THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Suite 400, Jersey City, New Jersey 07306 USA
Paper presented at the Marine Structural Inspection, Maintenance, and Monitoring Symposium
Sheraton National Hotel, Arlington, Virginia, March 18-19, 1991

# Requalification and IMR Program for the Belayim Field

**R. Brandi,** Tecnomare S.P.A., Venice, Italy
**H. Abu el Nasr** and **M. Keira,** Petrobel
**H. Hazem,** Enppi

ABSTRACT

A large requalification project is currently under development by Enppi and Tecnomare on behalf of Petrobel for the Belayim Field, Red Sea. In this framework a conspicuous number of platforms, partly severely damaged, were subject to structural analysis.
Integrity assessments were carried out and the necessary repair interventions were established in order to provide an adequate level of safety. A suitable data base and an inspection program were also established to maintain the structural reliability under control.

INTRODUCTION

The Belayim Oil Field is located in the Red Sea and consists of over 40 installations in water depths ranging from 12 to 45 metres. These installations have different structural complexities: many of them are single well templates or clusters, others are piled jackets supporting production equipment. One platform is manned on a permanent basis.
The platforms can be subdivided into two groups according to their installation dates. The group 1 platforms were installed between 1960 and 1967 whilst the plaltforms of group 2 were installed between 1978 and 1989.
During the year 1988 Petrobel decided to extend the operating life of the group 1 platforms by an additional 15 years: for this purpose the platforms needed a complete reanalysis to identify the necessary remedial actions. There were, in addition, some areas of insufficient corrosion protection also in the more recent installations of group 2.
Consequently Petrobel awarded a contract to Enppi and Tecnomare to encompass the following:

- structural reanalysis and integrity assessment of the group 1 platforms
- design of repairs for group 1 platforms
- cathodic protection reanalysis for all the platforms
- engineering assistance to construction and offshore work.

This paper deals with the structural engineering work performed on the group 1 platforms and focuses mainly on the criteria that have been used for the integrity assessment and on the description of the remedial actions that were recommended.

OBJECTIVES AND OVERALL PROGRAM

For all 13 platforms of group 1, installed between 1960 and 1967, an operating life extension was required to the year 2005. Some of them had severely damaged members.
The main objectives of the project were to:

- assess the structural integrity
- identify the remedial actions
- design the repair interventions necessary to ensure adequate structural safety
- establish the inspection criteria and a minimum inspection program for the extended operating life.

The engineering work, which the paper is referred to, started at the end of 1988 and was completed by October 1989. The design of the repairs and the tender documents for the offshore work were completed by July 1989. It may here be recalled that a massive work was needed at the beginning of the project, when the structural identification was in progress: data acquisition was mostly paper work from design reports and past inspection reports, yet some lack of information required a short term survey to be carried out to complement the available information.
All the information relevant to the geometry and status of the platforms was stored in a Data Bank.

This proved to be a very helpful tool because it made it easy to file a large amount of data in a format ready to interface with the procedures of analysis to be used through the requalification process.
The Data Bank will be constantly updated during the ongoing life of the structures in order to retain records of relevant events and inspections.

INTEGRITY ASSESSMENT

The structural analyses to assess the static strength were performed for the 100 year environmental condition and for the operating storm condtion, associated to the appropriate dead and live loads, in accordance with the API Recommended Practice for designing fixed offshore platforms.
The implicit criterion was that the Belayim platforms should have the same design strength as if they were new platforms to be installed right in 1990.
The intention was to maintain this straightforward criterion as far as possible and possibly investigate special cases by more refined assessments.
This philosophy proved to be successful, because the main structural members of the platforms resulted to be adequate to sustain the prescribed loads, unless they were damaged.
The damaged members were, on the other hand, severely corroded or bent by impact: due to the severity of their conditions the remedial actions had to be chosen in a rather drastic way, by replacing the damaged members or by restraining them by bracings.
These repairs were also designed to the same extreme conditions as used for the structure assessment.
A different situation appeared for the tubular nodes of the legs, which resulted to be inadequate to this criterion: a specific analysis was therefore performed to assess their strength by means of an empirical calibration.

