FITNET FFS PROCEDURE

FITNET FITNESS-FOR-SERVICE (FFS) PROCEDURE

Revision MK8

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NOTE

This **FITNET FFS Procedure** (Revision MK8)has been developed within the European Fitness for Service Thematic Network (FITNET TN) and is not a standard. It is developed under the rules of CEN Workshop Agreement 22 (CWA22) to provide guidelines for assessing the structural significance of postulated or detected flaws with respect to FRACTURE, FATIGUE, CREEP and CORROSION damage in metallic structures with and without welds. It provides updated and validated FFS procedure in a unified form to be used to ensure and enhance structural safety and efficiency of in-service structures and new engineering structures at design stage.

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Foreword

European **Fit**ness-for-Service **Net**work (**FITNET**) was a four-and-a-half-year thematic network developed within the "Competitive and Sustainable Growth (GROWTH)" research programme of the European Community under the contract of GIRT-CT-2001-05071. This thematic network started to work in February 2002 with the objective of developing and extending the use of fitness-for-service procedures to assess postulated or real damage due to **FRACTURE**, **FATIGUE**, **CREEP** and **CORROSION** in metallic structures. About 60 experts from 16 European countries (as well as from Japan, Korea and USA) covering universities, research and technology organisations and a wide range of industrial sectors have provided contributions for the development of this **FITNET FFS Procedure** which addresses the analysis of four major failure modes.

The **FITNET FFS Procedure** is designed to assess the structural integrity of metallic welded or non-welded structures transmitting loads. In particular it embodies techniques for dealing with defects (known or postulated) to be present, in a structure together with the possible growth of such defects by a range of mechanisms and the assessment techniques required to evaluate the failure risk.

Flaws (such as cracks, welding defects and corrosion damage etc.) can arise during the manufacture and/or use of metallic components in engineering structures. For safety-critical structures such as aircraft, pressure vessels and pipelines, the failure of a single component due to the presence of a flaw can threaten human life, as well as having severe economic and environmental consequences. Other flaws can be harmless, as they will not lead to failure during the lifetime of the structure and hence repair of such flaws or replacement of the respective component is economically wasteful. The **FITNET FFS Procedure** can be used by expert engineers working in the field of structural safety, advanced manufacturing and design to assess the structural significance of such defects or postulated cracks or damage. The use of the FITNET FFS Procedure at the design and fabrication stages of advanced metallic structures working under static or cyclic loading conditions is also covered to provide an effective engineering tool for decisions with respect to material selection and fabrication route for an expected applied stress.

The **FITNET FFS Procedure** is developed by the expert members of the four Working Groups (WG):

WG 1: FRACTURE: Coordinated by S Webster, CORUS, UK

WG 2: FATIGUE: Coordinated by JJ Janosch, CARTEPILLAR, France

WG 3: CREEP: Coordinated by RA Ainsworth, BRITISH ENERGY, UK

WG 4: CORROSION: Coordinated by R Koers, SHELL, The Netherlands

This unified **Fitness-for-Service Procedure,** adopted by the European standardisation body of CEN via a "**CEN Workshop Agreement 22 (CWA22)**", covering four major structural failure modes, universally applicable to all major industries, able to be used at all stages of the life cycle of structures, aims to reach wider use in Europe and in the world for safer structures. The Italian standardisation organisation UNI has worked with the FITNET experts within the framework of the CWA22. This document is the 8th revision of the FITNET FFS procedure developed during the last four and half years. The FITNET FFS Procedure revision MK8 (January 2008) consists two volumes; Volume I: FITNET FFS Procedure, Volume II: Annexes.

In addition to these two volumes, there exists Case Studies and Tutorials as an additional information to provide selected validation cases and material for training and education.

A wide range of technical sources in the field of Fitness-for-Service technology, such as existing international or national standards; BS 7910, R6, API 579, WES 2805 codes, procedures of various industries, results of completed and on-going research projects (e.g. SINTAP) are used to develop this FITNET FFS procedure. A number of well-documented case studies are used for validation of assessment steps and routes to avoid non-conservatism in the procedure and check the sensitivity of an assessment to the selection of input parameters, assumptions and correlations. Further improvements and revisions in this **FITNET FFS Procedure (Rev. MK8)** will be carried out within the CEN standardisation process as well as after having users experience.

