Damage of Metalworkses under the Complex Varying Loading

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During the whole macro-elastic construction deformation in the stresses (tensions) concentration zones there are cases in which local plastic deformation occur and further its developing can brings to low-cyclic destruction or speed up multi-cyclic destruction. Hence, in the fatigue calculations, question about the destruction kind (low- or multi-cyclic or destruction during one time loading) should be solved. The estimation criterion for phenomenon mechanism is a fact of presence or absence mechanical adaptation for intended loading regime, which sets up computationally, particularly with the help of multimodel method.

In the case of mechanical adaptation, only micro-plasticity hysteresis is observed, under the separate material grains deformation and for fatigue resistance estimation models of multi-cyclic fatigue are applicable. If there is no mechanical adaptation then macro-plastic hysteresis is observed, resulting in low-cyclic destruction.

1. For fatigue resistance estimation there is important to take into account the tension state in the concentration zone and anisotropy of material influence. Moreover it is necessary to take into account “instant” damage. That's why the damage estimation has been carried out by means of following equation:

$$\mathbf{D} = \mathbf{F}\left(\frac{\varepsilon_{\max}}{\varepsilon_p}\right) + \sum_{k=1}^{N} \mathbf{f}\left(\frac{\Omega_k}{W_p}\right) + \sum_{k=1}^{N} \mathbf{f}\left(\frac{\omega_k}{W_p}\right), \qquad (1)$$

where D is damage, ε_{max} is maximal eigenvalue of strain tensor for history of loading, Ω_k is irreversible work of one-sided plastic deformation in k^{th} cycle; ω_k is irreversible work of cyclic plastic deformation in k^{th} cycle; ε_p, W_p are material constants, namely the limit deformation and work of static deformation in the experiments on sample collapse (**Picture 1**).

The approach of D estimation, mentioned above, close to the [4]. Since $f(\ )$, corresponding to the part in D under one-axial loading, equals zero if asymmetrical coefficient **R**= – **1** , then destruction accrues in this case is an effect of nonreversible cyclic deformation work. Hence, corresponding all to one cycle:

