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Probabilistic Re-Analysis of Existing Offshore Structures
Contrôle probabilistique de plates-formes marines existantes
Probabilistische Überprüfung existierender Offshore-Konstruktionen

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SUMMARY
When the necessity for re-qualification of an offshore structure arises, the basic problem encountered is that decisions may not be supported by code criteria. Current code criteria are not flexible in terms of additional information aquired after the design stage. One has to turn to methods based on reliability analysis supported by the information gained from field experience, maintenance and monitoring. These methods are briefly discussed here and three case studies are presented to illustrate their applicability to various situations.

RÉSUMÉ
Lorsque se présente la nécessité de reclassement d'une plate-forme marine, le problème principal est que les décisions ne peuvent s'appuyer sur les critères de projet existants. Les critères de projet courants ne se prêtent guère à l'assimilation des informations supplémentaires acquises après la phase d'étude d'un projet. Il faut par conséquent adopter des méthodes basées sur des analyses de fiabilité en exploitant les données obtenues directement sur le terrain, dans le domaine de la maintenance et du contrôle. Ces méthodes sont brièvement expliquées et trois cas sont présentés pour illustrer leur faculté d'application à différentes situations.

ZUSAMMENFASSUNG
Das Hauptproblem beim nachträglichen Nachweis existierender Offshore-Konstruktionen besteht darin, dass Entscheidungen nicht von Normenkriterien getragen werden können. Aktuelle Normenkriterien sind nicht flexibel genug, um zusätzliche Erkenntnisse nach der Bemessungsphase zu berücksichtigen. Mann muss zu Methoden der Sicherheitstheorie zurückgreifen, unterstützt von Informationen, die während der Betriebs- und Überwachungsphase der Konstruktion gewonnen wurden. Diese Methoden werden hier kurz diskutiert und drei Fälle werden beschrieben, um ihre Anwendung in verschiedenen Situationen dazustellen.

1. INTRODUCTION

Offshore exploitation is nowadays a mature field. Several platforms have been in operation for over twenty years, often exceeding their original design lifetime and experiencing extreme environmental actions, damages and possible reduced maintenance and repair due to periods of depressed international offshore market. Re- qualification of these structures for extended lifetime is a major issue in the offshore industry. Offshore operators must balance their decisions between required levels of safety and available budgets.

This has resulted in the rationalization of the decision process and of the re-analysis procedures necessary to re-qualify existing offshore structures. Efficient and sophisticated techniques have been developed in the last decade for that purpose which incorporate modern structural and reliability analysis methods.

This contribution discusses experience gained from the implementation of reliability methods and appropriate criteria for the re-qualification of existing offshore structures. The difference between prior uncertainty modeling and reliability updating on the basis of available information is emphasized. The methodological approaches are illustrated in case studies dealing with re-qualification of platforms in various offshore locations.

2. OVERALL RISK DECISION APPROACH TO OFFSHORE REQUALIFICATION

Various aspects have to be taken into account in the decision process for offshore platform re-evaluation, and consequently several parties might be involved, each of them contributing with, or requiring, different types of information. The final decision is gradually reached by pooling all these contributions into one. These contributions are coming from:

- <u>Design</u>.
- <u>Field experience</u>.
- <u>Re-qualification analysis</u>.
- <u>Economical analysis</u>.

The above listed contributions lead to the collection of information that are of very diverse nature, e.g. in terms of type of data and category of persons/deciders who provide them. In particular, both numerical and non numerical information have to be used.

The general practice in re-evaluating offshore structures is that of relying on a "rational approach". The safety and economy implied by certain decisions are evaluated by means of both statistical/probabilistic considerations (risk analysis), and economical analysis (cost/benefit analysis).

3. USE OF RELIABILITY METHODS

3.1 Prior uncertainty analysis (design stage)

The largest uncertainties exist at the design stage. Not only is the loading environment partially known but also the specific quality of manufacture and construction is under control to a limited extent. Furthermore the actual load-effect relationships involve some systematic but also random variability. All these uncertainties can be modeled by random variables. In order to provide safety criteria appropriate limit states "g" have to be defined; failure occurs when $g < 0$.

