Paper No.
04103

CORROSION2004

EVALUATION OF IMPRESSED CURRENT SYSTEM ON FPSO'S BY USE OF CP COMPUTER MODELLING

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ABSTRACT

During the 90's the floating production systems have been more and more common on the different oil fields worldwide. FPSOs are new built "tankers" or modified existing "tankers". Cathodic protection of an FPSO is in most cases based on IC and designed according to "ship standards". One significant operational difference between a ship and an FPSO is that a ship is in dock each 3 to 5 years for repair of coating etc. An FPSO is in operation for typically 15 to 30 years, with no coating repair. This will result in a major increase in the current requirements from launch to the end of operational life. The number of IC anodes is in most cases too few and the size of shielding around anodes is too small. CP modeling has shown that this may result in both significant over protection and at the same time under protection. CP modeling has shown to be an excellent tool for optimizing anode number, positions and shielding size.

Keywords: Impressed Current, IC, Computer modeling, cathodic protection, CP, FPSO, overprotection

INTRODUCTION

Floating production units are more and more used in the offshore industry. An FPSO (Floating Production Storage and Offloading) unit is one of those. Many of these systems are converted tankers, or are new build ship based on modified tankers.

The corrosion protection externally for these units is often based on a coating system and cathodic protection. Impressed Current (IC) has by far been the most common system for the FPSOs, which also has been widely used within the shipping industry.

For the regular shipping industry the ships will go in to dry dock a minimum of every 5 years, for maintenance purpose. This allows for repair of coating system, shielding and anodes systems. This essential maintenance will provide a coating system with low percentage coating breakdown and thereby a relatively low current output from the IC system.

If standard ship solutions are selected the number of anodes is low (4 to 8) with a relatively small shielding around the IC anodes.

FPSO can be in operation for even more than 30 years. Within this period, there will be no docking and the coating system will degrade more or less according to the design figures. In order to evaluate the development of the IC performance, CP computer modeling has been used to evaluate several scenarios for the different FPSOs.

FPSO'S CP DESIGN CHALLANGES

CP design of FPSO's has to consider the following:

- Coating degradation (no coating repair during operation)
    - Increase in coating breakdown can result in a current output requirements form the IC anodes, which is up 20 times higher final than initially.
- Coating disbonding
- Hydrogen embrittlement
- CP potential window (-800 mV to –1050 mV)
- Size of IC anodes
- Size of primary and secondary IC shield.
- Drain to chains
- IC system also connected to risers, flexible risers of other materials as duplex and super duplex and/or high Strength Steel.
- Connected pipelines
- Connected subsea structures hydrogen embrittlement sensitive material
- Sacrificial anode system on the FPSO, thrusters, sea chests, turrets, riser protectors, etc.
- Sacrificial anode system on connected structures as e.g. subsea structures, pipelines, buoys, etc.
- Different phases both before operation and under operation
- Should IC system be activated in harbors during rigging of topside?
- Should IC system be activated during offloading of oil/gas?

All this elements has to be considered and the importance for the single one or combination will differ for each FPSO rebuild or development.

COMPUTER MODELLING

Introduction

The model calculations have been carried out using the SEACORR/CP computer program. This program was developed for use on CP problems in the mid 80's, and has been applied on a commercial basis since that time. The program, which utilizes the Boundary Element Method (BEM), makes it possible to model large and complex offshore structures in detail. The boundary conditions, i.e. the current density potential relationships at the metal surface is handled by selecting data from an extensive database containing data obtained from real CP system performance and laboratory tests.

The predictive power and capabilities of this program have been verified through measurements and comparison with CP performance data in a large number of contracts for major oil companies around the world.

The Behaviour of Steel in Seawater

The corrosion behavior of steel exposed to seawater, i.e. the reaction kinetics for steel, is described as a potential/current density relationship. These relations (boundary conditions) are called polarization curves. The polarization curves are modeled as time dependent, non-linear polarization curves. Polarization curves for different calcareous deposit/coating qualities can be obtained from the SEACORR/CP database.

Polarization data for steel is stored in a basic data file in the format of digitized polarization curves. This file includes a number of instantaneous (potentio-dynamic) polarization curves. These are obtained by changing the potential (polarizing) of steel panels with a specific history, i.e. a specified condition of the calcareous coating. Each curve is defined by specifying the cathodic current density for different potentials between -600 mV and -1200 mV (vs. Ag/AgCl).

Curve no. 1 represents the initial polarization curve upon switching on the cathodic polarization of steel in seawater. Curve no. 10 represents the steady state condition for the same surface after a 'high quality' calcareous coating has been formed on the surface. High quality is defined as the best practically obtainable quality after a polarization period and will vary with the specified environmental conditions. Intermediate curves represent intermediate stages defined by time after start-up and current density- and potential history.

Models

The simulation boundary conditions are linear relations based on the current density levels and coating breakdown at different stages of operational life.

Drawings of the FPSOs hull have been used to generate the geometry of the model. The following main cases have been evaluated:

Case 1 - FPSO with turret ahead of the front

20 IC anodes, shield size 3.2 x 3.5 m
6 IC anodes, shield size 2.4 x 4.8 m
8 IC anodes, shield size 2.4 x 4.8 m
12 IC anodes, shield size 2.4 x 4.8 m

Case 2 - FPSO with a “central” turret

28 circular IC anodes and shield size of 4 m in diameter

Case 3 - FPSO with a “central” turret

20 IC anodes, shield size diameter 1.2 m and 6.5 m
8 IC anodes, shield size diameter 1.2 m and 6.5 m

Case 4 - FPSO with risers mounted along the shipside and with chains on each corner.

12 IC anodes and two anodes sizes and shield size. Largest shield size 6 * 11 m.

Case 5 - FPSO with two IC anodes each side in front and two anodes each side aft. The chains are mounted in each corner.

Different anode number and configuration have been evaluated for the above four cases. Different shielding sizes have been simulated.

The fifth case is a CP inspection case.

CP DESIGN BASIS

The CP design for the FPSOs have not been done according to one given standard. The design basis for case 1 and 2 are presented in Table 1 and Table 3, respectively. FPSO case 3 and 4 have been performed according to the description above with a fixed current density level of 35 mA/m^2 and an IC capacity factor of 1.5.

Typical standards for CP design of offshore structures, which are also suitable for FPSOs and connected structures:

- Norsok M-503 standard
- NACE 0176 1994
- DnV RP B401 1993
- Company standards

STANDARD SHIP CP DESIGN

In order to calculate the required protection current and thereby the number of anodes based on a coated ship, a calculation is often performed as follows:

Calculate surface area to protect: A
Calculate the required current: $I = A * 0.035\ mA/m^2$.
0.035 mA/m^2 includes effect of operational life and coating breakdown. This is a typical current density level used independent of operation life and coating breakdown!!

Calculate the required IC current capacityImax =I * 1.5

The number of anodes required is typical based on anodes with output capacity from 100 to 600 A.

The number of IC anodes and the size of the shielding around the anodes can be checked by use of BS 7361. This formula is mainly applicable for disc-shaped anode.

$$r = \frac{\rho * I}{2 * \pi * (E_0 - E)}$$

r	=	radius of anode shield (m)
ρ	=	Environmental resistivity (ohm * m)
I	=	current (A)
E_0	=	general potential of the Hull when protected (V)
E	=	the most negative potential that can be withstood by the Hull paint near the edge of the shield (V)

RESULTS FROM THE EVALUATIONS

The results from the different cases are presented in tables and figures attached.

Table 4 presents the results by use of the BS 7361 to estimate the require size of the dielectric shield. For a current output of 75 A the shield size is estimated to a radius of 8 m(!) to a avoid potential levels more negative than –1100 mV.

Case 1 result is presented in Table 1 and 2 and Figure 1 to 4.

With the selected size of anode shielding the of 2.4 * 4.8 m, the number of anodes has to be 14 or more with a final current of approximate 36 A per anode.

With 8 anodes and an anode shielding size of 2.4 * 4.8 m and a current output per anode of approximate 62 the potential window will be from –800 mV to –1250 mV.

Case 2 results are presented in Table 3, 5 and 6 and Figure 5 to 11.

As part of the case 2 evaluations a simulation of the CP performance of only sacrificial anodes on thrusters has been performed. A plot of the potential distribution is shown in Figure 6. This shows a well-protected structure even with no IC anodes activated. This protection capability may cause IC system.

With the IC system activated and the coating breakdown and current density according to design, there will be experienced potential level more negative than –1100 mV already after 3 year (!). After 10 years in operation the potential outside shielding may reach -1380 mV.

Case 3 results are presented in Table 7 and Figure 12 to 19.

Increasing the shielding from a diameter of 1.2 m to 6.5 based on 8 IC increases the most negative potential from –7160 mV to –2381 mV.

Increasing the shielding from a diameter of 1.2 m to 6.5 m based on 24 IC increases the most negative potential from –2749 mV to –1607 mV.

Case 4 results are presented in Table 8 and Figure 20 to 24.

From Table 8 it is seen that over protection on the coating outside the anode shielding may occur after around 8 years in operation. After 15 years in operation the most negative potential outside shielding is –1306 mV. This quite negative figures is seen even with a shielding size 6 m *11 m.

Case 5 evaluation is presented below

CP INSPECTION AND MONITORING

Control of the CP protection level is important in order to secure a well-protected FPSO. It is important that the potential level is maintained at the required protection window. The monitoring system or the reference cells connected to the regulation system of the IC system is installed for different purpose. Dependent on the position of the reference cells, they can be used for regulation against over protection (too negative potential) or to avoid under protection. Some of the regulation systems have a fixed setting against which the outputs from the IC anodes are regulated. If the potential level is set to –850 mV, than there will be on/off or step wise regulation around this set potential.

The potential level on these regulation reference cells may not always reflect the actual operational window on an FPSO hull. The most positive potential will be found on the position most remote from the anodes and /or at the place with most “shadow”.

In Figure 28 and 29 we have presented potential profiles from CP measurements by use of reference cells around an FPSO (Case 5). This shows relatively large potential window knowing that this is in the early phase with “no” coating breakdown. Even with a well-protected level in year 1, the FPSO is further polarized up to year 5.

CONCLUSIONS

When designing an IC system for floating production units as e.g. an FPSO, it is very important to take the consequence of the limited possibility for coating maintenance offshore. Therefore the coating will degrade and the current requirement will increase. Several design rules gives level of breakdown for different coating types as a function of operational life. There are conservatism built in to the design rules, but the design figures should define the base case.

The required size of anode shielding is dependent on required operational current output over life. End of operational life will give worst situation, but there several FPSO in operation with to small shielding compared to the number of anodes and the IC output. The consequences can be:

- Coating disbonding and further increase in current requirements. Critical potential level is questioned, but –1100 mV is an “accepted “ limit
- Hydrogen embrittlement of the structure steel is also a possibility. Critical potential level defined to –1100 m, this level is not well documented for carbon steel and is questioned.