The fatigue analyses were performed on a probabilistic basis. The results showed a general undersizing of the connections with respect to what a new design would have called for, in accordance with the available design data.
On the other hand the available inspection results gave no evidence of any fatigue damage so far.
A calibration was therefore performed on the theoretical results of the fatigue analyses in order to reasonably fit the evidence.
The final outcome was a rational inspection planning for the time ahead, in order to detect in the most efficient way any possible appearance of fatigue cracks.

In the following paragraphs more insight is given into the tubular node resistance assessment and calibration, and eventually an outline of the recommended remedial actions is given.

Tubular Node Strength

A large number of nodes resulted not to meet the design requirement of the punching shear stress check, as shown in tab. I.
In many instances the ratio between the actual stress and the allowable stress, hereafter called "utility ratio" or U.R., resulted to be higher than 1.6.
In several instances a value over 2.5 was reached, 2.9 being the maximum computed value, for the node illustrated in fig. 1.
The calculations were reviewed and proved to be consistent with the project premises.
There was no evidence, however, of any failure or damage to the most stressed connections, which had been inspected by close visual inspection and MPI.
No record of the most severe storms already survived by the platforms was available, but the probabilities could be evaluated for a certain storm to have occurred at that site during the previous 20 years, with reference to the design 100 year storm.
Fig. 2 illustrates the relationship between the already spent operating life, the return period of a certain environmental condition and the probability that this condition has already been experienced by the platform.
From this figure it can be estimated with an accuracy of 99% that a 5 year storm, at least, has occurred during the past 20 years.
A structural analysis was therefore performed for that condition.
The utility ratios resulted to be in the order of 60% of the 100 years', yet in many instances quite exceeded the unity value. The maximum applicable value for this calibration purpose was found to be 1.6, in the node shown in tab. I.
As a consequence the stress level relevant to a utility ratio of 1.6 was assumed as an already survived stress level, that had caused no damage to the platform and that could be allowed to occur in future as limit target value.
No matter what the main reasons were for the discrepancy between theoretical predictions and empirical evidence, either in the in environmental design data or in the modelling uncertainties or both, the calibration

provided a way to mitigate significantly the remedial interventions. As a general criterion, for the nodes having a utility ratio below 1.6 no provision was made. For the platforms where the leg nodes had higher stresses, the grouting of the annulus between piles and legs was recommended (see tab. I).

Tubular Node Fatigue

A brief outline is given of the method that was followed to evaluate the risk of fatigue failure of the nodes. Basically a probabilistic assessment was performed and the results were calibrated against the observed evidences.

The fatigue damage computations were performed according to a stochastic approach: the stress response spectral density functions $Ps(\omega)$ were evaluated from the sea spectra $Ph(\omega)$, relevant to a multidirectional wave scatter distribution, and from the stress range response operators RAO $(\omega)$:

$$Ps(\omega) = RAO^2(\omega) \quad Ph(\omega) \qquad (1)$$

The cumulative fatigue damage $D(t)$ at a time t was calculated by summing up the individual contributions of the NJ sea states in accordance with the Miner's rule:

$$D(t) = \frac{t}{k}\,\Omega \qquad (2)$$

where the following definitions apply:

$$\Omega = (2\sqrt{2})^m\,\Gamma\left(\frac{m}{2}+1\right)\sum_{j1}^{NJ} \gamma_j\, f_j\, \sigma_j^m$$

m,k = parameters of SN curve (DoE T curve)

$\gamma j$ = probability of occurrence of the jth seastate

fj = expected frequency of upcrossing of mean sea level for the jth seastate

$\sigma j$ = standard deviation of the hot spot stress associated with the jth seastate.

The limit state for fatigue is reached at the time T, when the accumulated damage D(T) equals the limit value of damage at failure $\Delta$.

In order to account for the uncertainties inherent in the fatigue analysis process the fatigue parameters were considered as lognormal distributed random variables. This suggestion as well as the indications for the actual choice of the parameter values came especially from the work of P. Wirshing.

