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Testing and Monitoring Activities of Vega A Project

Essais et surveillance du système offshore de Vega A

Prüfungs- und Überwachungstätigkeiten im Vega A System

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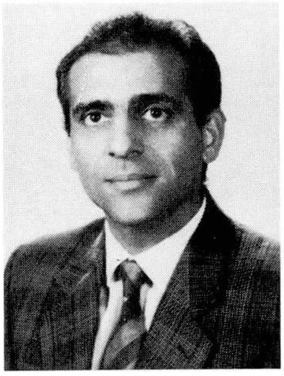

Ostilio Spadaccini, born 1946, obtained his Civil Engineering Degree from the University of Pisa. For ten years he was Technical Manager in a Steel Construction Company and is now professor of Steel Structures in the Civil Engineering Department of University of Florence and consultant for marine structures with SELM, Società Energia Montedison.

SUMMARY
The Vega Field offshore system, the most important on the italian shelf, includes a fixed drilling and production platform located in 123.0 m water depth, a sealine comprising three 2.3 km lines connected to a single point mooring structure for a 250,000 DWT tanker. Continuous and extensive testing and monitoring activities were performed during construction and installation; structural and cathodic monitoring systems were provided to collect usable data for the periodic inspections during the 25 year operating life.

RESUME
Le système offshore de Vega, le plus important du plateau italien, est composé d'une plateforme fixe de forage et de production, située à une position où la profondeur d'eau est 123 m, d'une sealine d'une longeur de 2,3 km ayant trois lignes différentes connectées à une structure du type monobouée pour amarrer un pétrolier de 250.000 DWT. Des activités élaborées d'essais et de surveillance furent effectuées pendant la construction et lors de l'installation; des systèmes de surveillance de la structure et de la protection cathodique furent installées, afin d'obtenir des données à utiliser lors de l'inspection périodique au cours de 25 années de vie opérationnelle.

ZUSAMMENFASSUNG
Das Vega Offshore System, das wichtigste des italienischen Plateaus, besteht aus einer 123 m wassertief stehenden Bohrungs- und Produktionsplattform und drei 2,3 km langen Förderleitungen, verbunden mit einer Mono-Boja für einen 250.000 DWT Tanker. Während Zusammenbau und Installation wurden fortgesetzte Prüfungs- und Ueberwachungstätigkeiten durchgeführt. Ueberwachungssysteme für Struktur und kathodischen Schutz dienen der Aufnahme von periodischen Daten zur Systeminspektion während der vorgesehenen 25 Betriebsjahre.

1. INTRODUCTION

Vega field, operated by SELM, Società Energia Montedison, contains more than 1 billion bbl of oil, of which about 30% may be recoverable. The crude has an API gravity of 15.5°, a pour point of 18°C and a viscosity of 1.000 c.p. when "alive" and warm. The crude properties dictate use of several special production and transport techniques involving light oil blending, heating and thermal insulation of sealine. Vega is located in Italian waters between the southeastern coast of Sicily and the island of Malta, about 15 miles offshore Ragusa. The field, which lies under a maximum water depth of about 131 m, is some 14 km long and varies in width from 1 to 2 km. The entire field area is highly faulted and fractured, which contributes significantly to producibility of the carbonate reservoir. The reservoir lies at subsea depths ranging from 2440 m to 2650 m. Productive thickness averages some 250 m and ranges to 350 m maximum [1].

Vega is a large enough structure to require at least two platforms for its development. The scheme selected for the first phase of the Vega oil field development includes a drilling and production platform, eight leg jacket type, 140 m high and weighing 11,000 tons, the sealine which comprise three different lines, two 10" thermally insulated lines and an 8" for diluent, a single point mooring system located 2.3 km from the platform and a storage tanker specially converted for service as floating storage offloading unit of 250,000 DWT. The system was designed for a life of 25 years with a design production flow of 60,000 BOPD.

Before starting the development of the field and drilling activity a site survey, soil sampling and geotechnical investigation were performed to provide information concerning the surface and subbottom conditions, and to determine the soil conditions related to installation of the gravity buoy and the platform with its pile foundations. Environmental loads (wind, wave and current) based on historic data were analyzed for the 100, 25 and 1 year storms. For 100 year storm the maximum wave was 18.3 m height, period of 13.0 sec. and length 273.8 m in the WNW direction, associated with a maximum instantaneous gust of 59.0 m/sec. The 25 year wave height distribution and associated wave periods were used in fatigue analysis. The 1 year return period storm current was assumed to act collinearly and simultaneously with all waves and was used to calculate the fatigue wave loading.

