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Technical Review of ISO 2394 General Principles on Reliabilities for Structures

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Reports in the OTO series can be obtained from
Research Strategy Unit, Bootle, Merseyside, L20 3DL
Fax: 0151 951 3098

Technical Review of ISO 2394 General Principles on Reliabilities for Structures

Prepared by
MSL Engineering Limited

CONTENTS

1. INTRODUCTION

This report concerns a critical technical review of the Revision of the First Edition of ISO 2394, General Principles on Reliability for Structures, issued by BSi Standards for comment as Document 96/105 174 DC. The thrust of the review is to identify changes arising from the introduction of this current Revision, the implications of the changes, and the impact of the proposed requirements on the development of international standards for offshore structures for petroleum and natural gas industries.

ISO 2394 is an International Standard intended to serve as a basis for committees responsible for preparing standards or codes of practice for structures in general. The document deals with a broad range of issues and contain aspects that can be considered innovative in relation to most offshore design/assessment documents. The review will be focused on those aspects and their possible implications on design/fabrication/maintenance of offshore structures.

Section 2 of this report reviews the various sections of ISO 2394 and highlights key aspects as well as the main inclusions / alterations in relation to the first edition. Section 3 expands on the most important of these aspects.

2. REVIEW

2.1 INTRODUCTION

The sections *0 - Introduction* and *1 - General* of the revised version are similar to sections 0 - Introduction and 1 - Scope and field of application of the previous version. The main changes are:

- Explicit inclusion of maintenance and repair in the scope and field of application of the Standard.
- A greater emphasis on the important issue of structural appraisal of existing structures, an entire chapter (Chapter 8) being dedicated to this issue.
- Inclusion of a section on definitions and explanations. Unfortunately, some of the terms need better definition. The distinction between structural element and structural system should be made clearer, as reliability analysis at element and at system level are mentioned further in the document.
- The term structural integrity used in the previous version seems to have been replaced by the term robustness (the ability of a structure not to be damaged by events like fire, explosions, impact or consequences of human errors, to an extent disproportionate to the original cause). It would be important to differentiate robustness of the structure from robustness of the mathematical model used for the limit state function.

2.2 REQUIREMENTS AND CONCEPTS

Section 2.1 - Fundamental Requirements has been modified, in the revised version, so that the structure is required now to be robust not only in relation to damage due to fire, explosions or impact but also in relation to damage caused by human errors.

In the previous version, the expression 'with appropriate degrees of reliability' was introduced, but with relatively little explanation. This is dealt with, in more detail, in this revised version, by the introduction of Section *2.2 - Reliability Differentiation*, describing the factors to be taken into account when selecting target reliability:

- causes and mode of failure (collapse with/without warning)
- consequences of failure
- costs of reducing failure risk (similar to ALARP)
- social and environmental conditions.

This section also spells out the key factors to be covered in design:

- serviceability
- choice of values for action variables
- target reliability
- robustness
- quality of soil investigations
- accuracy of mechanical models
- stringency of detailing rules.

Design is covered further in Section *2.3 - Structural Design*. It stresses that failure can occur as a result of extreme foreseeable situations as well as human errors, and unforseeable events. It implies that the structure should be designed with sufficient reliability in relation to foreseeable actions, but also with alternative load paths to allow for element damage arising from human error or unforseeable events.

Section 2.4 - *Conformity* was included to deal with Quality Policy issues and replaces Chapter 7 - Quality Control of the previous version. *Section 2.5 - Durability and Maintenance* is also new.

2.3 PRINCIPLES OF LIMIT STATE DESIGN

Section *3.1 - Limit States* was modified in the new version by the introduction of the notion of reversible and irreversible exceedance of limit states. Although the exceedance of an ultimate limit state tends to be irreversible and, the first time this occurs, it causes failure, exceedance of some serviceability limit states may be reversible and may not lead to failure.

Section *3.2 - Design* continues to recommend the use of a partial safety factor format for most design cases, but now also allows the use of fully probabilistic methods in special design cases. The previous minimum lateral resistance requirement was removed (hopefully now covered by robustness requirements).

