"Application of finite element analysis techniques for predicting crack propagation in lugs" by O.Gencoz, U.G.Goranson and R.R. Merill - INT.J.Fatigue July 1980

Definitions

P	Load
d	Lug Internal Diameter
c	Lug Strap Width
t	Lug Thickness
Ψ	Angle from symmetric axis

Cosine Pressure Distribution

The accepted practice is to represent the radial pin-bearing pressure acting on the lug hole inner boundary described by the following expressions:

$$\sigma_r = \frac{4P}{\pi . d . t} . \cos\psi \qquad \text{For } -\frac{\pi}{2} \leq \psi \leq \frac{\pi}{2} \qquad (1.0)$$

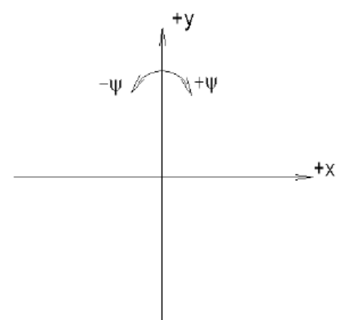


Figure 1.0 – Axis system for Equation 1.0

Where Ψ is measured from the symmetrical axis (as shown in figure 1.0).

Non-linear FEA has shown that when lugs are in compression the cosine distribution is a good representation of actual pin loading for solid pins. However, for hollow pins the Gencoz distribution is a better representation.

Gencoz Pressure Distribution

Finite element models of lugs, for calculation of internal stress distributions and stress intensity factors, were initially loaded using the distribution as described by equation (1.0). Resulting boundary stresses based on this approach did not agree with stresses obtained from photoelastic test results.

A paper published by Gencoz, Goranson and Merrill has shown a deflection incompatibility between the lug and pin. The findings from his work resulted in a trigonometric series being derived, see equation (2.0).

$$\sigma_r = \frac{4P}{\pi d t}\left[\cos\Psi - \sum_{n=5,9}^{\infty} \frac{5}{14(n-1)(n-8)} \cdot \cos n\Psi - \sum_{n=3,7}^{\infty} \frac{2}{5(4-n)^2} . \cos n\Psi\right] \qquad (2.0)$$

The trigonometric series in equation (2.0) converges rapidly and requires few terms to obtain the correct pressure on the inner surface. Figure 2.0 depicts the Gencoz distribution on a lug pin. Comparing the loading distribution derived by Gencoz to photoelastic test results shows a good comparison of circumferential stresses with differences of approximately 10%.

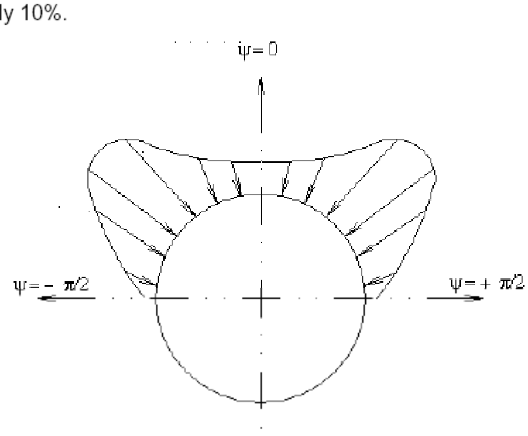


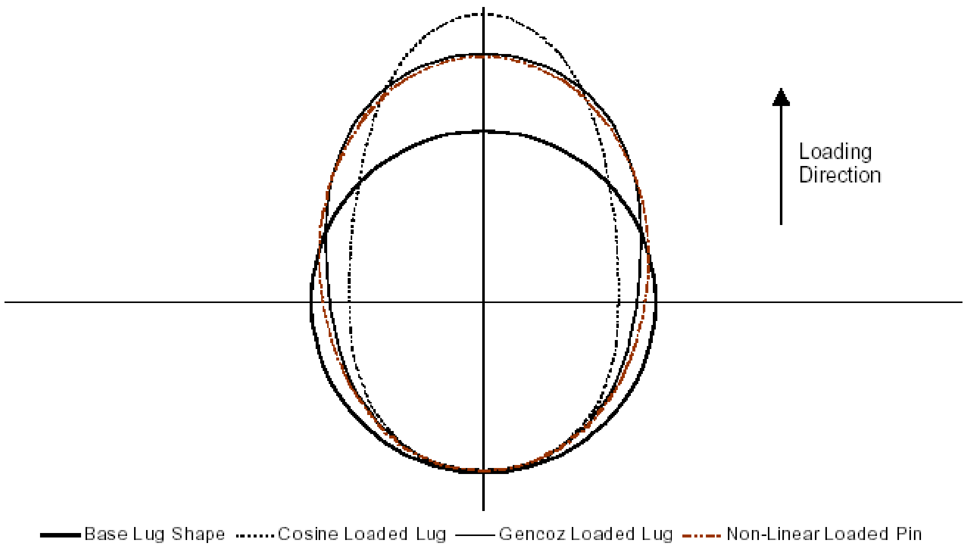
Figure 2.0 – Gencoz distribution on lug pin

