PROGRESS TOWARDS A UNIFIED STRUCTURAL INTEGRITY ASSESSMENT PROCEDURE: THE SINTAP PROJECT

A. C. Bannister°, S. E. Webster°, M. Koçak[+], R. A. Ainsworth[†], K. Wallin* and J. Y. Barthelemy**

The SINTAP project, part funded by the European Union under the Brite-Euram scheme, commenced in April 1996. It has a duration of three years and involves a consortium of seventeen organisations from nine European countries. The aim of the project is to derive a unified structural integrity evaluation method for use by European industry. Although many such methods exist, most have conflicting approaches, unspecified levels of empiricism or do not fully reflect the performance of modern materials or the current state of knowledge. The SINTAP project covers both modelling and experimental work, and a large element of the project is concerned with transfer of knowledge and data. The derivation of a procedure applicable to a wide cross-section of users by its ability to offer routes of varying complexity, reflecting data quality, is therefore the principal aim of the SINTAP project.

INTRODUCTION

Structural Integrity Assessment procedures are the techniques used to assess the fitness-for-purpose of critical components and welded structures. Such approaches can be used at the design stage to provide assurance for new structures, at the fabrication phase to ensure the integrity in the construction and at the operational phase to provide assurance throughout the life of the structure. Used correctly, they can prevent over-design and unnecessary inspection and provide the tools to enable a balance between safety and economy to be achieved.

While different failure modes such as fracture, plastic collapse, fatigue, creep and corrosion can be assessed using such procedures, the SINTAP project is concerned with those of fracture and plastic collapse and the interaction between the two. SINTAP (Structural INTtegrity Assessment Procedure) is a multi-disciplinary collaborative project part-funded by the European union with the aim of devising a unified procedure for such assessment.

° British Steel, Swinden Technology Centre
[+] GKSS Research Centre
[†] Nuclear Electric Limited
* VTT Manufacturing Technology
** Institut de Soudure

The industrial need for the procedure is reflected in a number of facts and trends as detailed below:

(i) The existence of a large number of fitness-for-purpose methods in use, both in Europe and worldwide, and the increased use of such procedures in a wide range of industries.
(ii) The presence of unspecified factors of safety, empiricism and undefinable reliability levels associated with such approaches.
(iii) Developments in design philosophies allowing loading in the plastic regime, such as limit-state design, and the increasing demands of industry to exploit the properties of modern materials and joining methods.
(iv) The existence of a wide range of material suppliers, material users, designers, safety assessors, research institutes and standards development bodies involved in integrity assessments.
(v) The move towards European standardisation in materials supply, fabrication and construction (such as EN Standards and Eurocodes).

PHILOSOPHY AND APPROACH OF THE PROJECT

In view of the nature of the project and the necessity to consider carefully the requirements of the end user, a wide-ranging consortium is participating in the project which is structured in three steps: As a first step a comprehensive collation of existing data, procedures and codes has been completed. Experimental work to cover omissions and to validate the approaches and assumptions has now commenced as the second step. Thirdly, the best practice approach is being derived with consideration of the needs of the practising engineer within a wide range of European industries. The principal technical objectives of these tasks are:

Task 1: Mismatch. To quantify the behaviour of mismatched welded joints and to provide recommendations for their treatment in a procedure.

Task 2: Failure of Cracked Components. To extend the understanding of the behaviour of cracked components in the specific areas of constraint, yield/tensile ratio, prior overload, leak-before-break, stress intensity factors and limit load solutions.

Task 3: Optimised Treatment of Data. To provide an industrially-applicable method for a reliability-based defect assessment procedure.

Task 4: Secondary Stress. Determination and validation of the most appropriate method of accounting for residual stress, including a compendium of residual stress profiles.

Task 5: Procedure Development. Development and validation of procedure.

A key aspect of the procedure is that a range of assessment routes can be followed which reflect the quality of the input data: The most sophisticated and accurate levels require accordingly high quality input data, while conversely, knowledge of only basic parameters is penalised by a higher degree of conservatism; A data quality matrix, Fig. 1, forms one of the key decision steps in selecting the appropriate route.

REVIEW OF EXISTING PROCEDURES

As an initial starting point, the current situation concerning existing procedures and their pending development was assessed[1]. The two principal methods used are the Failure Assessment Diagram (FAD) and the Crack Driving Force (CDF). The former method is used in approaches such as R6[2], BS PD 6493[3], SAQ[4], EXXON[5], INSTA[6], MPC[7] and API 579[8]; the CDF approach is favoured in ETM[9] and GE-EPRI[10] procedures. The critical review of these procedures was carried out in terms of fifteen key areas[1]. The advantages and disadvantages of each were assessed and analytical comparisons carried out. The review demonstrated that there is relatively little difference between results obtained using the different procedures and that the major discrepancies arose primarily due to the limit load or stress intensity factor solutions that each applies rather than any fundamental difference in concept. Furthermore, although FAD and CDF routes represent two different calculation methodologies, the underlying principles remain the same. Demonstrating compatibility between the two approaches was therefore seen as a key issue within the SINTAP procedure.