The FITNET TN consortium consists of following member and participant organisations in alphabetical order:

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GKSS RESEARCH CENTRE (Coordinator), Germany

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Slovenia

UNIVERSITY OF OSAKA
Japan

VTT
Finland

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Mustafa Koçak, FITNET TN Coordinator GKSS RESEARCH CENTER, Germany

10th January 2008, Geesthacht

Introduction

Presence or occurrence of damage in engineering components may have different origins and growth mechanisms depending on the application area, type of the component and loading conditions etc. Four major failure modes; *fracture, fatigue, creep and corrosion* have generally been identified as most frequent failure modes of engineering structures and hence different Fitness-for-Service (FFS) methodologies developed to cover these failure mechanisms. Certainly, failure of a component may include numbers of these four basic mechanisms and their interactions at different stages of the damage process in service.

Numbers of FFS procedures (include analytical methods) have been specifically developed and used to address the components of a particular industrial sector. A number of industrial sectors, such as nuclear power, petrochemical, offshore, aerospace or pipeline girth weld applications have partly established FFS standards in place for the assessment of flaws found in-service. However, their use in design and fabrication of new engineering components has been limited to some areas. Furthermore, some methods for design and remaining life assessments of metallic structures with or without welds are still unduly conservative in different loading regimes. Hence, there is still a need to generate a unified, comprehensive and updated FFS methodology endorsed by CEN for standardisation in Europe. Therefore, European Community funded project FITNET in the form of Thematic Network (TN) organisation has started in 2002 to review the existing FFS procedures and develop an updated, unified and verified European FITNET FFS Procedure to cover structural integrity analysis to avoid failures due to fracture, fatigue, creep and corrosion.

FITNET Fitness for Service (FFS) Procedure aims to provide better design principles, support for fabrication of new components and advanced analysis routes for prevention of failures in-service due to fracture, fatigue, creep and corrosion damages (no coverage of structural instability due to buckling). FITNET FFS Procedure can be used to establish the size limits for defects in various metallic engineering structures can provide substantial cost savings in operating such structures. The use of FITNET FFS Procedure involves making a critical engineering assessment of a component containing a defect to ensure its structural integrity for its intended design life or its next inspection period. The outcome of the assessment of a component in service is a decision to operate as is, repair, monitor (including re-setting of inspection intervals), or replace. Therefore, in this document engineering assessment procedures containing analytical expressions have been developed to assess (primarily to provide conservative estimation of the critical condition) the structural significance of the flaws or damage. Conventional design approach and operation principles implicitly assume that the component (load-carrying) is defect-free. However, even components fabricated by “good workmanship” principles may contain or develop cracks and hence need to be assessed using modern FFS methodologies for provision of structural safety, improvement of in-service inspection intervals and/or for establishment of life extension measures.

The FITNET FFS flaw assessment methodology in the form of a “step-by-step” procedure is set out for assessing a welded or non-welded metallic component containing a known or postulated flaw under static, fatigue, creep loading conditions or component subject to a corrosion damage (e.g. metal loss). The technical content of the procedure will contain **prescriptive** (defined, mandatory methodology for decision making analysis) and **informative** (guidance for user as recommendations) sections. Prescriptive parts aims to provide an engineering methodology for assessing flaws to reach a decision about the component. The informative parts serve to provide *best-of-knowledge recommendations* to the user. These parts may contain information without sufficient validation.

When a defect has been detected in a component that has been in service, the conservative assumption for the analysis of continuum damage is that the crack initiated early in life. This approach should be adopted unless there is evidence to the contrary. However, the FITNET FFS procedure is not being developed only for the assessment of damage of structures in-service, but also aims to be applied to a component at the design or fabrication stages as well as should be applied to a failed component to clarify the cause of the failure. Therefore, FITNET FFS Procedure is applicable to four major stages of a typical component life:

1) Design of New Component, 2) Fabrication Support and Quality Assurance, 3) Assessment of In-Service Component, 4) Failure Analysis

The overall flow-chart of the FITNET FFS Procedure is shown below to demonstrate its basic features.