2.4 BASIC VARIABLES

Section *4.1 - General* was expanded, giving general concepts of probabilistic modelling of basic variables. *Section 4.2 - Actions* remains broadly the same, with a slight modification to incorporate the concept of bounded/unbounded actions. *Section 4.3 - Environmental Influences* was introduced in the new version dealing with mechanical, physical, chemical or biological actions that may deteriorate the material. *Section 4.4 - Properties of Materials and Soils* was expanded with the inclusion of a note highlighting the uncertainties involved in evaluating soil properties and the need for the extent of the investigation to be accounted for in the probabilistic modelling. *Section 4.5 - Geometrical Quantities* remains broadly the same: variability of geometrical variables can be considered small or negligible and such variables may be treated as non-random, except for shape imperfections which may have a substantial impact on the instability of some structural elements.

2.5 MODELS

This chapter was considerably expanded, with new sections covering:

- action models, divided into basic action variables (metocean data, eg) and the 'load conversion variable' W (a response surface converting wave height into base shear, eg). The need for special treatment for dynamic action and fatigue is highlighted
- geometrical properties model, including shape imperfections
- material properties and static response
- dynamic response
- fatigue
- model uncertainty
- design based on experimental results.

2.6 PRINCIPLES OF PROBABILITY BASED DESIGN

This chapter is new and briefly gives the basic concepts of reliability based design, including:

- safety index and failure probability
- system versus component reliability

- target reliability
- calculation of failure probability for time-variant and time-invariant problems
- implementation.

2.7 THE PARTIAL SAFETY FACTORS FORMAT

This chapter remains broadly the same although rearranged and expanding more on load combination aspects.

2.8 ASSESSMENT OF EXISTING STRUCTURES

This chapter deals with the important problem of reassessing existing structures. The important question of reassessment in view of improved knowledge is however avoided.

2.9 ANNEXES

The following informative annexes are given in the new version:

A. Quality management and quality assurance (new)

B. Examples of permanent, variable and accidental actions

C. Models for fatigue (new)

D. Design based on experimental models (new)

E. Principles of reliability-based design (new)

F. Combination of actions and estimation of action values (new).

3. RELEVANT ISSUES

3.1 ELEMENT VS. SYSTEM RELIABILITY

Most (possibly all) offshore design and/or assessment codes are structured on an element failure basis. In a recent HSE funded study[1], a redundancy (defined as peak load / first component failure load) of 1.10 was found for a sample jacket structure and of 1.25 for a sample jack-up structure, based on pushover analysis carried out using CAP/SeaStar. Based on this kind of analysis engineers could, in principle, benefit from such margins in obtaining more efficient designs. Prediction of system reliability, however, is an evolving subject and different engineers using different FE packages tend to obtain widely different results. Recent efforts have concentrated in understanding structural system behaviour and attempting to find some common ground in the various algorithms being used. Furthermore, considerable uncertainties are usually associated with foundation behaviour. Further advances are needed in these areas before system-based design codes become a reality.

3.2 RELIABILITY DIFFERENTIATION

Perhaps the most important decision committees responsible for drafting standards or codes of practice have to take relates to the recommended minimum level of structural reliability (target reliability). The ISO document briefly mentions some of the aspects to be taken into account such as causes and consequences of failure, cost of reducing failure risk, social and environmental conditions. Some of the costs associated with these aspects may be, to some extent, quantified (enhancement of inspection/maintenance procedures, disruptions in production, compensation for death/injury). On the other hand, it may be quite difficult to assign a cost value to social and environmental consequences.

Target reliabilities are, quite often, established on the basis of previous structures of similar nature, with the disadvantage of perpetuating past safety margins. Operational aspects may also influence the choice of target reliability: a smaller reliability level might be used for an unmanned unit or if personnel can be quickly evacuated.

Overall, there seems to be little consensus on the best approach for selecting target reliabilities[2]. The approach given to overall safety on the North Sea is based on the ALARP principle (As Low As Reasonably Practicable) and on safety cases evaluated on an individual basis. Further guidance on the central issue of target reliability seems to be necessary, possibly by including a new annex which recognises the, at least, partial success of calibration in providing a first guess at this supplemented by a sound, but partly subjective, view of the success or otherwise of the structures used in the calibration process.

3.3 ROBUSTNESS

The robustness requirement implies the provision of alternative load paths within the structure so that failure of one element does not precipitate overall structural failure. This is not usually a explicit requirement for the component-oriented design and assessment codes. used in the offshore industry. Some offshore designers prefer to build redundant load paths by means of extra braces and/or legs but cost efficiency points in the direction of minimised redundancy, as in minimal structures. An adequate balance between reliability and cost efficiency has to be achieved, but little guidance is given in the ISO document on how this should be achieved. A first pass at this would be to require non-redundant components have a failure probability equal to that of the system (approximately one order of magnitude difference[1]).