Safety is assured by requiring that the limit state will be reached with a small probability, which is dependent from the joint probability density function of the stochastic variables defined in the problem.

Numerical methods for reliability calculation have been developed during the past decade and the first order reliability methods FORM have been recognized as very accurate and efficient [1-3]. The probability of failure by using FORM is estimated by:

$$P_f \approx \Phi(-\beta) \qquad (1)$$

where $\Phi(.)$ is the standard normal distribution function and β is the reliability index.

3.2 Updating through additional informations (re-design stage)

Additional informations gained during lifetime of the structure can be quantified and implemented in order to update original or codified safety levels. Two basic cases are briefly described next, updating of limit states and updating of random variables.

In many cases, inspection results can be interpreted as artificial limit states and can be applied directly in the updating procedure of the originally estimated failure probabilities. The updated failure probabilities P'_f are then evaluated as conditional probabilities. The following two fundamental cases are classified:

$$P'_f = P[g_0(X) \leq 0 \mid g_1(X) = 0] \qquad (2a)$$

$$P'_f = P[g_0(X) \leq 0 \mid g_1(X) > 0] \qquad (2b)$$

where $g_0(X)$ is the original limit state function and $g_1(X)$ the artificial limit state function formulated from the inspection results. The vector (X) includes all basic variables in g_1 and g_0. Examples of equation (2a) are measurements carried out under proof - loading, observations of crack lengths, and of deformations (or settlements). A typical example for equation (2b) is the survival of the structure (or of the structure components) under high loads. Updated failure probabilities are derived within a first-order reliability method framework [3]. The influence of a possible lifetime extension can be taken into account by modifying the distribution function of the time dependent basic variables in the original limit state function $g_0(X)$.

In some cases only specific influencing parameters such as material strength or geometrical dimensions are inspected. After the inspection, updated distributions are given to the influencing random variables resulting to a decrease or an increase of the reliability index.

3.3 Compatibility of safety requirements with reliability analysis techniques

Safety requirements for structural design and re-design cannot be established on the basis of pure science. A rational approach for the requirements must be a synthesis of:

1. basic understanding of structural behavior;
2. basic knowledge of current practice concerning workmanship, equipment, and construction methods etc.;
3. experience gained from the behavior of existing structures;
4. economical, social, political and legal considerations;
5. reliability theory;

The classical codified safety requirements, for example the partial safety factor format, cannot be applied in the evaluation of the reliability of existing structures since they are not flexible in terms of additional information. The probabilistic reliability theory constitutes a rational tool for updating additional information and comparing the actual reliability level with the assumed reliability level (inherent in present codes).

4. CASE STUDIES

4.1 Mechanical impact re-assessment of North Sea platform

Re-qualification of an existing platform located in the British sector of the North Sea was required both for production systems reliability and structural integrity. The platform is a "K"- bracing steel jacket type, located at a water depth of about 142 m. The aim of the study was to extend the platform lifetime and to update the overall safety level.

Structural safety assessment was performed taking into account:

- updated environmental load;
- re-analysis of ship traffic in the vicinity of the platform;
- structural re-analysis of the jacket;
- jacket inspection.

Due to over-stressed members found after the jacket structural re-analysis, the main emphasis was paid to assess the platform damage resistance after a ship collision. The scope was also to verify the British authority requirements which state that the structure should be capable of withstanding an impact from a 2500 tons vessel with a velocity of 0.5 m/s. Assuming that all the kinetic energy is absorbed by the installation and that an added mass factor of 0.4 must be applied an impact energy of 0.44 MJ is obtained. Norwegian authorities requirements were also considered, which specify a design impact from a supply vessel of 5000 tons at a velocity of 2.0 m/s and an added mass factor of 0.4 for broad side collisions and 0.1 for bow collisions. This results in impact energies of 14 MJ and 11 MJ respectively.

