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A COMPUTERIZED CP RETROFIT DESIGN OF THE NINIAN NORTHERN PLATFORM

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ABSTRACT

In 1986, routine underwater inspection found evidence of accelerated sacrificial anode consumption on the Ninian Northern Platform's subsea structure. A significant number of sacrificial anodes distributed throughout the structure were affected. Their effective service life was greatly reduced compared to a design life expectancy of 30 years. In addition, the structure's Impressed Current (IC) system had never operated as designed, due to probable pipeline interference problems and therefore its output was, and would always be, limited to avoid excessive pipeline overprotection. However, some pipeline overprotection still existed under these limiting conditions. With this in mind, it was obvious that a retrofit design of the cathodic protection (CP) system was required to satisfactorily protect the subsea structure from corrosion in the future.

Initial calculations using traditional design formulae indicated an overall retrofit installation cost of approximately $ 12 million. The final design has an estimated maximum cost of $4.25 million (present day value). The saving of $7.75 million has been made as a result of using advanced computer technology.

The work included surveying the platform using a specialist technique including current density measurements to establish the actual requirements for cathodic protection. This data was then used to create a computer model which subsequently simulated the past, present and future performance of the structure's CP system. From this, the IC system has been set at an optimum level to avoid pipeline overprotection, and the additional sacrificial anode material required to avoid underprotection on the jacket has been calculated from present day to the year 2007.

INTRODUCTION

The aim of this paper is to present a step by step guide to the work involved in designing a cost effective CP retrofit programme for the Ninian Northern's structure.

BACKGROUND INFORMATION

The Ninian Northern Platform (NNP) is the smallest of three platforms installed in the Chevron operated Ninian Field, located 240 miles north east of Aberdeen, Scotland. It has an 8 leg steel jacket weighing 41,000 tons and stands in 141 m water depth. Originally, to protect the Northern Platform's subsea structure from corrosion, a hybrid CP system was designed and installed. An impressed current (IC) system with 12 seabed anodes was to supply 70 % of the 5800 Amp total current requirement. The remaining 30% was to be supplied by Al-In-Zn sacrificial anodes. Prior to energising the IC system problems were found on the Ninian Southern Platform which employs a near identical impressed current system. The anomalies were found on the oil and gas export risers and consisted of:

A. Extreme overprotection (-2000 mV with reference to (wrt) Ag/AgCl).

B. Severe pitting on the electrically isolated riser caused by interference current 'leaving' the riser at weak points in the coating and 'entering' nearby jacket members. All risers are now electrically bonded to structures.

The anomalies were attributed to the high current contribution from IC anodes. As a result, it was decided not to energise the 6 anodes closest to the pipeline approaches and corresponding risers on NNP. Obviously this meant the hybrid system has never operated as designed and only 2 IC anodes had operated continuously throughout with the sacrificial anodes providing the majority of the required current.

Fig. 1 attached, shows a plan view of NNP's IC system.

Fig. 2 attached, shows the IC output since jacket installation. As can be seen, the IC system has never been set to provide the current it was designed to give the structure. However, CP levels throughout the years have always been within specification (-800 to -1100 mV wrt Ag/AgCl). To achieve these satisfactory levels of protection, the additional current was supplied by the sacrificial anodes. The extra workload placed on these anodes would obviously reduce their design lifetimes. In 1986, evidence of this was found when a number of these anodes were observed to be greater than 75 % consumed, i.e. their service lifetime has been reduced from 30 to about 9 years. The heavily consumed anodes were distributed throughout the structure, although most were confined to conductor guide frames and complex node geometries, ie where current demand had been highest and IC contribution had been lowest due to shadowing effects.

Using traditional design formulae and Det Norske Veritas (DnV), BS and NACE guidelines, the cost of retrofitting the conductors and guide frame areas was estimated at $ 3.4 million alone. The cost of retrofitting the entire structure was projected as being $ 10.2 - 13.6 million. Installation costs alone account for 90 % of this total.

