Calibration Of Partial Safety Factors For Fatigue Design Of Steel Bridges

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ABSTRACT: The aim of this paper is to propose a new framework for assessment of fatigue partial safety factors with focus on steel bridges welded joints. Fatigue resistance S-N curves for constant amplitude (CA) and variable amplitude (VA) loadings are defined using a novel probabilistic approach based on Maximum Likelihood (ML) and Monte-Carlo Simulations (MCS) methods. The proposed framework includes ML-MCS-based S-N curves of different welded detail categories and it is applicable for the case of deterministic and probabilistic CA loadings as well as for VA loadings. One example is developed, that of a typical bridge fatigue sensitive welded joint. The results are compared to Eurocode standards both in terms of partial safety factor values and of characteristic S-N curves.

1. INTRODUCTION

Over the last thirty years significant attention has been paid to the probabilistic methods for the assessment of fatigue reliability. By the early 90's considerable effort has been made to implement these methods for application in steel bridges with focus on fatigue sensitive details under the long-term effect of traffic loading.

The common approach to the formulation of the fatigue limit state is based on S-N curves in combination with Miner's linear damage accumulation rule (Miner (1945)). Fatigue life assessment of steel bridges asks for consideration of welded joints; a common assumption in fatigue analysis of welded joints is that the crack initiation phase is almost non existent and that all the fatigue life is taken by the crack propagation phase (Gurney (1979)). Within this hypothesis the linear elastic fracture mechanics shows that the S-N curve is a straight line having slope of $-m_1$ in the log(S-N) plane, where S is the stress range and N is the number of cycles to failure; the line is assumed to become horizontal at the crack growth propagation threshold (constant amplitude fatigue limit (CAFL)). Traditional fatigue analysis of welded joints is based on the nominal stress approach wherein characteristic S-N curves are based on constant amplitude (CA) fatigue tests; due to inherent randomness in fatigue life, a statistical evaluation of fatigue test data is required. Characteristic S-N curves in the Eurocode standards are determined by fitting a linear regression to the failure data, disregarding all run-outs and somewhat arbitrarily fixing the CAFL at $5 \cdot 10^6$ cycles (European Committee for Standardization (1989) and Euler and Kuhlmann (2014)). Since most structures experience variable amplitude (VA) loading during their life the fatigue life assessment of welded details under VA loading is needed. It is generally accepted that even infrequent CAFL-exceeding cycles are responsible for lowering the stress range threshold for crack propagation, thus enabling stress ranges below CAFL to also contribute to damage as crack develops. To take into account this behavior, a modified S-N curve having a slope of $-m_2$ below the CAFL can be considered for damage accumulation (modified Miner's rule, Haibach (1970)). The target value of the accumulated damage indicating fatigue failure is subject to considerable uncertainty and it is still under debate. For welded joints the common assumption is to consider the critical damage, D, as a Log-Normal random variable with mean equal to 1 and standard deviation equal to 0.3 (Joint Committee Structural Safety (2013)).

The fatigue verification using the concept of partial safety factors, as recommended in EN 1993-1-9 (European Committee for Standardization (2005)) is based on characteristic CA S-N curves and on modified Miner's rule .

The aim of this paper is to suggest a new framework for assessment of fatigue resistance partial safety factor for the case of CA deterministic and probabilistic loadings and VA loadings. Fatigue resistance S-N curves for CA and VA loadings are defined using a novel probabilistic approach based on the Maximum Likelihood (ML) and Monte-Carlo Simulations (MCS) methods. Both failure and run-out points of experimental CA and VA fatigue datasets are used. The ML-MCS based approach allows to overcome the following limitations of Eurocode approach: 1) Run-out data points are not considered; 2) the CAFL is arbitrarily fixed at $5 \cdot 10^6$ cycles; and 3) the choice of second slope, $-m_2$, and of critical damage, D, for welded joints, has not been rigorously validated by experimental VA fatigue test results.