According to this methodology the limit equation at failure can be expressed in terms of time to failure T by introducing a bias factor B:

$$T = \Delta k/(B^m\Omega) \qquad (3)$$

The variables of the limit state equation (3) are lognormally distributed. As a consequence also the time to failure T is a lognormal random variable having a median value $\tilde{T}$ and a coefficient of variation $C_T$. The probability of failure at service time $T_s$ is given by:

$$pf = \tilde{p}\,(T<T_s) = \Phi(-\beta) \qquad (4)$$

where $\Phi(.)$ is the normal cumulative distribution function and $\beta$ is defined as the safety index:

$$\beta = \frac{\ln \frac{\tilde{T}}{Ts}}{\sqrt{\ln(1 + C_T^2)}} \qquad (5)$$

The characteristic values for $\Delta$ and k were taken from literature (see ref. 1, 2) because those variables had no reasons to be altered by the particular situation of the case. The stress uncertainty factor B needed, however, a special consideration due to the poor quality of the available environmental data: more specifically the wave scatter diagrams were derived from experimental wind data as it was not possible to get them directly from the wave statistics. No appropriate basis was found in the literature to support an a priori evaluation of the uncertainty related to the specific situation. In the end a coefficient of variation $C_B = 0.40$ was tentatively assumed, on the basis of typical offshore figures, and a sensitivity analysis was performed on the bias, which was made to vary from 1.0 to 0.4.

The results of the analysis relevant to B = 1.0 showed that the lowest values of the expected lives for the nodes of most platforms (all except for one, which was in safer condition) were in the order of 1 to 30 years. The relevant safety indexes had values ranging from -2.6 to 0.2.

The notional probabilities of survival for the most critical connection of each platform were, at the inspection date, ranging from $5\ 10^{-3}$ to $5\ 10^{-1}$.

An estimate of the notional probabilities that no fatigue failure had appeared in all the platforms gave a value as low as $1.5\ 10^{-13}$, rating this event as extremely unlikely.

This assessment appeared inconsistent with the results of the past inspections: the surveys had been carried out in 1987, after 24 years of service on an average, and, out of a total number of 100 brace / chord connections inspected by CVI and MPI, no defective situation was reported, but one suspected crack. The model uncertainty bias was therefore tentatively reduced and eventually set to B = 0.4.

In this way the notional probabilities that no fatigue failure had appeared in all the platforms (except for the platform where a suspected crack had been found) gave a value of $4.5\ 10^{-3}$. This value was still low and gave an indication of an unlikely event, but could reasonably be taken as a lower bound of confidence to fit a situation where no defective weld had been detected so far.

This calibration was used to adjust the fatigue endurance estimate of the nodes. The lowest values of the expected lives for the nodes of most platforms (all except for one which was in safer condition) resulted to be in the order of 15 to 150 years. The relevant safety indexes $\beta$ had values ranging from -0.5 to 2.3.

On the basis of these results the nodes were grouped into classes of criticality in order to give the priorities to the inspection program.

## SUMMARY OF INTERVENTIONS

An intervention plan was to be established, having the following main scopes:

- give the structures adequate strength with respect to operating and extreme loading
- ensure that fatigue could not endanger the platforms
- ensure adequate corrosion protection for the extended life.

In addition to refurbishment and minor repairs to the steelwork, the main categories of intervention were:

a) deck structure strengthening for increased deck loading
b) strengthening or replacement of severely damaged members
c) leg grouting to reinforce inadequate tubular nodes
d) additional anodes installation.

Fig. 4 illustrates an intervention on a main member with excessive out-of-straingthness. Figure 3 illustrates a typical solution that was adopted to replace a severely corroded main member. The clamps were designed to be grouted and prestressed. The tubular had hinged connections to the clamps in order to make the installation work easier. As anticipated in the preceding part of this paper these interventions were designed according to the applicable rules for the offshore structures design and construction.

The leg tubular nodes having inadequate strength, on the basis of the integrity assessment, were recommended to be reinforced by filling the leg-pile annulus with grout. This provision was recommended for five out of the thirteen platforms under consideration and was adequate to bring the working stress below the "calibrated" target.

A summary of the remedial interventions is given in tab. II.

As far as fatigue was concerned, the results of the inspections reported a safe condition and encouraged maintaining the life extension plan. An appropriate inspection program was, however, to be established in order to ensure an early detection of possible cracks. The results of the fatigue analysis, calibrated by the inspection evidences, were used to set up a node classification by criticality and eventually to recommend inspection sequences and frequencies.

