

Abstract

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

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Submitted in partial fulfilment of the  
requirements for the degree

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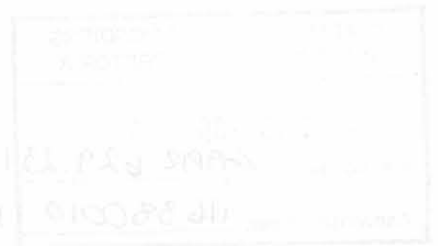
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# Abstract

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

by

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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

# Samevatting

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

deur

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*Sleuteltermes:* voertuig strukture, belastings, VESB, strukture ontwerp, vermoedheidskade, 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 vermoedheid. 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 vermoedheidsprobleme op te los. Die kern van die VESB metode is die proses om groot hoeveelhede belastingsdata te kondenseer na 'n enkele vermoedheidsbelasting. Die VESB word afgelei deur die berekende skade van die metings te gebruik

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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

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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
$a_{equiv}$	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
$\Delta F_{equiv}$	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
$n_{equiv}$	equivalent number of cycles

## LIST OF SYMBOLS

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## List of acronyms

$2N_f$	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
$\Delta\sigma_{equ}$	equivalent stress range
$\sigma'_f$	fatigue strength coefficient
$\sigma_{1/2}$	principal stresses
$\sigma_{equ}$	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 Française 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