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Original Research Article

Fatigue hazards in welded plate crane runway girders – Locations, causes and calculations

Kazimierz Rykaluk [a], Krzysztof Marcinczak [b,*], Sławomir Rowiński [b]

[a] Wrocław University of Environmental and Life Sciences, C.K. Norwida 25, 50-375 Wrocław, Poland
[b] Wrocław University of Technology, Wybrzeże Wyspiańskiego 25, 50-370 Wrocław, Poland

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ABSTRACT

Steel crane runway beams compared with other building structures are exposed to extremely complex load-stress conditions. It turns out, that significant from the point of view of the resistance of the crane runway beams is a cyclic nature of fluctuating loads, which leads to formation of numerous cracks and damages. This effect is especially characteristic for webs in plate I – cross sections of crane runway beams. The complex state of stresses is generated by overall bending that causes normal and shear stresses – σ_x, τ_{xz}, and by crane wheel eccentric load that produces respectively stresses – $\sigma_{z,x}$, $\sigma_{o,x}$, $\tau_{o,xz}$. Stress components produced by overall bending are determined as I kind stress, whereas the stress components from the crane wheel load are introduced as II kind stress. Such a combination of stresses lowers the fatigue strength of the web, which is ignored by many rules specified in standards. Limited fatigue strength is observable, among others, in crane rails splices. The results of numerical analyses obtained as II kind stresses in the web located directly beneath the crane rails splices that occur as: orthogonal contact, bevel contact and stepped bevel contact as well, confirmed the complexity of the issue. Following that, other factors, not being defined yet, but affecting the stress state of the both crane rail and crane runway beam are scheduled to be studied, as for instance, the eccentric load induced by crane trolley in mentioned above elements.

1. Factors that influence the lowering of the fatigue strength of welded steel structures

When compared to other types of structures, crane runway beams operate under very complex load-stress conditions. One of the parameters describing the conditions of operation that affects fatigue loads is load spectrum. Fig. 1 shows, according to [1,2], schematic scatter bands of the relative stress variation ranges of stresses $\Delta\sigma_i/\Delta\sigma_{max}$ in crane runway beams, and railway bridges. The latter are widely regarded in the construction industry as structures of heavy fatigue exposure. The presented charts show (Fig. 1) that the stress intensities in crane runway beams, over the variation range spectrum, are much larger than the intensities in the spectrum of railway bridges. Detailed spectrum histograms

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* *Corresponding author.*
E-mail address: krzysztof.marcinczak@pwr.edu.pl (K. Marcinczak).

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Nomenclature

a	spacing of long transverse ribs
a_w	design weld thickness
a_1	axial spacing of transverse ribs
b_r	width of crane rail foot
b_s, t_s	width and thickness of a single rib
c_s	leg of right-angled triangular notch for a weld
e_y	eccentricity of vertical wheel load
e_z	distance from the top of rail surface to the web-top flange joint
f_y	nominal steel yield strength
F_z	vertical wheel load
h_r	depth of the crane rail
H_T	transverse crane wheel load
h_w, t_w	depth and thickness of the beam's web
J_f	second moment of area of an upper crane beam flange
J_r	second moment of area of the rail about its horizontal centroid axis
J_y	second moment of area about y–y axis
K	drive force
L	theoretical span length of a beam
l_{eff}	length of the uniform distribution of stresses $\sigma_{z,x}$
$l_{w,eff}$	effective length of the weld
M_T	torque
M_y	bending moment about y–y axis
N	design life time of a beam expressed as a number of cycles
N_0	number of cycles of a permanent fatigue strength
n_i	i-cycle of fatigue load
n_k	number of wheels in one crane runway beam
$p_{i(i=a,k)}$	parameter
r	relative number of investigated crane runway beams
R_e	yield stress
R_m	ultimate static tensile stress
Q_c	load due the crane self-weight
Q_e	equivalent fatigue load
Q_{gr}	load-bearing capacity of the long, transverse rib
Q_h	Hoist load
ΔQ_i	range of crane load variability at i-cycle
Q_{max}	characteristic value of the maximum wheel load
S	static moment of the cross-section portion over the z–z coordinate
t_f	thickness of the flange in a cross-section
V_z	shear force
z_1	distance of a butt weld from external surface of the top flange
β_k	effective concentration factor
Δ_o	initial deflection (flexure) of the web
φ_1, φ_2	dynamic factor due to self-weight of crane and hoist load, respectively
φ_{fat}	dynamic fatigue factor
$\varphi_{fat,1}$, $\varphi_{fat,2}$	dynamic fatigue factor for a self-weight of the crane and to hoist load, respectively
λ_i	equivalent factors of fatigue damages
x_τ	distance from main maximum shear stresses $\tau_{1,2}$ to axis of the beam's support
ψ	relief factor
γ_{Ff}	partial factor for equivalent constant amplitude stress range $\Delta\sigma_E$, $\Delta\tau_E$
γ_{Mf}	partial factor for fatigue strength $\Delta\sigma_C$, $\Delta\tau_C$
γ_{M0}	partial factor of load-bearing capacity of the cross-section
σ_x	normal stress of the I kind in the longitudinal direction – x
$\sigma_{E,2}$	equivalent normal stress for 2 million cycles
$\sigma_{M,x}$	normal stress of the I kind due to bending moment M_y in the beam cross-section
$\sigma_{o,x}$	local normal stress of the II kind in the web, directly beneath the concentrated force F_z along x-axis
σ_T	normal stress due to torque
$\sigma_{T,x}$	normal stress due to torque along x–x axis
$\sigma_{T,z}$	normal stress due to torque along z–z axis
$\sigma_{z,0}$	normal stress of the I-kind beneath the force F_z
$\sigma_{z,x}$	vertical normal stress of the II-kind induced by force F_z at x distance from applying point
$\Delta\sigma$, $\Delta\sigma_i$	amplitude normal stresses range under cyclic load and in i-cycle, respectively
$\Delta\sigma_{max}$	maximum amplitude normal stresses range under cyclic load during the life time
$\Delta\sigma_{x,E,2}$, $\Delta\sigma_{z,0,E,2}$	equivalent constant amplitude stress range related to 2 million cycles along x–x and z–z axis, respectively
$\Delta\sigma_{x,C}$	reference value of the fatigue strength along x–x axis
$\Delta\sigma_{z,0,E,2}$	equivalent constant amplitude stress range along z–z axis related to 2 million cycles
$\Delta\sigma_{T,E,2}$	equivalent constant amplitude stress range due to torque related to 2 million cycles
$\Delta\sigma_{z,C}$	reference value of the fatigue strength along z–z axis
$\Delta\sigma_L$, $\Delta\tau_L$	constant fatigue strength at N_L cycles
$\Delta\sigma_C$, $\Delta\tau_C$	reference value fatigue strength at N_c = 2 million cycles
$\Delta\sigma_E$, $\Delta\tau_E$	equivalent constant amplitude stress range related to n_{max}
$\tau_{1,2}$	main shear stress
$\tau_{T,xz}$	shear stress due to the torque at plane xz
$\tau_{V,xz}$	shear stress of the I kind under transverse force V_z
$\tau_{o,xz}$	local shear stress of the II kind at xz plane under the concentrated force F_z
τ_{xz}	local shear stress of the I kind at xz plane
τ_Q	shear stress in the weld
$\Delta\tau$	amplitude shear stress range under cycle load
$\Delta\tau_{xz,E,2}$	equivalent amplitude shear stress range at xz plane related to 2 million cycles
$\Delta\tau_{1,2}$	amplitude main shear stress range
$\Delta\tau_Q$	amplitude shear stress range in the weld under cyclic load