Traditional formulae and guidelines tend to be conservative. High current density requirements and high anode resistance values specified by various bodies give rise to this conservatism. For more detail consult Reference 1. The specified values are largely for new, unpolarised steel and DnV does actually give a current density value for stable fully polarised steel. However, with the data available at the time, it was uncertain if the Northern structure was in a stable, fully polarised condition. As a result, initial design current densities had to be used in the above considerations.

With these points in mind and also considering the complex, asymmetrical nature of the existing CP system, it became apparent the 'traditional type' retrofit designs would most probably be inefficient from both a CP and cost point of view. It was therefore decided to follow another more sophisticated route using the services of CorrOcean. This paper summarises the route taken.

THE WORK INVOLVED

Cathodic Potential/Current Density (CP/CD) Survey

Valuable information about the properties of a CP system can be obtained by studying the potential profiles over a structure.
Normally, cathodic potential levels are measured using a silver/silver chloride (Ag/AgCl) half cell. The half cell can be ROV mounted or hand held by a diver and is normally 'stabbed' to make an electrical contact at the location to be measured, held there until the reading stabilises and then the potential level recorded. A steel structure is deemed to be satisfactorily protected from corrosion if the potential levels are within a -800 mV to -1100 mV range wrt Ag/AgCl.

Whilst potential levels tell us something about the existing corrosion protection on a structure at a point in time, they do not give any real indication about the demand the structure is making on the CP system to achieve these protection levels (i.e. current density requirement, sacrificial anode consumption rate, current drains and shadowing effects). To obtain this information, it is necessary to use an additional piece of specialised equipment. This equipment, the "CP Pipeline Reader" (CPPR) essentially comprises two reference cells located in a rotating T sensor unit which measures the potential drop between the two cells in the seawater at a fixed distance from a particular location. The cell rotation effectively compensates for cell drift providing high sensitivity and accuracy for electric field gradient measurements. If the seawater resistivity is known, the current density at that location can be computed. The direction of current flow can also be determined with this system. If the current is flowing out of a location, the location is considered anodic wrt the surrounding area. If the current is flowing to a location, the location is cathodic wrt the surrounding area.
The combination of using a conventional Ag/AgCl half cell and the specialised current density equipment described above can be used to give a comprehensive representation of the efficiency and effectiveness of a CP system. A survey using such a combination is termed a CP/CD survey. It was concluded in March 1987 that such a survey was necessary for NNP's structure.

During July 1987, a CP/CD survey was carried out on NNP's jacket, risers, conductors and pipeline approaches. The equipment, as described above, was mounted on an ROV and launched from the platform. (See fig. 3). Initially it was thought that about 3,000 data points could be taken within the time schedule. However, due to efficient project planning, nearly 11,000 data points were taken.

Initial Analysis of Survey Data

An initial analysis of both the survey CP data and visual inspection of sacrificial anodes revealed the following:

a. *Of the original sacrificial anodes, 15 % were greater than 75 % consumed.*

b. *The CP levels on the pipeline approaches were typically -1300mV wrt Ag/AgCl. These levels are in the range at which hydrogen embrittlement/blistering may occur.*

c. *The average current density was 50mA/m^2 (about 4.5mA/ft^2) on the structure and 75mA/m^2 (7mA/ft^2) on conductor and guide frame areas. These figures indicate the structure to be fully polarised and below the 90mA/m^2 (8.5mA/ft^2) given by DnV for average maintenance design current density on a fully polarised structure. NACE does not give such value and only states that a current density range of 86-216mA/m^2 (8-20mA/ft^2) for unpolarized structures.*

d. *The structure was considered satisfactorily protected wrt the standard guidelines.*

Creation and Calibration of a Computer Model

<u>Why use Computer Modelling ?</u> The analysis of the survey data confirmed the uneven current distribution of both the IC system's contribution and that of the heavily consumed anodes. In addition the CP/CD levels varied throughout the structure.

The analysis also confirmed that any manual retrofit design using standard guidelines would not provide the optimum effectiveness from both a CP and a cost point of view. Therefore computer modelling and simulation techniques were used to choose a suitable design to meet the varying and uneven CP conditions of the structure.