For coated system with a combined IC and sacrificial anodes, it is important to position reference cells distant form sacrificial anodes. Even with this precaution; initially with a good coating system the protection capability for sacrificial anodes has a long range and this may influence the IC system’s regulation system. In worst case the IC system will not fully activate and the control setting point need to be adjusted.

Computer modeling is an excellent tool for designing and evaluating IC system:

- Establish size of shielding and number of anodes
- What-if or sensitivity analysis
- Positioning of IC control reference cells
- Detect any dark spots
- Operational and inspection planning

TABLE 1

CASE 1 - DESIGN DATA FROM DNV RP-B401

		Initial	Mean	Final
Current density, Hull	mA/m^2	150	70	90
Coating breakdown, 5 years	%	2	5	8
Coating breakdown, 10 years	%	2	8	14
Coating breakdown, 20 years	%	2	14	26

TABLE 2

CASE 1 - POTENTIAL LEVELS FOR THE RESPECTIVE SIMULATIONS

No. of anodes	Operational year	Max. potential (mV)	Min. Potential (mV)	Reference figure
20	20	-825.8	-1044	Figure 1
12	20	-835.1	-1139	Figure 3
12	18	-811.9	-1068	
8	20	-838.7	-1293	Figure 4
8	15	-850.1	-1212	
6	20	-805.1	-1371	Figure 2

TABLE 3:
CASE 2 - DESIGN INPUT DATA

Current density Mean Final (@ -900 mV vs. Ag/AgCl)	 120 mA/m^2 170 mA/m^2
Coating breakdown 1 year 5 year 10 year 15 year 20 year/final	 3.2 % 8.0 % 14.0 % 20.0 % 26.0 %
Seawater resistivity	0.34 Ωm
Seawater temperature	-2°C to 16°C
Design life	20 years
Anode shield diameter	4.0 m

TABLE 4 ANODE SHIELD RADIUS BASED OM BS

r (m)	ρ (ohm * m)	E_0 (V)	E (V)	I (A)	Nos. of anodes
1	0.2	-0.8	-1.1	9.4	53.0
2	0.2	-0.8	-1.1	18.8	27.0
3	0.2	-0.8	-1.1	28.3	18.0
4	0.2	-0.8	-1.1	37.7	14.0
5	0.2	-0.8	-1.1	47.1	11.0
6	0.2	-0.8	-1.1	56.5	9.0
7	0.2	-0.8	-1.1	66.0	8.0
8	0.2	-0.8	-1.1	75.4	7.0
9	0.2	-0.8	-1.1	84.8	6.0
10	0.2	-0.8	-1.1	94.2	6.0

TABLE 5

CASE 2 - SUMMARIZES THE KEY DATA FROM THE DIFFERENT FIGURES

Plot reference	Description	Year of operation	Min potential (mV)	Max potentia l (mV)
Figure 6	Sacrificial anodes only. IC system not energized	1	-958	-809
	IC system energized. Mean current density.	1	-1030	-846
	IC system energized. Mean current density.	5	-1190	-833
Figure 7	IC system energized. Mean current density.	10	-1380	-820
Figure 8	IC system energized. Mean current density.	15	-1550	-804
Figure 9 Figure 10	IC system energized. Mean current density.	20	-1710	-788
Figure 11	IC system energized. Final current density.	20	-1790	-760

TABLE 6

CASE 2 - MAXIMUM AND MINIMUM POTENTIAL ON ANODE SHIELDS

Operational year	1	5	10	15	20
Max. Potential	-941 mV	-1070 mV	-1105 mV	-1185 mV	-1261 mV
Min. potential	-2223 mV	-3539 mV	-5173 mV	-6793 mV	-8405 mV

TABLE 7

CASE 3 - POTENTIAL LEVELS FOR THE RESPECTIVE SIMULATIONS

No. of anodes	Operational year	Shielding diameter (m)	Max. potential (mV)	Min. Potential (mV)	Reference figure
8	20	1.2	-679	-7160	Figure 12, 13
24	20	1.2	-801	-2749	Figure 14 - 16
8	20	6.5	-802	-2381	Figure 17
24	20	6.5	-808	-1607	Figure 18, 19

TABLE 8

CASE 4 - POTENTIAL LEVELS FOR THE RESPECTIVE SIMULATIONS

No. of anodes	Operational year	Max. potential (mV)	Min. Potential (mV)	Reference figure
12	1	-779	-1056	Figure 21
12	10	-789	-1223	
12	15	-763	-1316	Figure 22, 23
12	20	-761	-1460	Figure 24, 25

TABLE 9

READINGS FROM FIXED REG\ULATION REF.CELLS OM CASE 5 FPSO

	Potential starboard [mV]	Potential port [mV]
Readings year 1		
Rectifier forward	126 (-924)	128 (-922)
Rectifier aft	70 (-980)	120 (-930)
READINGS YEAR 2		
Rectifier forward	106 (-954)	100 (-950)
Rectifier aft	66 (-984)	80 (-970)
READINGS YEAR 5		
Rectifier forward	56 (-994)	60 (-990)
Rectifier aft	34 (-1016)	42 (-1008)

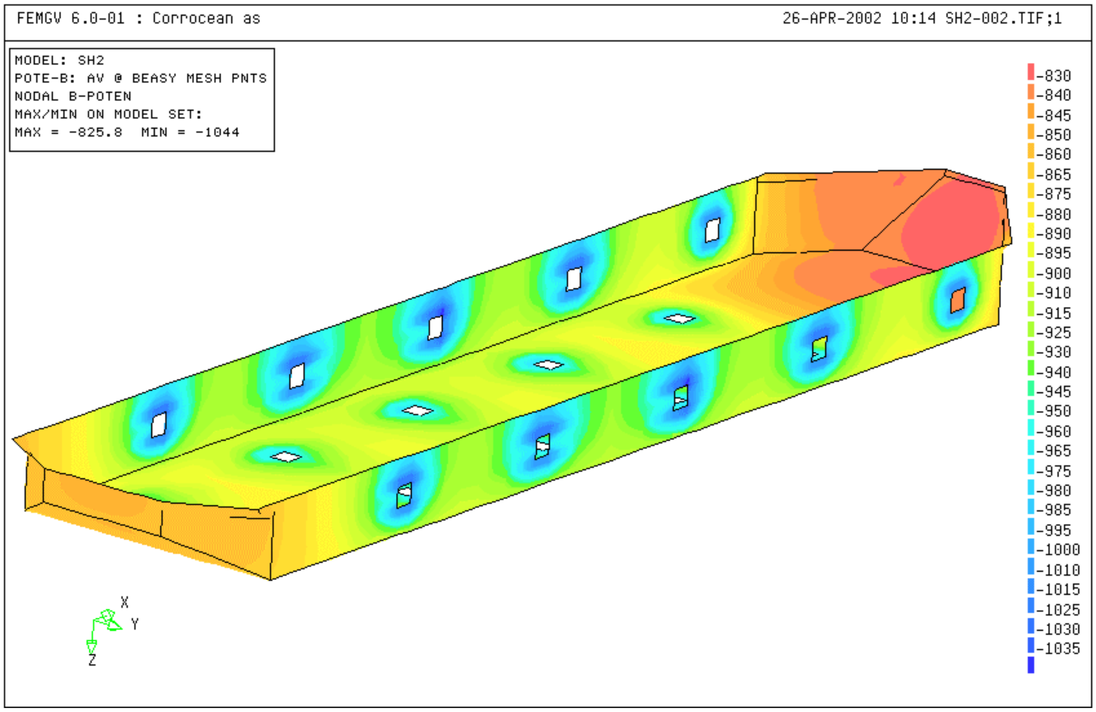


FIGURE 1

CASE 1 - POTENTIAL DISTRIBUTION AT THE END OF DESIGN LIFE. 20 ANODES

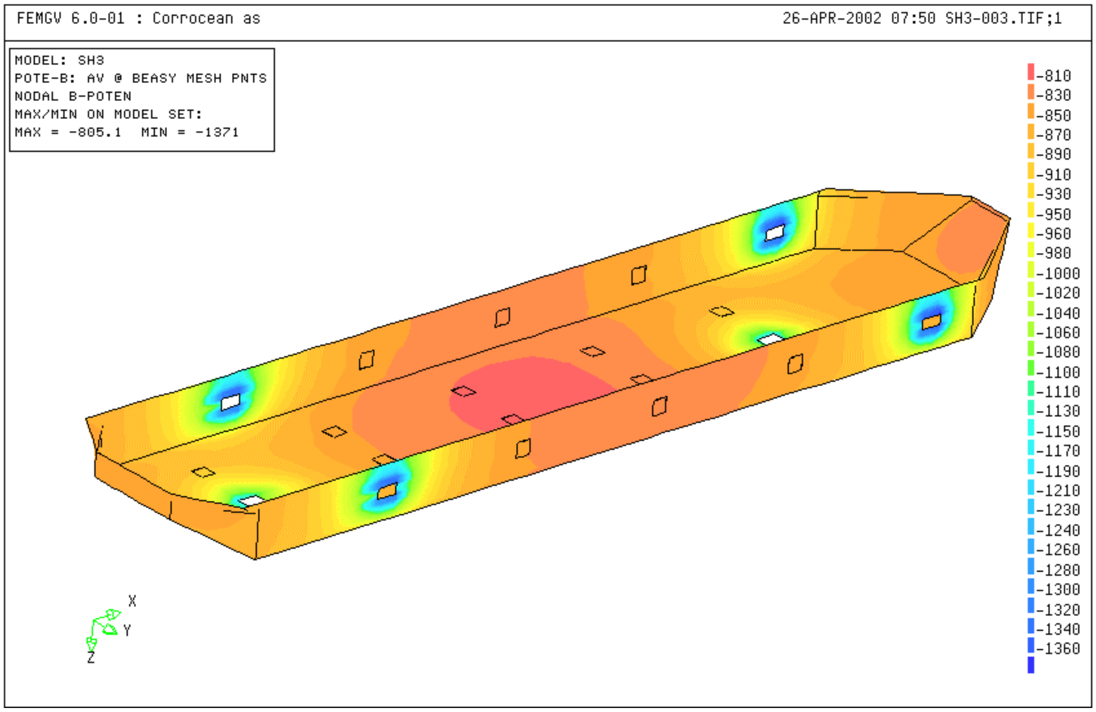


FIGURE 2

CASE 1 - POTENTIAL DISTRIBUTION AT THE END OF DESIGN LIFE. 6 ANODES.