The paper is organized as follows:

- The ML-MCS based probabilistic approach for assessment of fatigue resistance models under CA and VA loadings is shortly recalled;
- The framework for partial safety factor calibration using ML-MCS based fatigue resistance S-N curves is presented;
- An application of the framework to a typical bridge fatigue sensitive welded joint is considered;
- Results are discussed and comparisons with partial safety factor values recommended in EN 1993-1-9 are made.

2. RESISTANCE MODELS

In this section the ML-MCS based probabilistic approach for assessment of fatigue resistance models under CA and VA loadings is shortly recalled. Detailed description of the approach can be found in (D'Angelo and Nussbaumer (2014)).

2.1. *CA S-N curve*

The relationship between the fatigue log-life, Y, and the nominal applied log-stress range, X, is modeled as:

$$Y = \frac{m_0 + m_1 X}{step(X-V)} + \varepsilon(0, \exp(\sigma)) \tag{1}$$

where X is the natural logarithm of the stress range S, Y is the natural logarithm of number of cycles, N, and V is the natural logarithm of the CAFL. The error term, ε, is modeled as a Normal random variable with location parameter, 0, and scale parameter $\exp(\sigma)$.

The CA stochastic model is characterized using model parameter vector $\underline{\theta} = (m_0, m_1, \sigma, \mu_V, \sigma_V)$, where m_0 is the intercept of the S-N curve in log-log plane, m_1 is the slope of the S-N curve, σ is the natural logarithm of the scale parameter of the Normal random variable Y and μ_V, σ_V are respectively the location and the scale parameter of the Log-Normal CAFL distribution. The expected value of model parameter vector, $\underline{\hat{\theta}}$, and the Variance-Covariance matrix, $\underline{\underline{\rho}}$, are estimated by applying ML approach to experimental CA fatigue data points (x_i, y_i). Both failure and run-out data points are taken into consideration, the latter in terms of censored data.

2.2. *VA S-N curve*

The relationship between the fatigue log-life, Y, and the nominal applied log-stress range, X, is modeled as:

$$Y = \begin{cases} m_0 + m_1 X + \varepsilon, & \text{for } X > V \\ m_0 + V\Delta m + (m_1 - \Delta m)X + \varepsilon, & \text{for } X \leq V \end{cases} \tag{2}$$

where $(m_1 - \Delta m)$ is the slope of the S-N curve below the CAFL.

Fatigue resistance under VA loadings is expressed using Miner's linear accumulation rule. Critical damage, D, is modeled as a Log-Normal random variable with location parameter, μ_D, and scale parameter, σ_D. The parameters of D Log-Normal distribution are assessed by applying the ML approach to observed values of cumulated damage, d_i; d_i values are generated from VA experimental test results using MCS approach. Both failure and run-out data points are considered.

The complete stochastic model for CA and VA loadings is defined by the model parameter vector $\underline{\Theta} = (\underline{\theta}, \mu_D, \sigma_D)$, the parameter Δm and the Variance-Covariance matrix $\underline{\underline{\Sigma}}$.

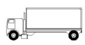
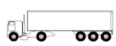
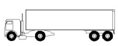
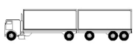
Lorry	Perc.	N_v	N_{ax}	N_{cyc}
	40%	$800 \cdot 10^3$	2	$1.6 \cdot 10^6$
	10%	$200 \cdot 10^3$	3	$0.6 \cdot 10^6$
	30%	$600 \cdot 10^3$	5	$3.0 \cdot 10^6$
	15%	$300 \cdot 10^3$	4	$1.2 \cdot 10^6$
	5%	$100 \cdot 10^3$	5	$0.5 \cdot 10^6$
				$6.9 \cdot 10^6$

Table 1: Yearly loading cycles according to Tab 4.7 of EN 1991-2-2003, short influence line bridge.

3. FRAMEWORK FOR PARTIAL SAFETY FACTOR CALIBRATION

The typical design equation for verification of a structural component (Faber and Sorensen (2003)) is:

$$G = \frac{zR_c}{\gamma_M} - (\gamma_{F1}F_{c1} + \ldots + \gamma_{Fn}F_{cn}) = 0 \qquad (3)$$

where R_c is the characteristic value for the resistance, z is a design variable, F_{ci} is the characteristic value of the i^{th} action effect, γ_M is the partial safety factor for the resistance and γ_{Fi} is the partial safety factor for the i^{th} action effect.