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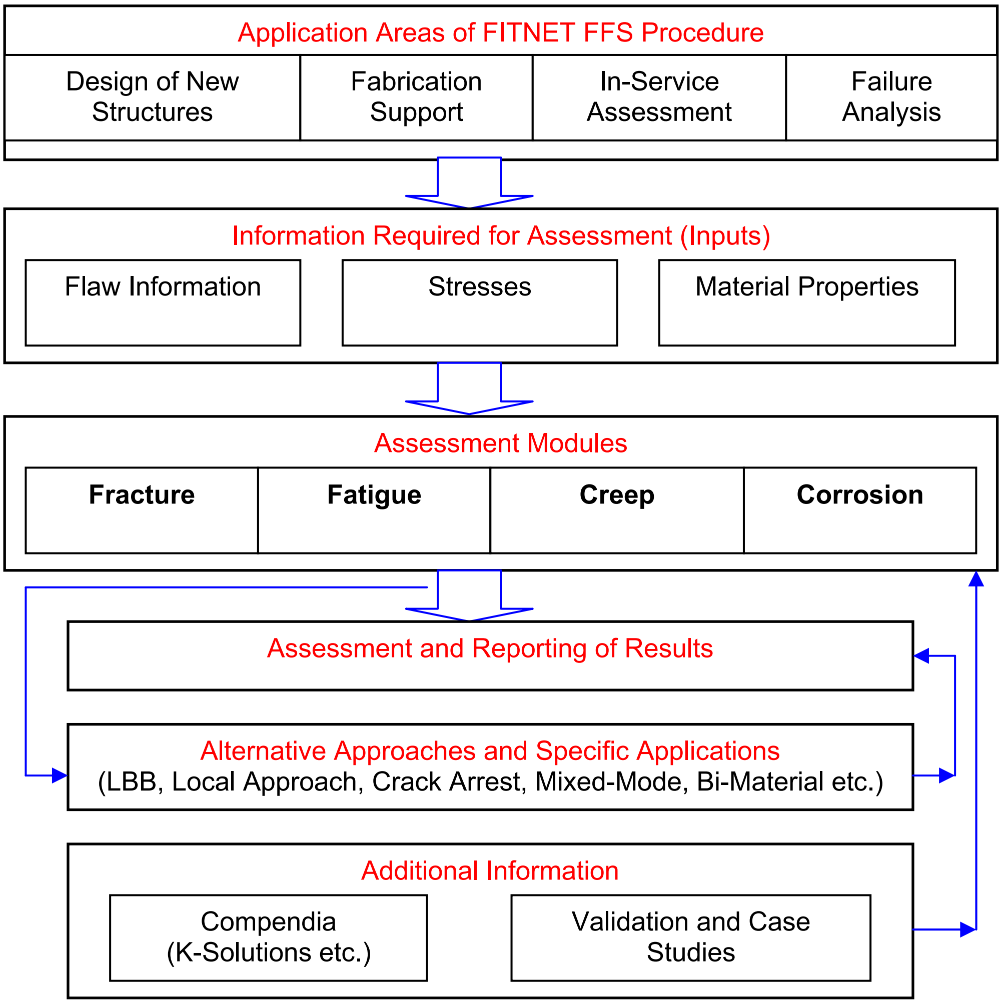

Overall structure of the FITNET FFS Procedure

For the application of this FFS procedure to optimise the **design of a new component**, it is usually a *postulated defect* is used to assess the critical condition of a new component for a given material, load/stress conditions and geometry of the component. In this context, a postulated initial defect size will be based on the non-destructive evaluation (NDE) detection limit. Depending on the design philosophy (safe-life or damage tolerant design etc.) in combination of the NDE technique is used as well as good description of the loading conditions of a new component, FITNET FFS can provide information for re-selection of material, design&fabrication route and NDE technique.