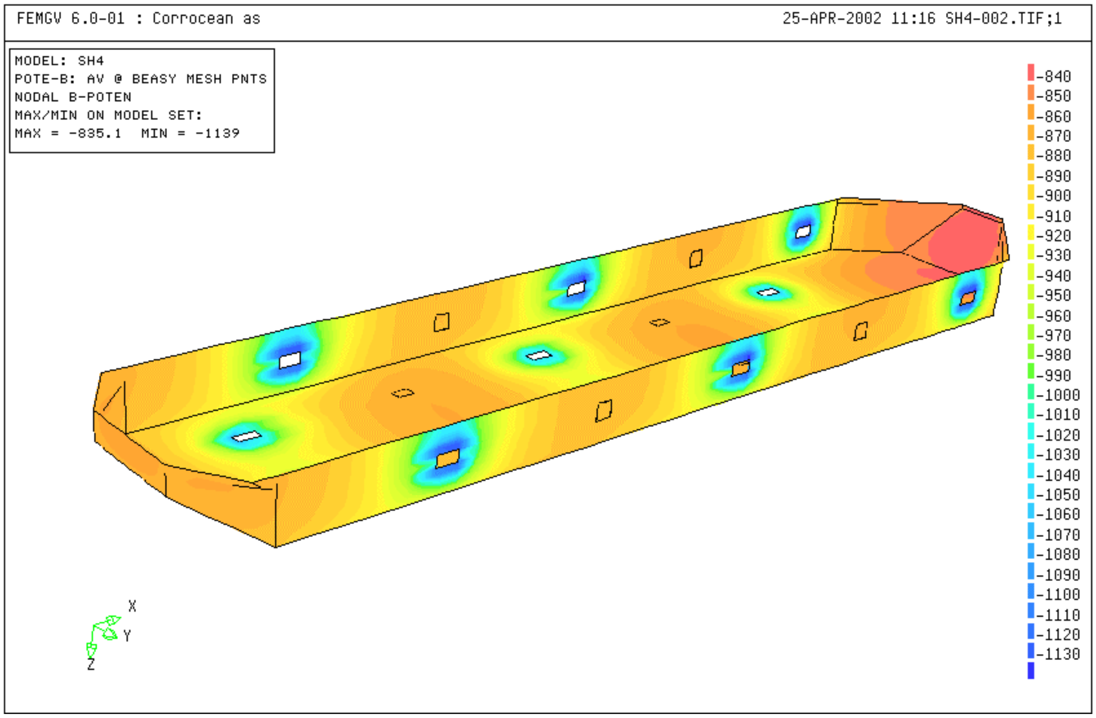


FIGURE 3

CASE 1 - POTENTIAL DISTRIBUTION AT THE END OF THE DESIGN LIFE, 12 ANODES

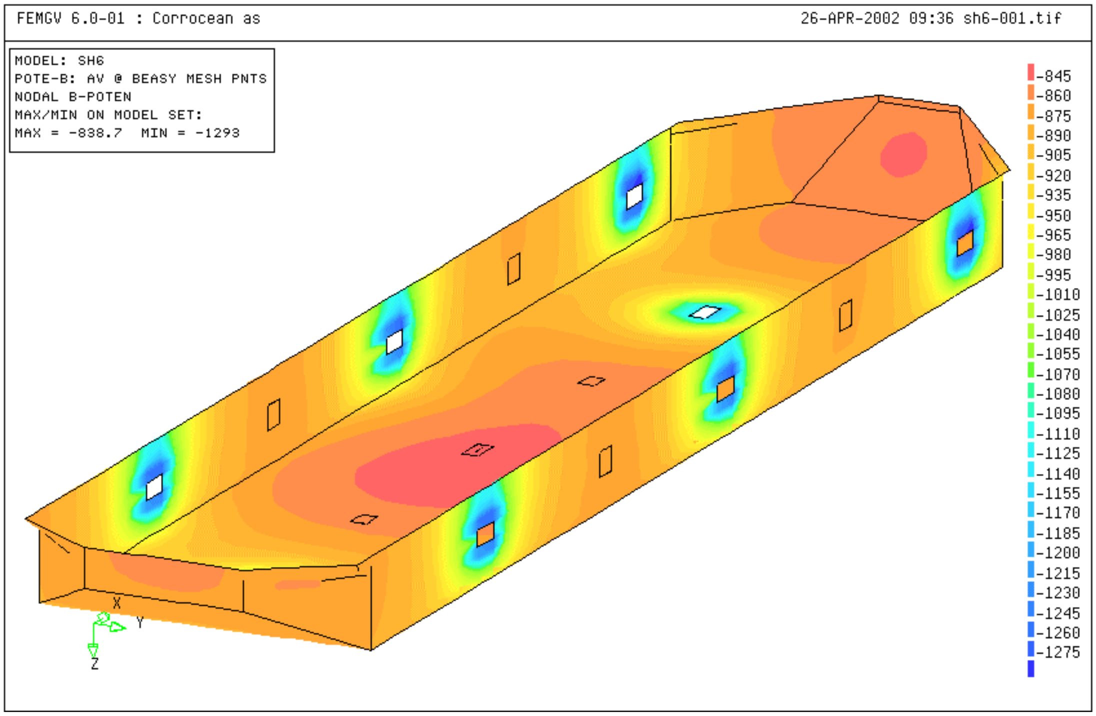


FIGURE 4

CASE 1 - POTENTIAL DISTRIBUTION AT THE END OF THE DESIGN LIFE, 8 ANODES

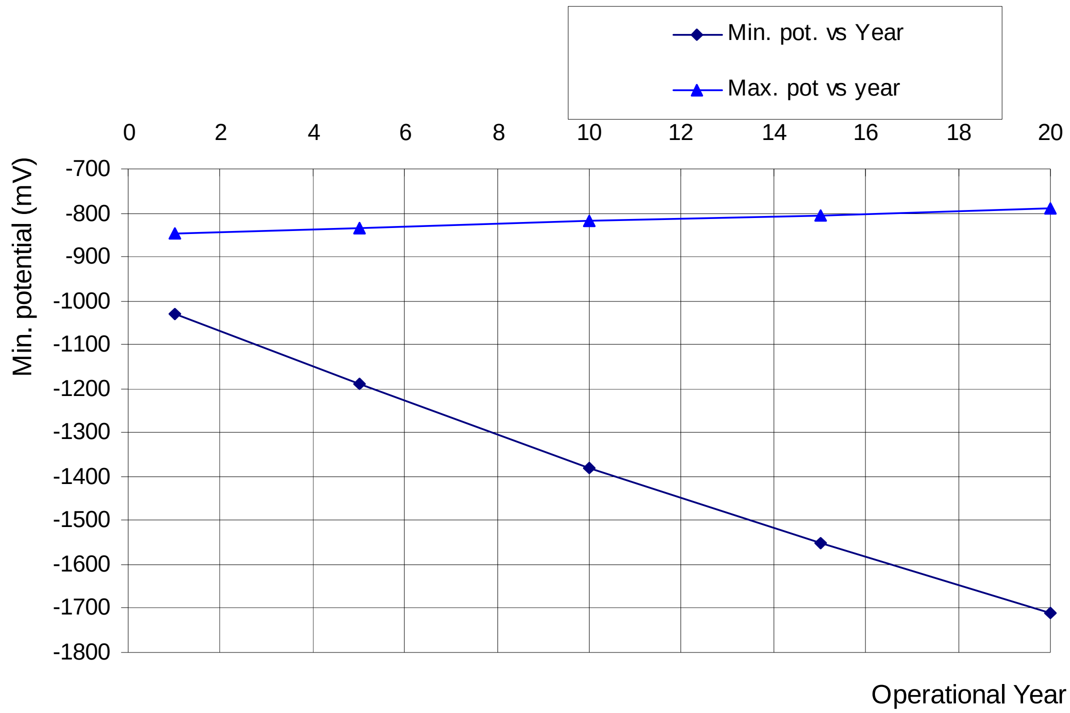


FIGURE 5

CASE 2 - MINIMUM AND MAXIMUM POTENTIAL ON THE FPSO OUTSIDE THE IC SHIELDING

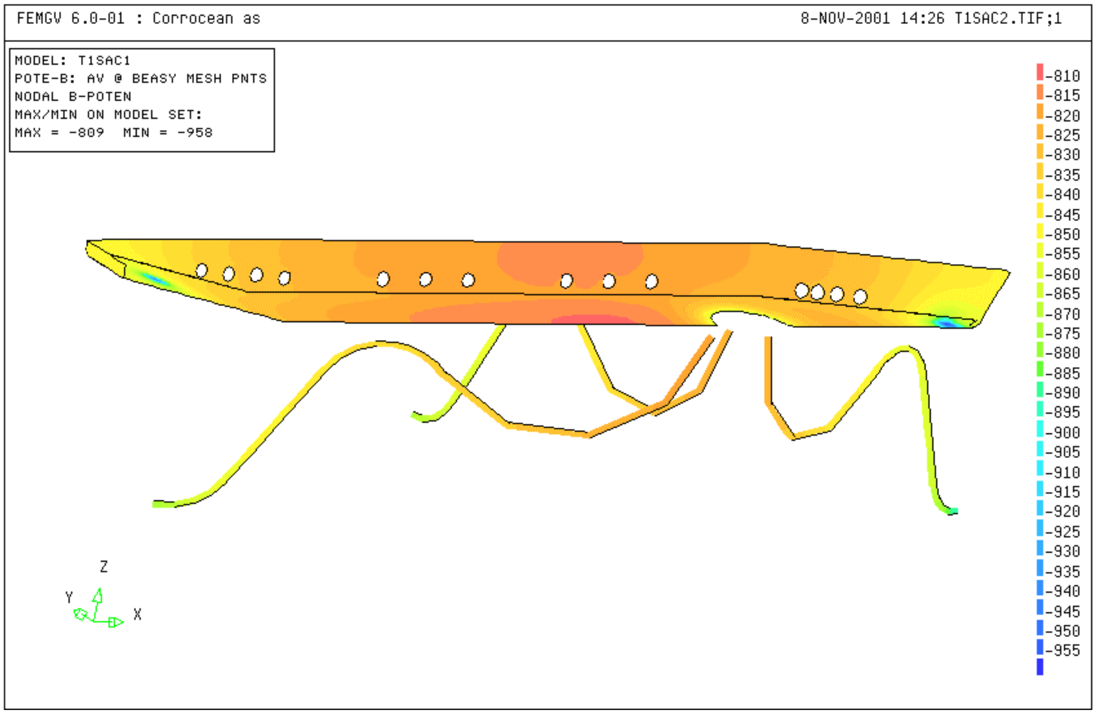


FIGURE 6

CASE 2 – POTENTIAL DISTRIBUTION ON HULL WITH ONLY SACRIFIAL ANODES ON TRUSTERS AND TURRET. IC SYSTEM NOT ACTIVATED

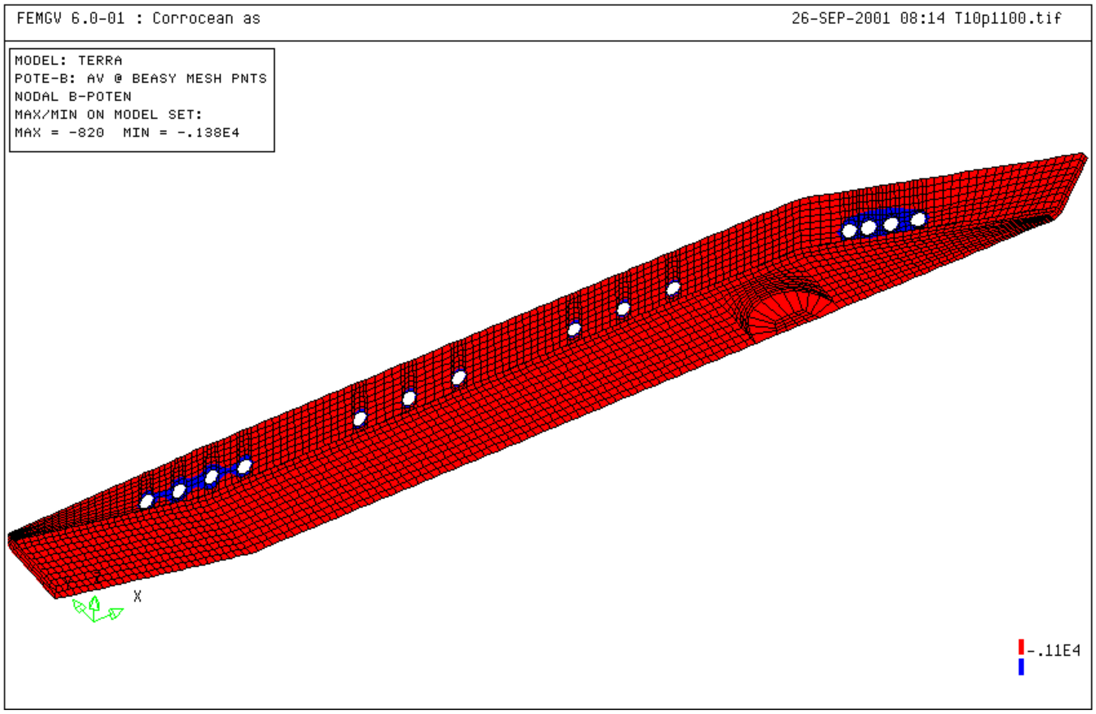