<u>Creation and utilisation of a CP model for NNP.</u> In order to predict quantitatively, potential levels associated with different CP designs the 3-dimensional electrical field in seawater has to be calculated. Measurements of potential and current density are required mainly on the surface of steel and anodes. Therefore the Boundary Element Method (BEM) is ideally suited for CP simulations and which is incorporated in the SEACORR/CP [1)], an advanced program for CP calculations including pre- and post processing of data. This programme utilises special tube elements to model structural components and CP distribution on steel jackets more easily and has been used effectively for a variety of tasks eg. the design of CP systems, analysis of CP problems, anode retrofitting, support of CP survey data presentation and assistance with CP system maintenance and operation. For more details consult reference (2).

[1)] *developed by CorrOcean a.s in collaboration with CONOCO Inc., Computational Mechanics Ltd and Fegs Ltd.*

In order to build the structural geometry more efficiently the co-ordinates and diameters of the members were taken from an existing structural model. Conductors, risers, caissons, steel in mud and pipelines etc. had to be added in order to correctly represent the effective exposed steel surface area influencing the CP performance. An interactive graphical pre-processor was used to conduct these adjustments efficiently and with confidence.

The combination in the SEACORR/CP of BEM with advanced pre- and post processing maximises versatility, accuracy and convenience for the user. The structural model of NNP is shown in figure 4. Existing sacrificial and impressed current anodes were added with the aid of a digitizing unit. The next step was to test the model under conditions found during the survey.

Calibration of the CP model of NNP. *The CP condition of the surface of anodes and steel can be characterized by the relationship between potential and current density, which can vary with location and time. The model was calibrated using the CP conditions measured during the survey. Checks, adjustments and rechecks were performed to meet CP/CD levels, anode consumption rates and IC contribution noted at the time of the survey. Due to the complexity of the polarisation conditions a time step simulation was conducted to include the major historical events since the launch of the platform to the year of the survey (fig 3). This enabled an accurately calibrated model to be obtained which was the tool used from this point onwards for all analysis design and simulation work.*

Optimisation of the Impressed Current Output.

The CP levels along the pipeline approaches were measured during the survey as being typically -1300mV wrt Ag/AgCl. At this potential level there is a risk of H_2 *evolution causing embrittlement/blistering. Since the risk of pipeline failure/s are difficult to quantify and put any time scale to, it is obviously good practice to maintain CP levels within the range of -800 to -1100mV which is accepted to eliminate this risk. It was therefore decided to achieve an impressed current output from all 5 operational anodes whereby the pipeline CP levels were equal to or more positive than - 1100mV. The relevant simulation work was undertaken using the computer model and it was found that an IC output of 650A was the optimum value. This is compared with an output of 1560A in July 1987 and a design operating output of 4060A. (See fig. 2). Subsequent pipeline surveys (1989) have shown that the reduction has provided the desired potential level on the pipeline approaches,*

Simulations to Identify Retrofit Requirements.

Obviously, operating at such a reduced output will also have an effect on the CP levels throughout the structure. This brought us on to the next stage of the project which involved simulating the CP/CD levels on the structure for the next 10 years with an IC output =650A. By stoping the simulation every year from 1987 to 1997, we were able to analyse the entire structure and identify areas which fell outwith our requirements for any particular year. Tables were also generated from the model giving CP and CD levels for each node area on the structure. A similar simulation was run with the IC switched off. This was done to determine if maintaining the IC system at 650A and installing a number of retrofit assemblies would be more economically attractive than switching off the complete IC system but installing more anode assemblies.

Retrofit Requirements

Computer model simulations enabled a study to be conducted of each individual area on the structure which fell outwith our protection requirements. These requirements were based on any part of the structure having a CP level equal to or more negative than - 870mV. This figure was derived from:

A. -800mV is the DnV, NACE etc. guideline for minimum protection.

B. -20mV was the average potential variation noted due to shadow effects at complex nodes, conductors, etc.

C. -50mV is the seasonal variation in potential taken from data obtained over the years from reference electrodes located on the jacket.

ie A+B+C= -870mV

For each area falling outwith this requirement, the amount of anode material necessary to provide adequate protection to the year 2007 was calculated using surface area, CP requirement and CP level data from the computer. The computer model has the ability to identify when a particular area requires retrofitting. As a result, we are able to design a retrofit programme whereby anodes would be installed one year before they were actually needed. In this way, the structure is kept satisfactorily protected at all times.