According to the design equation (3) a reliability analysis can be made with the following limit state function:

$$g = zR - (F_1 + \ldots + F_n) = 0 \qquad (4)$$

The general limit state equation (4) and the general design equation (3) will be adapted to the considered fatigue case (CA deterministic loadings, CA probabilistic loadings, VA loadings) in the following three subsections. The partial safety factor for fatigue loadings γ_F can be settled to 1.0 by proper choice of load model.

3.1. CA deterministic loadings

3.1.1. Definition of Load Cases

In order to compare findings for VA and CA loadings on a common basis, load case points are defined using the concept of CA equivalent stress range. Three different Rayleigh VA loading spectra are considered in order to take in account the influence of the loading spectrum position on the assessment of the partial safety factor for fatigue resistance, γ_M. The scale parameters σ_R of the three considered loading spectra are defined in order to have $\varsigma = 50\%, 5\%, 0.01\%$ ($\sigma_R = 5.4, 9.4, 19.5$ MPa), where ς is the percentage of cycles in the spectrum with stress ranges exceeding the ML estimate of the 0.05 quantile of the CAFL.

The total number of cycles, N_{tot}, is defined according to Tab 4.7 of EN 1991-2-2003 (European Committee for Standardization (2002)) for the case of roads with high percentage of trucks ($N_{obs} = 2 \cdot 10^6$ per year and slow lane). The case of road bridges with short influence line (one axle gives one stress cycle) is considered in this study. The relationship between the number of cycles and the stress range of the loading spectrum is:

$$n(s) = N_{tot} \cdot f_S(s; \sigma_R)\, ds = N_{tot} \frac{s}{\sigma_R^2} \exp\left(\frac{-s^2}{2\sigma_R^2}\right) ds \qquad (5)$$

The load case l is represented by the pair $(S_{eq}, N_{eq}|_{\sigma_R})_l$; a total number of 30 load cases are considered: $\underline{Seq} = (5, 15, \ldots, 95)^T$ MPa and $\underline{\sigma}_R = (5.4, 9.4, 19.5)^T$ MPa.

For each load case l, the equivalent number of cycles $N_{Eq,l}$ is then computed as follows:

$$N_{Eq,l} = \frac{S_{Eq,l}^{\hat{m}_1}}{\exp(\mu_D)} \int_0^\infty f_S(s; \sigma_R)\, s^{-\hat{m}_1}\, ds \qquad (6)$$

For simplicity, median S-N curve having single slope equal to m_1, is used for the definition of the equivalent number of cycles, $N_{Eq,l}$.

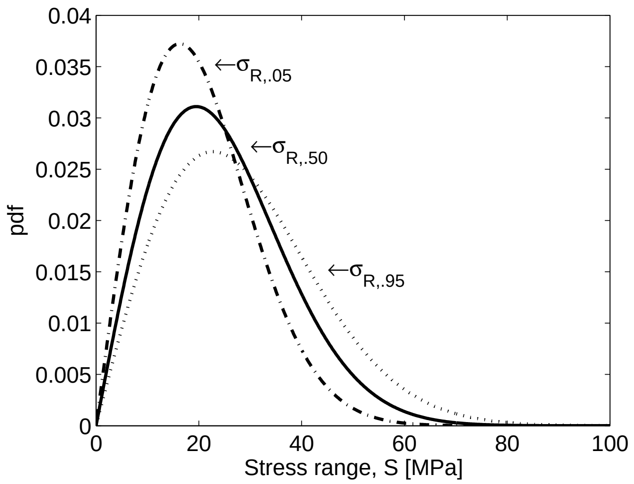


Figure 1: Rayleigh loading spectrum, $\sigma_R = 19.5$ MPa.