FIGURE 7

CASE 2 - POTENTIAL AFTER YEAR 10. BLUE COLOR SHOWS AREAS WITH POTENTIAL LOWER THAN -1100 MV.

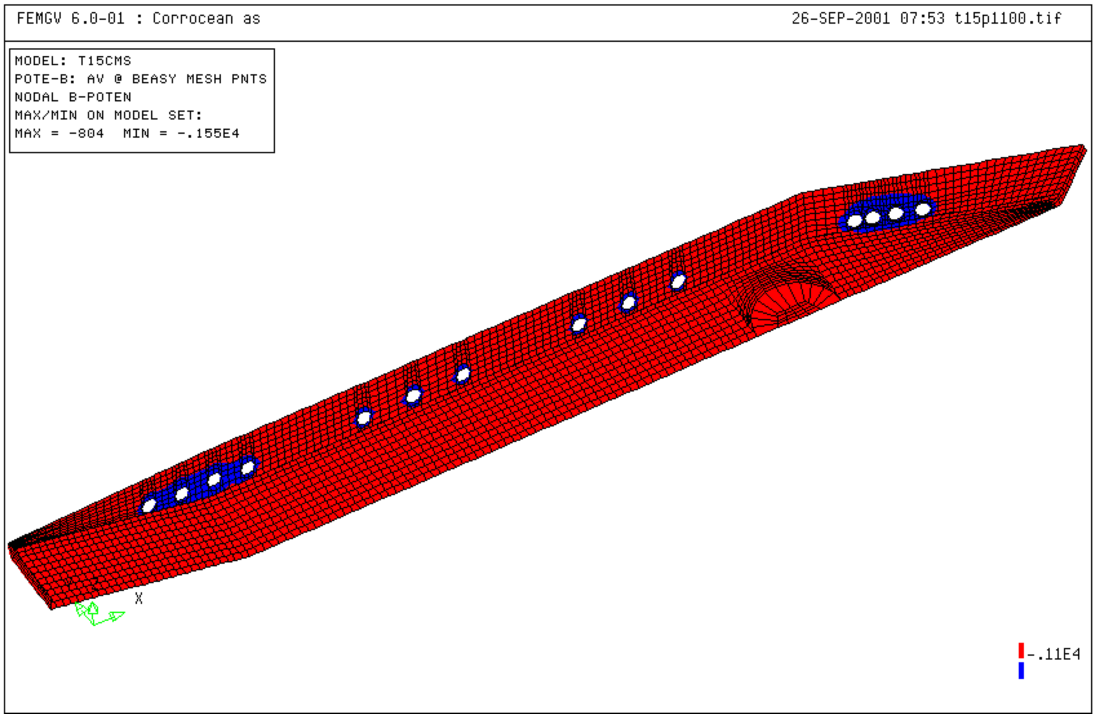


FIGURE 8

CASE 2 - POTENTIAL ON FPSO HULL, YEAR 15. BLUE COLOR SHOWS AREAS WITH POTENTIAL LOWER THAN -1100 MV.

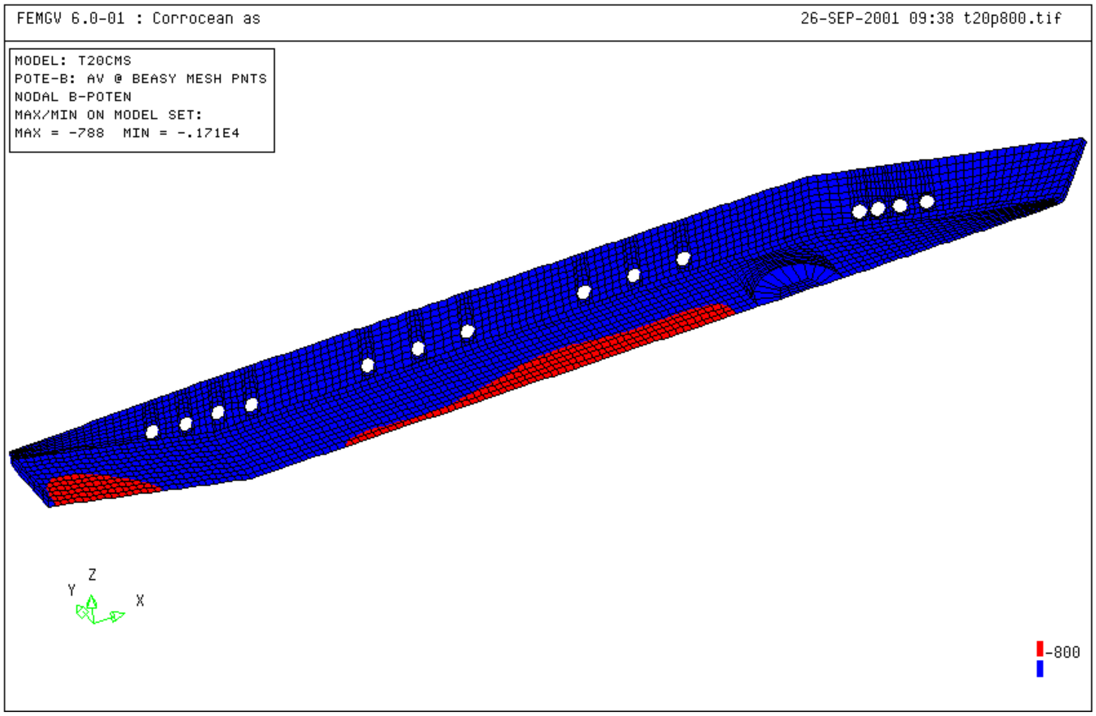


FIGURE 9

CASE 2 - POTENTIAL ON FPSO HULL, YEAR 20. RED COLOR SHOWS AREAS WITH POTENTIALS HIGHER THAN -800 MV.

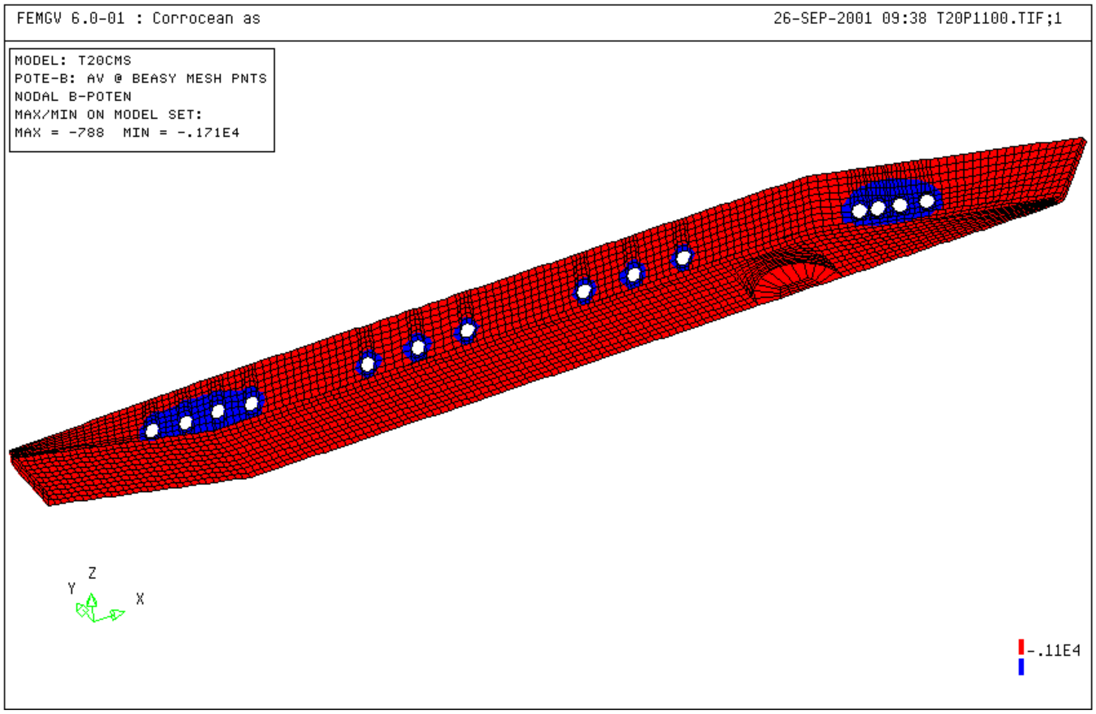


FIGURE 10

CASE 2 - POTENTIAL ON FPSO HULL, YEAR 20. BLUE COLOR SHOWS AREAS WITH POTENTIALS LOWER THAN -1100 MV.