Using a computer spreadsheet and a local model (e.g. a typical model or conductor guide frame area on the structure as per Figures 5 & 6), 3 anode sizes were created with optimum geometries to give maximum current/weight efficiency. Different anode sizes were chosen to give flexible options for retrofitting areas where access may be a restriction and also where the amount of material per assembly can be maximised. The end result would be to achieve an option with maximum current distribution possible, using the minimum number of anode assemblies. The installation of assemblies is the dominant cost in a retrofit programme.

Computer Simulation of Proposed Retrofit Design with IC = 650A.

For each node area, conductor, riser, etc. on the structure, the number and type of anode and assembly was reviewed so that the necessary current requirement could be achieved in the most efficient manner. Local models represent the geometry in more detail and use surface elements which can take care of shadow effects and corner effects (Fig. 5). Local models were used to study the current distribution on complex nodes, conductor guide frames and conductors to ensure that the placement of any retrofit assembly would properly protect the area in question.

Once this was complete, the proposed retrofit design was installed on the computer model. A simulation was then run on the computer with the IC output = 650A over a period of 20 years (ie. to the year 2007) to confirm that the proposed design satisfied the requirements.

The 20 year simulation showed the proposed retrofit design, with a constant IC output = 650A, would be successful in protecting the structure from corrosion at least to the year 2007.

Checking the Design in a 'Worst Case Scenario'

The aim of this part of this work was to study the CP protection levels throughout the retrofitted structure at some point in its life during a total IC system failure. In addition, it was assumed it would not be possible to either partially or totally restore the IC system for a full 12 months.

This worst case scenario was chosen to occur in 1999, i.e approximately mid way through its design life.

The simulation showed the vast majority of the structure would stay well within our - 870 mV requirement throughout the 12 month period. There were however a small number of locations which would fall outwith this requirement during this period - some immediately after the IC output fails.

Nevertheless, the most positive CP level predicted during this period would be - 828 mV wrt Ag/AgCl. Bearing in mind this is still well within minimum protection guidelines and assuming this condition to be temporary, it can be concluded the retrofit CP system could still satisfactorily protect the structure for at least 12 months in a worst case scenario.

RETROFIT INSTALLATION

The retrofit design entailed the installation of a total of 1273 anodes which are to be attached via:

a. 418 bracelet type assemblies.

b. Anode carrying members along the -52, -74.5, -97.5, and - 119.25m conductor guide frames.

c. 18 caps with anodes attached to be fitted on top of open pile guides. (a high current drain was noted at the open end on the surveyed piles)

In late 1988/early 89, 80 % of 'a', 100 % of 'b' and 100 % of 'c' were installed with the completion of a. being undertaken in 1991 and 1994.

COST COMPARISON - WHY CHOSE THE IC OUTPUT = 650A OPTION ?

About 90 % of the retrofit design was installed in 1988/89 at an estimated cost of $ 3.8 million. The remainder will be installed over 1991 and 1994 at a total estimated cost of $ 0.425 million. In addition, to maintain the existing IC system over the next 20 years will cost an estimated $ 0.6 million.

An estimate has been made for a retrofit design with the IC system switched off. The estimated cost would be in the order of $ 5.1 million which is a higher overall cost to the design with the IC output = 650A. Additionally, if we adopted this design, for the same overall cost, we would be abandoning a system that is already in place and therefor making the structure rely solely on sacrificial anodes, thus rendering the CP system far less flexible that at present. Also, with an IC output of 650A there is a large amount of redundancy in the system and therefore failure of up to 3 seabed anodes can be tolerated at any one time.

CONCLUSIONS

Using computer modelling and simulation techniques, we have been able to designed a retrofit CP system which has been shown to satisfactorily protect the NNP structure, risers, conductors and pipeline approaches to the year 2007.

The total cost of the CP/CD survey and initial report plus all the analysis, computer modelling and design work was under $ 300,000. It should therefore be noted this type of survey and design work is appropriate and can be justified for large, complex structures where retrofit costs are high.

