Probabilistic Based ISI and Life Extension

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1. INTRODUCTION

The concept of applying a Bayesian technique to the re-cycling of in-service-inspection (ISI) data was presented in references 1 and 2. In reference 3, a computer based expert system, to carry out a Structural Risk Reliability Analysis (SRRA) of welded joints was presented. These two principles have been developed and combined with a probabilistic Risk Assessment (PRA) to form a complete methodology for a probabilistic based safety justification and life extension.

The principle bases of this methodology is as follows:-

i) Derive a range of initial best estimates for the probability of failure of pipe and vessel welds using the expert system.

ii) Optimise the ISI using PRA results.

iii) Re-cycle the ISI results to gain* confidence in best estimate.

iv) Use the knowledge from (3) together with the re-validation inspection, to assess a life extension potential for the plant components.

(* It is by no means certain that confidence gain will always be achieved. This outcome is dependent upon the ISI results and is one of the major attractions of this methodology.

2. MODEL DEVELOPMENT

The SRRA model presented in reference 3 has been expanded to include the effect of ISI on the probability of failure for either a full or sample inspection policy. Care has been taken not to treat repeat ISI's, using the same techniques and equipment, as independent inspection. Areas of stress concentration, i.e. where the crack growth to failure is preceded by crack initiation, have also been added. This has highlighted both the problem of combining probabilistic based crack initiation with crack growth and the effect of none linear elastic fracture mechanics conditions at areas of high stress concentration.

Every attempt has been made to verify the predictive ability of the model. This has included a comparison with an independent data base on defect density and distribution in welds and model pressure vessel test. These comparisons have been bery successful and have given a high degree of confidence in the model. However, such validation in no way provides any form of proof, that the final probability of failure in any particular application, is correct. It is for this reason that the ISI data is essential to build up confidence in the original prediction.

The modelling to obtain confidence from the ISI data has been modified to accept the form of data generated by the SRRA model to obtain the failure probability. However, it is of course necessary to simplify the failure analysis iteself, in order to be able to carry out the confidence updating on 80 to 100 alternative data sets.

3. PRINCIPLES OF METHODOLOGY

3.1 Probabilistic Analysis and Ranking

Figure 1 is a schemiatic of how the basic principles of this method dovetail together.

This figure shows that the SRRA starts the process by providing a best estimate of the proability of failure. Because the model has been put together as an expert system it is cpable of providing a comprehensive break down of the components that make up the plant. This work can run alongside the basic design or can be carried out retrospectively on an already design plant.

It is at this stage that some analysis use the probability of failure results to rank the components for ISI. The policy being forward here, however, is to take these results a stage further and use them as data input to a PRA analysis. The PRA assigns a probability to each of a number of levels of contamination release. These are then compared with an acceptable probability of occurrence as a function of contamination release. From this the plants overall balance of risk can be assessed which is the starting point for the ranking procedure. Each level of release traces back to a complex interaction of component and system failures. The component failures, within the individual systems, can now be ranked to give their relative effect on risk. In this way those areas of the plant that are closest to, or even above, the criteria and therefore of concern, can be identified. This approach better identifies the areas of greatest risk to safety, while the initial ranking is of more use for plant availability.

It is possible to carry out this part of the analysis using pessimistic world data. Those areas near or above the acceptance criteria can then be re-cycled using the SRRA model to give a better estimate. This means that a ranking across the whole plant cannot be made with this reduced SRRA set, however, since the critical areas of the plant have been identified, it is only necessary to rank the components and welds within these areas. For availability one is forced back to the world data which suffers from its lack of detailed application.

Returning to figure 1, it can be seen that after the PRA analysis, then for any particular area of the plant the failure probability is either acceptable or unacceptable.

3.2 Confidence from ISI

First consider the situation where the PRA gives an acceptable safety risk. This implies that from an analytical view point there is no need for an ISI programme; the plant is fully justified! However, there remains the basic question of how much confidence can be placed in the predicted failure probabilities and hence in the safety justification. The objective of the ISI policy must, therefore, be to build confidence in the original probability analysis. This implies that the effect of the ISI on the probability of failure is not the key concern. True, any ISI must affect the probability but if a sample ISI is to be put forward it is doubtful that this will significantly affect the overall plant safety. For example if 80% of the risk is contained within the sample, and here we assume the ranking has correctly identified this sample, then reducing the probability of failure by two decases for this sample° only gives a factor of five to the overall probability of failure. Despite the above, it would be imprudent not to inspect the high risk areas. Furthermore these areas are the ones most likely to give a positive outcome. but, the basic justification for a sample size ISI must lie in its role as a confidence building exercise and not a failure rate reduction procedure.