As for the cathodic protection, the already existing anodes were considered as effective for reuse only when at least 60% of their original mass was still available. A number of additional new anodes had to be installed in order to ensure adequate protection for the extended life.

## REFERENCES


1. Wirshing P.H., Probability Based Fatigue Design Criteria for Offshore Structures, API PRAC Project, N. 81-15, 1983.

2. Wirshing P.H., Fatigue Reliability for Offshore Structures, Journal of Structural Engineering, Vol. 110, N. 10, 1984, ASCE Paper N. 19235.

3. Wirshing P.H. and Chen Y.N., Considerations of Probability - Based Fatigue Design for Marine Structures, Marine Structural Reliability Symposium, Arlington, Virginia, 5-6 October 1987.

4. API-RP-2A Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms, 18th edition.

5. Brandi R. and Rossetto P., Use of Inspection Data for Structure Integrity Assessment, Conference on Offshore Mechanics and Arctic Engineering, Houston, Texas, 1990.

| INSTALLATIONS | PRESENT STATUS : UNGROUTED | | | AFTER GROUTING | | |
|---|---|---|---|---|---|---|
| | N° NODES U.R. >1.0 (CONNECTIONS) | N° NODES U.R.>1.6 (CONNECTIONS) | MAX U.R. | N° NODES U.R.>1.6 | N° NODES U.R. > 1.6 | MAX U.R. |
| 113 M1 | - | - | - | - | - | - |
| 113 M2 | 12 | 4 | 2.1 | 2 | - | 1.15 |
| 113 M3 : M7 | - | - | - | - | - | - |
| 113 M8 | 39 | 6 | 2.0 | 4 | - | 1.10 |
| BM3 | 55 | 25 | 2.6 | 11 | - | 1.37 |
| BM6 | 21 | 8 | 2.9 | 4 | - | 1.57 |
| F10 L.Q. | 58 | 20 | 2.7 | 12 | - | 1.47 |

TABLE I - LEG NODES UTILITY RATIO (U.R.) SUMMARY (100 YEAR STORM)

| INSTALLATION | A (Q.TY) | B (Q.TY) | C | D (Q.TY) | E | F | G |
|---|---|---|---|---|---|---|---|
| 113-M1 | - | - | YES | 40 | YES | YES | - |
| 113-M2 | 4 | 4 | YES | 21 | YES | YES | YES |
| 113-M3 | - | 4 | YES | 19 | - | YES | - |
| 113-M4 | - | 4 | YES | 21 | - | YES | - |
| 113-M5 | - | - | YES | 13 | YES | YES | - |
| 113-M6 | - | 4 | YES | 15 | YES | YES | - |
| 113-M7 | 4 | 6 | YES | 18 | - | YES | - |
| 113-M8 | - | - | YES | 19 | - | YES | YES |
| BM-3 | 2 | - | YES | 28 | YES | YES | YES |
| BM-6 | 4 | - | YES | 10 | - | YES | YES |
| F10 L.Q. | - | 5 | YES | 58 | - | - | YES |
| R.L.P. PLATFORM | - | - | YES | - | YES | YES | - |
| P.P.1 PLATFORM | - | 4 | YES | 60 | - | YES | - |

NOTE

A - JACKET UNDERWATER MEMBER REPLACEMENT (BY CLAMPS)
B - JACKET ABOVE WATER MEMBER REPLACEMENT (BY WELDING)
C - PAINTING AND COATING
D - ANODES TO BE INSTALLED
E - DECK STRENGTHENING
F - ANCILLARIES REFURNISHMENT
G - PILE/LEG GROUTING