The total cost to install this design is estimated as being $ 4.25 million (present day value). Comparing this to a cost estimate of $ 10.2 -13.6 million using traditional techniques, it can be concluded we have successfully created a very efficient and cost effective retrofit programme for the Ninian Northern's structure.

ACKNOWLEDGEMENTS

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REFERENCES

1. *Strommen R. D., Keim W., Finnegan J., Mehdizadeh, P., Advances in Cathodic Protection Modelling Utilizing the Boundary Element Method, Nace/Corrosion/86, March 17-21, Houston, Texas.*

2. *Strommen, R. D., UK Corrosion 1985, 4-6 November 1985, Review of Offshore CP Design Criteria Based On In-situ Current Density Measurements, UK Corrosion 1985, 4-6 November 1985.*

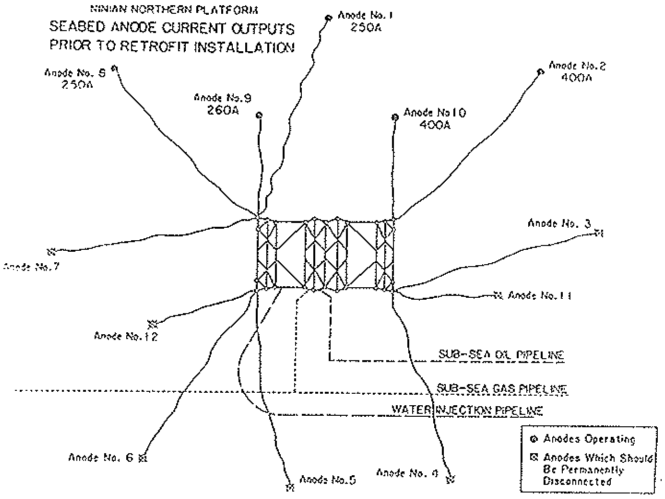

Figure 1 - Seabed anode current outputs prior to retrofit installation

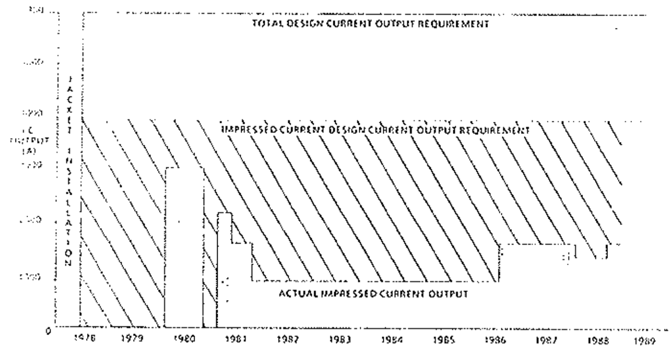

Figure 2 - Impressed current output history

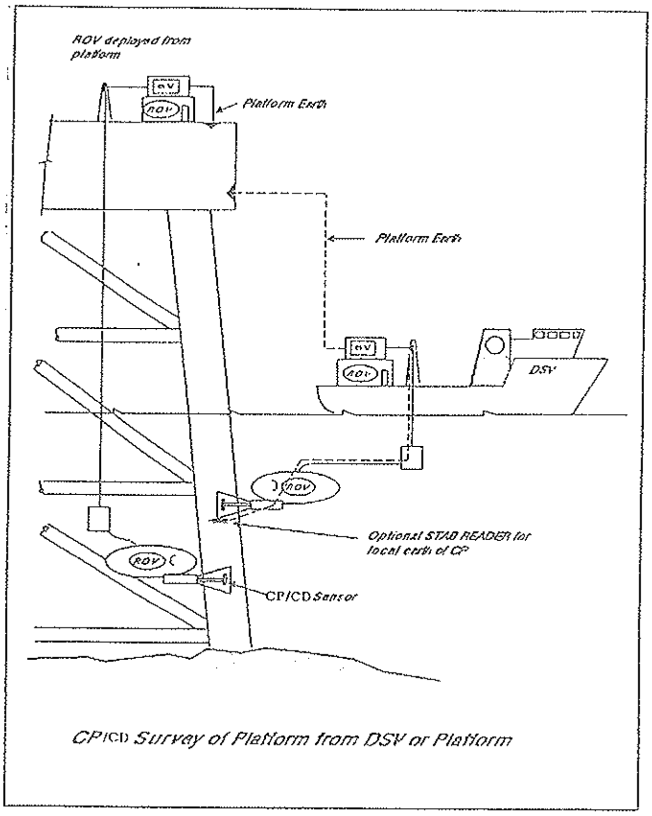

Figure 3 - CP/CD survey of platform from DSV or platform

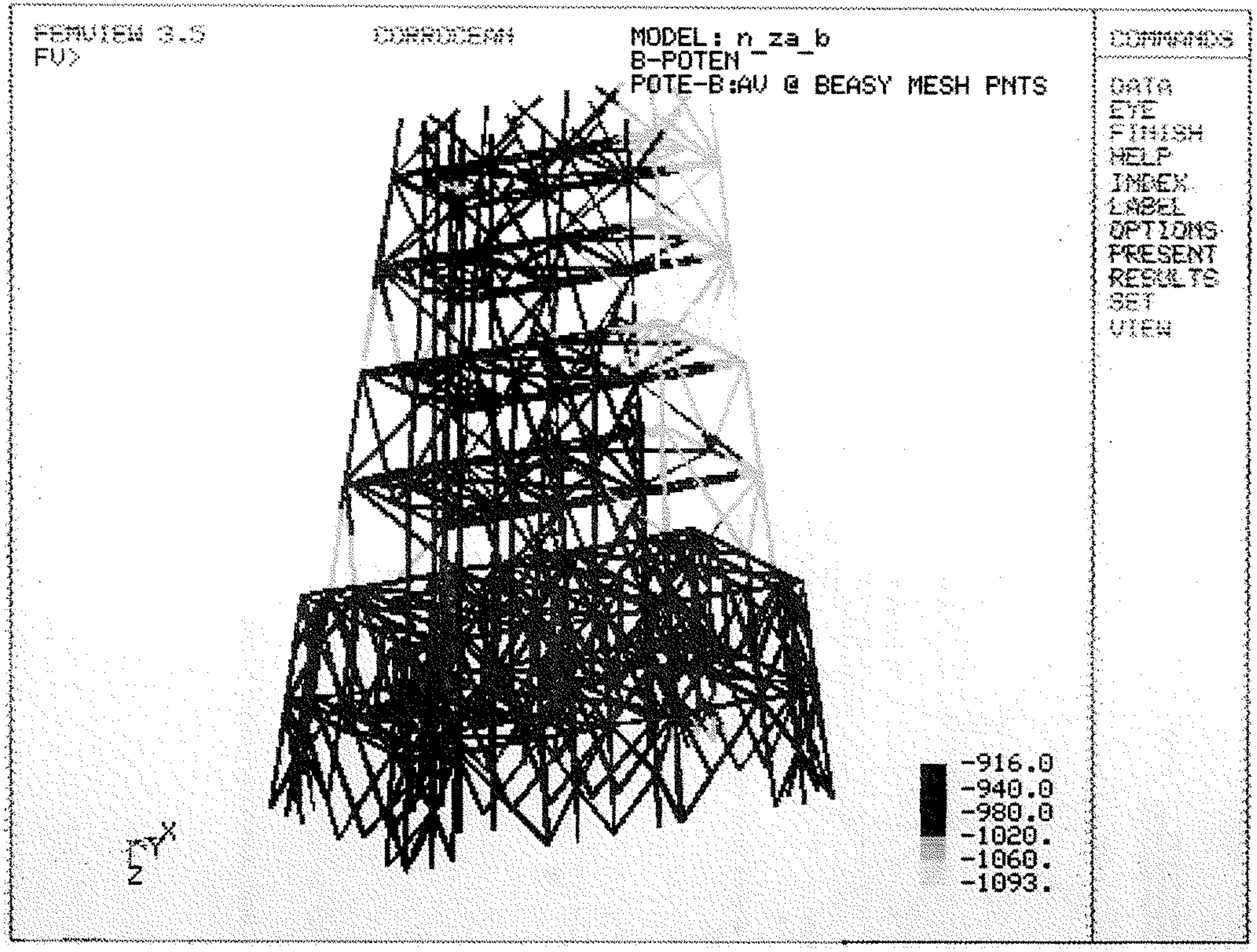

Figure 4 - Plot A.II.48: Protected and unprotected steel area for stabilized conditions for the entire jacket

