Wheels and rails at high speeds and axle loads (MU18):

Probability of subsurface fatigue initiation in rolling contact

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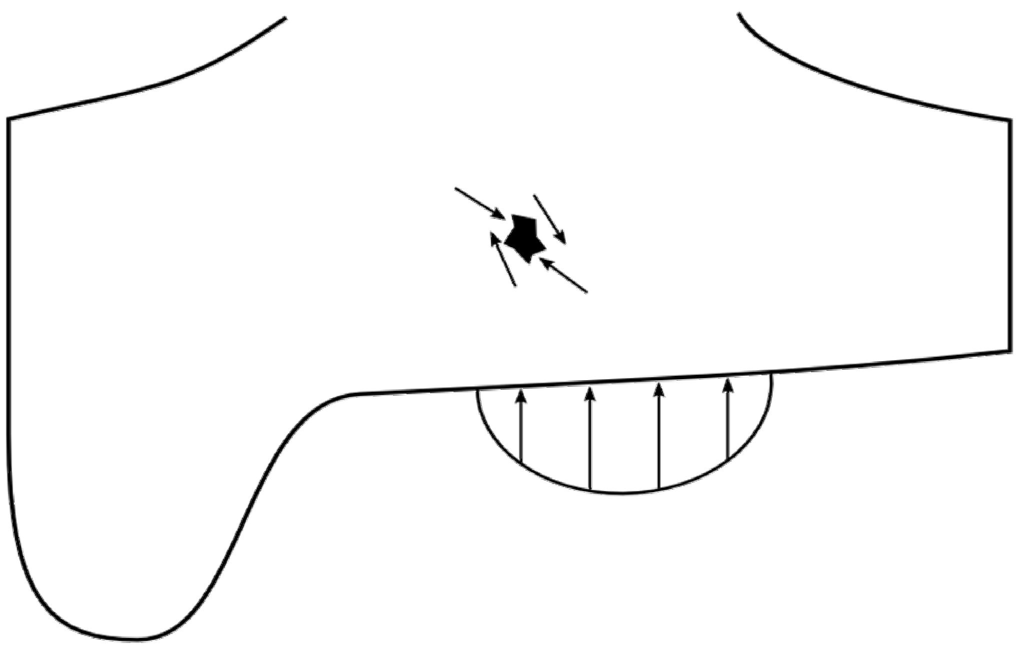
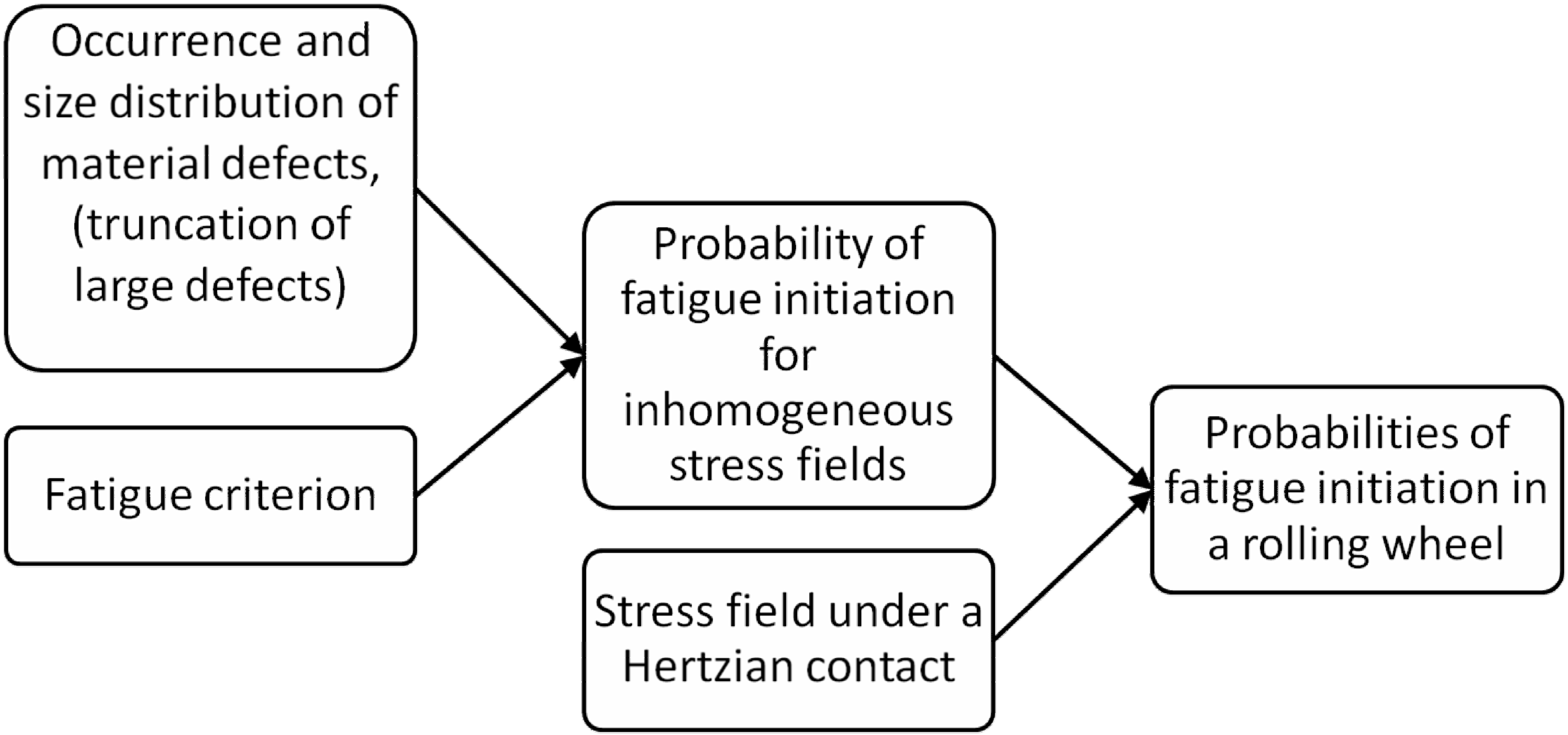
Introduction