At this point the SRRA is re-used to investigate the effect of changing the basic assumptions originally used to build up the failure probability. No area need remain sacrosanct, crack growth rates, cyclic duty, build standards, whatever. All can be varied together or separately to produce a number of, what were called in Reference 1, probability failure sets (PFS's). This is not unlike the sensitivity analysis except the process is taken a stage further. Each PFS is assigned a probability of being true, this can be a weighted distribution or a constant for each PFS. All PFS's are then run through the simplified probabilistic model to predict the effect of the sample ISI and the Bayesian logic introduced as real ISI data becomes available (see Reference 1). The changing probability associated with each PFS is now used as an indicator as to the reasonableness, or otherwise, of our original analysis (see Reference 2).

3.3 ISI as Front Line Safety

Consider the situation where the PRA gives an unacceptable safety risk a situation which we hope will not occur too often. If the plant is still at the design stage then clearly the first course must be to look again at the plant design or the component build inspection. However, if the plant is already in service or the design cannot be changed, then the ISI must be seen as a way of reducing the probability of an in-service failure. Note, that this now implies that the ISI is part of the front line safety justification and becomes mandatory. Since the SRRA, presented here, contains a routine to evaluate the effect of ISI on the probability of failure then the area of concern must be recycled to include the ISI programme. If a pre-service-inspection (PSI) is applied, this is treated as a 'zero time' ISI by the SRRA. An interesting situation arises if the PSI alone, reduces the failure probability to an acceptable level. This, presumably, changes the need for ISI from 'mandatory' to 'highly desirable'. What it really means is that the build inspection should be improved? Given that this is not the case then the optimum way forward is to incorporate the ISI programme into the normal operational shut downs and see if this is sufficient to reduce the in service failure probability. Note, that if the PRA is identifying an area of concern, then the ranking within that area will play a significant role in optimising this mandatory ISI.

The above should identify an ISI programme to reduce the probability of failure to an acceptable value which means the logic in figure 1 now leaves by the acceptable path. In this case, it is not the sample ISI that is used for confidence building, but the more extensive front line safety ISI programme. In principle, however, the logic is no different except that now we have a different slant to the problem. The requirement for a front line safety ISI programme was based on the original best estimate failure probability, but again, this implies that this evaluated probability of failure is correct. It is quite possible that the true probability of failure was always at an acceptable level, it was only the pessimistic analysis that suggested otherwise. Our sensitivity analysis must now include an acceptable set of data or stress cycles so that the re-cycled ISI data has a suitable set to compare with. If the assertion of a pessimistic original analysis is true, the ISI data should indicate this. In this way we may be able to adjust our belief in the component performance and hence in the necessary level of the ongoing ISI programme. But note, it is always possible that the ISI data may infer that the original assessment was correct or even the inverse is the true situation, with the obvious indications on the level of ongoing the ISI programme?

3.4 Life Extension

Expanding this methodology to include life extension is a natural progressin of the modelling. If no ISI has been carried out during the normal life of the plant then the SRRA is used with the life time extension inspection (LTEI) acting as an ISI but with the principle objective of measuring its affect on the probability of failure to the end of the extended life. In this way the risk associated with the proposed life extension, given LTEI, can be compared with the risk accepted during the normal life of the plant to aid in the decision regarding life extension.

In the above analysis the time in service to-date must be included to establish the defect distribution at the time of the inspection. Since the inspection efficiency associated with the LTEI is independent of the plant history, the final probability of failure evaluated for the life extension is dependent on the initial start of life assumptions about the defects and the fatigue usage. Whilst the plant usage will help to identify the fatigue usage it will not help to justify the mapping from plant usage to fatigue usage (an assumption that is often implicitly assumed to be true) nor the start of life assumptions. True to LTEI can be used as a single reference check on this but clearly it is here that any ISI during the normal plant life is of most value. If sufficient ISI has been carried out such that the Bayesian re-cycling can establish a reasonable degree of confidence in the original start of life assumptions, then the physical confidence given by the LTEI can be confidently supported by the life time extension SRRA.

4. EXPERIENCE

Various parts of the model have been used to date (2) & (3) but only recently has the full methodology shown in figure 1 been used. This application has been for existing plant that has received no PSI but has been subject to a sample ISI programme for some years. During that period defects have been found and some repairs have had to be made.

The re-cycling of this data has, in all the cases so far examined given confidence that the plant is performing satisfactorily. There have, however, been cases where the ISI programme has had to be increased because of an initial loss of confidence from the ISI results. In this and other instances, the model has proved to be very useful in aiding difficult decision making.

No direct life extension application has yet been made.