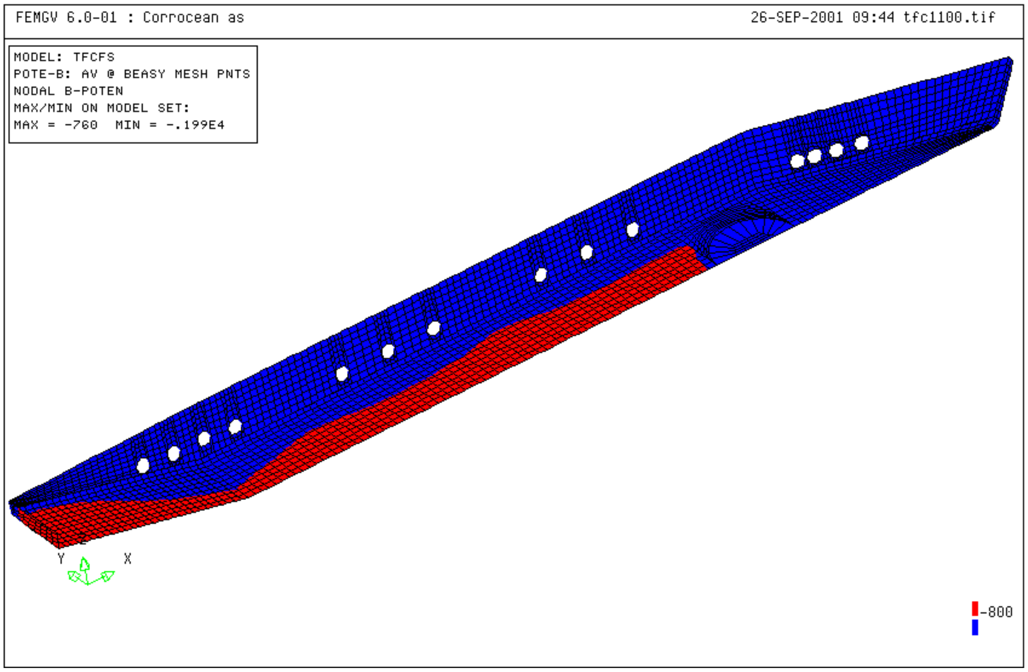


FIGURE 11

CASE 2 - POTENTIAL DISTRIBUTION ON FPSO HULL, YEAR 20. FINAL CURRENT SCENARIO. RED COLOR SHOWS AREAS WITH POTENTIAL HIGHER THAN –800 MV.

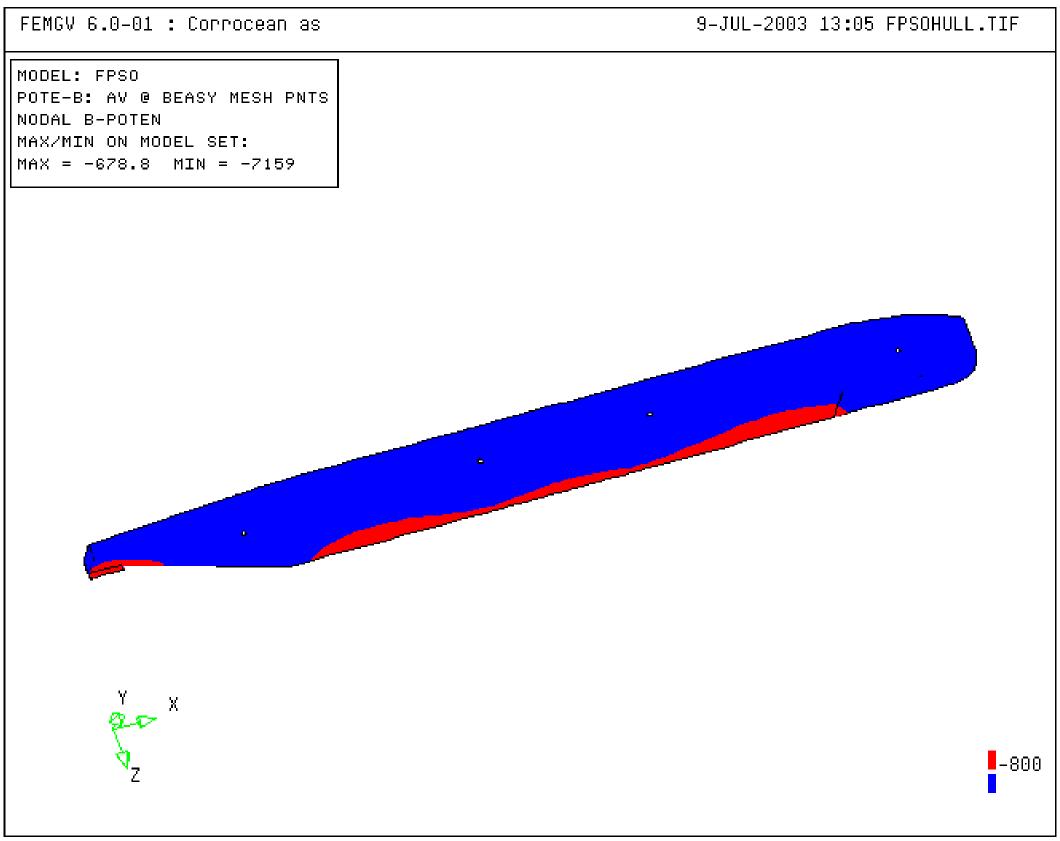


FIGURE 12

CASE 3 - POTENTIALS ON THE HULL WITH ORIGINAL 8 IC ANODES. BLUE COLOR POTENTIAL INDICATES MORE NEGATIVE THAN – 800 MV AG/AGCL (PROTECTED AREAS).

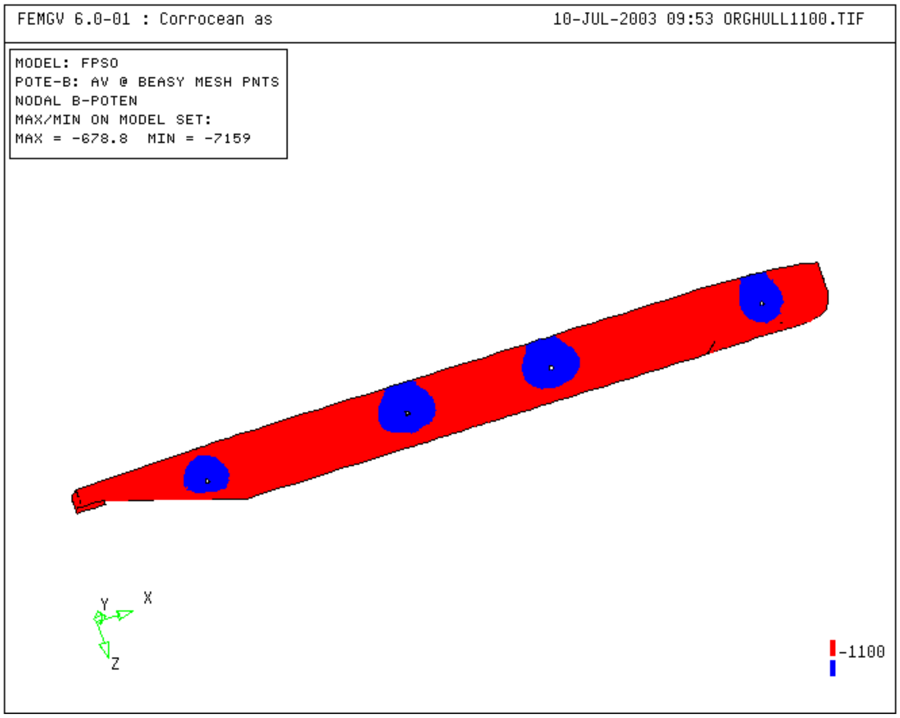


FIGURE 13

CASE 3 - POTENTIAL PLOT FOR THE HULL WITH RED COLOR INDICATING AREAS WITH POTENTIAL MORE POSITIVE THAN – 1100 MV AG/AGCL AND BLUE COLOR MORE NEGATIVE THAN –1100 MV AG/AGCL.

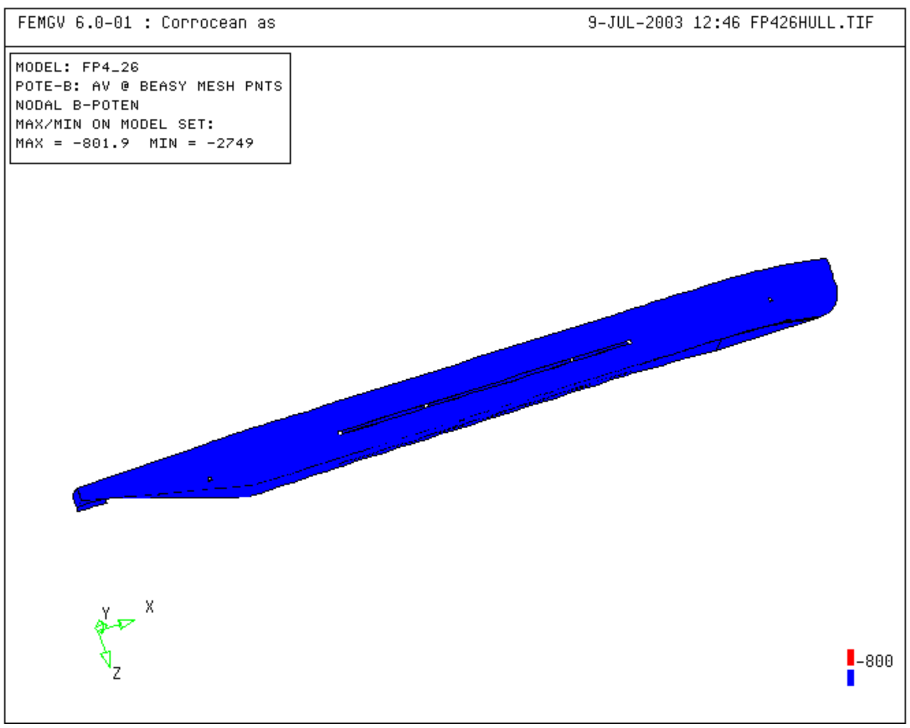


FIGURE 14

CASE 3 - POTENTIAL DISTRIBUTION ON THE HULL WITH A TOTAL OF 24 ANODES AND SHIELDING SIZE 1.2X1.2M. BLUE COLOR INDICATE POTENTIAL MORE NEGATIVE THAN –800 MV AG/AGCL.

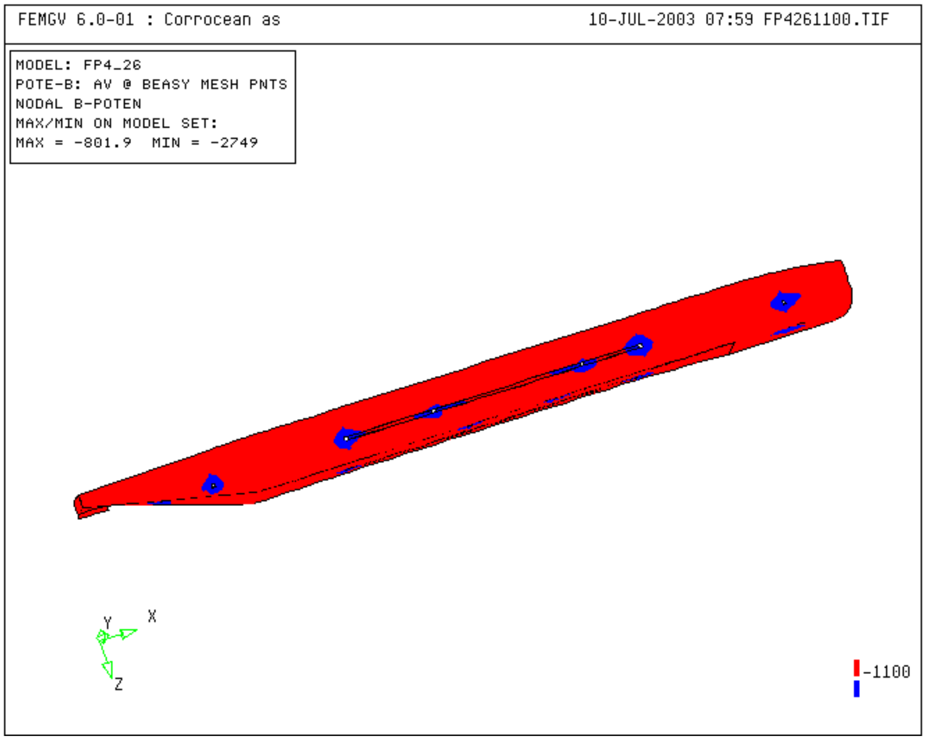


FIGURE 15

CASE 3 - POTENTIAL PLOT FOR THE HULL WITH RED COLOR INDICATING AREAS WITH POTENTIAL MORE POSITIVE THAN –1100 MV AG/AGCL..24 ANODES AND SHIELDING SIZE 1.2X1.2 M.