- Railway wheels suffer from fatigue cracks that can be initiated at a subsurface material defect
- Defects appear randomly, thus making wheels suffering randomly from fatigue cracks
- It will be shown how the probability of fatigue initiation can be estimated with a combination of a statistic analysis, contact mechanics and a fatigue analysis



Outline of method



Occurrence and size distribution of material defects

- The sizes *D* of defects are assumed to be exponentially distributed with mean *m*. The probability distribution of defects being larger than *d* is

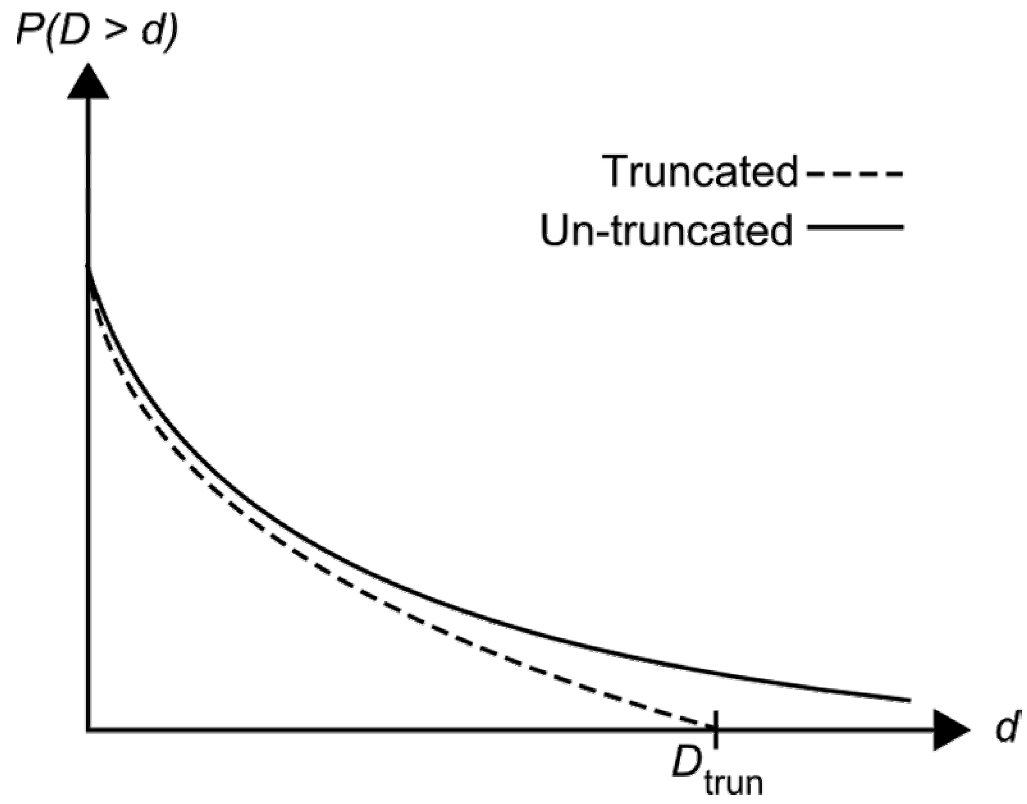
$$P_D(d) = \mathrm{P}(D > d) = \exp\left(-\frac{d}{m}\right)$$

- The occurrences of defects in material volumes are assumed to be Poisson distributed with the intensity λ_0
- The intensity λ_0 can be estimated from results of ultrasonic scans of wheels, where the ratio of wheels with defects is designated as *A*

Truncated defect size distribution

- Material specimens can be removed, if found to have a defect greater than D_{trun}
- A truncated defect size distribution is then

$$P_{D\mathrm{trun}}(d) = \mathrm{P}(D > d) = \begin{cases} \dfrac{P_D(d) - P_D(D_{\mathrm{trun}})}{1 - P_D(D_{\mathrm{trun}})} & d < D_{\mathrm{trun}} \\ 0 & \text{otherwise} \end{cases}$$



Fatigue criterion

- When a material defect is present, the fatigue limit decreases
- A simplified Murakami relation gives the relation between the reduced fatigue limit and defect size

$$\frac{\tau_{\mathrm{e,red}}}{\tau_{\mathrm{e}}} = \left(\frac{D}{D_0}\right)^{-1/6}$$

- The equivalent stress measure to quantify the fatigue is here taken as the Dang Van stress τ_{DV}

Probability of fatigue initiation for inhomogeneous stress fields

- For a material point with a certain stress state and an existing defect, the probability of fatigue initiation is established with the fatigue relation between stress and defect size

$$P_I(\boldsymbol{x}) = \mathrm{P}(\text{initiation at defect}) = \exp\left(-\frac{D_0}{m}\left(\frac{\tau(\boldsymbol{x})}{\tau_e}\right)^{-6}\right)$$