APPENDIX – FEA Confirmation of Gencoz Loading Distribution

The diagrams below illustrate the effectiveness of the Gencoz distribution to represent a non-linear FEA using gap elements. The base lug shape shows the profile of the lug bore prior to any loading. The other profiles show the deflected shape of the lug bore after the application of:

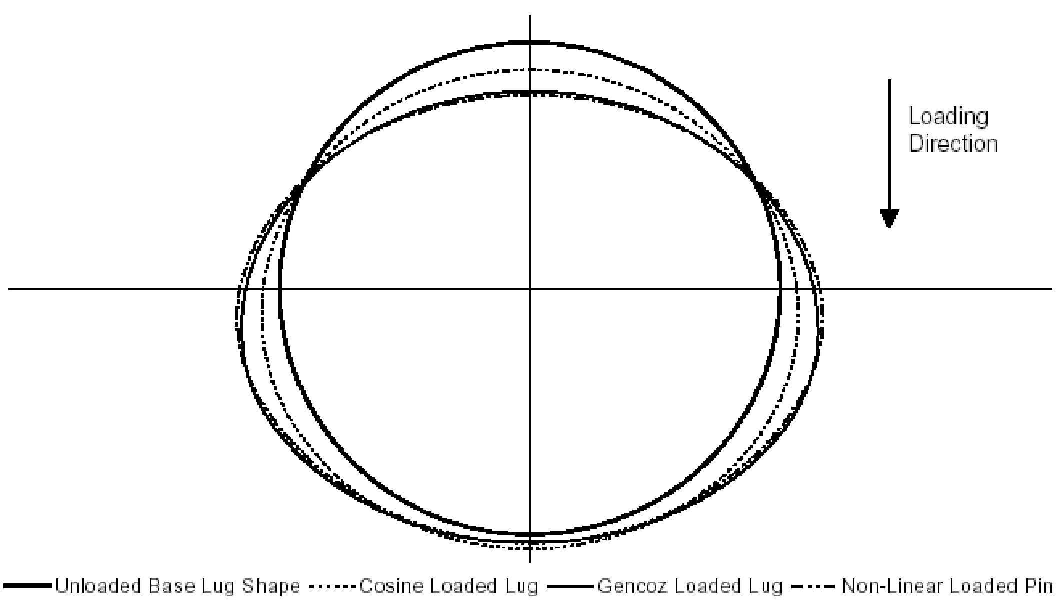
i) Cosine distributed load (Equation 1.0) on the lug, with no pin acting as reinforcement
ii) Gencoz distributed load (Equation 2.0) on the lug, with no pin acting as reinforcement
iii) Non-Linear Loading using gap elements between the lug and a pin. The pin having a D/t of 8.

The diagram below shows the tensile loaded case. The deformed lug profile of ii) and iii) show similar magnitudes, proving that the Gencoz distribution is a good approximation in this situation.