The probability of failure is evaluated as follows:

$$P_f = P_c \bullet P_m$$

where P_c is the probability of platform-ship collision and P_m is the member probability of failure conditioned to ship impact.

The failure probability analysis associated to passing vessels was simplified by the fact that P_m was considered equal to unity. A ship traffic analysis in shipping lanes near the platform location was performed, considering also updating for future ship traffic development.

In case of a visiting vessel (supply vessel) platform collision, the limit state can be defined as:

$$g = E_m - E_s$$

where E_m is the energy absorption capability of the impacted member and E_s is the ship impact energy. The probability of failure has been calculated using FORM by introducing the following random parameters:

- ship mass and impact velocity;
- strength and geometric characteristics of the impacted member.

The results have shown that the Norwegian authorities requirements are not fulfilled; the British authorities requirements are fulfilled and the annual probability of failure considering revised data on distributions of impact masses and impact velocities found in the literature is in the order of 10^{-3}.

The reliability analysis has indicated that the structure cannot sustain an impact from a vessel since stress redistribution is not possible. This is due to the high number of members over-stressed and to the type of joints.

In these platforms the ability of a "K"-bracings panel to transmit shear is lost if the compression brace buckles. From the study it was concluded that appropriate provisions to avoid vessel impact or to increase the impact load absorption capability must be considered.

4.2 Fatigue re-analysis of steel gravity platforms in the Gulf of Guinea

For offshore structures the fatigue limit state is governing the structural dimensions of several member and particularly of joint connections. Therefore, efforts of inspection campaigns for re-qualification purposes are aimed to assess the structural integrity of such joints, and to detect possible cracks and corrosion damage. However, due to the considerable costs, only a limited number of joints can be inspected.

The inspection results together with the design data representative of the platform have been first implemented in a software system that integrates the data base with procedures of analysis required in a re-qualification process [8]. Procedures include statistical analysis, damage accumulation analysis, crack growth analysis.

The statistical analysis package was required to correlate damage joint characteristics in order to define probability distributions of representative deterioration parameters for not inspected joints. Where applicable, such an approach has been integrated in three steps:

- creation of the sample population and definition of explanatory variable such as water depth, element type, joint geometry, material, design fatigue life, etc.;
- definition of statistical model for the deterioration parameters (i.e. pitting depth, probability of crack presence, crack depth, actual thickness) by using analytical methods of variance;
- computation of response for not inspected joints.

The damage accumulation package has allowed to compute, for each joint, the probability of failure due to fatigue in the hypothesis of linear damage accumulation (Miner's rule).

A crack growth analysis was performed, to determine failure probabilities by means of a fracture mechanics approach. The model based on the Paris and Erdogan [10] law was established for a semi-elliptical crack in an infinite plate according to current practice [9,11]. The stochastic model applied to fatigue crack growth accounts for uncertainties in loading, initial defects, material parameters and in computation of stress intensity factors. The crack growth model has been combined with FORM to compute failure probabilities.

Figure 1 shows the decrease of the reliability index with time for a critical joint. The three curves represent:

- prior reliability index without considering inspection results;
- posterior reliability index "conditioned" by inspection results, i.e.:
    - joint itself has been inspected and no crack, or a crack of given depth has been found,
    - other joints of similar characteristics have been inspected and found without crack, or with a crack of given depth, thus resulting in an updating of the considered not inspected joint.

Figure 2 illustrates results obtained for another critical joint of the same platform and emphasizes the time dependency of the following parameters:

- prior reliability index without information through inspection;

- posterior reliability index corresponding to conditional failure probability index "given" that no crack has been observed;

- range of acceptable safety level (based on the considerations mentioned before);

- inspection effort to achieve acceptable safety level for a desired additional lifetime.

The results have been generally used to judge the Inspection Repair Maintenance (IRM) program versus extended life of service. The benefits associated with the use of the illustrated procedure include:

- improved safety related to the knowledge of the risk associated to the extension of the platform life;

- sound evaluation of the relative importance of detected defects on the structural safety;

- optimization of future survey by screening out not critical joints.