The effect of earthquakes on the structural behaviour of the platform were considered on the basis of a seismological and vibratory ground motion evaluation. This included modelling of seismicity and definition of seismogenic provinces, selection of attenuation functions, probabilistic analysis and vibratory ground motion.

2. MAJOR VEGA A COMPONENTS

The first stage of Vega field development was dependant upon the following factors:

- oil type and reservoir characteristics,
- water depth and environmental conditions (wind, sea, seismic),
- soil conditions and stratography,
- drilling of the wells during onshore platform construction to allow an early production,
- simultaneous drilling and production activities.

The adopted solution with a fixed platform, sealine and single point mooring allowed applicable operational requirements and safety aspects to be satisfied.

2.1 Platform

A subsea template with 18 well slots was fabricated and installed in September 1983 before starting drilling operations. This is a 37 m long structure, with four 36" grounted piles. Sufficient stiffness was provided to meet tolerance needs of future tieback connections between predrilled wells and fixed platform. Specifically an acceptance limit of 1 degree was set for the structure planarity. To meet this tolerance a jack levelling system was provided complete with : two electronic inclinometers installed with two indicators, one local,

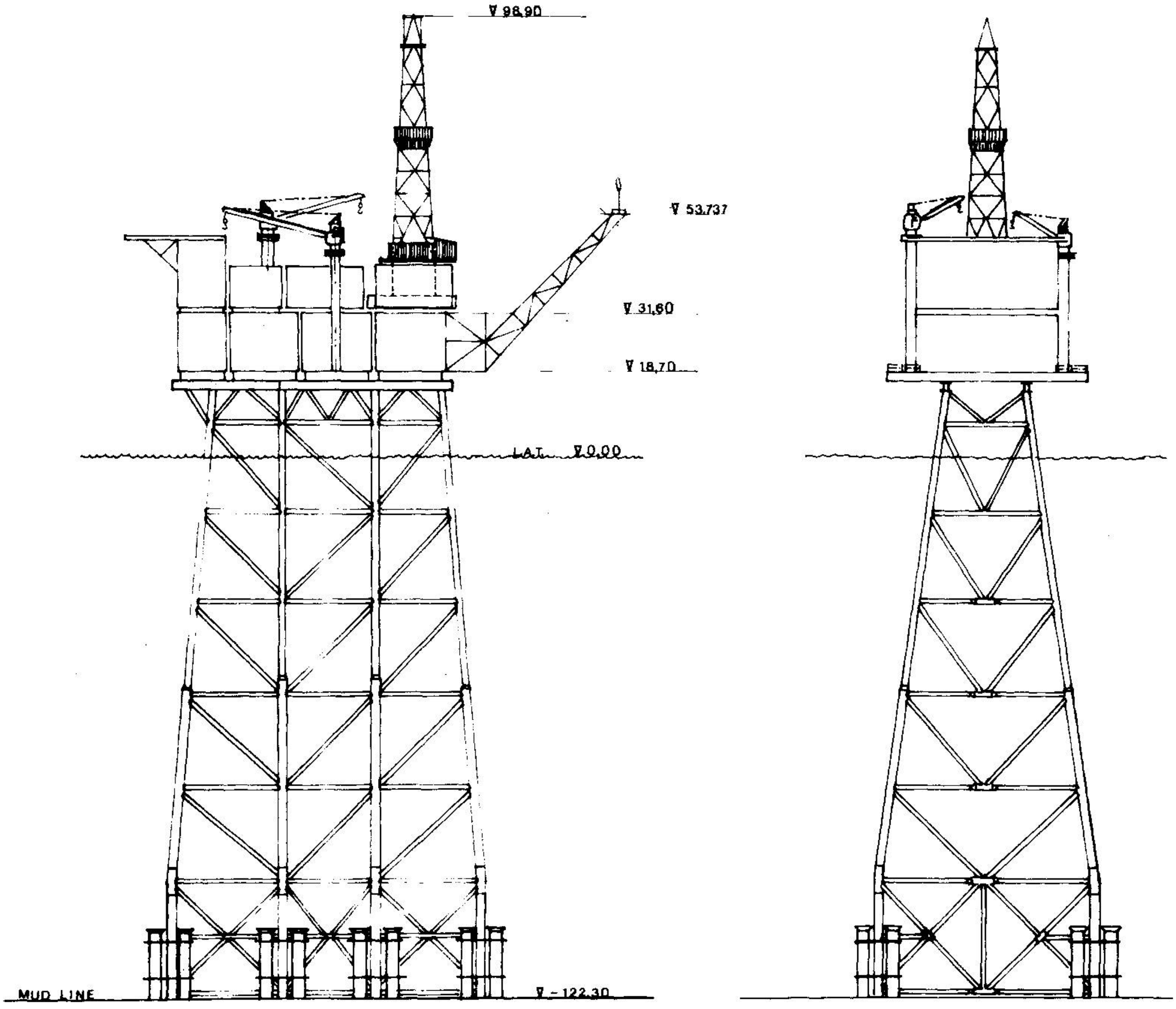

Figure 1 : North West and South West views of Vega A platform.

installed on the template, one remote installed on board installation barge; an optical slope indicator on the template as a back-up of the electronic system.

