# FATIGUE EQUIVALENT STATIC LOAD: METHODOLOGY FOR THE DESIGN OF VEHICLE STRUCTURES

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# Abstract


**FATIGUE EQUIVALENT STATIC LOAD: METHODOLOGY FOR THE DESIGN OF VEHICLE STRUCTURES**

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*Keywords:* vehicle structures, fatigue loads, FESL, structural design, damage, finite element analysis, durability, cost effective, measurements

This study is concerned with the design of vehicle structures through the use of Fatigue Equivalent Static Loads (FESL). A large percentage of failures of mechanical structures can be attributed to fatigue. Furthermore, it is also generally accepted that defective structural design is mostly caused by insufficient knowledge of the input loading. The fatigue loads experienced by vehicle structures are especially difficult to quantify. In the current competitive markets, it is essential to use a pro-active, timely and cost effective process to solve fatigue related problems. The heart of the FESL methodology is the ability to condense a large amount of input load data into a single fatigue load. This is achieved by calculating the damage of the measurements and converting it to an equivalent stress, through the use of a calibration matrix obtained from a unit-load finite element analysis. A Fatigue Equivalent Static Load can now be determined, and the vehicle structure can be evaluated for durability.

# Samevatting

**VERMOEIDHEID EKWIVALENTE STATIESE BELASTING: METODIEK VIR DIE ONTWERP VAN VOERTUIG STRUKTURE**

deur

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*Sleutelterme:* voertuig strukture, belastings, VESB, strukture ontwerp, vermoeidheidskade, eindige element analise, koste effektiwiteit, metings

Die studie handel oor die ontwerp van voertuig strukture deur gebruik te maak van die Vermoeidheid Ekwivalente Statiese Belasting (VESB) metodiek. 'n Groot persentasie van falings in meganiese strukture kan toegeskryf word aan vermoeidheid. Verder, word dit ook algemeen aanvaar dat oneffektiewe struktuur ontwerpe hoofsaaklik te danke is aan onvoldoende kennis van die inset belastings. Die inset belastings wat voertuie ervaar is veral moeilik om te kwantifiseer. In die hedendaagse kompeterende markte is dit belangrik om 'n pro-aktiewe, tydige and koste-effektiewe proses te gebruik om vermoeidheidsprobleme op te los. Die kern van die VESB metode is die proses om groot hoeveelhede belastingsdata te kondenseer na 'n enkele vermoeidheidsbelasting. Die VESB word afgelei deur die berekende skade van die metings te gebruik

om die ekwivalente spanning af te lei. Deur gebruik te maak van 'n kalibrasie matriks, verkry deur middel van 'n eenheidsbelaste eindige element analise, kan die ekwivalente spanning en gevolglik die VESB belasting bereken word. Die meganiese struktuur kan nou geëvalueer word vir vermoeidheidskade.

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# List of symbols

| | |
|---|---|
| $[M]$ | mass matrix |
| $\{\ddot{D}\}$ | node acceleration vector |
| $\{\dot{D}\}$ | node velocity vector |
| $\{d\}$ | node displacement vector |
| $\{f\}$ | applied nodal load vector |
| $\{f_t\}$ | Applied time-varying nodal load vector |
| $[C]$ | damping matrix |
| $[K]$ | stiffness matrix |
| $a$ | crack length |
| $a_{cal}$ | calibration or acceleration load |
| $a_{eqv}$ | equivalent acceleration load |
| $b$ | Basquin's fatigue strength exponent |
| $C$ | constant relating to the SN-curve (fatigue ductility coefficient) |
| $c$ | fatigue ductility exponent |
| $D_{tot}$ | total damage |
| $D_i$ | damage fraction |
| $E$ | Young's elasticity modulus |
| $f(g)$ | correction factor that depends on geometry, loading and crack shape |
| $\Delta F_{eqv}$ | fatigue equivalent static load |
| $F_{FEA}$ | applied FEA force |
| $F_{meas}$ | measured forces |
| $F_{unit}$ | unit load |
| $\Delta K$ | stress intensity range |
| $K_\epsilon$ | local strain concentration factor |
| $K_\sigma$ | local stress concentration factor |
| $K_t$ | theoretical stress concentration factor |
| $L_c$ | calculated fatigue life |
| $n_{eqv}$ | equivalent number of cycles |

| | |
|---|---|
| $2N_f$ | number of reversals to failure |
| $N_i$ | number cycles to failure |
| $n_i$ | number of load cycles |
| $s_{fail}$ | distance to failure |
| $S_{cal}$ | calibration FEA stress |
| $S_{FEA}$ | calculated FEA stress |
| $S_e$ | fatigue limit stress |
| $S_u$ | ultimate stress |
| $S_y$ | yield stress |
| $\alpha$ | angle of reference |
| $\Delta\epsilon_p/2$ | plastic strain amplitude |
| $\epsilon$ | strain |
| $\epsilon'_f$ | fatigue ductility coefficient |
| $\epsilon_{a/b/c}$ | measured strains |
| $\nu$ | Poisson ratio |
| $\Delta\sigma$ | stress range |
| $\Delta\sigma_{eqv}$ | equivalent stress range |
| $\sigma'_f$ | fatigue strength coefficient |
| $\sigma_{1/2}$ | principal stresses |
| $\sigma_{eqv}$ | equivalent stress |
| $\sigma_a$ | stress amplitude |
| $\sigma_f$ | fracture stress |
| $\sigma_m$ | mean stress |
| $\sigma_n$ | remote nominal stress applied to the component |
| $\tau_{max}$ | maximum shear stress |

# List of acronyms

| | |
|---|---|
| AFNOR | Association Fracaise de Normalisation |
| ARMA | Autoregressive Moving Average |
| ASTM | American Society of Testing and Materials |
| BS | British Standard |
| CAD | Computer Aided Design |
| ECCS | European Convention for Constructional Steelwork |
| FDRS | Fatigue Damage Response Spectrum |
| FE | Finite Element |
| FEA | Finite Element Analysis |
| FEM | Finite Element Model |
| FESL | Fatigue Equivalent Static Design |
| FFT | Fast Fourier Transform |
| GUT | Grand Unified Theory |
| LEFM | Linear Elastic Fracture Mechanics |
| LVDT | Linear Variable Differential Transformer |
| MBS | Multi-Body System |
| MPC | Multiple Point Constraint |
| PSD | Power Spectral Density |
| RPA | Remote Parameter Analysis |
| SABS | South African Bureau for Standards |
| SAE | Society of Automotive Engineers |
| SN | Stress Life |
| SRS | Shock Response Spectrum |
| UKOSRP | United Kingdom Offshore Steels Research Project |
| VESB | Vermoeidheids Ekwivalent Statiese Belasting |