3.1.2. *Definition of objective function*

The design equation is defined as:

$$G = \frac{y_c(z \cdot X_{Eq})}{\gamma_M} - Y_{Eq} = 0 \tag{7}$$

where z is a design variable, y_c is the characteristic value of the fatigue resistance (expressed in log-number of cycles), which depends on the deterministic log-stress range $X_{Eq} = \ln(S_{Eq})$, and Y_{Eq} is the equivalent log-number of cycles (deterministic). The characteristic value of the fatigue resistance, y_c, corresponds to 5% probability of failure.

The limit state equation is defined as follows:

$$g = Y(z \cdot \ln(S_{Eq})) - Y_{Eq} = 0 \tag{8}$$

The probability of failure is:

$$P_f = \int_{g \leq 0} f_X(\underline{x}) d\underline{x} \tag{9}$$

where $f_X(\underline{x})$ is the joint probability density function of the model random variables.

The objective function is:

$$T(\gamma_M) = \sum_{d=1}^{N_{det}} \sum_{l=1}^{N_{lc}} (P_f^t - P_f)^2 \tag{10}$$

where N_{lc} is the number of load cases, N_{det} is the number of the considered details and $P_f^t = \Phi(-\beta^t)$ is the annual target failure probability. According to JCSS PMC Part 1 (Joint Committee Structural Safety (2013)), the tentative annual target reliability index $\beta^t = 4.2$ should be considered as the most common fatigue design situation (*safe life, high consequences*); this target level can be then conservatively used for existing structures.

The value of the partial safety factor $\hat{\gamma}_M$, which corresponds to the annual target failure probability P_f^t, is computed by minimizing the objective function $T(\gamma_M)$ with a Newton Raphson search algorithm. At each step of the minimum search algorithm, the probability of failure P_f is computed by the MCS method.

3.2. *CA probabilistic loadings*

3.2.1. *Definition of load cases*

In order to have probabilistic definition of load cases, the scale parameter of the Rayleigh spectrum is modeled as a Normal random variable, having mean equal to the values used for CA deterministic case and coefficient of variation equal to 0.1. By using Equations (5) and (6) it is possible to relate the uncertainty on $N_{Eq,l}$ to the uncertainty on σ_R:

$$N_{Eq,l} = \frac{N_{tot} S_{Eq,l}^{\hat{m}_1}}{\exp(\mu_D)} \int_0^\infty \frac{s}{\sigma_R^2} \exp\left(\frac{-s^2}{2\sigma_R^2}\right) s^{-\hat{m}_1} ds \tag{11}$$

The uncertainty on $N_{eq,l}$ is quantified by sampling random values of σ_R and fitting generic probability distribution to sampled values of $N_{Eq,l}$. Since the transformation given in Equation (11) is not linear, non-Normal probability distribution could be chosen to fit sampled values of $N_{Eq,l}$.

3.2.2. *Definition of objective function*

The design equation and the limit state equation are defined by considering $N_{Eq,l}$ as a random variable instead of a deterministic value:

$$G = \frac{y_c(z \cdot X_{Eq}))}{\gamma_M} - y_{Eq,c} = 0 \tag{12}$$

where $y_{Eq,c}$ is the characteristic value of the equivalent number of cycles, corresponding to the 0.5 quantile of Y_{Eq} distribution. The limit state equation, the formulation of the probability of failure and the objective function are the same as for the case of CA deterministic loadings (see Equations (8), (9) and (10)).

3.3. VA loadings

3.3.1. Definition of load cases

VA load cases are defined using a Rayleigh loading spectrum, having scale parameter σ_{R^*}. Eight different values of σ_{R^*} are considered, giving $\varsigma = (50\%, 75\%, 5\%, 1\%, 0.5\%, 0.1\%, 0.05\%, 0.01\%)$, where ς is the percentage of cycles in the spectrum with stress ranges exceeding the ML estimate of the 0.05 quantile of the CAFL.

