I-182 Influence of friction on crack propagation

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1.Scope of study

Friction is considered to reduce the stress concentration of the eyebar head, thus is considered beneficial for fatigue. The amount of friction force between the surface of two adjoining eyebar heads is usually not known, so is stress concentration factor(SCF) and stress intensity factor(SIF). Evaluation of SCF and SIF reduction is the objective of this study. The analysis is conducted using finite element model. Meshing is relatively coarse in order to handle the unstable characteristic of nonlinear friction analysis. Improvement of fatigue strength of eyebar due to friction will be evaluated later.

2. Finite element model

Dimensions of the eyebar used in this study are identical to the eyebar taken from the Liberty Bridge. The eyebar is modeled by three-dimensional isotropic solid elements. Bottom surface of the elements are in contact with the adjoining eyebar (**Fig.1**) .

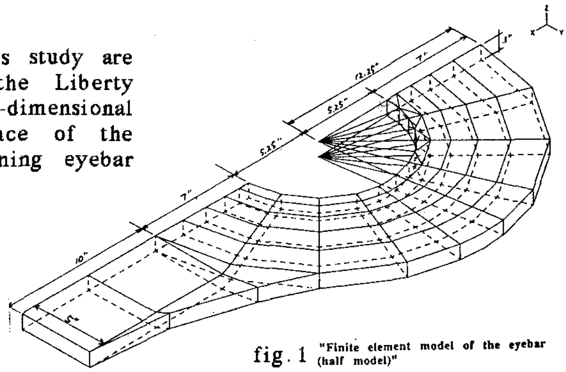


fig. 1 "Finite element model of the eyebar (half model)"

Two types of load are applied to the eyebar: surface load (or clamping force) (N) and tension force (Fs) which acts on the shank at the end in a longitudinal direction and is increased from zero to the maximum. The definition of the forces are expressed as follows: Fs=pAs, N=wAc, Ffr=myuN, where p is average tension stress in the shank. A limiting tension stress in the shank plim is defined as plim=Ffr/As.

The crack is a through-thickness crack. **Fig.2** shows elements around crack and their stress distribution.

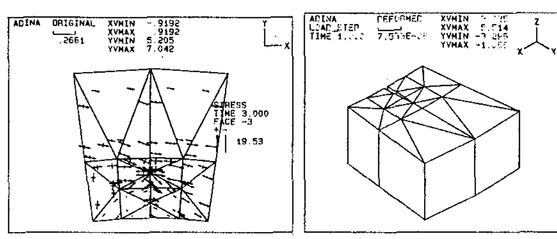


fig.2 Elements around the crack

3.FEM Analysis

Five types of model shown in TABLE-1 were analyzed to find the influence of friction and crack length.

Table 1

model	friction	crack	analysis
AICRACK	0.2	no	N.L.
AISLIP	no	0.564"	L(Linear)
AIOPEN	0.2	0.564"	N.L.
AISLIP2	no	0.728"	L
AIOPEN	0.2	0.728"	N.L.

4.FRICTION ANALYSIS

Friction analysis is achieved by using iteration procedures to develop a balanced force field in the whole body of the eyebar model. The tangential component of the traction force on the surface is compared with the friction force in each iteration step and the condition of the contact surfaces are checked. The distribution of the friction force per unit area is shown in Fig.3.The result of friction analysis was coincide with measured stress distribution of the eyebar as shown in **fig.4**.

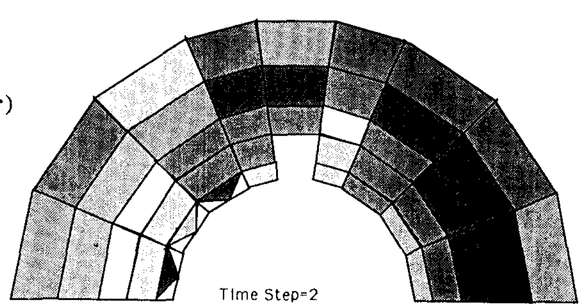


fig.3 distribution of friction force

5. Stress Intensity Factor

Stress intensity factor is obtained from two different methods. First method is from the distribution of stresses. The SIF is derived from $K_I = \sigma_x \sqrt{2\pi r}$. K_I is independent of location. Second method uses the gradient of FEM variational index. K_I values obtained from FEM analysis are shown in TABLE-2.