To avoid the interaction between soil and structure flexible type connections were provided between 30" conductor pipes and template so that a defined maximum load would be transmitted to the template.

The jacket is an eight leg tubular space frame structure, as indicated in figure 1, approximately 140 m high, with bottom dimensions of 68x58 m and top dimensions of 46x18 m. There are six horizontal frames spaced at roughly 24 m intervals, each of which supports the construction guide frame.

The platform deck is composed of two skid beam rows on which each production and drilling modules is placed and supported in four points. Modules have independent structures and are not connected to one another structurally to respect the design dynamic seismic behaviour. The platform is supported by 20 steel vertical piles driven to approximately 65 m below the sea bed. These piles were driven using an underwater hammer.

Auxiliary temporary buoyancy tanks were connected to the jacket for use during the launch and positioning on the template. The main advantage of this type of self-up-ending jacket is the reduction of time required for installation. However, on the other hand, this procedure has some impact on the installation safety because it is impossible to perform any kind of emergency action after jacket launching. These considerations required that the weight of the structure and the buoyancy distribution be continuously monitored throughout fabrication [2].

The maximum weight of a single module is about 1300 tons, the total operating weight of topside modules is about 13,300 tons. Two flexible appurtenances, flare and drilling rig, required a special dynamic analysis under seismic loads since the pseudo-static analysis used for design of module structures was not considered sufficiently conservative.

2.2 Single point mooring (SPM)

The SPM is an articulated column anchored to the sea bed by a gravity base. The storage tanker is permanently moored to this column by a rigid yoke [3], see figure 2.

The gravity base, 33 m square and 13 m high and weighing 750 tons supports at its centre the universal joint. Due to the poor soil characteristics 2 m deep skirts under the base drums and beams, see figure 2, are necessary for stability. The universal joint connects the base to the lower part of the column by self-lubrificating bushings which allow column articulation. A cylindrical steel column is the largest component of the mooring system with a dry weight of 2000 ton, a diameter of 9 m and 125 m length. The column contains heavy ballast materials in its lower part and tanks for buoyancy and stability in its upper part. At the top of the column a triaxial joint is installed which gives the yoke adequate degrees of freedom with respect to rotation, pitch or roll.

2.3 Sealine

The sealine comprises three separate lines, two 10" thermally insulated lines for oil service and one 8" uninsulated line for diluent. The 10" lines are a novel design comprising an insulated double pipe system and special forged connectors. This solution has the following advantages:

- mechanical protection of thermal insulation during laying and during the life of the system,
- in the case of damage to one section of the pipeline the effect is localized and does not significantly affect the general thermal efficiency,

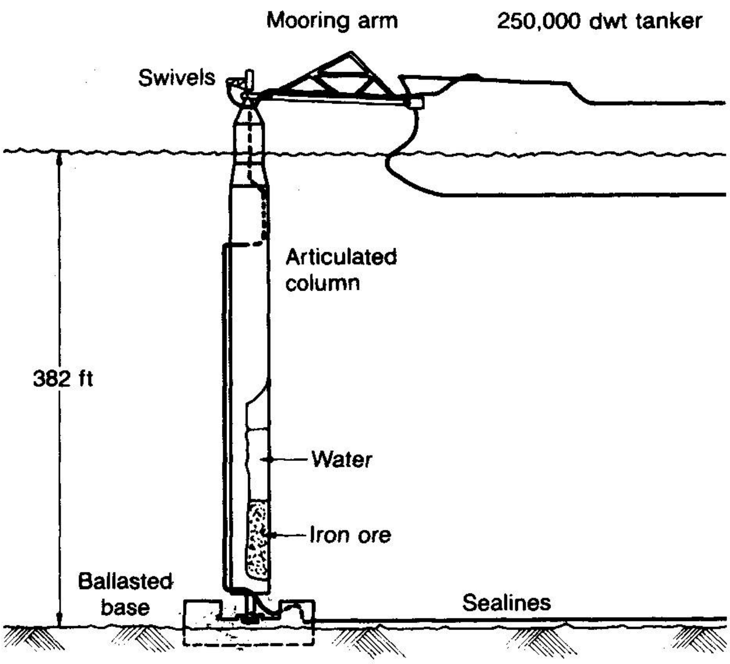

Figure 2 : Single point mooring for tanker at 2.3 km from platform.