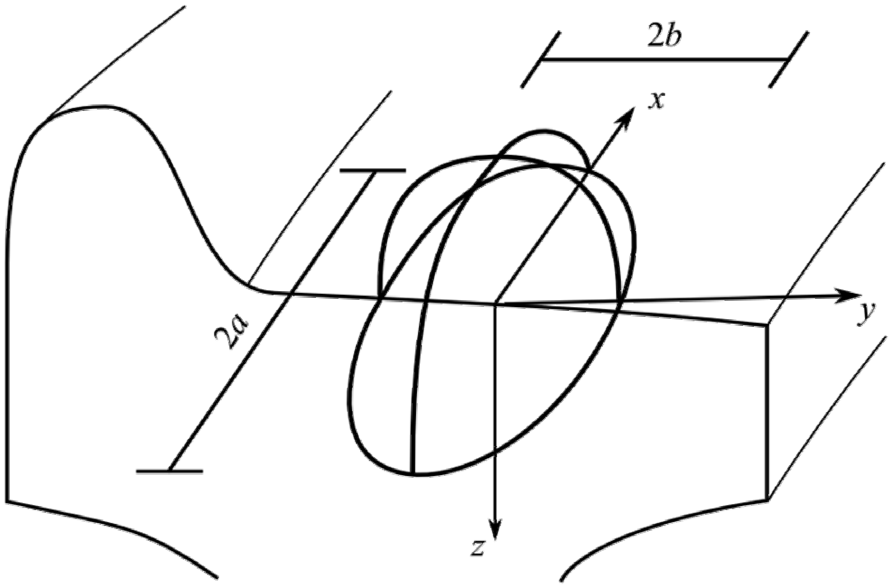
- The total probability of fatigue initiation in a volume is achieved with the Poisson process and integration of the varying probability density over the volume

$$P_\mathrm{V} = \mathrm{P}(\text{initiation in } V) = 1 - \exp\left(-\int_V \lambda_0 \exp\left(\frac{D_0}{m}\left(\frac{\tau(\boldsymbol{x})}{\tau_e}\right)^{-6}\right) d\boldsymbol{x}\right)$$

Stress field under a Hertzian contact

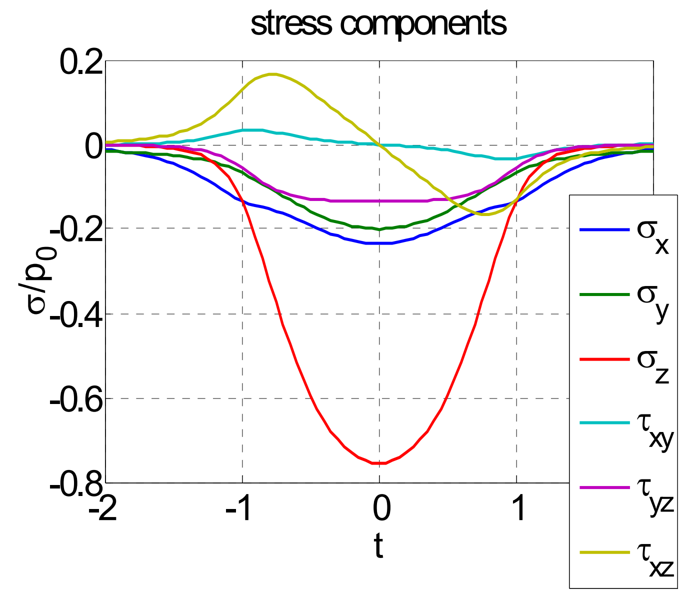
- With Hertzian contact theory the subsurface stress components can be determined
- With these the Dang Van stress field can be formulated for a typical railway contact patch and varying contact force as

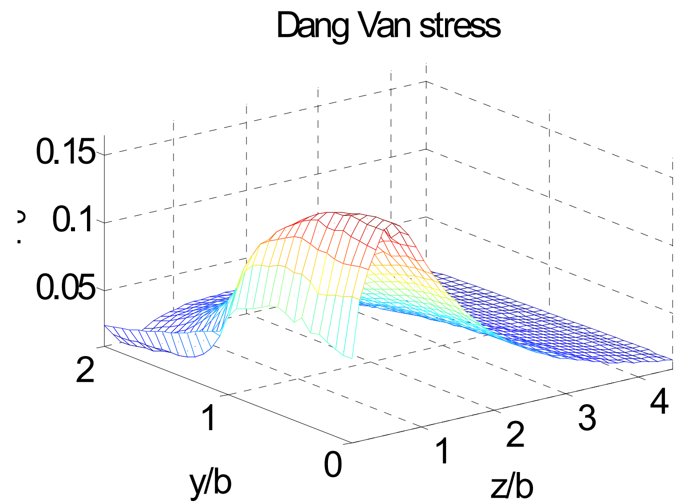
$$\tau_{\mathrm{DV}}(\boldsymbol{x}) = f\left(\frac{y}{b}, \frac{z}{b}\right) p_0$$



