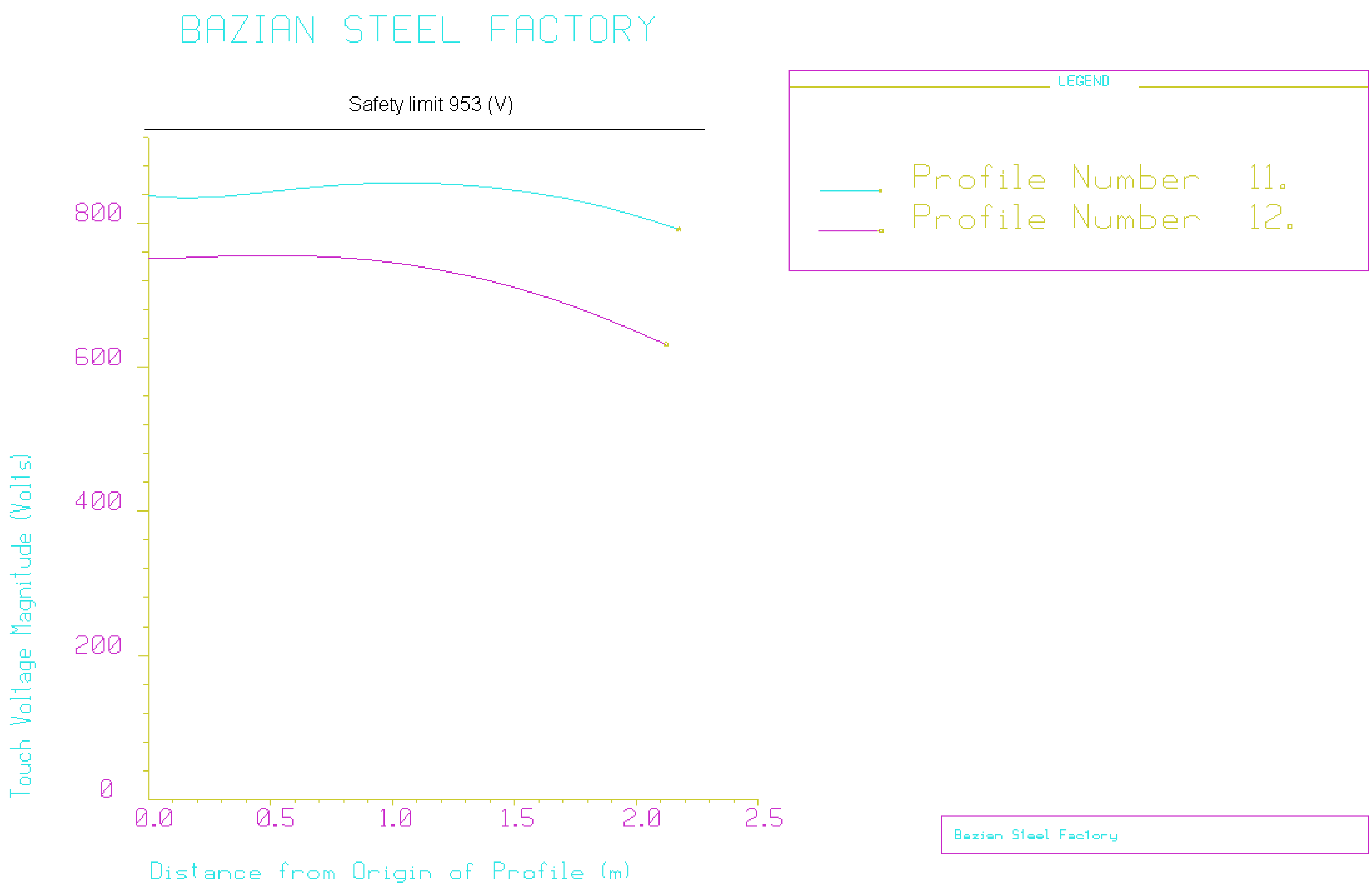
APPENDIX 9: Touch voltages within the switchyard