- good stress distribution between internal and external pipes.

3. CONSTRUCTION AND INSTALLATION

The most important testing and monitoring aspects during the construction and installation phase were:
- steel material control and welding quality control,
- weight and dimensional control of the structures,
- control and monitoring of marine operations (i.e. launching, docking, ballasting and piling for the jacket; floating, docking and ballasting for the SPM; laying for the sealine).

3.1 Materials

Two type of high strength steels (type I and type II) were used for the primary structure, basically in compliance with EU 25 Fe 510 with some modifications. The main differences between type I and II steel are: the requirement for type II of through thickness tensile tests per EU 164-83, and the thickness for type I is less than 60 mm. The maximum carbon equivalent (C.E.) according to the formula $C + Mn/6 + (C_r+Mo+V)/5 + (Cu+Ni)/15$ was 0.42% in ladle and 0.44% in the product, the soluble aluminium to nitrogen ratio to be at least 2:1. Impact test was in accordance with EU 45 with Charpy V-notch, specimen being removed transverse to the rolling direction and the minimum single value 27 J for thickness $\leqslant$35 mm at -20°C and for thickness >35 mm at -40°C.

The qualification tests for the base material were the following: tensile, bend, impact, ageing, drop weight, COD, macroetch. The qualification tests for the weldability were: cold short cracking test, impact in HAZ, hardness and macroetch of joints, COD in HAZ.

During the workshop construction of jacket nodes, some times during ultrasonic testing defects appeared in the welding especially for the type I steel, which at the next repair control were found to originate in the base material.

In the yard during the assembling of nodes with members by single side butt welds defects were originally found due to lack of accurate fit-up, welder not sufficiently skilled for the first pass of single butt weld, incorrect interpretation of UT results.

3.2 Weight and Dimensional Control

Continuous monitoring of the weight and dimensions during fabrication is essential for marine operations engineering.

For the jacket the weight and centre of gravity was monitored and the as built situation was used for final check of load-out, transport and launching.

One of main problems during the construction was the control of node geometry, however the tolerances achieved for the jacket were:
- the horizontal distance between the centre lines of adjacent columns at each horizontal frame within 6 mm,
- at each horizontal frame the diagonal distances measured at column centerlines not differ by more than 15 mm,
- jacket conductor guide centerlines are not deviate more than 12 mm from construction drawing.

3.3 Marine Operations

The marine installations of the jacket, S.P.M. and sealine included various monitoring activities during the launch phase, docking, ballasting and piling.

3.3.1 Jacket

During positioning, the jacket was continuously monitored using an acoustic system. This system, linked to crane barge with a cable and acustic hydrophone, comprised a microprocessor based control and telemetry unit (CTU) with internal sensors for roll, pitch and depth, and four external sensor transponder/remote transducer (TRT) units. The four TRT's were mounted at -120.3 m level on the inside face of legs. Four compact transponders were pre-installed on the template corners.

A control unit installed on the crane barge was used to request the CTU to select a master transponder and cause it to interrogate one of the four template transponders.

The above measurements were up-dated every 12 seconds either in hardware or acoustic telemetry.

A secondary jacket positioning system was provided utilizing underwater cameras and lights mounted on the template. Each camera and lighting arrangement was mounted on the three docking piles to provide an optimum view of the docking cone guides of jacket during the final stages of positioning.

One of the main problems in the design and the installation of the jacket was the presence of a calcarenite formation in soil extending from a level about 46 m below mud line and prediction of its load bearing capacity. The twenty 102 inch piles were designed to be driven vertically through pile sleeves, into which the piles are subsequently grounted. For the foundation piles the MENCK MHU 1700 hydraulic hammer was utilized. This hammer was equipped with sensors for the measurement of ram stroke, hydraulic oil pressure and impact velocity. This data was reviewed and used to obtain hammer performance characteristics for subsequent back analysis of the blow count records so that design load bearing capacities could be confirmed. Eight conductor 30" pipe were installed by driving to a penetration of 65 meters with a diesel hammer.
For the piles figure 3 shows that the average blowcount never exceeded 50 blows per meter. This observed driving behaviour demonstrates that the frictional