3.3.2. Definition of objective function

The design equation is defined as:

$$G = d_c - N_{tot} \cdot \left(\int_{\exp(v_c)}^{\infty} \frac{f_S(s;\sigma_R^*)}{\exp(y_c(z \cdot s)/\gamma_M)} ds + \right. \left. + \int_0^{\exp(v_c)} \frac{f_S(s;\sigma_R^*)}{\exp(y_c(z \cdot s)/\gamma_M)} ds \right) \quad (13)$$

where d_c is the characteristic value of the critical damage (corresponding to the median value of Log-Normal distribution) and y_c is the characteristic value of fatigue resistance in terms of log-number of cycles (see Equation (2)).

The limit state function is defined as follows:

$$g = D - N_{tot} \cdot \left(\int_{\exp(V)}^{\infty} \frac{f_S(s;\sigma_R^*)}{\exp(Y(z \cdot \ln(s)))} ds + \right. \left. + \int_0^{\exp(V)} \frac{f_S(s;\sigma_R^*)}{\exp(Y(z \cdot \ln(s)))} ds \right) \quad (14)$$

The probability of failure is defined similarly to the case of CA loadings (see Equation 9).
The objective function is:

$$T(\gamma_M) = \sum_{d=1}^{N_{det}} \sum_{j=1}^{N_{lc}} (P_f^t - P_f)^2 \quad (15)$$

where where N_{lc} is the number of load cases, N_{det} is the number of the considered details and $P_f^t = \Phi(-\beta^t)$ is the annual target failure probability.

The value of the partial safety factor $\hat{\gamma}_M$, which minimizes the objective function $T(\gamma_M)$, is computed again by using a Newton Raphson search algorithm in combination with MCS method.

4. STUDY CASE: WELDED COVER PLATE

The framework built in Section 3 was applied to a typical fatigue-sensitive bridge detail: a welded cover plate. The parameters of CA S-N curve were estimated using 26 experimental CA test results from NCHRP Project 12-7 and from PennDot Project 72-3 (Fisher et al. (1982)); in tested beams, the cover-plate thickness t_c, is lower than the beam flange thickness t_b, which is lower than 20 mm: the tested specimen is classified as FAT50 according to EN 1993-1-9. The parameters of VA S-N curve were estimated using 32 experimental VA test results from NCHRP Report 354 (Fisher et al. (1993)); in tested beams, $t_c = t_b = 25$ mm: the tested specimen is classified as FAT45 according to EN 1993-1-9. Considered cover-plate component can be then classified conservatively as FAT45 detail according to EN 1993-1-9 for generic CA and VA loadings.

4.1. S-N curves

The ML estimate of model parameter vector is:
$\hat{\Theta}^T = (29.02, -3.42, -0.54, 3.55, -1.62, 0.78, 1.39)$.
The parameter Δm is equal to 17.
The approximate Variance-Covariance matrix of model parameter vector is:

$$\underline{\underline{\Sigma}} = \begin{vmatrix} 8.61 & -2.30 & 0.04 & -0.01 & 0.07 & 0.00 & 0.00 \\ -2.30 & 0.61 & -0.01 & 0.00 & -0.02 & 0.00 & -0.00 \\ 0.04 & -0.01 & 0.04 & -0.00 & 0.00 & 0.00 & 0.00 \\ -0.01 & 0.00 & -0.00 & 0.00 & -0.00 & -0.00 & -0.00 \\ 0.07 & -0.02 & 0.00 & -0.00 & 0.17 & 0.00 & -0.00 \\ 0.00 & 0.00 & 0.00 & -0.00 & 0.00 & 0.01 & 0.01 \\ 0.00 & -0.00 & -0.00 & -0.00 & -0.00 & 0.01 & 0.01 \end{vmatrix}$$

4.2. CA loadings

The partial safety factor γ_M for CA deterministic and CA probabilistic loadings were computed by considering the sum of 30 load cases, as described in Section 3.1.1; the three loading spectra used to define CA load cases are represented in Figure 2. For the case of CA deterministic loadings the parameter σ_R is deterministic. For the case of CA probabilistic loadings the parameter σ_R is a normal random variable having coefficient of variation equal to 0.1. The uncertainty on N_{Eq} is related to the uncertainty on σ_R as described in Section 3.2.1. Figure 3 shows that $\hat{\gamma}_M$ is equal to 1.36 for the case