4.3 Re-assessment of seismic loading for a platform in the Adriatic Sea

This example deals with the re-assessment of seismic loading for a platform offshore Ancona in the Adriatic Sea. This platform has been designed in the late 70's according to the following criteria:

- design lifetime of 20 years;

- probabilistic evaluation of ground acceleration based on the attenuation law of McGuire [12] which is based on strong motion recordings from Western United States;

- definition of two different peak ground acceleration (PGA) levels [13]; Strength Level Earthquake (SLE) associated to a return period of 100 years, corresponding to an acceleration of 0.11 g; Rare Intense Earthquake (RIE) associated to a return period of 1000 years, corresponding to an acceleration of 0.2 g.

Figure 3 illustrates peak ground accelerations versus return periods for design and re-design.

After 10 years the safety of the platform has been addressed together with the consideration of a total lifetime of 30 years. Therefore, the criteria used in the design stage have been reviewed, evidencing in particular that recent developments allowed to account for:

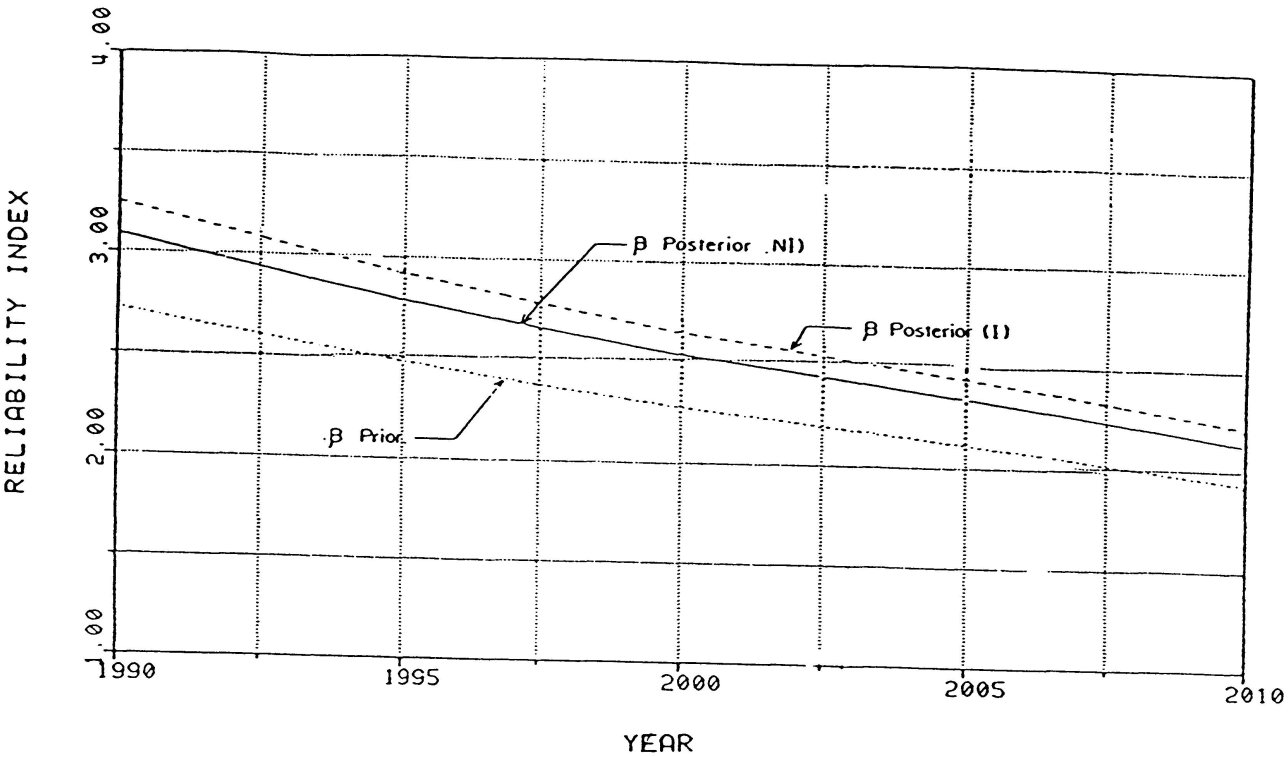

Fig 1 Reliability index vs. time for inspected (I) and not inspected (NI) joints.

