Chapter 5
Safety Considerations

5.1 Basic Principles

A component has to be designed for an adequate survival probability. The required survival probability depends on the

- Uncertainties and scatter in the fatigue assessment data
- Safety strategy
- Consequences of failure.

Uncertainties in the fatigue assessment data may also origin from the **fatigue actions**, such as

- Determination of loads and load history
- Determination of stresses or stress intensity factors from the model used for analysis
- Dynamic response problems.

These uncertainties can be covered by an appropriate partial safety factor for the fatigue actions γ_F, which is **not considered here**. However, it is emphasized that assumptions made at the design stage should be conservative and ideally checked during early stages of service operation.

Uncertainties in a fatigue assessment arising from the **fatigue resistance** data and damage calculation methods include:

- Scatter in fatigue resistance data,
- Scatter of verification results from damage calculations.

The last two sources of uncertainty are considered here. For normal applications, they are already covered in the fatigue resistance data given here. For special applications, the data may be modified by the selection of an adequate partial safety factor γ_M.

A.F. Hobbacher, *Recommendations for Fatigue Design of Welded Joints and Components*, IIW Collection, DOI 10.1007/978-3-319-23757-2_5

5.2 Fatigue Design Strategies

Different service operation conditions require different fatigue design strategies. The definition of a fatigue design strategy refers predominantly to the method of fatigue analysis, inspection and monitoring in service.

5.2.1 *Infinite Life Design*

This strategy is based on keeping all fatigue actions under an assumed resistance fatigue limit or threshold value. If regular in-service monitoring is **not** specified, the survival probability must be high. This strategy is most suited to components that experience very high numbers of cycles, which are uniform or preferably close to constant amplitude.

The strategy often relies on the assumption that there is always a fatigue limit below which infinite life can be expected. However, there are increasing doubts that this is the case for welded components. It is recommended that due consideration should be given to the adoption of am S-N curve that does not become horizontal at the CAFL or 'knee' point, but continues at a very shallow slope, as indicated in Sect. 3.2.

5.2.2 *Safe Life Design*

This design strategy is used in situations where regular inspection in service is not possible or the consequences of failure are very high. Consequently a very high survival probability is required.

5.2.3 *Fail Safe Design*

This design strategy is based on the assumption that the component or structure can tolerate extensive fatigue cracking without failing, possibly because it is statically over-determined (hyper-static) or there is an adequate redundancy. Regular monitoring in service is not usually provided. It is relied on the redistribution of forces if cracking does occur, which can be readily detected and repaired. Welded joints in such structures can be designed for a normal survival probability.

5.2.4 *Damage Tolerant Design*

This design strategy is based on the assumption that fatigue cracks will form but they will be readily detectable in service before they become critical.

Fracture mechanics can be used to calculate suitably inspection intervals. However, apart from fatigue considerations it may also be necessary to ensure that the material is sufficiently tough to tolerate the largest fatigue crack that could be present before it has been detected. A normal probability of survival is adequate.

5.3 Partial Safety Factors

The requirement for a partial safety factor to be applied to the fatigue resistance data $\boldsymbol{\gamma_M}$ depends largely on such circumstances as

- Fatigue design strategy
- Consequences of failure
- Practical experience in fields of application.

Examples of possible values for partial safety factors are given in Table 5.1, but no general recommendations can be given. In most cases of the use of the conservative fatigue resistance data given in the present recommendations, $\boldsymbol{\gamma_M = 1}$ should be adequate for design or assessment of components or structures of normal fabrication quality, which will be regularly inspected in service.