PROCEDURE DEVELOPMENT

Integration of Driving Force and Failure Assessment Diagram Methods

In view of the potential advantages to a user of being able to present the results of an assessment as either a FAD or CDF, a fully consistent set of equations is being developed within the SINTAP procedure such that while results can be presented in different ways, there is only one assessment result.

R6[2] and ETM[9] methods have been compared for compatibility in this respect[11]. Although there are various FAD and CDF approximations within these two procedures, compatibility is possible since the basic calculations required in both methods are the elastic stress intensity factor and the limit load. Preliminary analysis show that minor adjustments to the R6 and ETM formulations lead to a fully consistent route within which the results can be interpreted as either a FAD or CDF, as shown by means of one of the validation examples in Fig. 2.

Analysis Options

Within the framework of maintaining the FAD-CDF compatibility, a range of analysis options is offered which enables advantage to be taken from increasing data quality and which reflects the variation in user knowledge and experience; These are:

Level 1: Basic (only yield stress known)
Level 2: Material Specific: Assumed N (only YS and UTS known)
Level 3: Material Specific: Known N (full stress-strain curve known)
Level 4: Material and Geometry Specific: (Full stress-strain curve known, solution for J known)

In the above, N is the strain hardening exponent. At Levels 1 and 2, relationships between tensile parameters have been derived to enable estimation of UTS (for Level 1) and N (for Level 2) from knowledge of only the yield stress or yield stress/tensile ratio, respectively. By selection of appropriate mathematical descriptions for the functions used in the different levels it is ensured that conservatism decreases with increasing assessment level, reflecting an advantage for the user of obtaining the best possible quality of input data. A summary of the structure of the procedure, within the context of the software being developed, is given in Fig. 3.

SOFTWARE DEVELOPMENTS

Industrial examples of the use of procedures such as SINTAP have illustrated the benefits of having software available to automate the calculations. Because the application of the procedure, at its more complex options, may require iterative solutions and interactions between the various parts of the procedure, automation of the SINTAP procedure in the form of software is an integral part of the project[12]. Further advantages of this are repeatability, accuracy, accountability and validation, all of which lead to increased effectiveness of the user's time.

The principal factors considered in the development of the SINTAP software[12] are functionality, consideration of user requirements, modularity and validation. A schematic illustration of the architecture of the software is shown in Figure 3. Several of the consortium members have extensive experience of software development in existing codes and this has proved invaluable for the development of the SINTAP software, which is developing in parallel with the technical progress within the individual tasks and the overall procedure development.

DISSEMINATION AND EXPLOITATION

In common with the aims and objectives of the Brite-Euram initiative, dissemination and exploitation of results is a key aspect of the project. Many of the individual task and sub-task areas have contributed to the continuing development of procedures such as R6, PD 6493 and ETM. Furthermore, the collaborative nature of the project has enabled technology transfer across industries; specific examples include incorporation of the PISC/NESC data, knowledge from the Nuclear Industry on leak-before-break, data from the offshore industry on tubular joints and information on steel properties from extensive databases. This collation of existing, but latent, information from across European industry is only possible due to the large consortium. Contributions from the project will also be made towards the development of a CEN fitness-for-purpose standard with the remit of CEN121 WG14 Committee.

SUMMARY

Structural integrity assessment procedures are being increasingly used at the design, fabrication and operational stages of a structure's lifetime. Although much experimental work and data generation have been completed by European industry, a structured and systematic approach that enables information to be gathered from a wide cross section of industry is lacking; through its extensive consortium membership the SINTAP project aims to redress this aspect with the derivation of a single European procedure as its principal objective. The structure of the project is such that experimental and modelling work runs concurrently with collation of existing data, derivation of the procedure and

software development. Exploitation of results within the CEN framework should also ensure that the project outcome is made available for industrial users and is widely disseminated.

ACKNOWLEDGEMENTS

The authors wish to thank their respective companies and the DGXII Commission of the European Union for permission to publish this paper.

REFERENCES

(1) Ruiz Ocejo J., Gonzalez-Posada M.A., Gutiérrez-Solana F. and Gorrochategui I., 'Review of Existing Procedures', University of Cantabria Report SINTAP/UC/04, 1997.

(2) R6, 'Assessment of the Integrity of Structures Containing Defects', Nuclear Electric, Procedure R6, Revision 3, UK, 1997.