5. DISCUSSION

The discussion has been broken down into a series of sub-headings in order to cover as many points as possible but remain concise.

5.1 Absolute/Relative

The solution to a deterministic analysis is used in both a relative and absolute form. When comparing one design with another or ranking areas of a plant the values are used relatively. When used to justify a design it will appear as a comparative use but with the value used for comparison laid down by some regulative body. However, given that a value has been fixed in space, the comparison must be an absolute one.

The above logic must be true for the solution of an SRRA but its extension from a relative to an absolute value is generally treated with much greater scepticism. To a large extent this is probably due to the fact that the value from a design analysis has no interpretable meaning outside its own sphere of relevance, whereas an SRRA solution is a probability, which has immediate meaning over a broad general sphere. In this way its absolute value can be equated to our perception of risk in the real word, with the obvious consquence on its acceptance.

If the above were the only objective, then it would, at least technically, be no real objection. However, when comparing the probability of failure from an SRRA model with some acceptable probability of failure, the two probabilities do not generally originate from the same type of analysis. The acceptance probability will be based on a conglomerate of risks taken from the real world and determine by statistical inference; that is to say they are based on real data and hence give a demonstrable level of associated risk. The SRRA solution, however, is based on theoretical model which can never be fully validated, which is often sufficient reason for the sceptic to dismiss the solution.

It is the above reason that makes the re-cycling of ISI data so essential in building up confidence in the original analysis and was much of the driving force behind this methodology.

Completeness or 'Factor X'

The inability to prove completeness is seen as major shortcoming in any SRRA. There can be no denying the truth of this statement, but in essence this is just an expansion of the above argument regarding the absolute value. Here agains it is the ISI data that provides the confidence. Of course, the missing component, or something close to it must be in the sensitivity analysis which is used for the Bayesian comparison. At first it may seem difficult to include something that is unknown but the secret is to remember that what ever it is,it must affect one of the principle components that lead to failure.

5.3 Inspection Efficiency

The modelling has highlighted the need to be able to identify a good representation of the ISI efficiency. Whilst it is possible to vary the build inspection in the sensitivity analysis and then use the ISI data to derive confidence, the ISI data cannot be used to justify its own efficiency.

5.4 Critical Defect Size

The re-cycling of ISI data provides information only on the existence of defects within the inspection area. It cannot therefore be used to justify the critical defect size. Whilst non failure of components provides some information with respect to critical defect size, it is not generally very significant. The modelling can, however, provide a sensitivity analysis and hence measure the effect on confidence building with respect to failure probability.

6. CONCLUSIONS

A methodology has been presented that combines SRRA with ISI to attempt to allay some of the fears associated with probabilistic based methods.

The method develops naturally to a life time extension analysis. Experience to date has shwon that the application of the method to existing plant, built prior to modern rigours standars, has proved very valuable in gaining confidence in the plants ongoing safety.

References

1. Statistical Approach to the Analysis of ISI Data using the Bayes Method. 7th SMiRT Conference 1983.

2. Confidence Through Sample ISI. 8th SMiRT Conference 1985.

3. Probability Risk Ranking. 9th SMiRT Conference 1987.

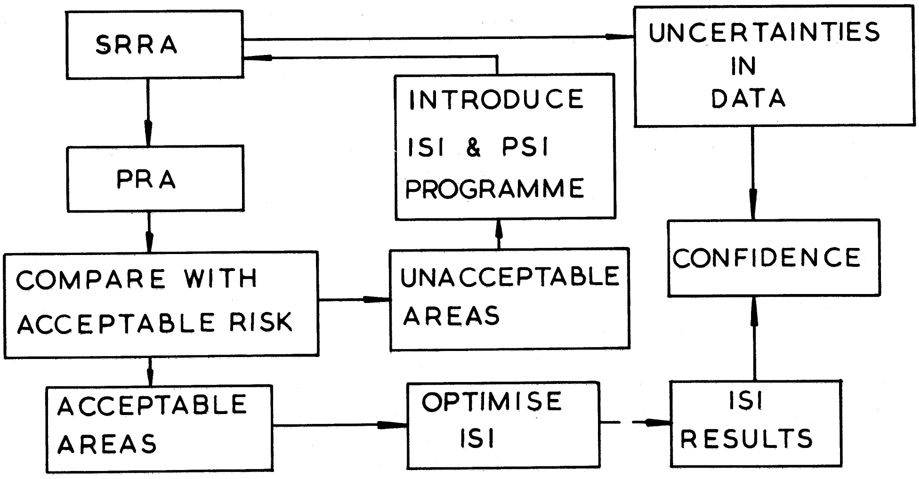

FIGURE 1.