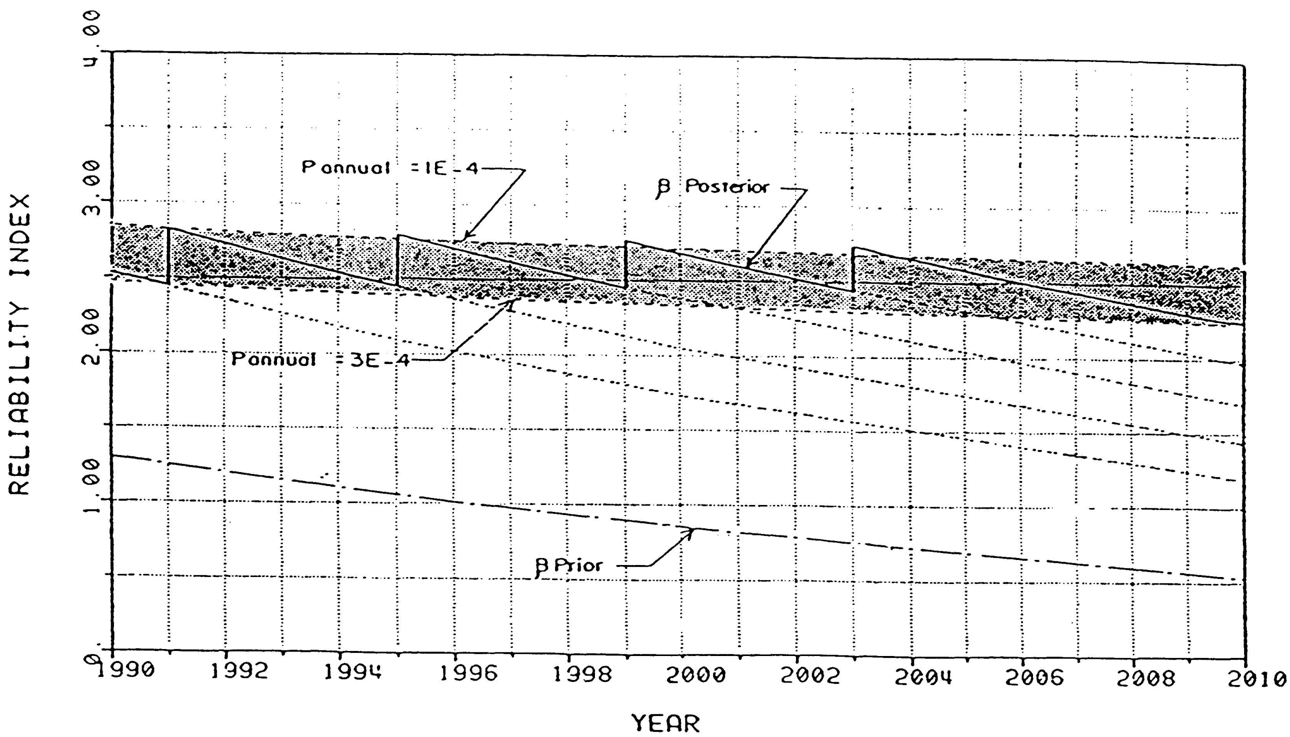

Fig 2 Reliability index vs. time and recommended inspection program.

- revised earthquake catalogues;
- specific attenuation relationship for the platform site [14];
- reliability based definition of the return periods at which SLE and RIE should be associated to be in accordance with current safety philosophy in the offshore industry [15]; SLE and RIE have been associated to 200 and 2000 years return periods respectively.