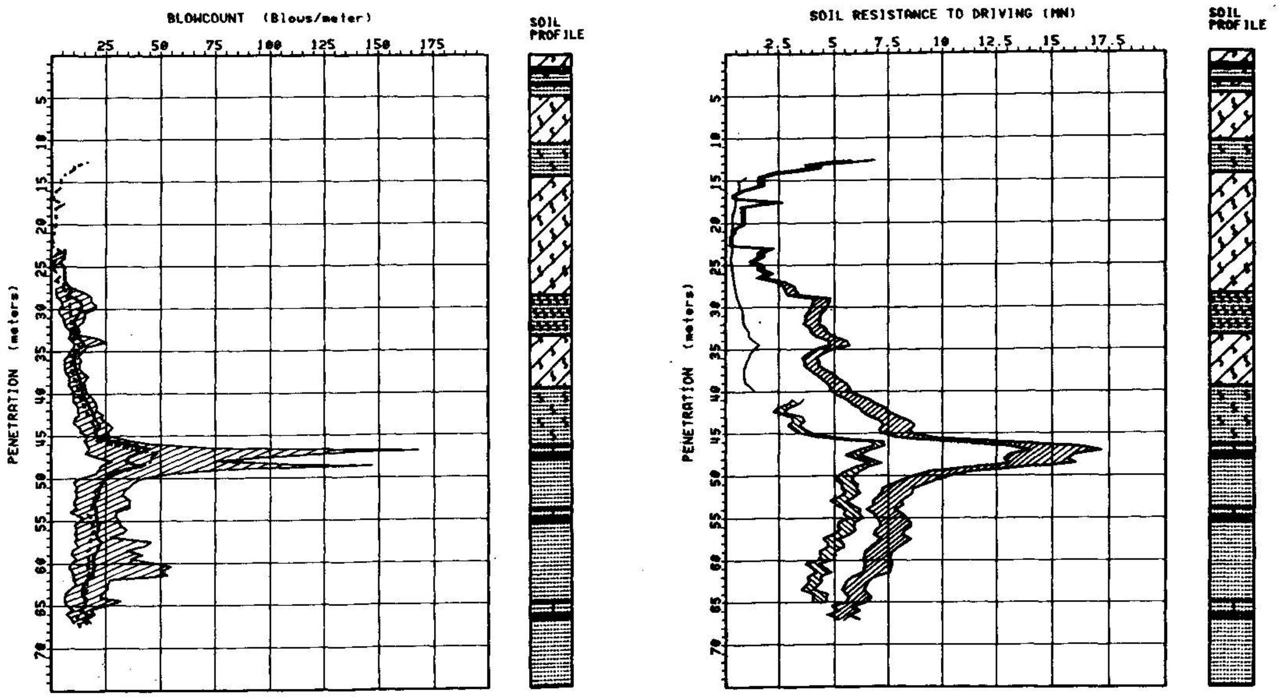

Figure 3 : Blawcount of foundation pile and soil resistance for pile and conductor during driving.

resistence acting on the piles was lower than expected due to remoulding and degradation effects, this also can be explained in terms of the excess energy available during driving.

The back analysis of soil resistence to driving is indicated in figure 3 with apparent difference in the driving behaviour of the piles and the conductors. For the piles, the increased resistance between 45 and 50 meters penetration appears to be completely lost shortly after penetration past the layer. The pile driveability behaviour was not fully understood. One feasible explanation that the length of strain wave generated by the MHU 1700 hammer reduces blowcount under easy driving conditions by maintaining relative movement between the pile and soil for a larger period.

The adequacy of the foundation however was confirmed by redrive tests, performed at a depth of 65 meters, the first after a set-up period of 148 hours, the second after a set-up period of 14 hours. These tests indicated that the set-up or strength gain of the Vega A soil was considerable, as a plotted on figure 4. From a soil resistence to driving of about 13 MN the driving resistence increased to 30 MN after 14 hours set-up, and about 45 MN after six days.

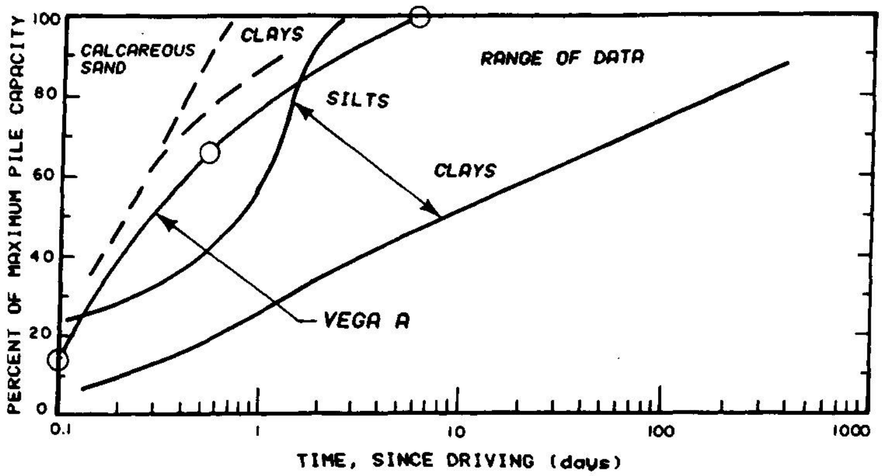

Figure 4 : Pile capacity for different soil conditions as a founction of time after driving.