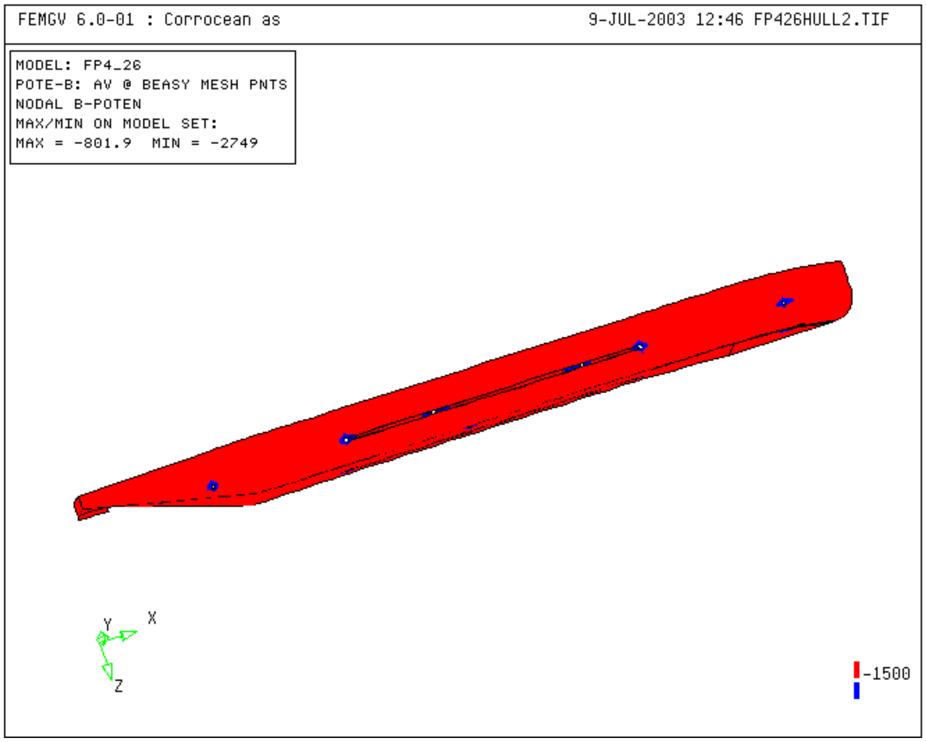


FIGURE 16

CASE 3 - POTENTIAL PLOT FOR THE HULL WITH RED COLOR ARE AREAS WITH POTENTIAL MORE POSITIVE THAN –1500 MV AG/AGCL. 24 ANODES AND SHIELDING SIZE 1.2X1.2 M.

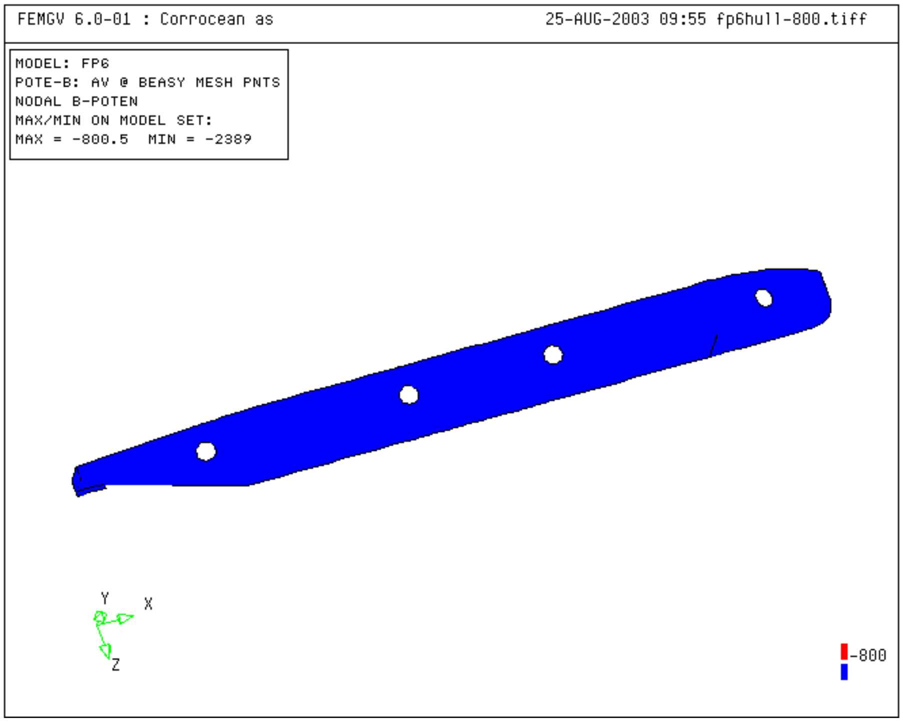


FIGURE 17

CASE 3 - POTENTIALS ON THE HULL WITH ORIGINAL ANODE NUMBER AND LOCATIONS. BLUE COLOR POTENTIAL INDICATES MORE NEGATIVE THAN – 800 MV AG/AGCL (PROTECTED AREAS).

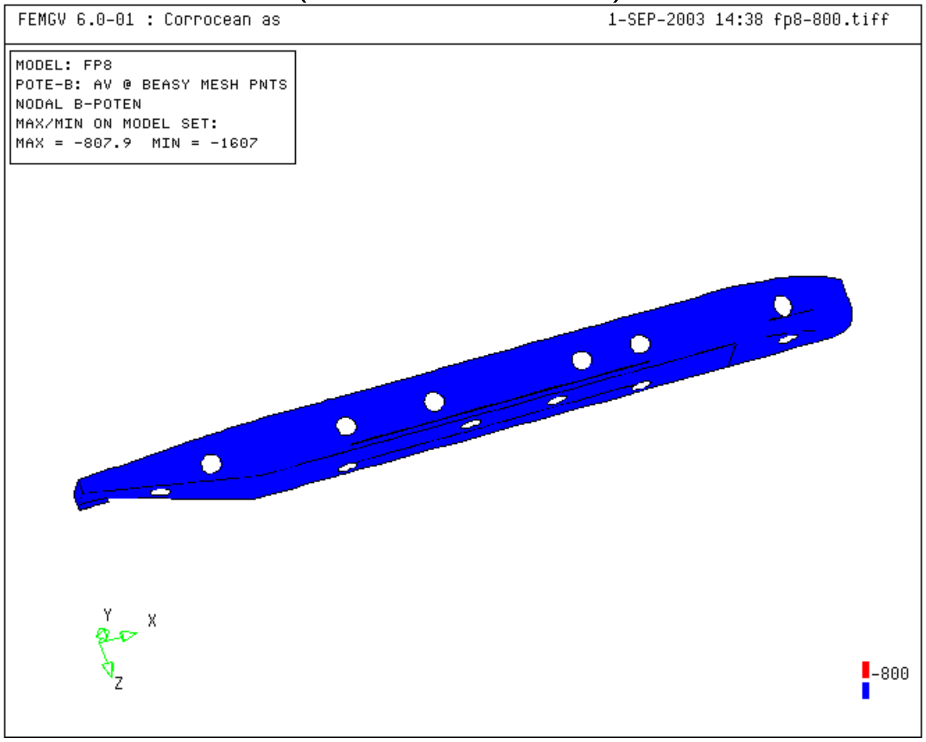


FIGURE 18

CASE 3 - POTENTIAL DISTRIBUTION ON THE HULL WITH A TOTAL OF 24 ANODES AND SHIELDING SIZE WITH 6.5 M IN DIAMETER. BLUE COLOR INDICATE POTENTIAL MORE NEGATIVE THAN –800 MV AG/AGCL

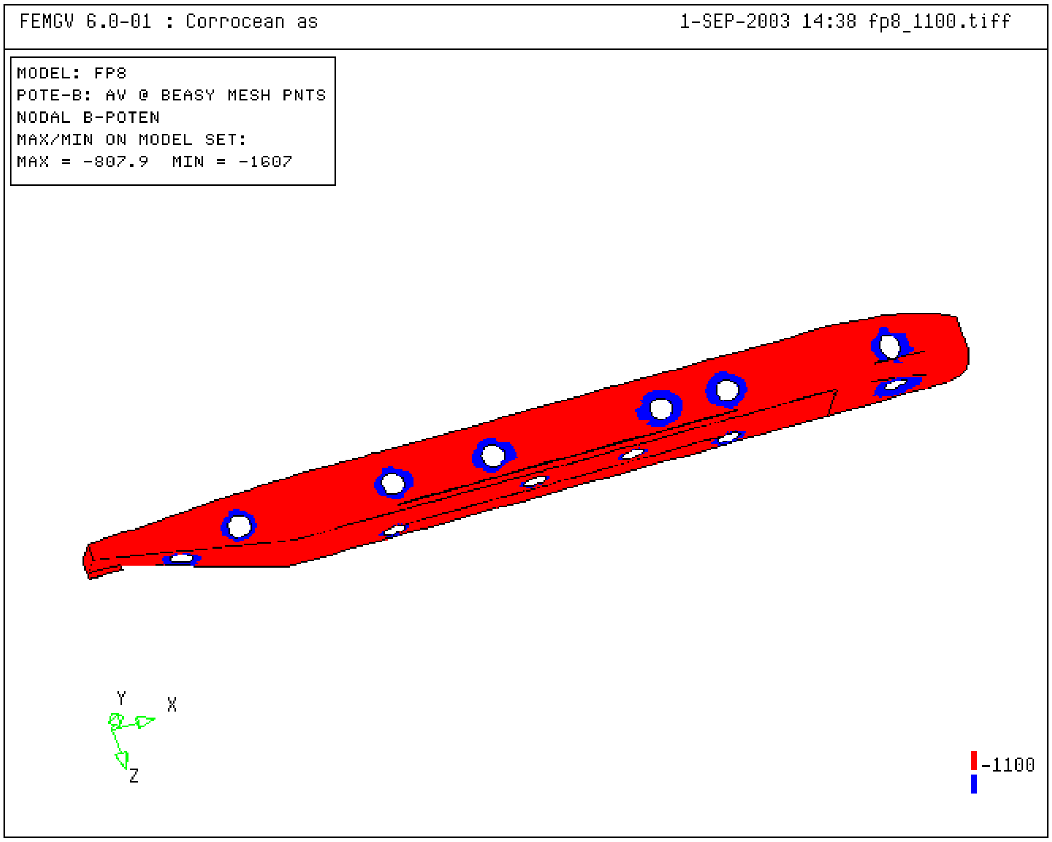


FIGURE 19

CASE 3 - POTENTIAL PLOT FOR THE HULL WITH RED COLOR INDICATING AREAS WITH POTENTIAL MORE POSITIVE THAN – 1100 MV AG/AGCL AND BLUE COLOR MORE NEGATIVE THAN –1100 MV AG/AGCL.