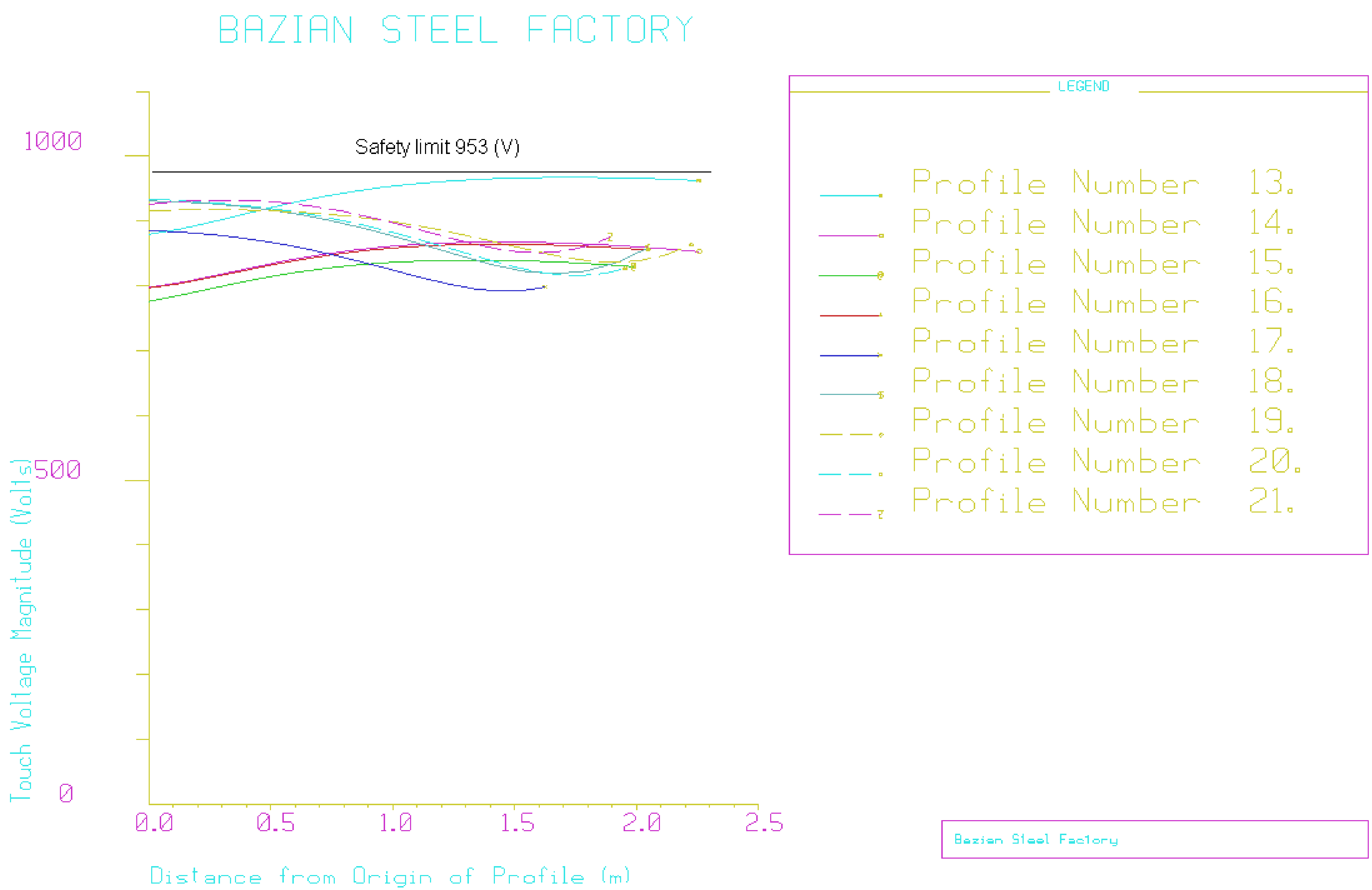
APPENDIX 10: Touch voltages in the transformer area