Two piles were also monitored during driving by means of three transducers and three accelerometers mounted inside the pile at approximately 10 m from the top. Unfortunately the blows were recorded only to a penetration of 40 m and 46 m, after which values were not reliable since damage to the cables caused loss of insulation and excessive signal noise on some or all the instruments. However the calculation of pile bearing capacity and soil parameters by a stress wave program at those penetrations confirmed the indicated data of soil resistance.

3.3.2 Single Point Mooring

The SPM base/column assembly was towed out of Augusta horizontally and, 6 miles away in about 100 m water depth, uprighting of the column was started. After 6 hours the column was vertical and ready to be towed to the site. The most original feature of the installation work was the placing of 10,000 tons of iron ore inside the column and base drums. The iron ore was mixed with water to a form of a slurry and then injected through 4" hoses by means of centrifugal pumps. Once the column had settled on the sea bed, and the mooring had been secured by a large amount of excess water in the column, base ballasting was started. The ballasting procedure had been studied in order to be carried out without the aid of divers, and special underwater connections had been designed to be operated by ROV. To set the base skirts into harder soil layers, 6500 ton of iron ore were injected to reach a total foundation penetration of about 5.0 meters.

3.3.3 Sealine

The control of any pipelay vessel's position is a major factor in the installation of a subsea line. The pipeline route between platform and SPM are specified within well defined limits and positional tolerances, to permit the correct installation of the expansion spools. For this positioning a primary Microfix and secondary transponder systems were utilized. Microfix is a short range position fixing system combining the proven microwave interrogation techniques and results in a repeatable accuracy of 1 meter. Another essential aspect is the monitoring of the pull on the line and its geometry during laying operations. The touch-down point resulting from theoretical calculation of free span and barge heading position was continually monitored on the bridge.

4. IN-SERVICE MONITORING AND INSPECTION

A complete program for in-service inspection contained within a procedural manual for all activities of inspection and monitoring has been prepared and already issued. On this basis the structures are monitored by area and all data are recorded.

Structural and cathodic protection monitoring systems were designed and installed on the platform which continuously collect data to be used in the in-service annual inspection program defined for detection and control of cracks and/or malfunctioning.

4.1 Structural monitoring

The system installed on the platform comprises performance and environmental instrumentation.

The performance instrumentation (strain gauges and accelerometers) provides an evaluation of the performance of the structure relevant to the dynamic behaviour and fatigue during its operative life. The accelerations are measured at the top of the jacket, level + 18,70 m. The model frequencies of the platform can be found from the position of the peaks in the acceleration spectrum.

The axial stress in two selected members is measured by eight couple of strain gauges placed in the middle span and at the opposite side of the section. The strain gauges are connected to the data acquisition system panel and the axial strain is obtained by combining strain measured by each couple. The purpose of this stress instrumentation is to provide data which may be used monitor fatigue. Strain gauges were selected to satisfy the following requirements: range $\pm$ 500 μm/m; accuracy $\pm$ 5 μm/m, measurement frequency range 0 to 0.8 Hz.

Environmental conditions are measured by two anemometers installed at the top of the drilling derrick and the living quarters and an acoustic type wave height measurement instrument.

For the SPM, the typical loads and motions can be considered as the addition of a component with low frequency and a component with high frequency varying with wave periods. The low frequency component is governed by a second order phenomena and is proportional to the square of the wave height, and its frequency is the natural frequency of the system (100 ÷ 400 sec.). The high frequency component is produced by the direct action of the waves on the structure, is proportional to the wave height, and its frequency is the wave frequency (3 ÷ 25 sec.). To monitor the SPM structures it is necessary to make the following measurements (see fig. 5) :

- the three angles between base/column, column/yoke and yoke/tanker by pitch-roll sensor;
- the load between the columns and tanker through the yoke by stress sensor.