Although the new return periods for the representative PGA's are more conservative than those assumed in design, the application of the new attenuation law and the more accurate characterization of seismicity allowed to obtain lower values for the peak ground acceleration. In particular, the SLE was associated to 0.09 g, while the RIE to 0.18 g, introducing a 10% - 15% reduction with respect to design values.

The new results expressed in terms of PGA versus return period are also included in Figure 3 demonstrating the lower values obtained through re-analysis. The method in Ref.[16] has been then used and the results have demonstrated that earthquake is not endangering platform safety, if compared to the original design assumptions.

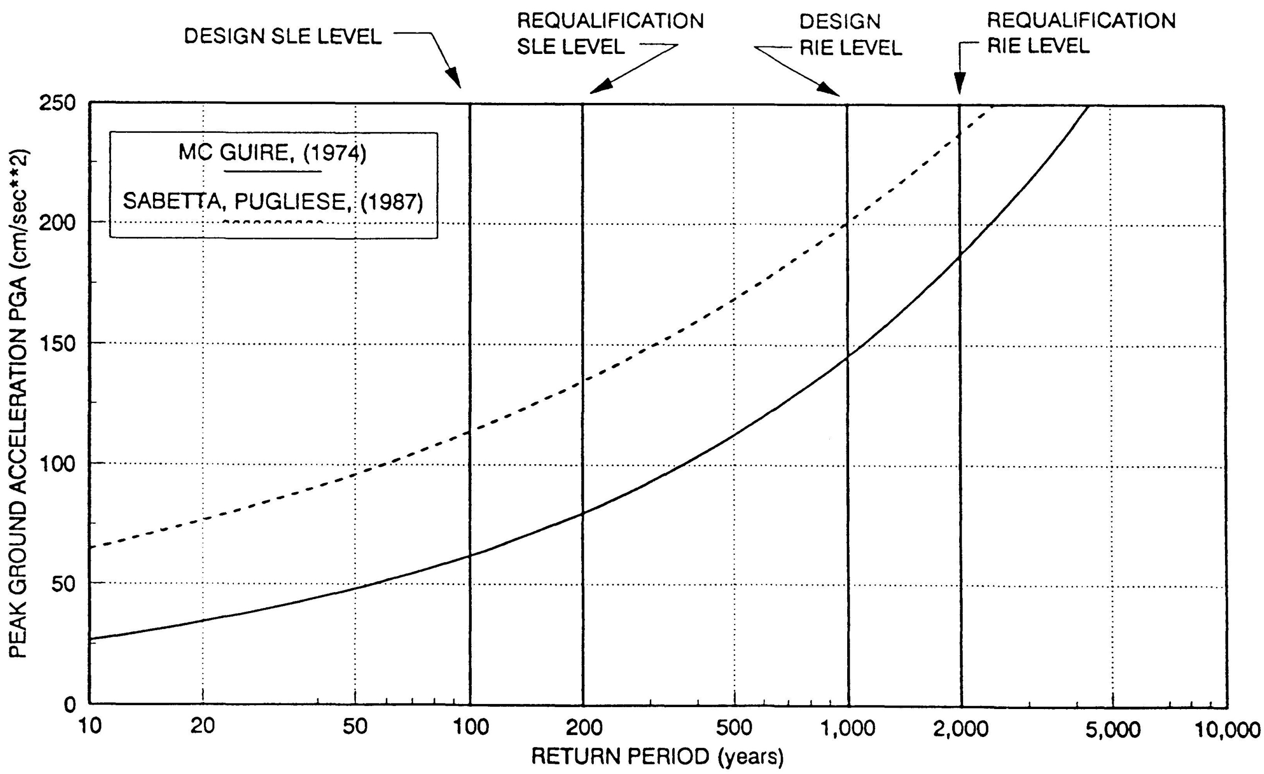

Fig. 3 Peak Ground Accelerations obtained adopting design and re-qualification attenuation laws

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