TABLE II - REMEDIAL REPAIRS SUMMARY

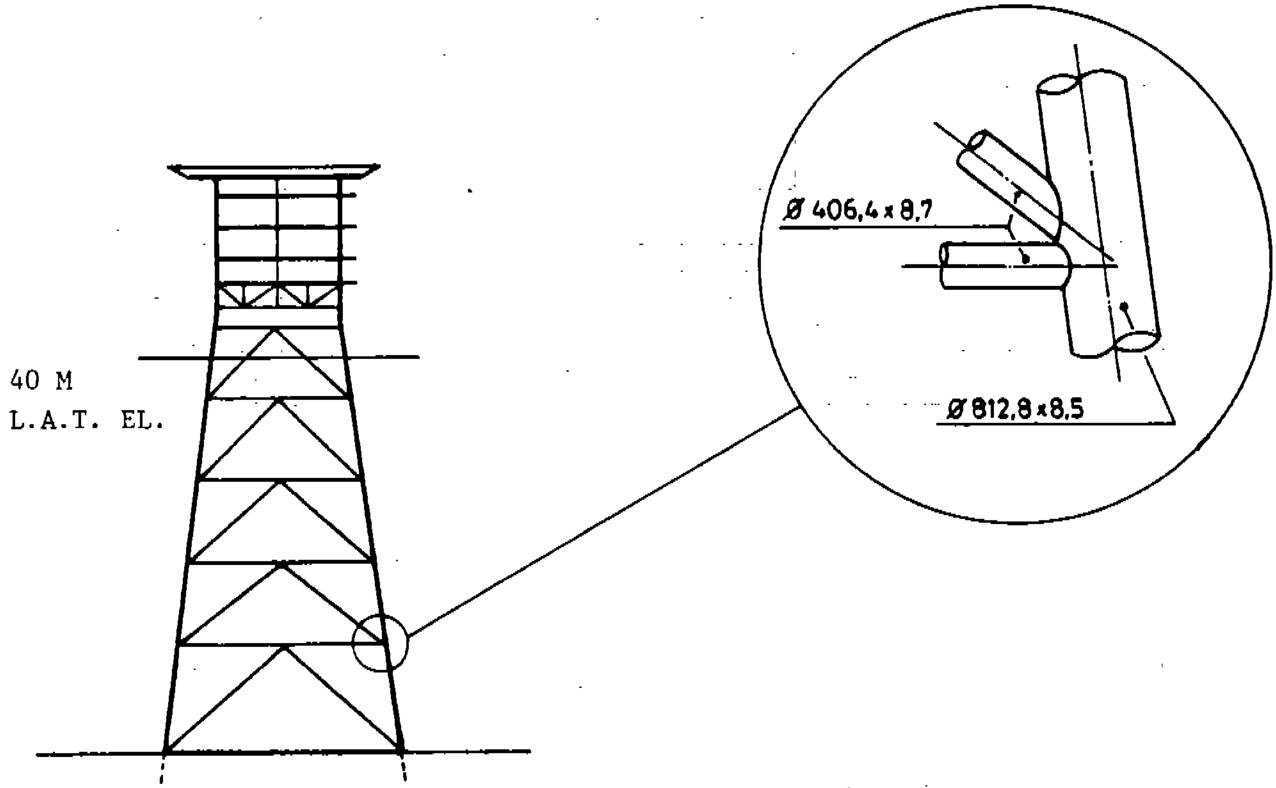


FIG. 1 - BELAYIM FIELD - F10 PLATFORM

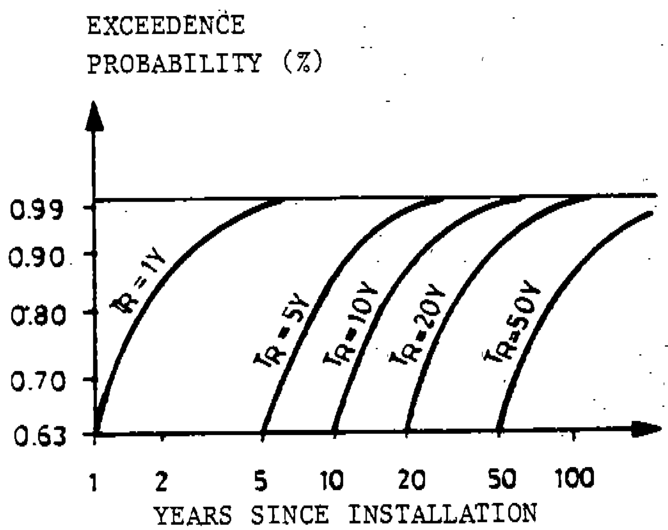


FIG. 2 - RELATIVE PROBABILITY OF