Dang Van stress evaluation under a rolling contact

- The stress field evolution due to a rolling contact is complex and involves all six components and are non-proportional
- The computerized methods needed to find the Dang Van stress that predicts fatigue initiation, are examined
- The resulting Dang Van stress can be given as a surface over the plane normal to the rolling direction





Probabilities of fatigue initiation in a rolling wheel

- The total probability of fatigue initiation in a rolling wheel is achieved by integration of the probability density over the wheel volume
- With cylindrical coordinates, the integrand for the initiation probability becomes

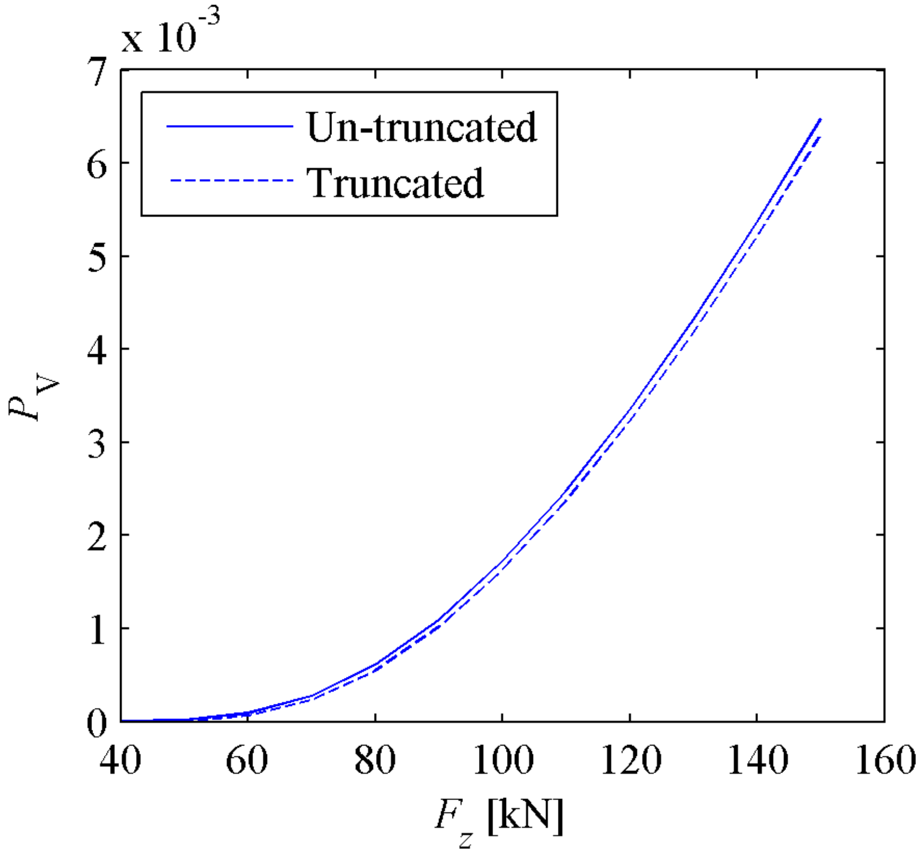
$$P_V = 1 - \exp(-2\pi\, R b^2 \lambda_0 \int_{X=-\infty}^{\infty} \int_{Z=0}^{\infty} \exp\left(-\frac{D_0}{m}\left(\frac{f(Y,Z)p_0}{\tau_e}\right)^{-6}\right) dY dZ\,)$$