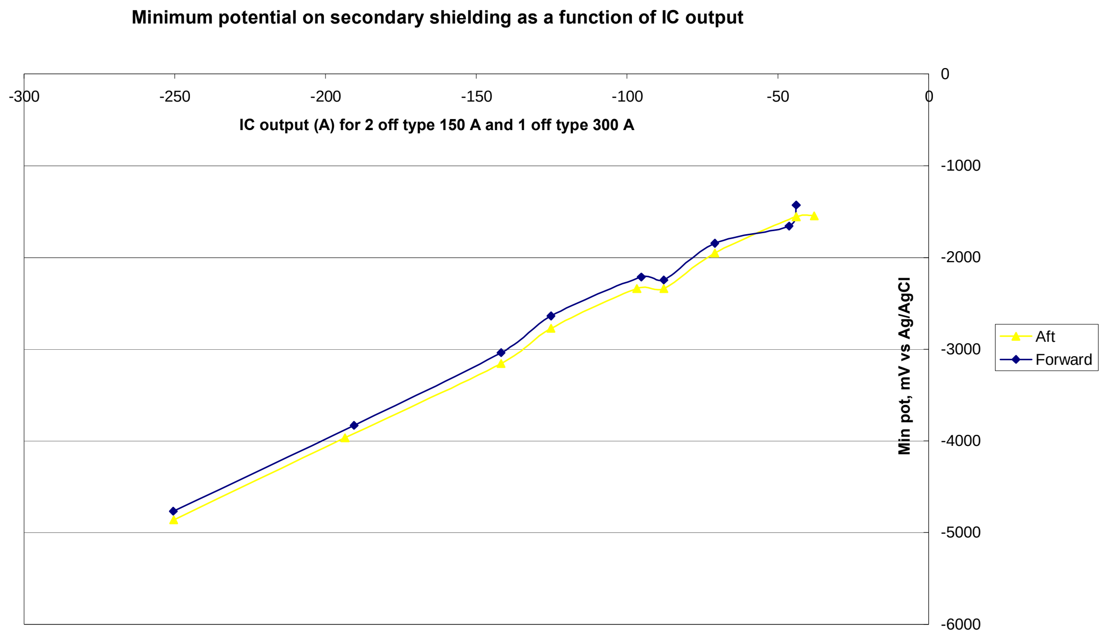


FIGURE 20

CASE 4 - MINIMUM POTENTIAL LEVELS ON THE SECONDARY SHIELDING AROUND IC ANODES

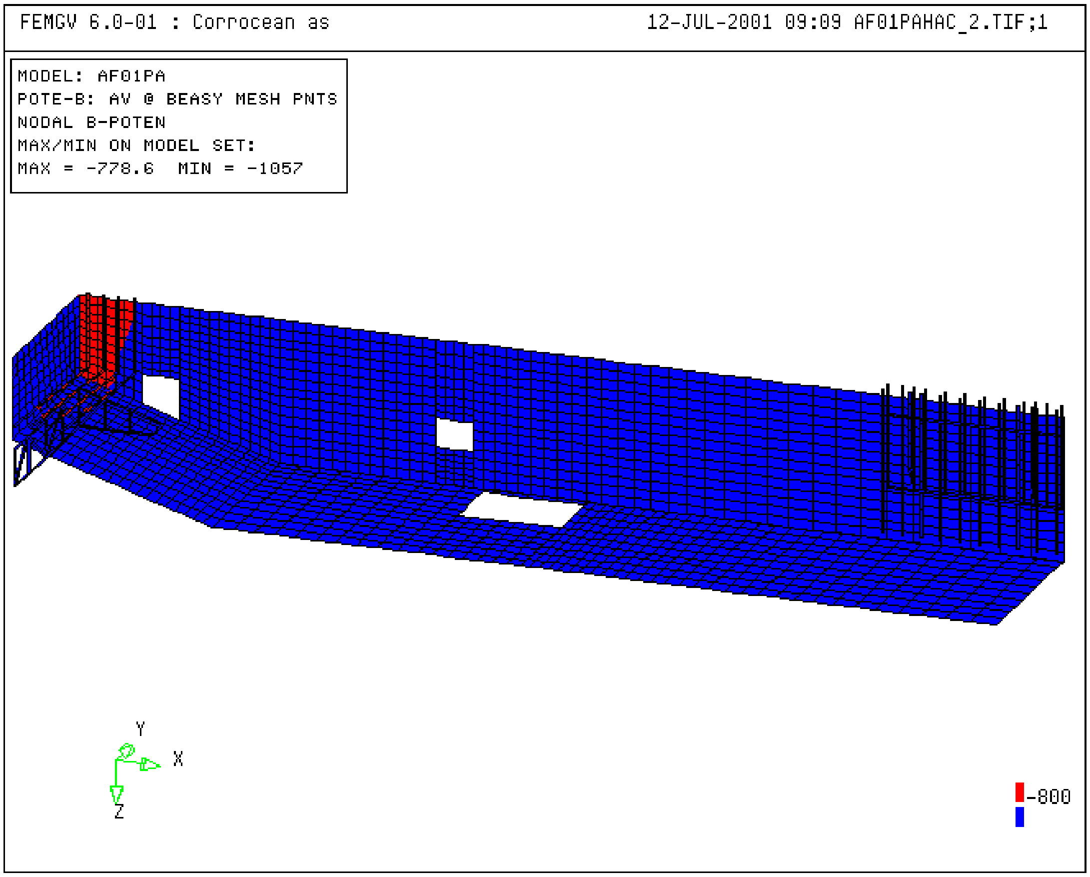


FIGURE 21

Case 4 Potential distribution after 1 year with 100% design IC - aft. Red is under protectCase 4

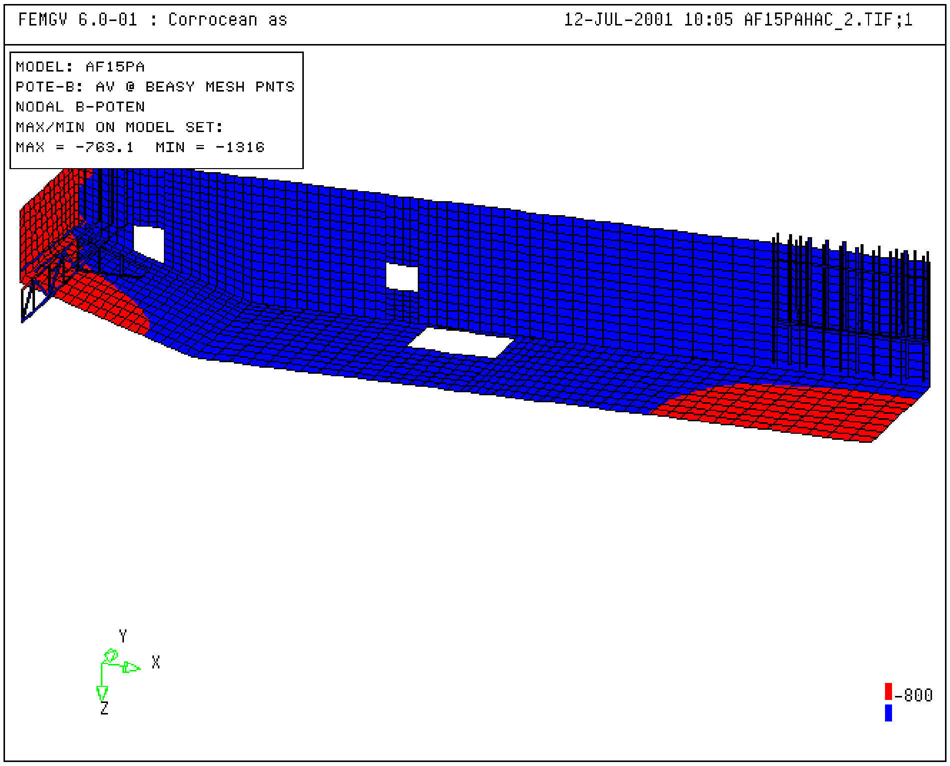


FIGURE 22

CASE 4 - POTENTIAL DISTRIBUTION AFTER 15 YEARS WITH 100% DESIGN IC - AFT. RED COLOR IS UNDER PROTECTED

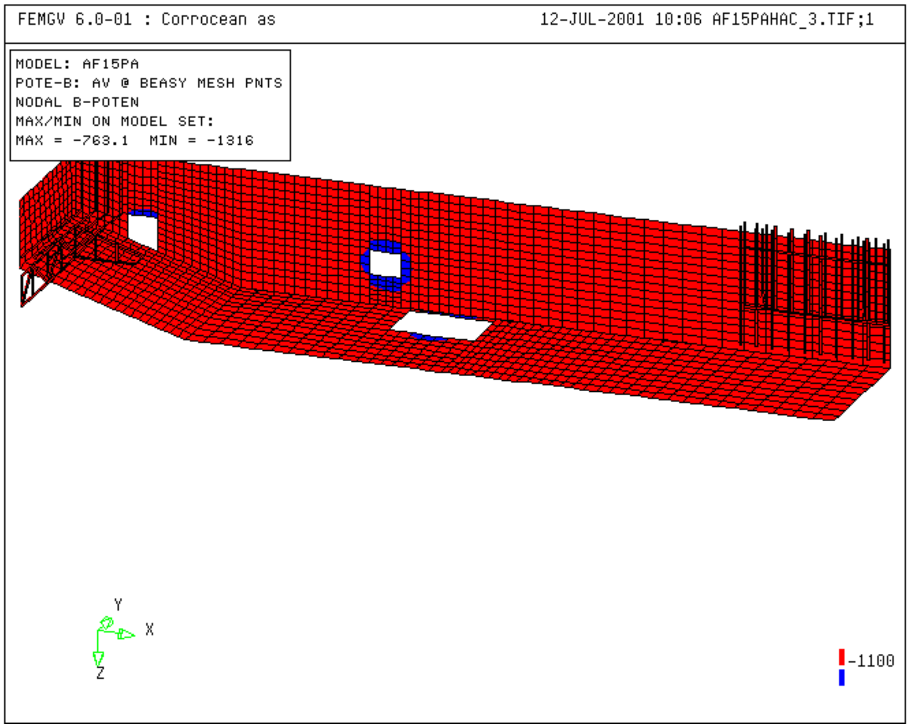


FIGURE 23

CASE 4 - POTENTIAL DISTRIBUTION AFTER 15 YEARS WITH 100% DESIGN IC - AFT. BLUE IS OVERPROTECTED (<-1100 MV)

