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RECOMMENDED PRACTICE

ENIQ Recommended Practice 9

Verification and Validation of Structural Reliability Models and associated Software to be used in Risk-Informed In-Service Inspection Programmes

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FOREWORD-BRIEF REVISION HISTORY OF RP9

The first issue of ENIQ Recommended Practice 9 (RP9) was developed by the ENIQ Task Group for Risk and was approved by the ENIQ Steering Committee for publication in May 2007. A number of smaller changes were made for the second issue of the document reflecting the development on the field in the last 10 years.

EXECUTIVE SUMMARY

This Recommended Practice (RP) has been developed as a consensus document amongst the members of NUGENIA Technical Area 8 (TA8) - ENIQ. Structural Reliability Models (SRMs) are commonly used to evaluate failure probabilities in the development of Risk-Informed In-service Inspection (RI-ISI) programmes. The main objective of this RP is to summarise the Verification and Validation requirements that a SRM and associated software should satisfy in order to be suitable for such programmes.

TABLE OF CONTENT

1. Introduction

Structural Reliability Models (SRMs) are commonly used to evaluate failure probabilities in the development of Risk-Informed In-service Inspection (RI-ISI) programmes. This report summarises the Verification and Validation (V&V) requirements that a SRM and associated software should satisfy in order to be suitable for the intended purposes.

These requirements are based on work performed previously in this area, mainly within the NURBIM project, in particular NURBIM report D2 “Definition of a set of criteria that should be met by a suitable structural reliability model” [1], and NURBIM report D4 “WP-4, Review and benchmarking of SRMs and associated software” [2].

2. Basic definitions

In the context of RI-ISI, a Structural Reliability Model (SRM) can be defined as an engineering tool based on Probabilistic Fracture Mechanics (PFM) or other structural reliability methods used to calculate component and piping failure probabilities. Generally, PFM and structural reliability analyses involve deterministic analysis procedures with random input variables. These analyses require numerical techniques as implemented in computer programmes.

Any engineering model that attempts to describe a process or mechanism should be accompanied by documentation and proof of its ability to perform the task accurately. These requirements are generally referred to as Verification and Validation (V&V) of the model. Firstly, however, it is important to establish what is required from the SRM software and how the concept of V&V applies to such a model [1].

<u>Verification:</u> The process of determining that a computational model accurately represents the underlying mathematical model and its solution [3].

<u>Validation:</u> The process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model [3].

3. Basic computer program quality assurance (QA)

The first and most fundamental requirement in terms of Verification is a record of the Quality Assurance (QA) process used in the production of the SRM and associated software. It is essential to ensure that a fully documented QA system has been applied, which ensures that the SRM software does what the developers intended it to do.

4. Scope and basic modelling principles and assumptions

A second fundamental requirement is a clear statement of the scope covered by the SRM/software and the basic principles and assumptions/limitations that are specifically or inherently included in it. This requirement has the following goals:

a. To provide clear guidance to any potential user of the scope of application of the model.

b. To establish where any simplifying assumptions have been made. For example, if the SRM software currently used to evaluate piping failure probabilities was developed to address cracks in the simple pipe-to-pipe butt weld geometry (cylindrical). More complex weld geometries (e.g. fittings, branch pipes, etc.) are approximated.

c. To assess whether the predicted probabilities are inherently pessimistic in any given situation or whether attempts have been made to make the predictions as realistic as possible. The best way to avoid this issue is to use best estimate values in the analysis.

5. Well grounded principles and assumptions

Having established the basic principles and assumptions within the SRM software, it is necessary to demonstrate that these principles and assumptions are well founded.

Many of the basic principles used in structural reliability modelling originate from codified deterministic analysis. It is important to ensure that any inherent pessimism, such as hidden safety margins in the deterministic analytical procedures, are clearly identified.

One important aspect of the model is the manner in which variables are treated as either probabilistic or deterministic variables. The choice of distributions to represent data can make significant differences to a given estimate, especially if that estimate is strongly dependent on the tails of the distribution. The reason behind a given choice of distribution should be made clear and wherever possible mechanistic reasoning for that choice should be given.

If no mechanistic reasoning can be given for an assumption and the choice is simply based on a best-fit evaluation of the data, then the comparison with other relevant distributions should be investigated. Sensitivity analyses should always be carried out to assess the influence of statistical distributions and choice of different parameters. The results of such analyses should accompany the SRM software documentation.

The possibility of interdependencies between different random variables should be investigated.

6. Experimental validation

As stated in [1], there is an inherent problem in trying to prove that a probability prediction is true because such a probability is not a property of the component or structure itself. However, it may be possible to demonstrate the validity of some of the constituent parts that make up the model.

This form of validation is primarily looking to demonstrate that the assumptions used in the model are well founded. This can be achieved by running the model, probably in an adapted or sub-element form, in order to reproduce experimental data that form the bases of the mechanistic assumptions on which the model is built. The available experimental data should be used to test as many different aspects of the proposed model as possible.

7. Comparison with industrial data (world data)

Since the objective of the SRM is to provide a realistic estimate for structural failure rates within industry, it would seem logical to argue that the historical data from the industry on such failures should be fundamental to the model validation. Unfortunately, due to the lack of adequate reliability data for the disruptive failure of components and structures there are inherent problems in using this means of validation.