- This integrand can be computed numerically at a relatively low cost

Results

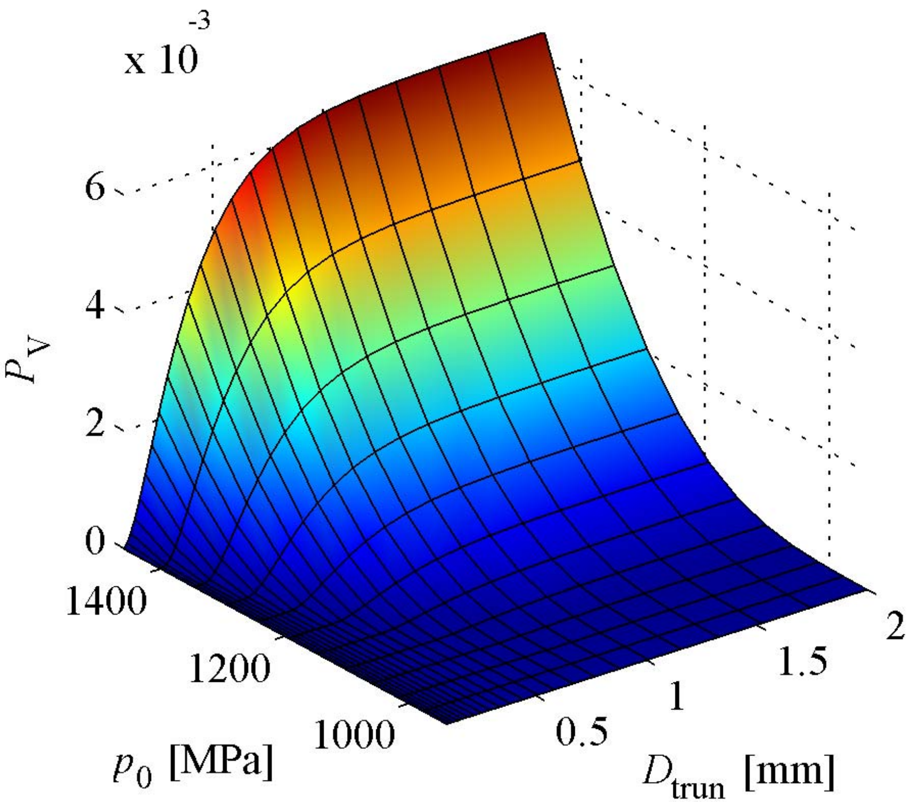
- The results are presented in the form of the probability P_v that fatigue initiates in the wheel during rolling
- Apart from examining the effect of varying contact force or maximum contact pressure, the effect of other parameters are studied
- Contact geometry relevant for railway applications is used – wheel radius 440 mm and rail head radius 286 mm

Truncation and normal contact force



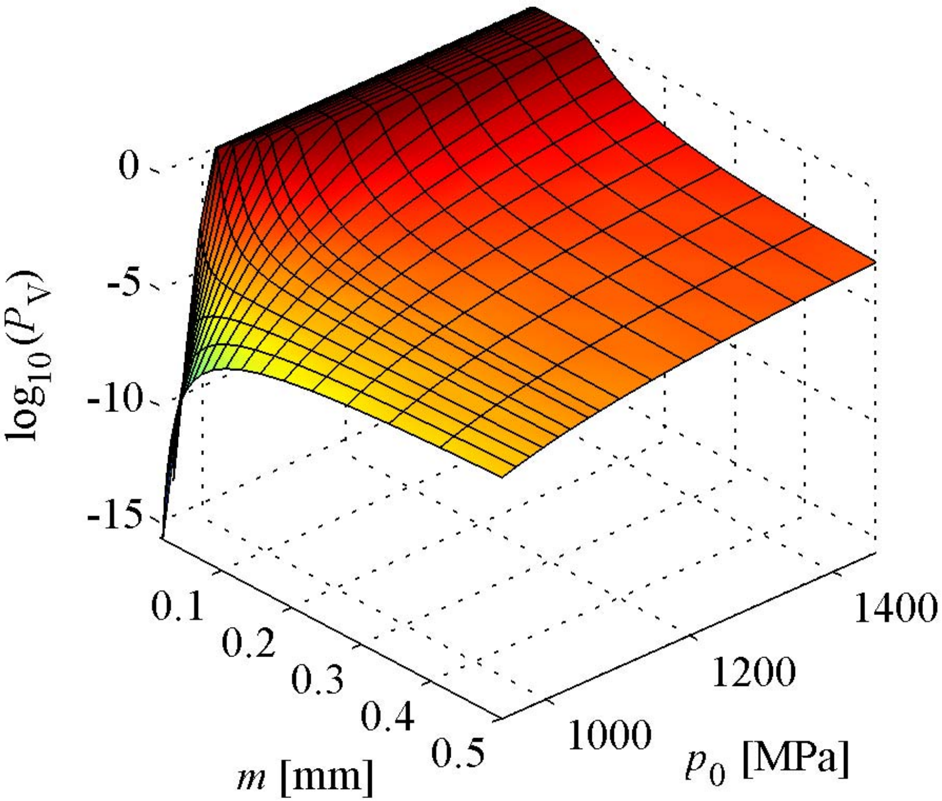
- When the normal contact force reaches 50 kN, an increase of probability is noticed
- The difference between no truncating and truncating for defects greater than 1 mm is small