$$\varphi(\omega/\omega_p)=(1-\varepsilon_{max}/\varepsilon_p)/N_p, \qquad (2)$$

where N_p – is a number of cycles before destruction when **R=–1.**

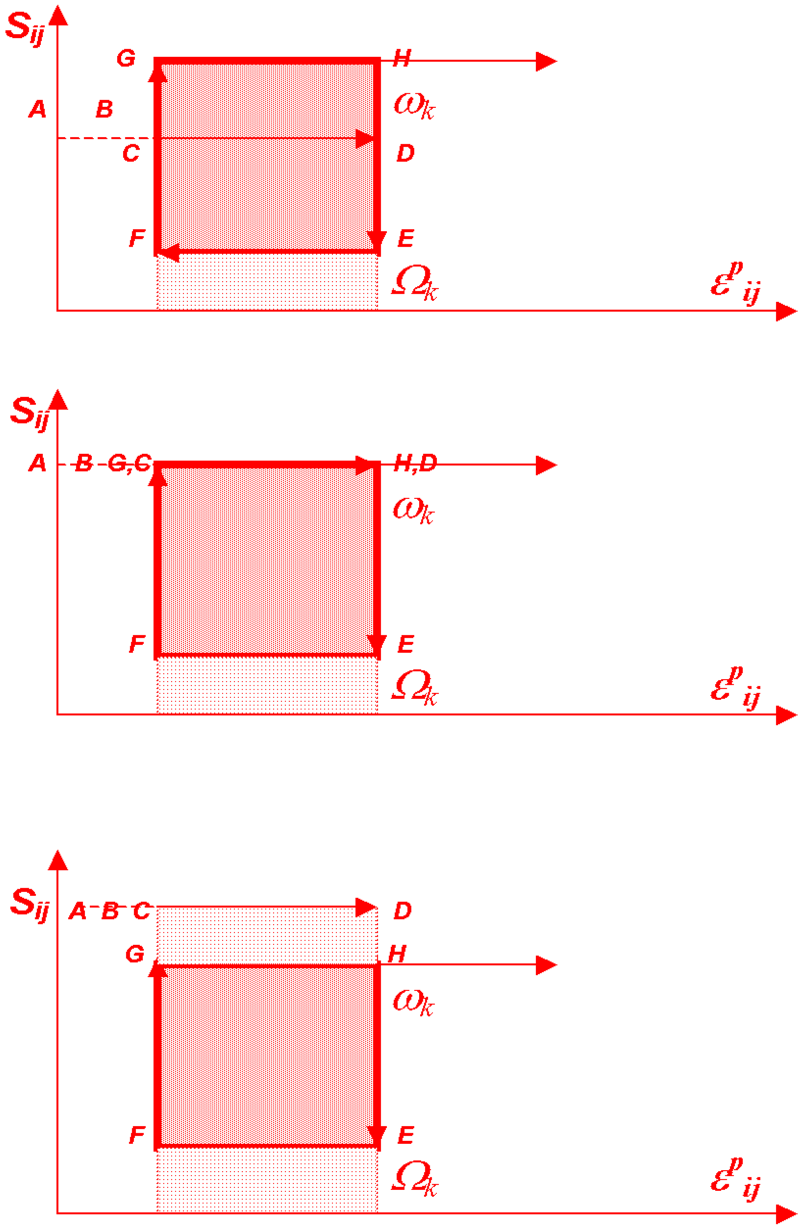
The first addend in **(1)** consults instantaneous plastic deformation accumulation, for metals it can be specified simply as $\varepsilon_{max}/\varepsilon_p$.

After this, from the independently $\varphi(\omega_{mid}/\omega_p)$ and **R** assumption, based on experimental results with **R!=–1,** we obtain:

$$f(\Omega/\omega_p)=(1-\varepsilon_{max}/\varepsilon_p)/N_p - \varphi(\omega_{mid}/\omega_p), \qquad (3)$$

where N_p – is a number of cycles before destruction,
ω_{mid} – middle loops area for N_p cycles.

Picture 1



2. Complex cyclic loading was investigated on tubular specimens of 1X18H10T steel under loading ways with partial and full unloading. Specific work of plasticity deformation before destruction, calculated by structural model and multisurface theory [1,2,3] turns out 343Mpa and 467Mpa. Experimental value under axial tension is 436Mpa. Odquist parameter equals 0.466; 0.560, 0.555 accordingly.

Investigations on box shaped beams under cyclic cross-bending through three point loading scheme. The sheet thickness, from which beams are prepared, is 4mm, breadth 6 and 3cm. Material characteristics: flow limit σ_Y=300Mpa, strength limit σ_S=450Mpa, real tear resistance σ_S=800Mpa, area under real deformation curve ω_p=420Mpa. Computational results and experimental data are in the table:

Exp. No	Beam length , m	Section height, mm	Maximal tension	$\varphi(\omega / \omega_p)$	Number cycles before destruc-tion

					Computation	Experiment
1	0.58	68	42	0.0028	100	237
2	0.58	68	50	0.0143	30	24
3	0.27	38	25	0.0184	70	64
4	0.27	38	30	0.0453	32	16
4	0.27	38	30	0.0468	49	16

We assumed: destruction is the cracks appearance about 0.1mm length.

3. Great influence to the construction fatigue exerts the skin layer existence (on the [5] data at the depth 0.125-0.22mm) with attenuate strength properties. The flow limit recedes up to 40% from integral value [5].

In the zones of stresses and deformation concentration the big gradient values taking place. The maximal tension estimation in the concentration zone brings the lower longevity value, comparing to the experiments. The possible explanation (interpretation) is: using this approach the found value reflect microcrackes formation in the maximal concentration point and does not take into account number of loops necessary for its diffusion.