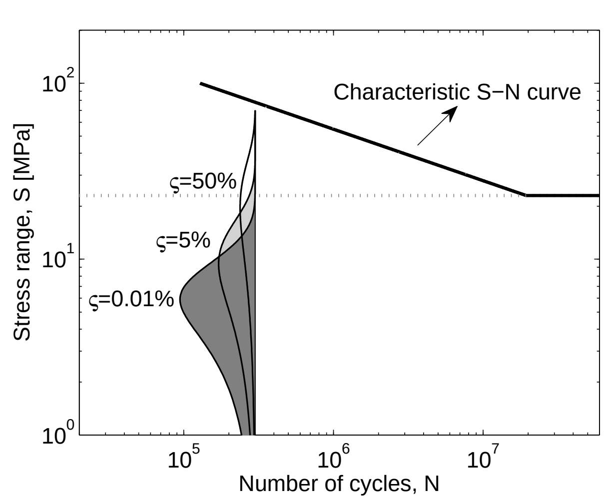


Figure 2: VA loading spectra with $\varsigma = 50\%, 5\%, 0.01\%$.

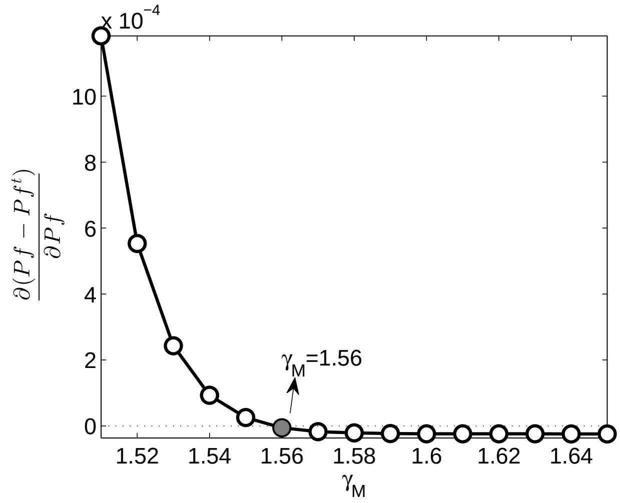


Figure 4: γ_M *search, VA loadings.*

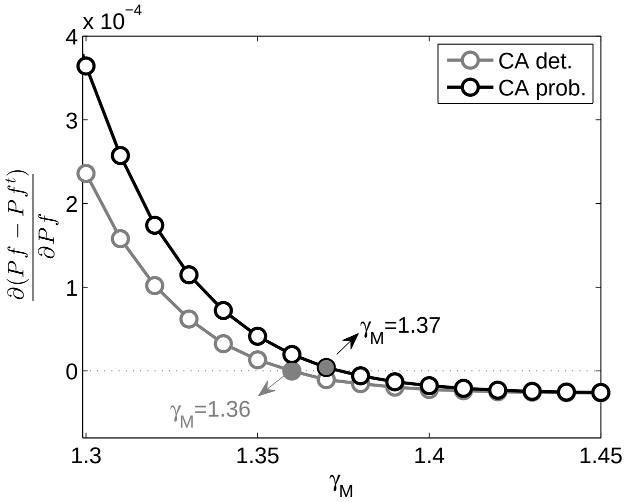


Figure 3: γ_M *search, CA loadings.*

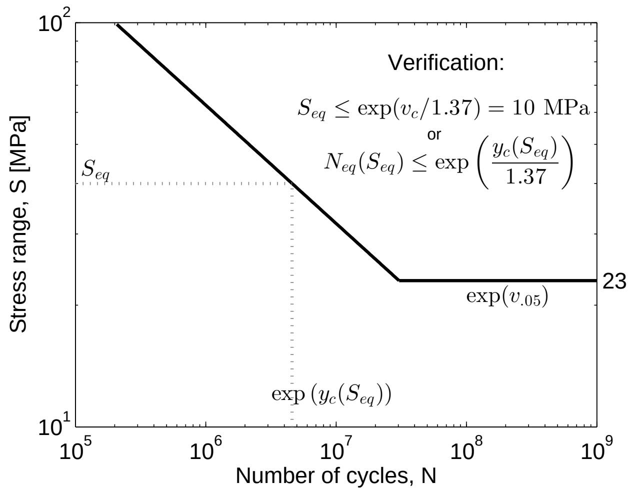


Figure 5: Fatigue verification, CA loadings.

of CA deterministic loadings and to 1.37 for the case of CA probabilistic loadings.