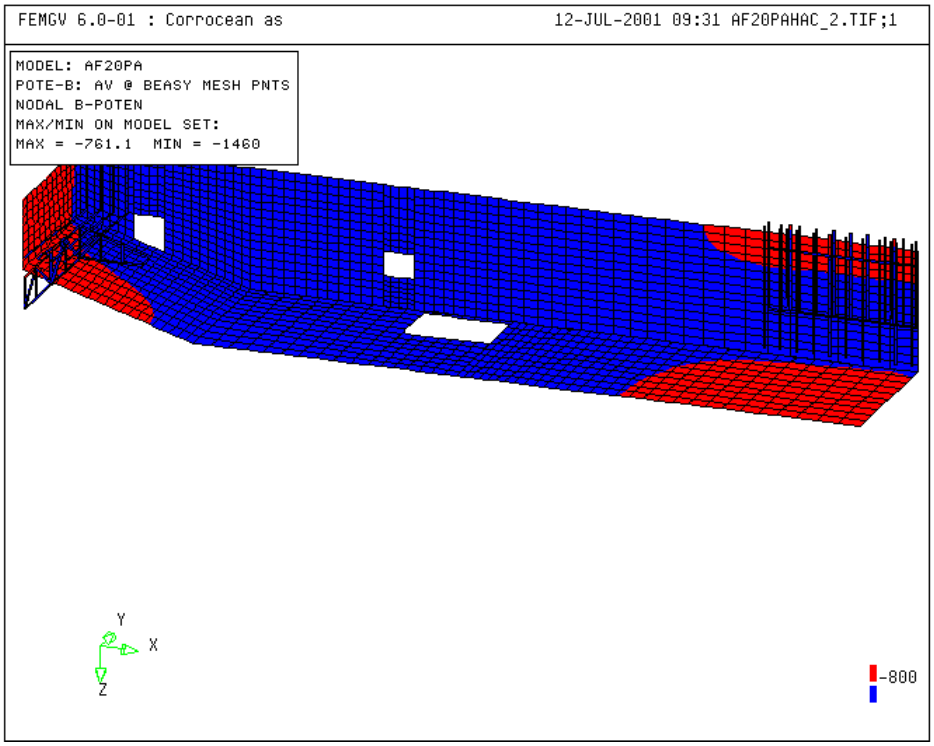


FIGURE 24

CASE 4 - POTENTIAL DISTRIBUTION AFTER 20 YEARS WITH 100% DESIGN IC. RED IS UNDER PROTECTED.

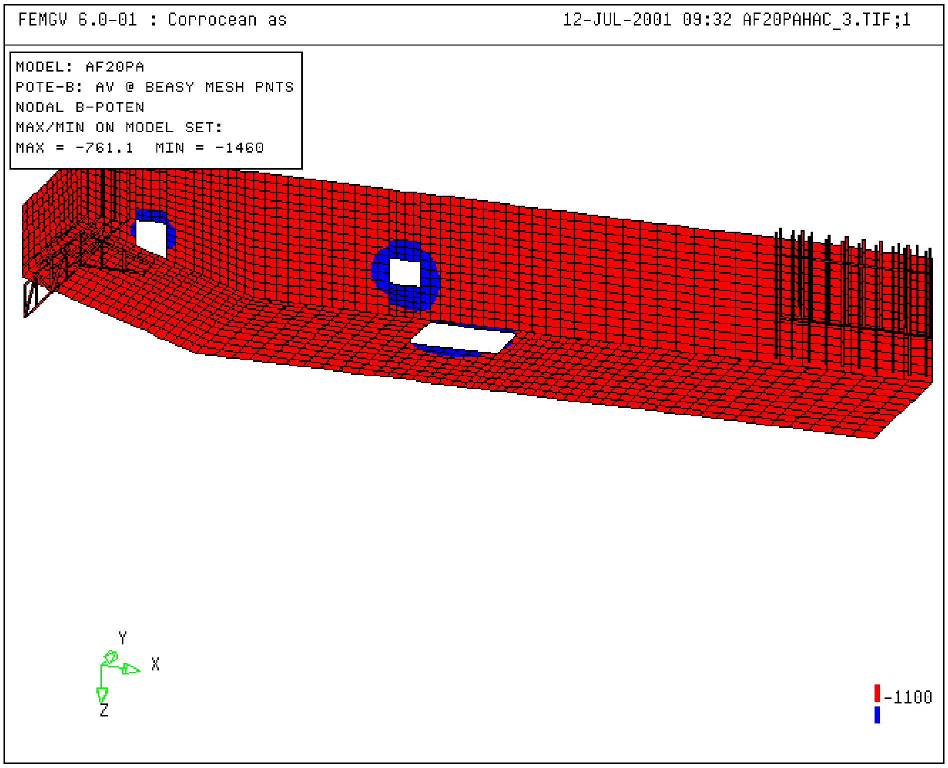
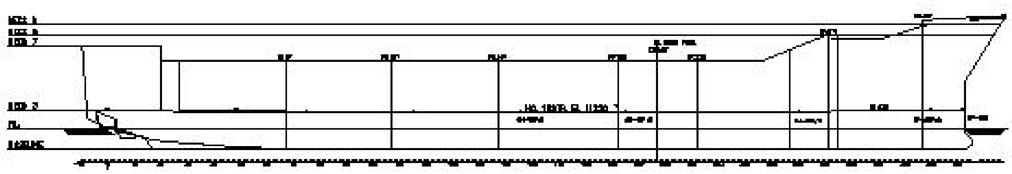


FIGURE 25

CASE 4 - POTENTIAL DISTRIBUTION AFTER 20 YEARS - AFT. BLUE IS OVERPROTECTED (<-1100 MV)



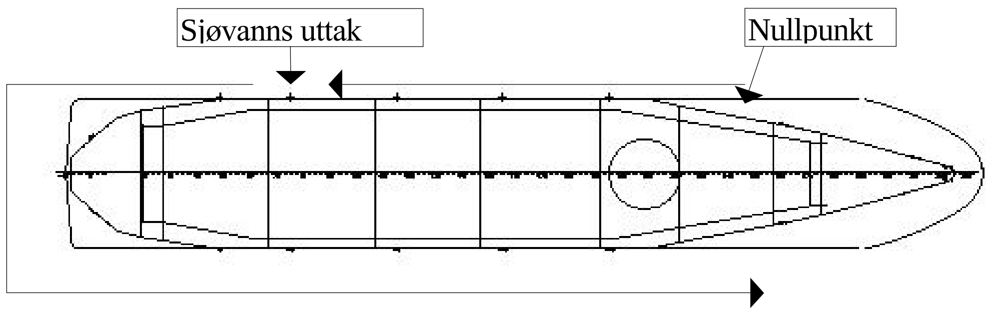


FIGURE 26

CASE 5 MEASUREMENT POSITIONS ALONG FPSO SIDE

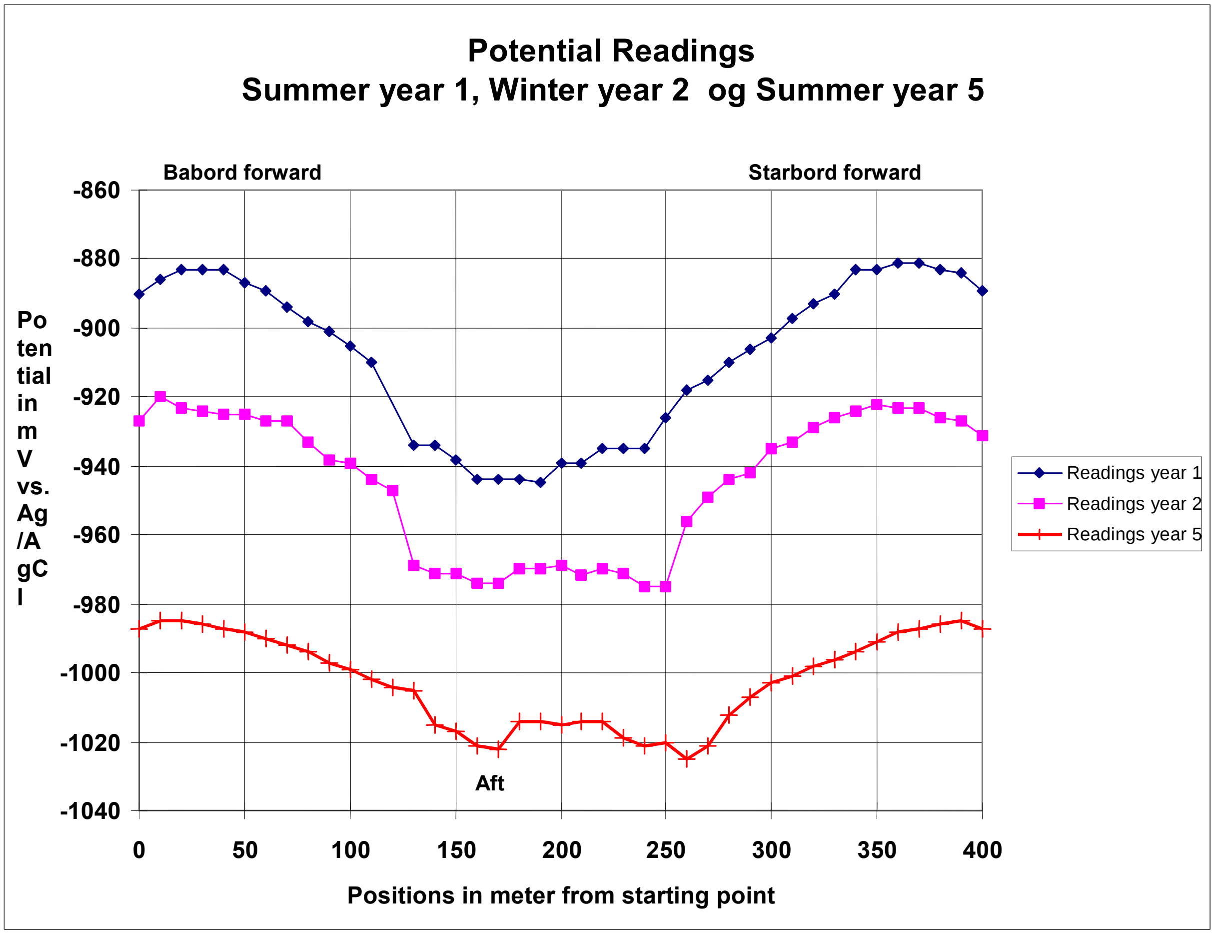


FIGURE 27

CASE 1 – MAXIMUM AND MINIMUMPOTENTIAL ALONG THE CASE 5 FPSO