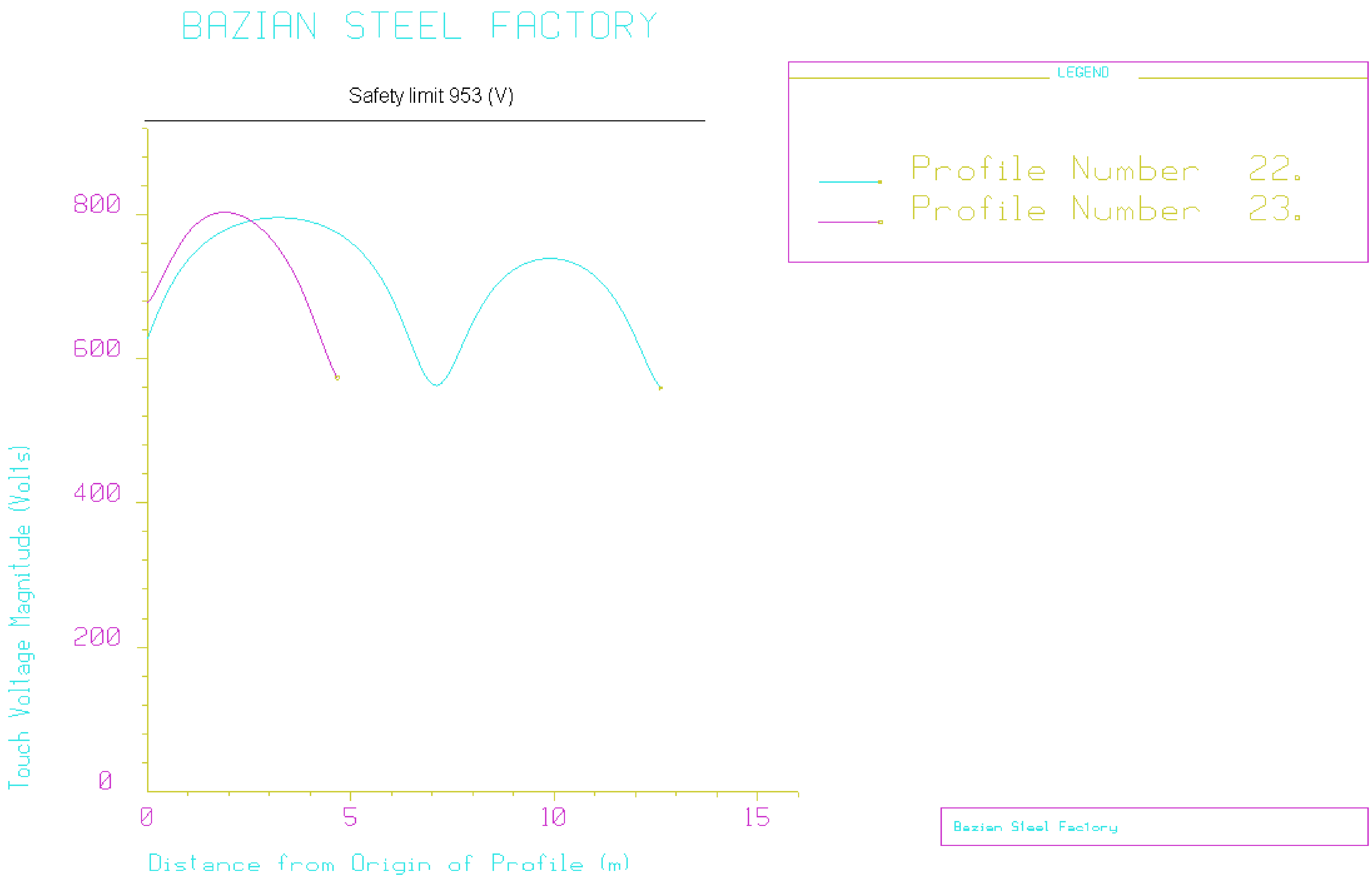
APPENDIX 11: Touch voltages around the entry gates