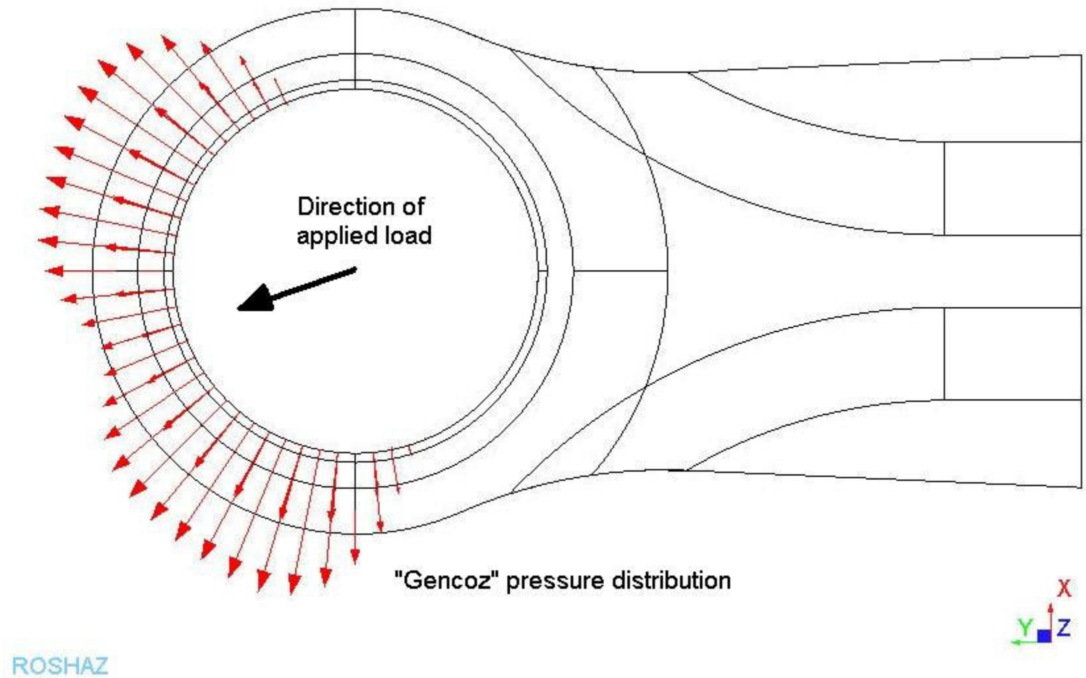
Tensile Loaded Lug

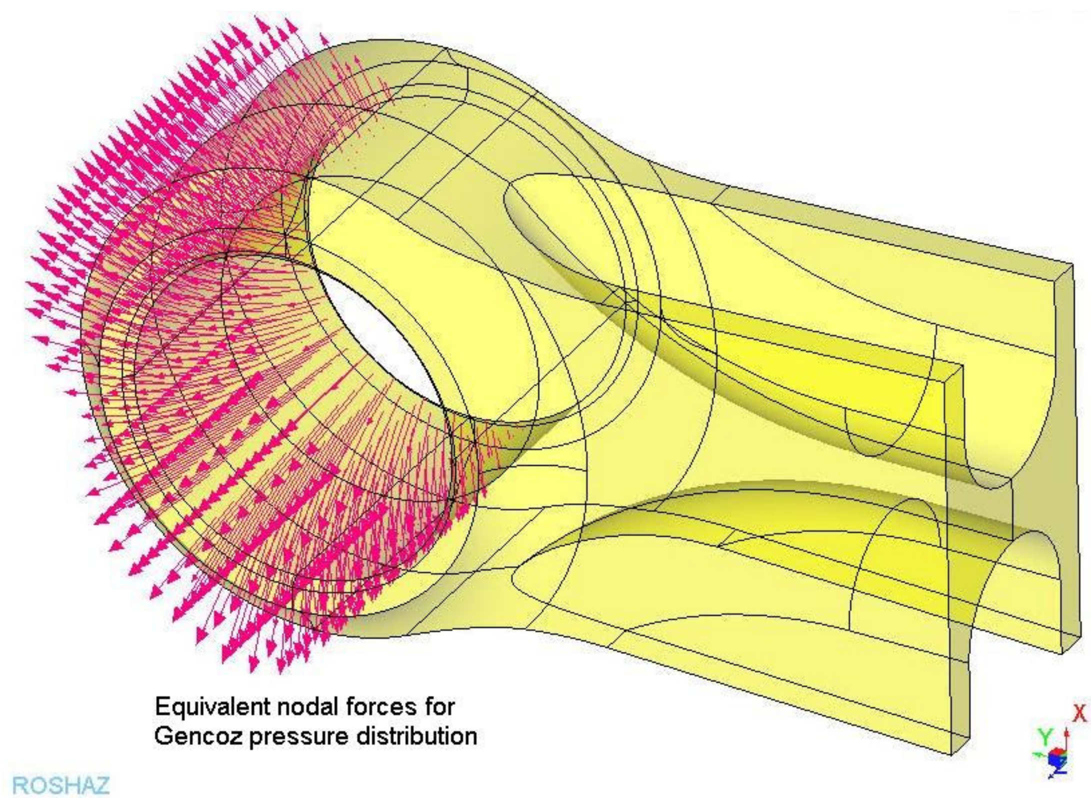
The diagram below shows the compressive loaded case. The deformed lug profile of ii) and iii) show similar magnitudes, proving that the Gencoz distribution is a good approximation in the compressive case.