R.Peterson [6] suppose to determine longevity before arising limit microcrack on tension state point, on the some distance δ from concentrator. Firstly this approach used for effective tension concentration coefficient determination in the case of static destruction. Further investigations [7,8] of this approach were disseminated to the on the case of more- and little-cyclic fatigue. But this approach does not use existence of plastic deformation in the concentration zone. δ size in the [7,8] considered as material characteristic, without dependence of concentration size and cyclic loading level. Along with is the influence of tension level to the δ size. Again, the influence does not take into account nonuniformity of tension state to the fatigue destruction.

Proposed method for calculational-experimental estimation of constructive element fatigue resistance consists of two steps. The first step – experimental determination of model. δ-characteristics. The second is computation of construction element and its destruction.

First step:

1. Experimental determination of fatigue curves on the smooth standard specimens for different R-values.
2. Construction of fatigue curves for specimens with tension concentrators and different R-values.
3. Numerical (in this case FEM) analyses of stress-deformed cyclic state in the concentration zone for specimens with concentrators.
4. On the computational results variable stress-deformed state, experiments and fatigue model the longevity is determined. Computations are made in element points with maximal tension gradient. During this calculation longevity distribution dependence form computation point "deep" arises.
5. Maximal deformation determination- ε_p in the maximal concentration point. The longevity level from δ-N_p curve δ can be determined
6. Base on the σ_a ,δ values $_p$

$$G = 1/\sigma_{1a} \, (d\sigma_1 / d\,x)|_{x=0\ p}), \qquad (4)$$

first main tension gradient is determined

Hence, on the first step of computations σ_a - δ curve for different tension concentrators arises.

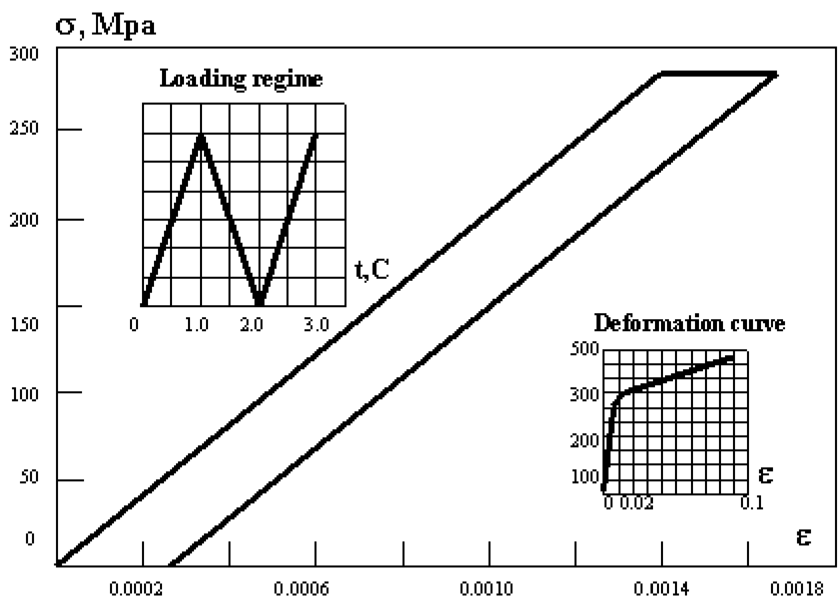
During the second step, using the previous computation result we obtain dependence ***lg*** N_p - $P_{max,}$, using

$$\sigma^*_{max}=\sigma_{max} + \sigma_m \sigma_{-1}/\sigma_u , \qquad (5)$$

where σ_m middle stress value per cycle, σ_{-1} strength limit of material, σ_m material strength limit from one axes experiments.