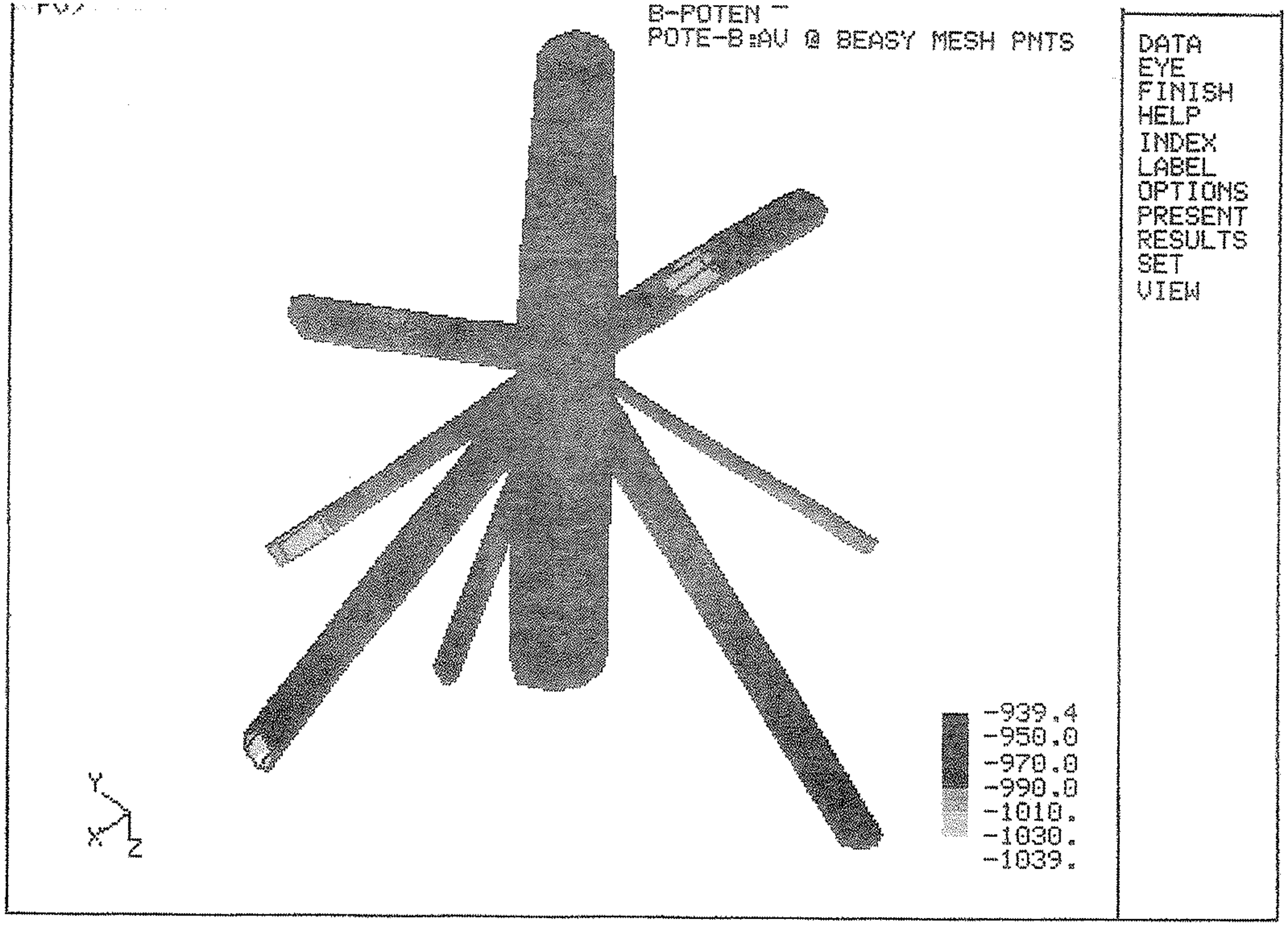

Figure 5 - Typical corner node potential distribution seen from outside the jacket. IC system active.