APPENDIX 12: Touch voltages around the substation fence

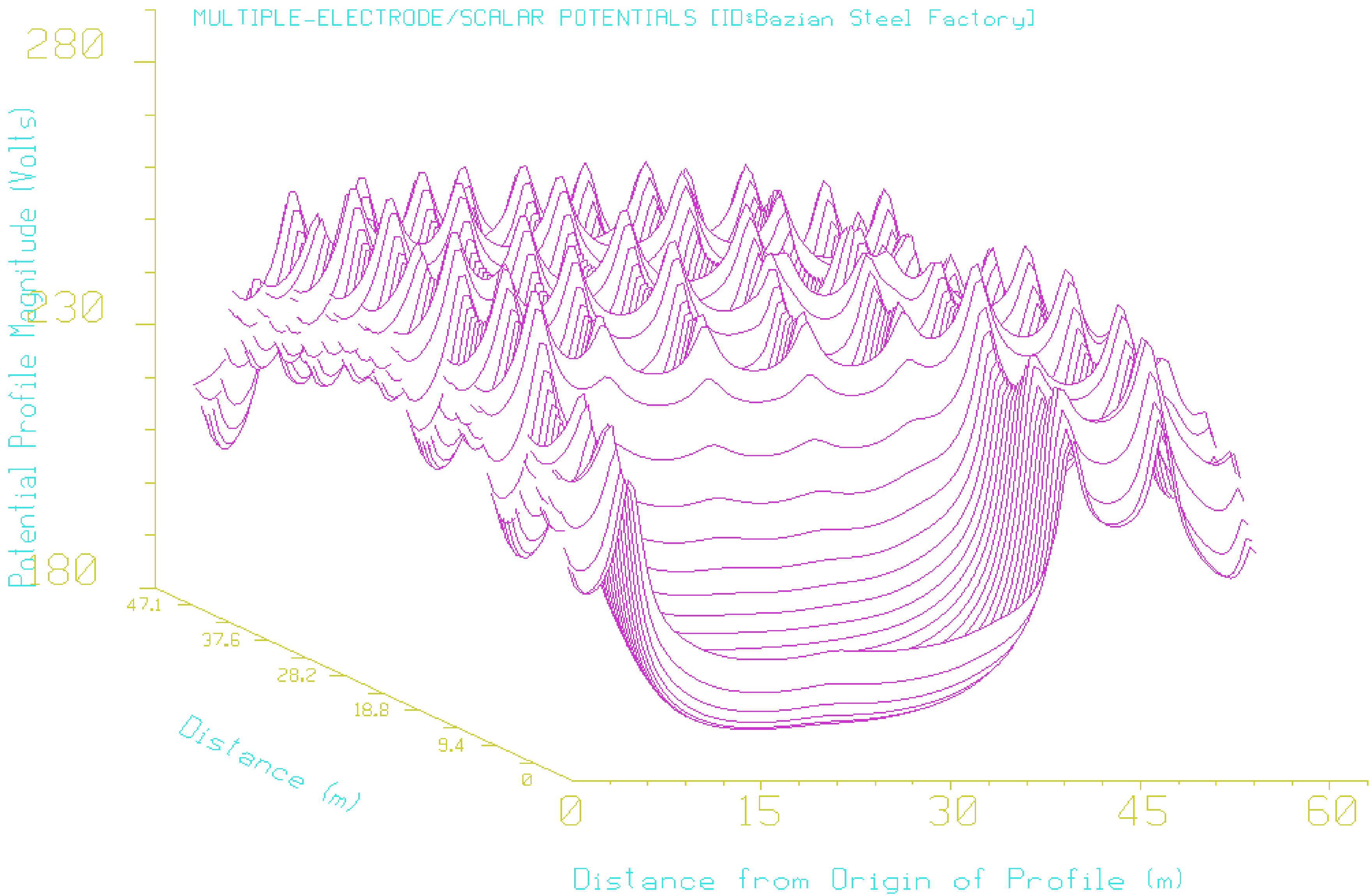


APPENDIX 13: Touch voltages around the capacitor banks

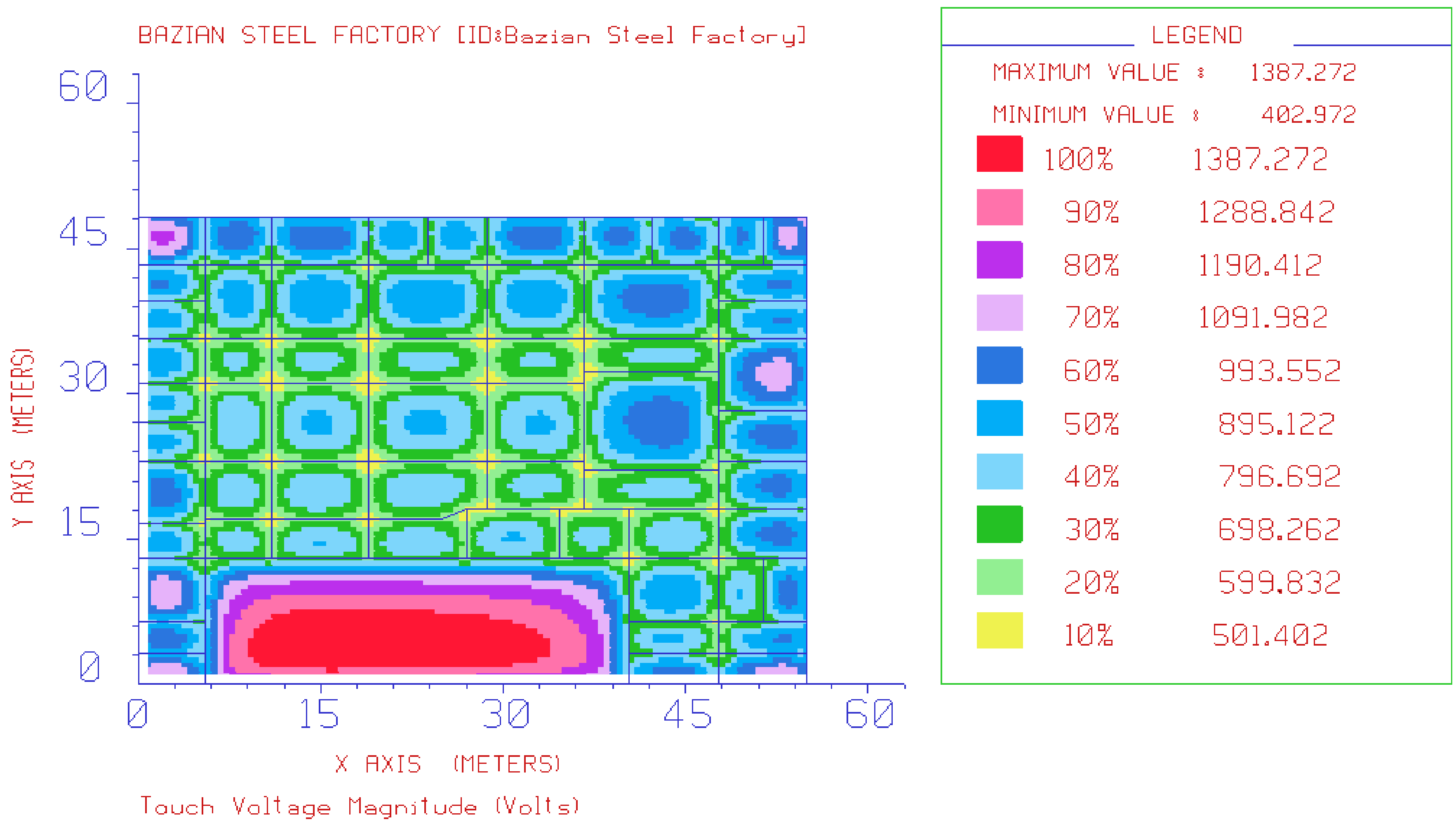


APPENDIX 14: Step voltages within the substation

APPENDIX 15: Scalar potentials (3D potential distribution) GPR-Grand Potential Rise



APPENDIX 16: Maximum touch voltages that appear within the substation (Layout)



APPENDIX 17: Maximum step voltages that appear within the substation (Layout)