The safety factors $\boldsymbol{\gamma_M = 1}$ are given in terms of stress. If safety factors are needed in terms of cycles, $\boldsymbol{\Gamma_M}$ may be calculated using the exponent **m** of the resistance S-N curve or Paris power law of crack propagation.It should be noted that the slope **m** of the S-N resistance curves may vary over the range of application (e.g. see Fig. 3.1).

$$\Gamma_{M,cycles} = \gamma_M^m \tag{5.1}$$

where $\Gamma_{M,\ \mathrm{cycles}}$ refers to a partial safety factor in terms of cycles and γ_M refers to stress. No general recommendations on partial safety factors can be given. For special fields of application, safety factors on load actions $\boldsymbol{\gamma_F}$ and on fatigue resistance $\boldsymbol{\gamma_M}$ may be established. Table 5.1 shows a possible example for $\boldsymbol{\gamma_M}$ which may be adjusted according to the special requirements of the individual application.

Table 5.1 Possible examples of partial safety factors γ_M for fatigue resistance

Partial safety factor γ_M → Consequence of failure	Fail safe and damage tolerant strategy	Safe life and infinite life strategy
Loss of secondary structural parts	1.0	1.15
Loss of the entire structure	1.15	1.30
Loss of human life	1.30	1.40

5.4 Quality Assurance

Weld quality assurance is based on adequate organization of work flow in design, fabrication, destructive and non-destructive inspection of materials and welds, and the individual acceptance levels for the different types of weld imperfections. Acceptable levels for different types of weld imperfections related specifically to fatigue resistance may be found in Sect. 3.8 or in other fatigue based weld quality codes [e.g. 53].

Since more general weld quality acceptance criteria are needed for practical shop fabrication, the standards ISO 5817 for steel and ISO 10042 for aluminium are widely used. However, it should be noted that these are based more on traditional perceptions of what constitutes good workmanship, than on objective criteria related specially to the influence of the imperfection on the strength, including fatigue strength of the welded joint. Consequently they can be irrelevant, over-conservative and even potentially unsafe from the fatigue viewpoint.

Nevertheless, there is a growing tendency to relate them to strength requirements. For example, ISO 5817:2006 quality level **D** might be specified for statically loaded structures and **B** for fatigue or special requirements, even though these levels are not completely consistent in terms of their effect on fatigue properties. Besides regulations and quality codes, the general standards of good workmanship should to be maintained. For conservative reasons, an ISO 5817:2006 level **B** or even **B+** may be specified or modified in conjunction with Sect. 3.8 or other weld quality codes with an adequate consideration to fatigue [e.g. see Ref. 53].

It is recommended to have a documentation or a drawing on which the required fatigue class for each weld is written. If an imperfection needs an assessment, it can be done on a basis of fatigue performance. A direct relation to quality groups of ISO 5817 and fatigue properties is given in Ref. [76], see also Appendix 6.4.

5.5 Repair of Components

The most common cause of damage in welded structures and components is fatigue. Before the start of any repair of such damage, it is vitally important to establish the reasons for its occurrence since these will influence decisions to be made about the need for repair and for the repair method [77–80]. Possible reasons for fatigue damage include:

- Under-estimation of service loading, number of cycles and shape of load spectrum
- Unexpected sources of fatigue loading
- Inadequate stress analysis
- Inadequate structural design, especially of weld details
- Unsuitable material e.g. regarding toughness, corrosion resistance or weldability

- Poor workmanship (e.g. parts missing or not properly positioned, unsatisfactory application of thermal cutting, significant weld imperfections such as poor penetration, severe undercut, severe misalignment, unauthorized welding of fabrication aids)
- Unexpected dynamic response leading to vibrations not considered in design
- Environmental influences detrimental to fatigue e.g. corrosion or elevated temperature
- Faulty operation, e.g. overload
- Accident, e.g. collision

In most cases of damage, design, loads and imperfections are the governing parameters of the failure, material properties are often secondary.

The actions to be taken should be based on the results of the investigations. Possible actions are:

- No repair
- Delayed repair
- Immediate repair
- More frequent or continuous crack monitoring, in-service inspection or vibration monitoring
- Change in operating conditions

A large variety of repair methods exist. They may generally include the following aspects:

- Removal of crack
- Modification of detail design
- Modification of service loading
- Selection of adequate material and repair welding procedure
- Application of a weld toe improvements technique (see Sect. 5.2)
- Quality control of the repair weld