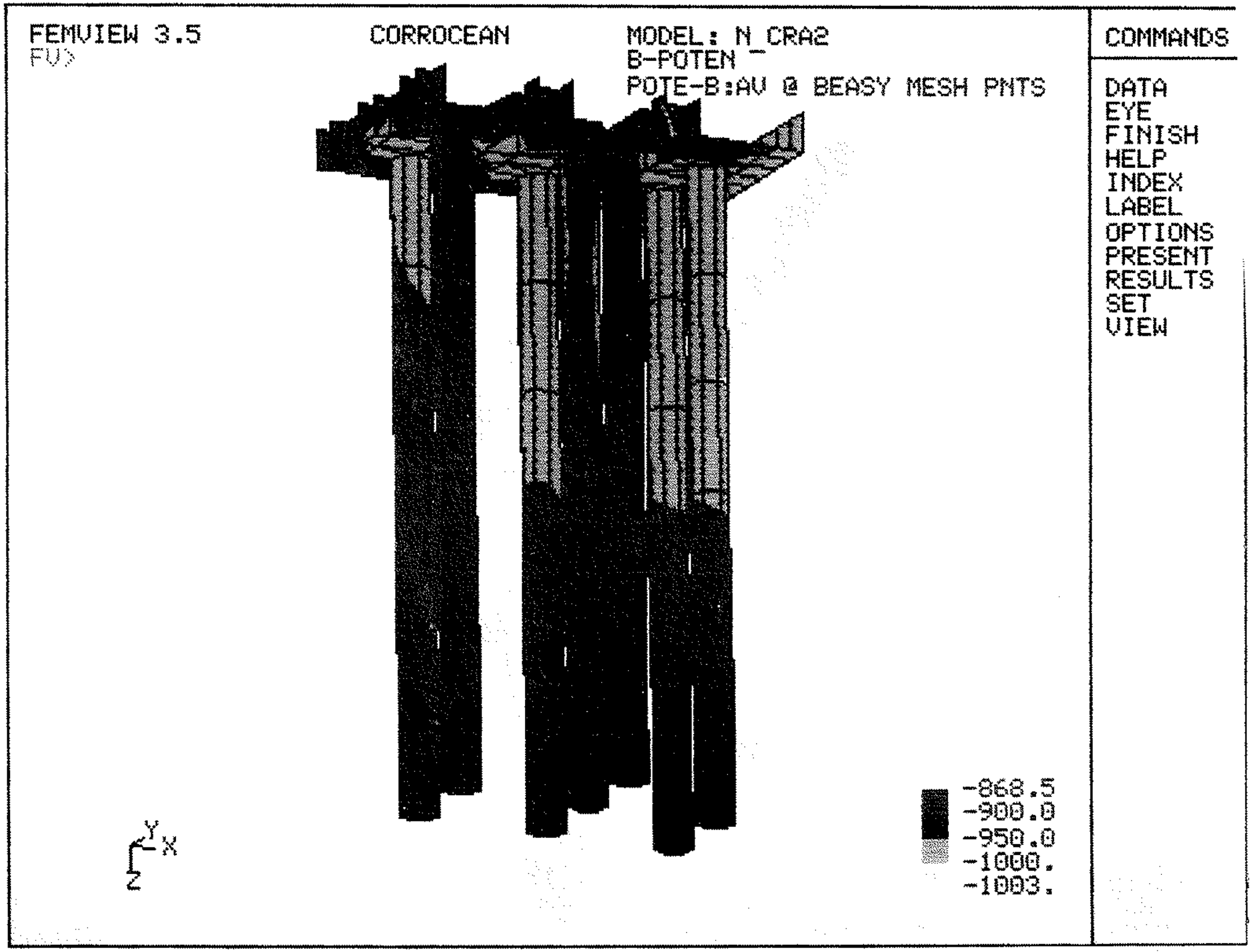

Figure 6 - Typical conductor frame potential distribution seen from inside the conductor region. IC system active.