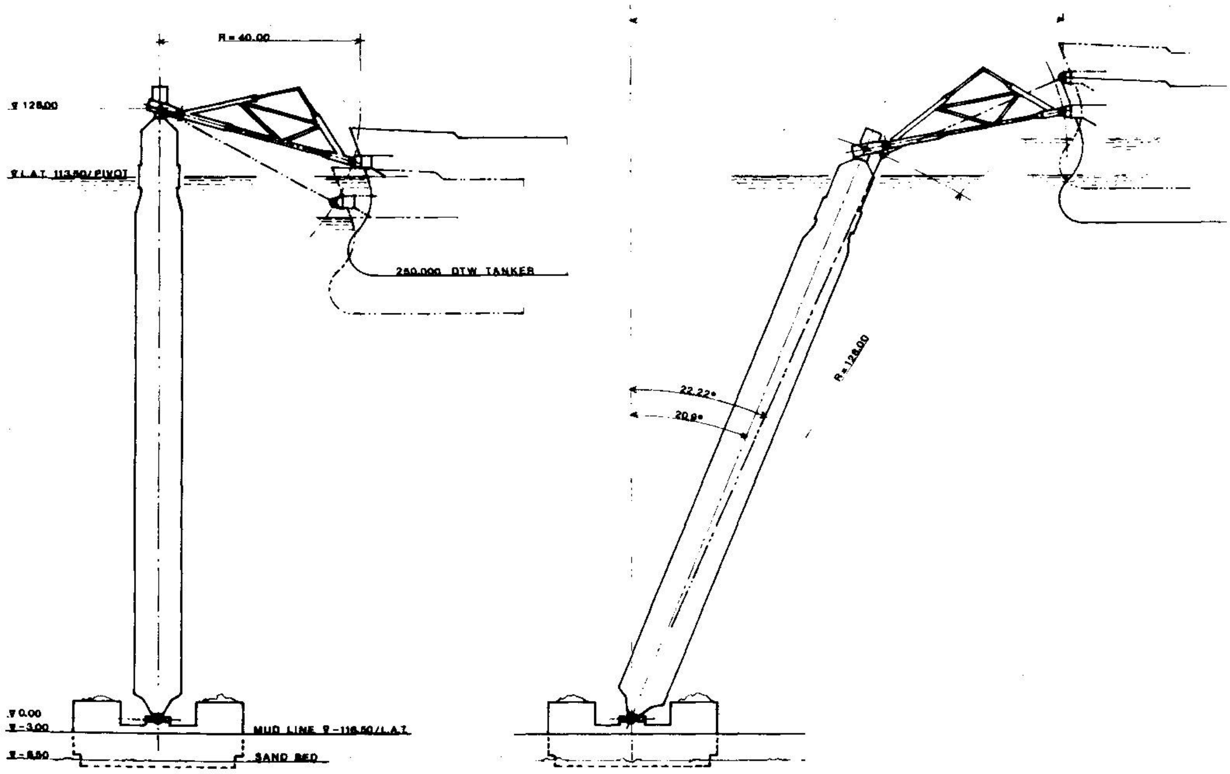

Figure 5 : Single point mooring movements of column, yoke and tanker

The implementation of this system has not yet been made and is currently under evaluation.

Another important problem in the in-service monitoring of SPM was the performance of the lower point bushings. These bushings are made of self-lubricating bronze material and have been designed for the life time of the system. To increase the confidence of the bushings an additional lubrication aid was provided to protect the mechanical parts and to monitor the wear of the self-lubricating material.

4.2 Cathodic Protection Monitoring

The permanent cathodic protection monitoring system is a means of supplying the state of metallic structures immersed in sea water during its operative life. Measurement of protection potential reached by joints, beams or other critical frames of the jacket allow the following:

- structure polarization course (first phase during calcareous deposit grouth) to be followed,
- control of the cathodic protection level reached and find out particular elements or zones which are under protected,
- perform in a timely manner the incidental retrofitting operations needed,
- collect data during the remaining period of operative life.

The influence of cathodic protection on the fatigue behaviour of a welded structure depends in a complex fashion upon the interaction of the mechanical, chemical and electrochemical parameters, on the crack initiation and the crack propagation [4]. Therefore the best way of improving fatigue life is still to delay crack initiation for as long as possible. Smooth shaped welds, post-weld improvement, and maintenance of a moderate potential are the best guarantee against the fatigue problem. During crack growth, moderate potential again provides the best compromise in reaching undesirable acceleration of growth rate.

The cathodic protection monitoring system is composed of:

- 30 underwater zinc reference electrodes, see figure 6,
- a control panel with a mimic diagram and the depolarizing unit.

4.3 Inspection Program

An inspection programme was designed to obtain information needed with regard to preventive maintenance of the structure and to assess the safety [5].

The inspection programme comprises:

- general visual inspection of the whole platform carried out every year at the beginning of the inspection period to discover any indication of deterioration which may require further inspection in that period,
- wall thickness measurement of jacket legs at water line,
- weld examination of a sample of selected highly stressed nodes to provide an early indication of distress.