Contents

3.4 HUMAN ERRORS AND QUALITY ASSURANCE

As far as offshore structures are concerned, the number of failures that can be classified as structural tends to be significantly smaller than the number of failures induced by human errors. An order of magnitude in probability of failure terms is often used. Such errors may be induced by many different aspects (communication, personnel selection and training, planning, etc.) related to individuals performing certain tasks as well as to the organisation and environment in which such tasks are performed.

Quality Assurance programmes are a key instrument in minimising such potential problems. The series of International Standards ISO 9000 to ISO 9004 is usually a reference for many organisations when developing their QA programmes. Some aspects are briefly summarised in Annex A of the revised version of ISO 2394.

Although these procedures may cover the actual fabrication of offshore structures (as fabrication of equipment and system seems to be the main drive of the ISO 9000 series), it is not obvious how QA procedures should apply to advanced computational structural analysis. It is relatively straightforward to establish conformity requirements for connectivity of FE elements, section properties and material properties. Experienced organisations would add to that adequate convergence criteria, mesh density, and aspect ratio of FE elements. Key aspects such as boundary conditions, load application and type of analysis (static vs. dynamic, eg) are nevertheless left to the engineer's choice. Here again experienced organisations can refer to past work to determine the reasonableness of the results obtained.

Another important facet of the problem relates to pieces of software developed for use in particular projects. Applying 'software house' QA procedures would possibly be too costly if that particular programme is not to be commercialised. Experienced organisations would make sure the programs were verified for specific applications and that their limits of utilisation were clearly defined and documented.

3.5 MAINTENANCE AND REPAIR

An adequate inspection programme and adequate repair are also key factors in preventing structural failures. Not all offshore codes deal with these aspects. An important recent development in this field is the introduction of rational reliability-based inspection planning. This is however not covered by ISO 2394. Various repair techniques have been developed by the offshore industry and these perhaps should be briefly mentioned in offshore codes.

3.6 STRUCTURAL RE-ASSESSMENT

Structural reassessment is recommended in ISO 2394 in situations where the structural layout has been modified, where the structure use is expected to change or where deterioration or damage are a concern. It does not seem to consider the situation in which the structure is being evaluated due to improved knowledge. The historic trend is for novel structures to be initially overdesigned and for their implicit safety margins to be progressively reduced in new designs as knowledge improves and experience is gained.

There have been notable exceptions, however, in which safety margins have had to be increased, potentially posing a stiff penalty on structures designed to old standards and now wishing for life extension and continued operation. The owner may have been driven to adopt an inadequate design due to errors or limitations of the design standard used. Improved knowledge could lead, for instance, to an increase in the predicted loading. A LRFD check would quickly render that structure inadequate. This is one of the special cases in which the engineer may need to go one step further and resort to a fully probabilistic assessment. As a given structure tends to be built by a single contractor with materials supplied by a single manufacturer, the coefficients of variation tend to reduce considerably and consequently the reliabilities will tend to increase[3].

3.7 FULLY PROBABILISTIC DESIGN METHODS

ISO 2394 allows the implementation of fully probabilistic modelling. This is not usually allowed for in most offshore assessment procedures, DnV being a notable exception. This allows, however, for a wide range of modelling assumptions to be made and adequate calibration methods need to be defined for consistent results to be obtained.

3.8 STRUCTURAL AND LOADING MECHANICAL MODELS

The credibility of any reliability-based assessment depends fundamentally on the accuracy of the mechanical models used to predict the limit states of interest. Quite often well established design models prove too conservative or inaccurate when used in a reliability assessment. Prediction of environmental actions has been historically considered an area of great uncertainty. Recent monitoring programs, however, have led to the development of more credible wave load recipes. Prediction of component strength is another area where improvements have been made, but uncertainties still remain on the effects of shape imperfections and residual stresses particularly with more slender structures. Prediction of system strength is a relatively new discipline which has also been evolving quickly and improvements are still needed, in understanding if not in the modelling itself provided of course that the user is suitably experienced. As far as offshore structures are concerned, it seems that foundation behaviour is one of the most uncertain aspects as highlighted by the recent pile-induced structural failures during Hurricane Andrew[4]. The other major area is fatigue behaviour which is treated separately in Annex C of ISO 2394.

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