4.3. *VA loadings*

The partial safety factor $\hat{\gamma}_M$ for VA loadings was computed by considering the sum of 8 defined load spectra, as described in section 3.3.1. Figure 4 shows that $\hat{\gamma}_M$ is equal to 1.56.

5. RECOMMENDATIONS FOR FATIGUE DESIGN

In this section two verification schemes are proposed for fatigue design under CA loadings and VA loadings.

The verification scheme for fatigue design under CA loadings is shown in Figure 5: $\hat{\gamma}_M = 1.37$ (CA probabilistic loadings) has been chosen; this verification is based on one-slope CA fatigue resistance characteristic S-N curve, assuming that the equivalent stress range, S_{Eq} exceeds the design value of CAFL, $exp(v_{.05}/\hat{\gamma}_M)$.

The verification scheme for fatigue design under VA loadings is shown in Figure 6; this verification is based on critical damage accumulation on the assumption that at least one cycle of the loading spectrum exceeds the design value of CAFL, $exp(v_{.05}/\hat{\gamma}_M)$.

The verifications schemes proposed above for fatigue design under CA and VA loadings are compared to EN 1993-1-9 format for fatigue reliability verification. The cover plate detail is classi-

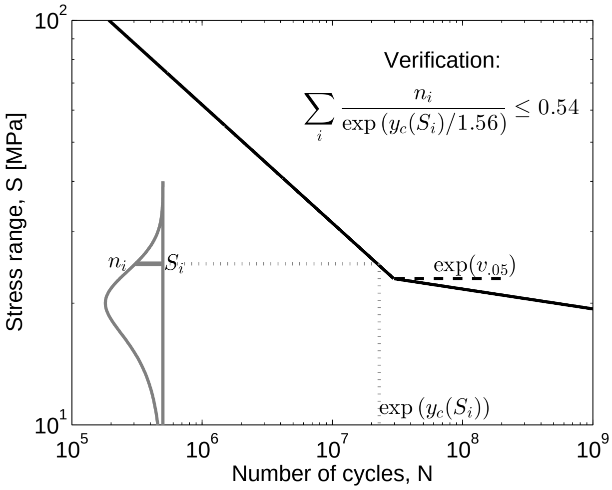


Figure 6: Fatigue verification, VA loadings.

fied as FAT45 as explained in Section 4. Since crack formation in the cover-plate could rapidly lead to structural failure, the case -*Safe life, High consequences*- is chosen in Table 3.1 of EN 1993-1-9.

Under these assumptions, the EN 1993-1-9 format for fatigue verification under CA loadings is the following:

$$\gamma_{Ff} \cdot S_{E,2} \leq \frac{S_c}{\gamma_{Mf}} \Longleftrightarrow S_{E,2} \leq \frac{S_c}{1.35} \tag{16}$$

where $S_{E,2}$ is the equivalent CA stress range related to 2 million cycles, S_c is the characteristic value of the fatigue strength at 2 million cycles, γ_{Ff} is the partial factor for fatigue loadings (which is set to 1.0), and γ_{Mf} is the partial factor for fatigue strength (which is set to 1.35). The verification format at 2 million cycles, given in Equation (16), is extended to the generic case of N^* number of cycles:

$$\gamma_{Ff} \cdot S_{E,N^*} \leq \left(\frac{2}{N^*}\right)^{\frac{1}{3}} \frac{S_c}{\gamma_{Mf}} \tag{17}$$

The definition of partial resistance factor γ_{Mf} in EN 1993-1-9 (Section 1.4, pp. 9, European Committee for Standardization (2005)) is ambiguous because γ_{Mf} is strictly defined for fatigue strength at 2 million cycles and it is generically applied for fatigue strength at all number of cycles .
The EN 1993-1-9 format for fatigue verification under VA loadings uses the damage sum D_d:

$$D_d = \sum_i^{N_{tot}} \frac{n_i}{N_i} \leq 1.0 \tag{18}$$

where N_i is the endurance obtained from the factored $\frac{s_c}{\gamma_{Mf}} - N$ curve.