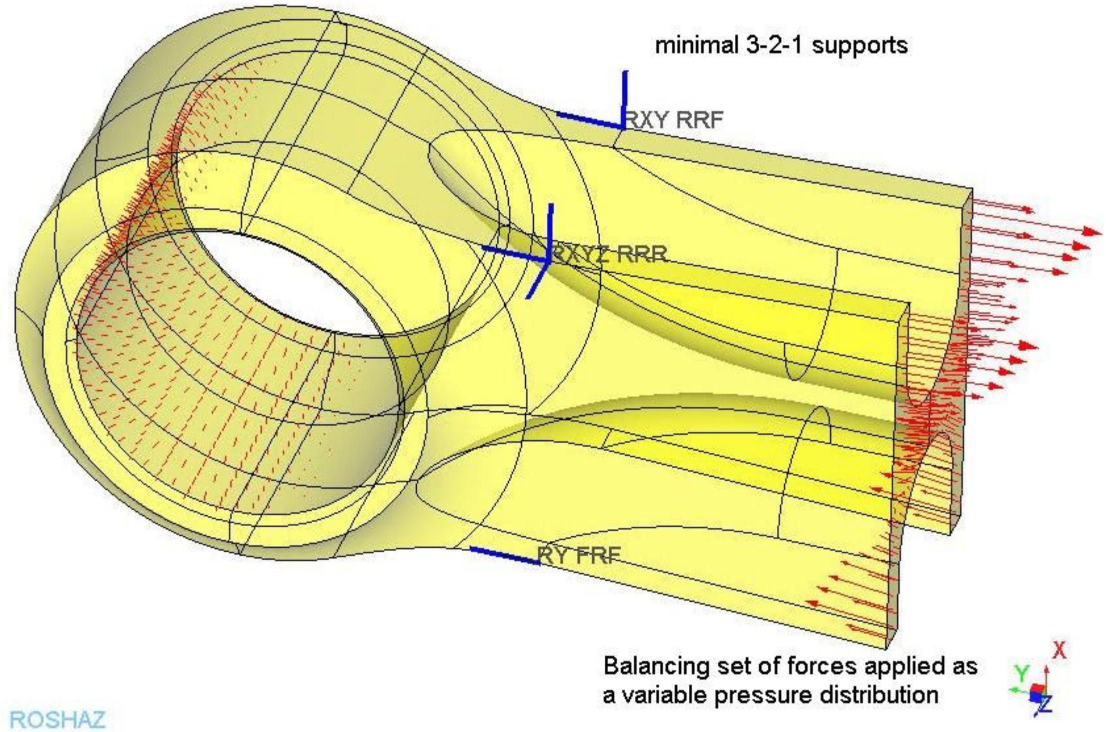


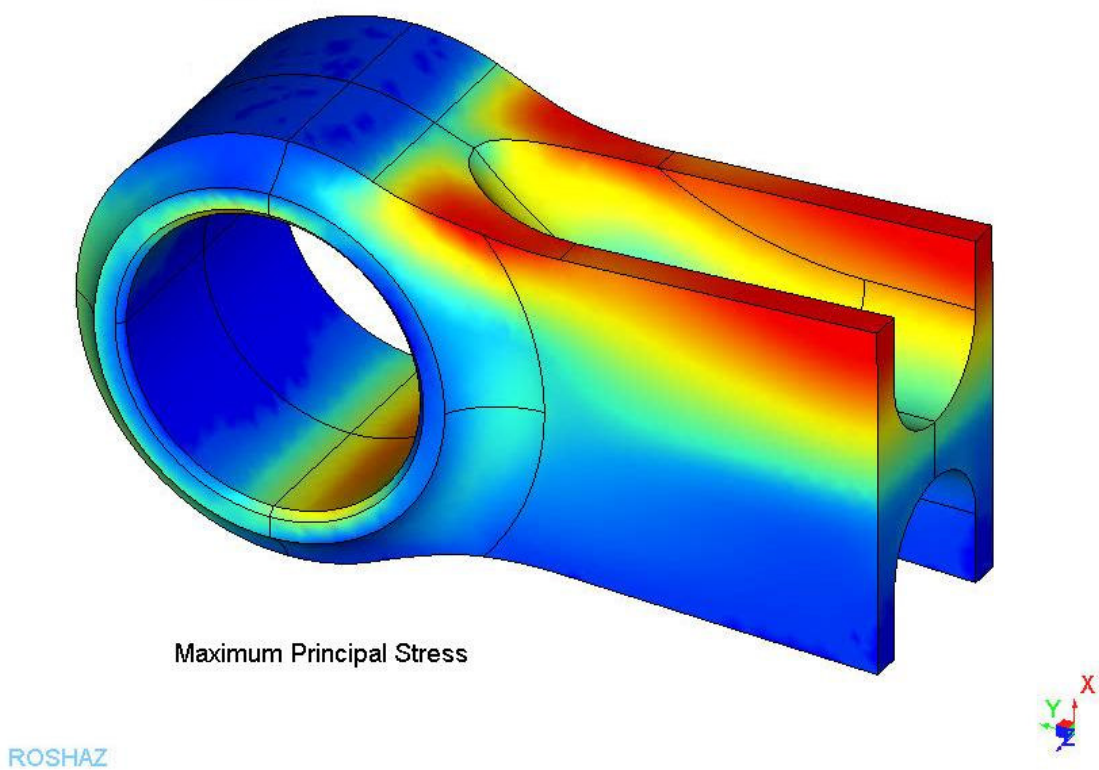
Compressive Loaded Lug

Simple FEA Example






minimal 3-2-1 supports
RXY RRF
RXYZ RRR
RY FRF
Balancing set of forces applied as
a variable pressure distribution
Y
X
Z
ROSHAZ


Maximum Principal Stress
Y
X
ROSHAZ