When comparing failure information from historical databases, several aspects and potential difficulties must be borne in mind. A broad discussion is given in [4].

Generally, the historical failure data provides a point estimate determined by simply adding all the known passive component failures together and dividing by the total pipe population data, expressed for instance in weld-years. However, this data is derived from a wide variety of conditions, environments and loads, among other factors that influence failure probability. If this data is to be used to validate SRM software predictions in some way, then the SRM software must be run so as to represent the world data against which it is to be compared. This type of comparison cannot be completed unless the necessary data is available, which is not normally the case. On the other hand, qualitative trends between historical failure data and SRM software predictions can be more readily compared.

In addition, large uncertainties inevitably exist with respect to rare events such as gross structural failures and failures of large pipes. More data is available on identified cracks and small leakages, which could be used for validation of the SRM software with the limitations stated above.

Experience gained from application of the RI-ISI scheme can provide confidence in the overall predictions of the SRM, provided that experience aligns with SRM predictions and expected plant behaviour.

8. Comparison with other SRMs (benchmarking)

Comparison of one type of SRM software against another is probably the most common method of providing verification for any given SRM software. There is, however, an inherent problem with such a comparison in that there is an implicit assumption about the correctness of one of the two models, i.e. the one that is being used to benchmark the other. There is also the question of whether or not any two SRM software packages should provide the same answer or not. If the models use different assumptions about the failure criteria or some other modelling assumption, then they will probably give different answers to a given problem. While recognising that there are limitations with this type of approach to V&V of any given SRM software, its outcome should still show consistency of the results obtained with the compared SRM software or it should provide a clear understanding of where any differences originate.

This approach was undertaken within the NURBIM project for fatigue and stress corrosion cracking [2]. The results showed good consistency and the differences were consistent with the assumptions and approximations made in the analyses. However, not all features of SRM software relevant to RI-ISI programmes (e.g. leakage evaluation and detection) could be compared.

9. The role of expert judgment

The lack of validated structural reliability tools and the scarcity of operating experience can sometimes justify the use of expert judgment. Generally, expert judgment can be used to derive data or probability distributions for use within an SRM. However, for the purposes of this document, it is envisaged that expert judgment can be used for V&V of SRMs, for instance, in evaluating the validity of the assumptions used, and in assessing the credibility of their predictions versus experimental and historical data.

Expert judgment can be the result of informal or formal processes, the former being the way expert judgment has traditionally been used, through the expert's implicit and undocumented reasoning, inferences and scientific knowledge. In contrast, more recent formal uses of expert judgment exist that are explicit, structured and well documented. They attempt to reveal assumptions and reasoning that are at the basis of a judgment and to quantify and document them so that they can be appraised by others [5].

It is strongly recommended that, in uses related to the verification of SRMs, expert judgment is carried out in a formal and structured way [6].

10. Summary of requirements for SRM software

SRMs (and associated software) are essential tools in the evaluation of failure probabilities for components in nuclear power plants. It is essential to verify and validate any SRMs used in the evaluation of failure probabilities. To this end, the following criteria should be met ([1], [7]):

1) The basic programming can be shown to have suitable quality assurance documentation.

2) The scope, analytical assumptions and limitations of the modelling capability are well defined.

3) The analytical assumptions in 2) are well grounded and based on theory that is accepted as representative of the situations considered by the given SRM.

4) The model is capable of reproducing the data on which its analytical assumptions are based and examples are provided that demonstrate its general agreement with available experimental data.

5) Model predictions are comparable with the world or field data, accepting the inherent limitations of this data.

6) The model has been benchmarked against other SRMs within the same field or scope and any differences are adequately explained.

Further key elements when applying SRM software are recognised as being:

- The choice of statistical distributions. The reasons behind a specific choice of distribution should be made clear and, if possible, a mechanistic understanding of the choice should be provided. If the choice is based on a best-fit evaluation of the data, then a comparison with other relevant distributions should be made. In many cases, when very small failure probabilities are evaluated, the tails of the distributions become important.

- Sensitivity analyses should always be performed to assess the influence of different parameters and choice of statistical distributions.

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ACRONYMS

RI-ISI: Risk-Informed In-Service Inspection

PFM: Probabilistic Fracture Mechanics

SRM: Structural Reliability Model

QA: Quality Assurance

V&V: Verification and Validation

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ABOUT NUGENIA and ENIQ

NUGENIA is an international non-profit association under Belgian law established in 2011. Dedicated to the research and development of nuclear fission technologies, with a focus on Generation II & III nuclear plants, it provides scientific and technical basis to the community by initiating and supporting international R&D projects and programmes. The Association gathers member organisations from industry, research, safety organisations and academia.

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The European Network for Inspection and Qualification (ENIQ) is a utility driven network working mainly in the areas of qualification of non-destructive testing (NDT) systems and risk-informed in-service inspection for nuclear power plants. Since its establishment in 1992 ENIQ has issued nearly 50 documents. Among them are the “European Methodology for Qualification of Non-Destructive Testing” and the “European Framework Document for Risk-Informed In-Service Inspection”. ENIQ is recognised as one of the main contributors to today’s global qualification guidelines for in-service inspection. ENIQ became Technical Area 8 of NUGENIA in 2012.

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