(3) PD 6493, 'Guidance Methods for Assessing the Acceptability of Flaws in Fusion Welded Structures', British Standards Institute, 1991.

(4) Andersson, P., Bergman, M., Brickstad, B., Dahlberg, L., Nilsson, F. and Sattari-Far I., 'A Procedure for Safety Assessment of Components with Cracks - Handbook', 3rd Revised Edition, SAQ/FoU Report 96/08, SAQ Kontroll AB, 1996.

(5) 'Fitness for Service Guide', EXXON Chemical, 1995.

(6) INSTA Technical Report, 'Assessment of the Integrity of Structures containing Discontinuities', Materials Standards Institution, Stockholm, 1991.

(7) MPC, 'Fitness for Service Evaluation Procedures for Operating Pressure Vessels, Tanks and Piping in Refinery and Chemical Service (FS26)'. Draft No.5, Consultant's Report, The Material Properties Council, 1995.

(8) API 579, 'Recommended Practice for Fitness-For-Service', Draft Issue 4, 1996, American Petroleum Institute.

(9) Schwalbe, K.H., Zerbst, U., Brocks, W., Cornec, A., Heerens, J. and Amstutz, H., 'The Engineering Treatment Model for Assessing the Significance of Crack-like Defects in Engineering Structures (EFAM-ETM 95', GKSS Forschungzentrum, 1996.

(10) Kumar, V., German, M. D. and Shih, C.F., 'An Engineering Approach for Elastic-Plastic Fracture Analysis', General Electrical Company, NP-1931, Research Project 1237-1, Topical Report, 1981.

(11) Ainsworth, R.A., Kim, Y.-J., Zerbst, U., Gutiérrez-Solana F. and Ruiz Ocejo J., 'Driving Force and Failure Assessment Diagram Methods for Defect Assessment', OMAE Conference, Lisbon, 1998.

(12) Phaal, R., Wiesner, C.S., Marshall, G.W., O'Sullivan, M., 'Structural Integrity Assessment Software - How Can It Help?', ASME - OMAE - Lisbon 1998.

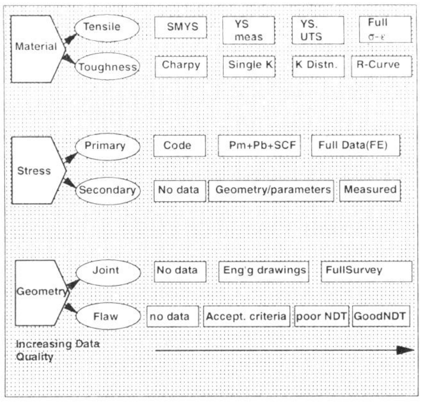

Fig.1 - Data Quality Matrix

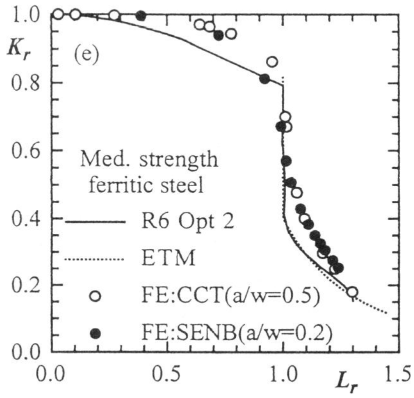

Fig. 2 - Example of Compatibility Between R6 and ETM Procedures

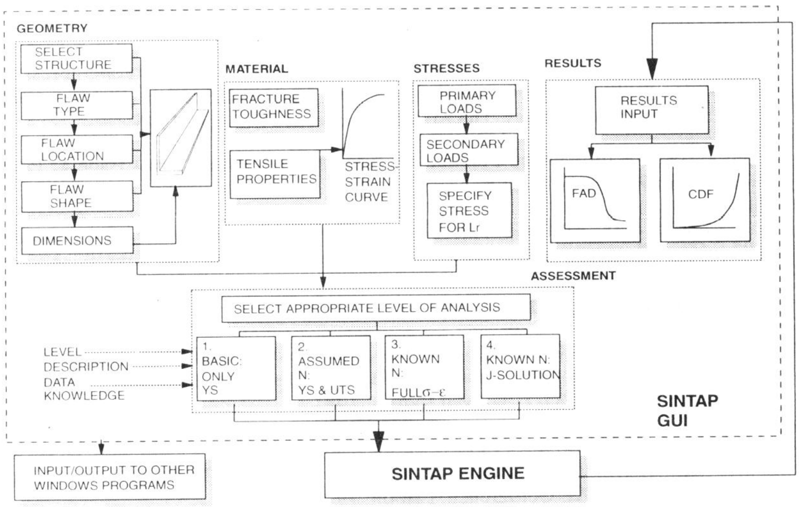

Fig. 3 - Architecture of SINTAP Procedure Software