ENVIRONMENTAL CONDITIONS

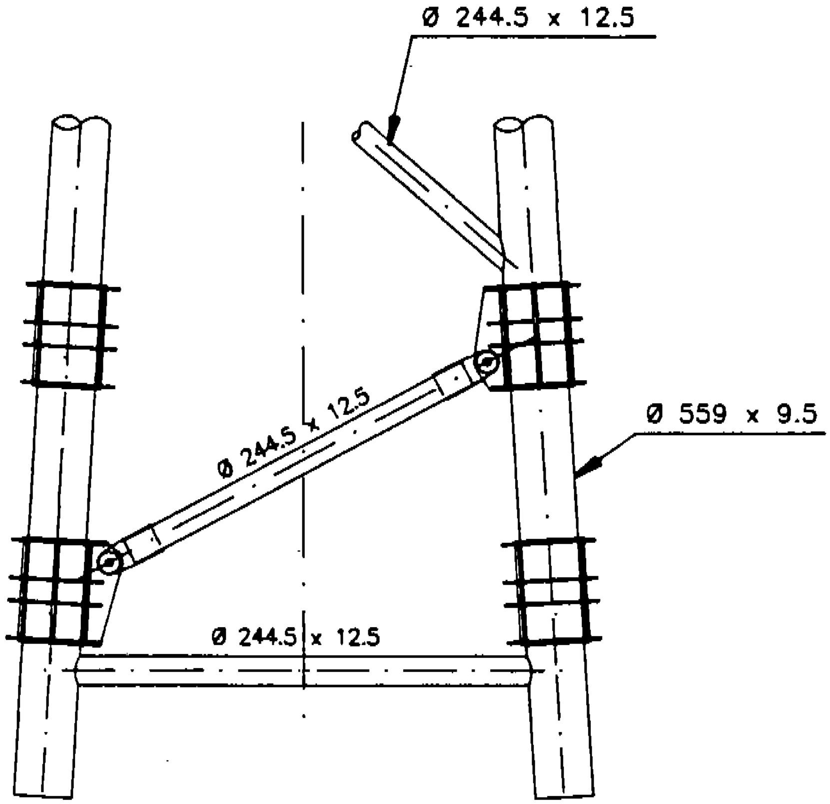


FIG. 3 - TYPICAL MEMBER REPLACEMENT

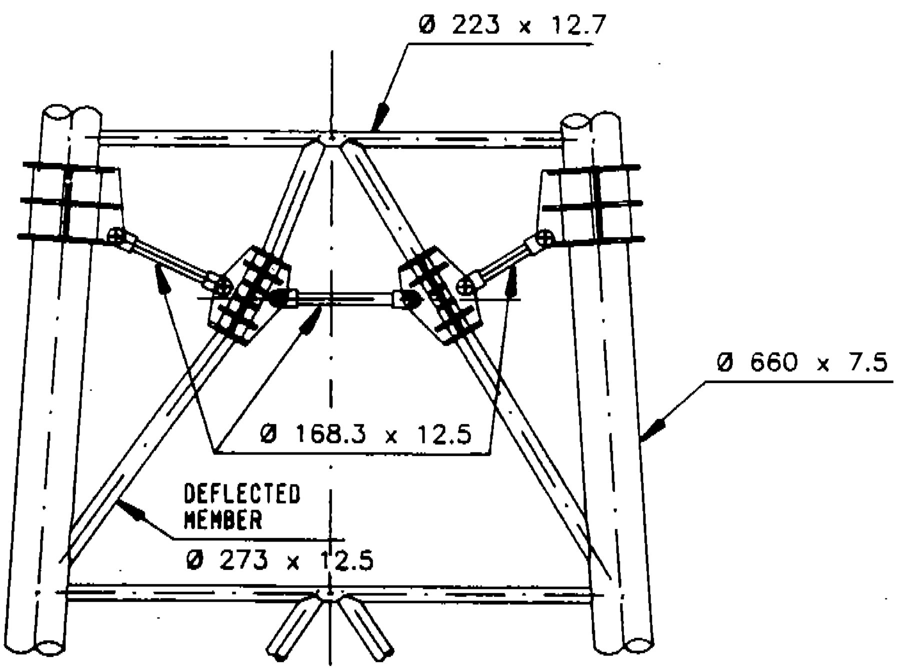


FIG. 4 - DEFLECTED MEMBER STRENGTHENING