TABLE-2 : K_I & ß

model	p/p_{lim}	Method-1		Method-2	
		K_I	ß	K_I	ß
AISLIP1		34.5	2.63	21.68	1.66
AIOPEN1	0.5	2.0	0.15	0.34	0.03
AIOPEN1	1.0	12.0	0.92	3.73	0.28
AIOPEN1	1.5	25.0	1.91	13.42	1.02
AISLIP2		33.0	2.18	21.44	1.42
AIOPEN2	0.5	2.0	0.13	0.5	0.03
AIOPEN2	1.0	12.0	0.79	3.93	0.26
AIOPEN2	1.5	24.0	1.59	12.82	0.85

K_I is also expressed as $K_I = \beta\sigma\sqrt{\pi a}$, where a is the length of the crack, and ß is the correction factor. ß calculated by FEM (method-1) for two different crack length are plotted in fig.5. The ß can be treated as multiple of two correction factor: ß=f1(a/ri)f2(p/plim), where f_1 is for geometry correction factor and f_2 is for friction correction factor.

Theoretical ß value is also plotted in the plot . f_1 is assumed to follow the Bowie's correction factor shown in fig.5. Then correction factor f_2(p/plim) is to be expressed in terms of p/plim.

The gradient of the finite element variational indicator (GVI) with respect to nodal point co-ordinates can be used to calculate the energy release rate. Results are shown in Table 2. S I F calculated from the G V I always gives smaller value.

Fig.4 Stress-xx distribution (FEM p/plim=1.5 and measured stress)

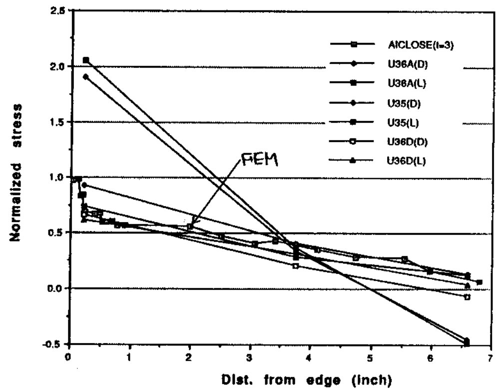


Fig.5 ß : FEM and theoretical value

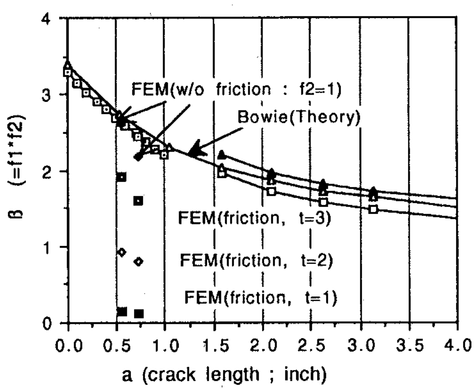
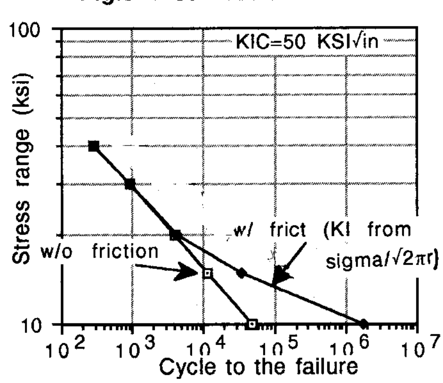


Fig.6 modification of S-N



6. Crack growth calculation

Crack growth rate is calculated by the numerical integration procedure to give S-N curve. The result is shown in Fig.6. Cycle to the failure is greatly increased by the effect of the friction. The S-N curve is not straight line on log-log plot any more because of nonlinear characteristic of friction. When the tension load is small, friction increases the life length of the eyebar more efficiently.

In case of eyebar, it is not easy to know how much friction exist between the surfaces. But if the friction forces are controled with adequate accuracy in the structure components, parameters for the fracture design can be modified to give better fracture characteristics.