The FITNET FFS assessment modules require, in general, for the components in-service the following interdisciplinary inputs:

- Description/knowledge (mechanism) of damage
- Determination of operating conditions, load/stress analysis
- Flaw characterisation (location, sizing via NDE or visual examination)
- Material properties (incl. environmental effects)

FITNET FFS assessment results may aim to provide information on **material selection** and hence the most suitable fabrication route for safe and economical performance. Analysis results can yield, for example, the required minimum fracture toughness for a given loading conditions and postulated defect size or can provide maximum tolerable defect size (e.g., weld imperfection) for a given material, loading conditions and fabrication route. Again an applicability of the FFS analysis in an efficient manner to support the fabrication route and quality assurance in addition to the conventional *good workmanship* principles will depend on the capability of the applied NDE technique and its probability of detection of a flaw. According to the practical workmanship criteria, no crack or defect may occur during the fabrication of a component is acceptable if size of the defect exceeds the detection limit of the NDE method used (i.e., some small flaws smaller than this limit may exist in the component). At this stage, FITNET FFS methodology can provide an engineering analysis to predict the critical condition of a new component using either postulated larger defect or defect size defined by the NDE detection limit and hence can give opportunity to the designer for possible reselection of failure criteria (i.e., against crack initiation or allowance for crack growth with respective inspection intervals), design load, material type or fabrication route.

It is often necessary to critically examine the integrity of new or existing constructions by the use of non-destructive testing methods, it is also necessary to establish acceptance levels for the flaws detected. In the present procedure, the derivation of acceptance levels for flaws is based on the concept of 'fitness-for-service'. By this principle a particular fabrication is considered to be adequate for its purpose, provided the conditions to cause failure are not reached, after allowing for some measure of abnormal use or degradation in service. A distinction has to be made between acceptance based on quality control and acceptance based on fitness-for-service.

Quality control levels are, of necessity, both arbitrary and usually conservative and are of considerable value in the monitoring of quality during production. Flaws which are less severe than such quality control levels as given, for example, in current application standards, are acceptable without further consideration. If flaws more severe than the quality control levels are revealed, rejection is not necessarily automatic. In such situations decisions on whether rejection and/or repairs are justified may be based on fitness-for-service, either in the light of previously documented experience with similar material, stress and environmental combinations or on the basis of 'engineering critical assessment; (ECA). It is with the latter that this FITNET FFS Procedure document is concerned. It is emphasised, however, that a proliferation of flaws, even if shown to be acceptable by ECA, should be regarded as indicating that quality is in need of improvement.

The quality of the major **input data** (flaw size, stresses and material properties) has a significant effect on the FFS analysis results, and hence efforts should be made to generate accurate data or use a good data bank. After conducting an assessment for a given component with in-service flaw, a sensitivity analysis with modified or new set of input data can provide accurate description of the limiting conditions of the component. If flaw indications are detected during in-service inspections of a component, the indications are carefully examined to determine the dimensions of these flaws. If multiple discrete flaws are in the same cross-section, the flaws may lead to flaw interaction and hence are treated as a single flaw, using the distance between adjacent flaws as the combination criteria.

Before performing a FFS analysis for **flaws detected in in-service components**, an investigation should be carried out to determine the most likely cause of cracking. At least, this should involve a combination of non destructive testing, visual examination and metallurgical examination (e.g., fatigue crack growth tends to be transgranular whereas creep crack growth is generally intergranular). If it is possible to identify the mode and mechanism of cracking, this should provide qualitative information on the relative contributions of the different mechanisms and phases to the overall damage process. Based on the results, a selection of the analysis module should be made.

Training and education of young engineers in Europe to conduct Fitness-for-Service analysis of engineering structures are essential to maintain level of knowledge achieved and to ensure safety of structures with and without welds. FITNET thematic network has developed training and education documents and conducted various seminars in Europe. FITNET FFS Case Studies and Tutorials Volume includes, therefore, a special section for this purpose. The tutorials part covers the use of the different modules of the procedure in a set of examples related with fracture, fatigue, creep, stress corrosion cracking and local thinned areas, as well as some crossed examples where different modules have to be used to assess the dominant failure conditions.

Finally, readers are asked to note to the Proceedings of the FITNET 2006 International Conference on Fitness-for-Service held on 17-19 May 2006, Shell Global Solutions, Amsterdam, (Ed. by M. Kocak), ISBN 978-3-00-021084-6. This volume contains 32 manuscripts which describe detailed features of the FITNET FFS Procedure and its various validations.

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