Base on the measurement data (acoustics defectologie and radioacoustic emission) was fixed that in cylinder and in internal base shelf zone (internal technology and exploitation deflects). During the calculation three possible directions of hypothesis cracks(parallel cylinder axe, normal to it, and under 45degrees) where investigated. Numerical was adjusted that by the crack with length 0.02m under the maximal possible loading the significant plastic deformation arise. At the first loading cycle in the especial tension point plastic deformation appears, but in the next cycles goes without plastic deformation and there is no hysteresis loop.

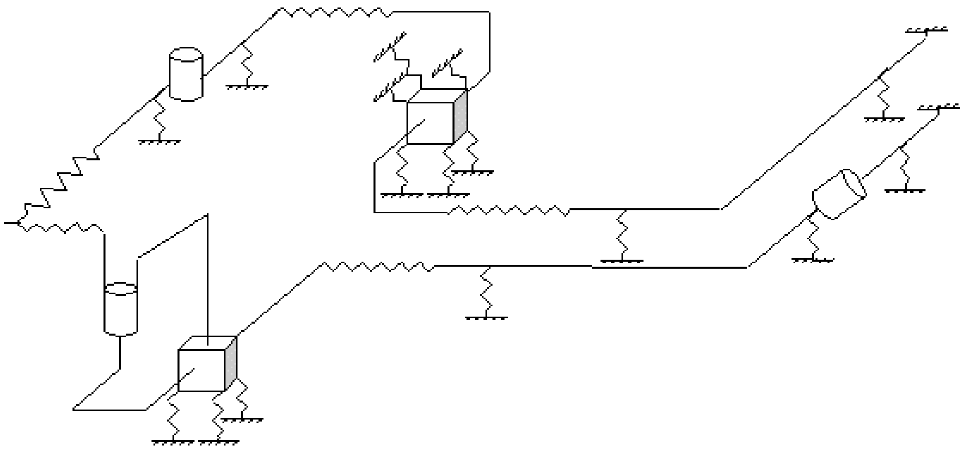
Picture 2



Material conforms to the cyclic zero-base loading and low-cyclic fatigue couldn't take place. The next extrapolation and acoustics defectologie data confirmed to this conclusion.

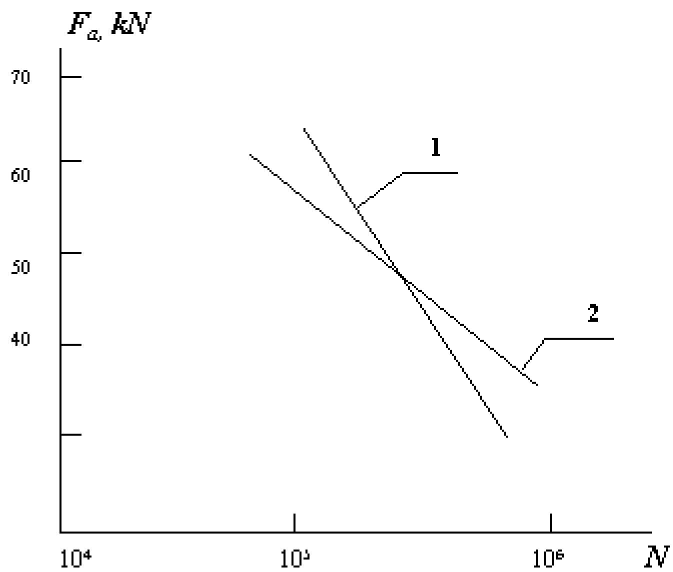
Analogous experiments were produced for pipelines (***Picture 3***), aerials for Far North climate.

Picture 3



Carries out longevity estimation of Hydro Electro Station inrush pipeline flanech connection by the conditions of axial distend force with the low cyclic component. The material is steel 45. In the zone of abrupt diameter change observed considerable tension concentration. Secondary plastic deformation no arise in the hole tension diapason, multi cyclic fatigue model was realized. On the picture (***Picture 4***) represented computational (1) and experimental (2) curves.

Picture 4



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