Highly-stressed nodes were selected for periodic weld inspection according to the following criteria:

- computed fatigue life, less than 60 years, inspected by magnetic particle inspection once in each cycle of five years, with additional sampling by close visual inspection,

- computed fatigue life, less than 200 years, in conjunction with stress interaction ratio greater than 0.8, inspected once by magnetic particle inspection and once by close visual inspection in each cycle of five years,
- punching shear factor greater than 0.9, one node weld per jacket level was selected for close visual inspection once in each cycle of five years,
- stress interaction rate greater than 0.9 selected for close visual inspection once in each cycle of five years.

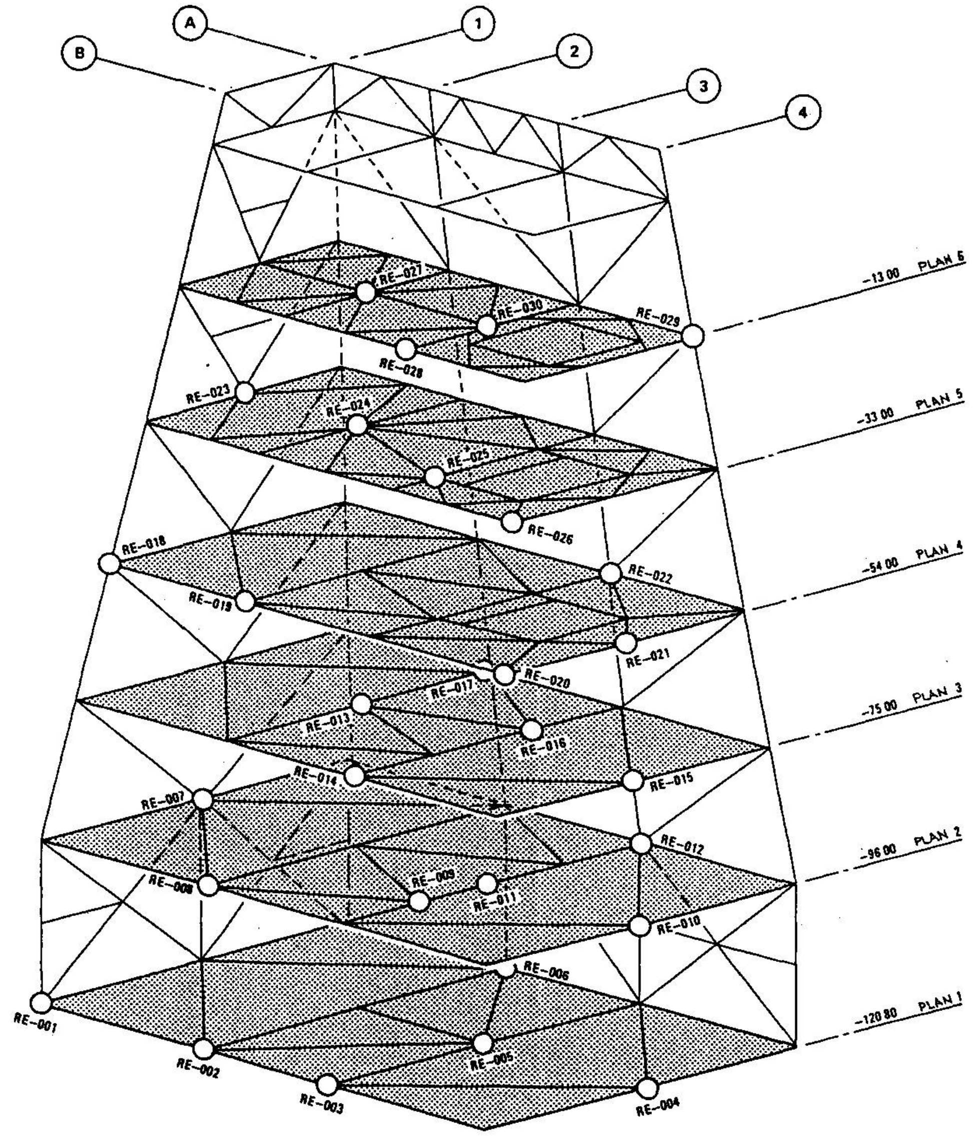

Figure 6 : Position of reference cells for cathodic protection monitoring system.

The inspection programme documentation lists inspection requirements during ordinary annual surveys, special surveys every five years and occasional survey after collision, eartquake or extreme storm.

5. CONCLUSIONS

During all phases of the Vega A project the main objective of inspection and monitoring activities was, and still is, to ensure the safety of the structure. Not only was personnel safety ensured, but also material losses or related problems were minimized.

Data obtained during construction and installation phases have been very interesting and will be useful for future similar projects.

The continuous monitoring and periodic in-service inspection programme assures continued safety and reduced maintenance costs.

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