The ML-MCS approach-based partial resistance factor, $\hat{\gamma}_M$, and the EN 1993-1-9 format-based partial resistance factor, γ_{Mf}, cannot be directly compared since γ_{Mf} is only valid for verification at 2 million cycles while $\hat{\gamma}_M$ is valid for all numbers of cycles. The comparison between EN 1993-1-9 format and ML-MCS format for fatigue reliability verification has to be done in terms of design value of fatigue strength at 2 million cycles, design value of CAFL and critical value of cumulated damage D_d^t.

Param.	EN 1993-1-9 $\gamma_{Mf} = 1.36$	ML-MCS CA $\hat{\gamma}_M = 1.37$	ML-MCS VA $\hat{\gamma}_M = 1.56$
m_1	-3	-3.4	-3.4
m_2	-5	-	-20.4
$S_{c,2\cdot10^6}$	45 MPa	51 MPa	51 MPa
$S_{d,2\cdot10^6}$	33 MPa	18 MPa	12 MPa
$\exp(v_c)$	33 MPa	23 MPa	23 MPa
$\exp(v_d)$	24 MPa	10 MPa	8 MPa
D_d^t	1.00	-	0.54

Table 2: Comparison between EN 1993-1-9 format and ML-MCS format for fatigue reliability verification.

6. CONCLUSIONS

The suggested approach for calibration of fatigue resistance partial safety factor improves the fatigue reliability verification format by: 1) A re-definition of the verification format in the log(S-N) plane, instead of (S-N) plane, allowing for the related partial factor, $\hat{\gamma}_M$, to be valid for all numbers of cycles (and not only at 2 million cycles); and 2) A more realistic consideration of the CAFL position and the S-N curve in the high-cycle fatigue (HCF) region ($N > 10^6 cycles$).

Both of points above improve consistency in achieving target levels of safety.
In order to improve the accuracy in estimation of the CAFL position and its variability, we need to

consider experimental fatigue data-sets having significant number of data points in the HCF region.

The study case considered in this paper showed that:

- The Eurocode-based characteristic S-N curve and the ML-MCS-based characteristic S-N curve are slightly different for $N \leq 5 \cdot 10^6$ cycles;
- The Eurocode format gives an under conservative estimate of the 0.05 quantile of the CAFL with respect to the ML-MCS approach;
- The Eurocode format gives an under conservative estimate of the design fatigue strength at 2 million cycles with respect to the ML-MCS approach;
- The Eurocode format gives an under conservative estimate of the design value of the critical damage, D_d^t, with respect to the ML-MCS approach (1.0 vs 0.54);
- The uncertainty associated with the loading does not affect the partial resistance factor for CA loadings (it goes from 1.36 for CA deterministic loadings to 1.37 for CA probabilistic loadings);
- The uncertainty associated with the loading affects the partial resistance factor for VA loadings (it goes from 1.37 for CA deterministic loading to 1.56 for VA probabilistic loadings);

It is recalled here that in order to set the partial loading factor to 1.0 the characteristic load model has to represent an extreme fatigue loading condition.

The reliability framework for calibration of fatigue resistance partial safety factor, set up in this paper and applied to welded cover plate detail, constitutes a powerful tool that can be used to revise the Eurocode basis for fatigue design of structures. The EN 1993-1-9 format for fatigue reliability verification and associated partial safety factors can be revised by considering different fatigue details and by further differentiating between 1) CA verification; 2) VA verification using lambda factors; and 3) VA verification using damage sum. The framework presented in this work can be easily adapted for the differentiation above.

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