Continuation on truncation



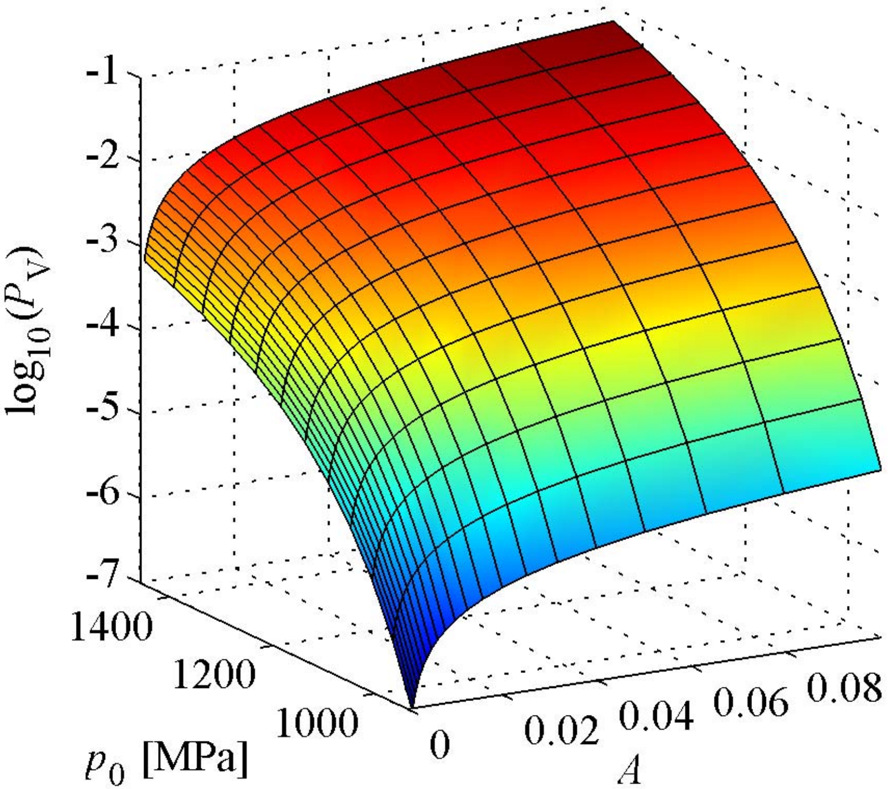
- The effect of truncation can increase, if truncation can be made for smaller defects
- The probability is seen to decrease when truncating is made for 0.5 mm or smaller
- To test for such small defects may not be practical

Dependence on mean defect size *m*



- The mean defect size has large effect on the resulting probability
- An increased *m* can both lower and increase the probability, depending on the contact load

“Wheel steel quality” – the *A* measure



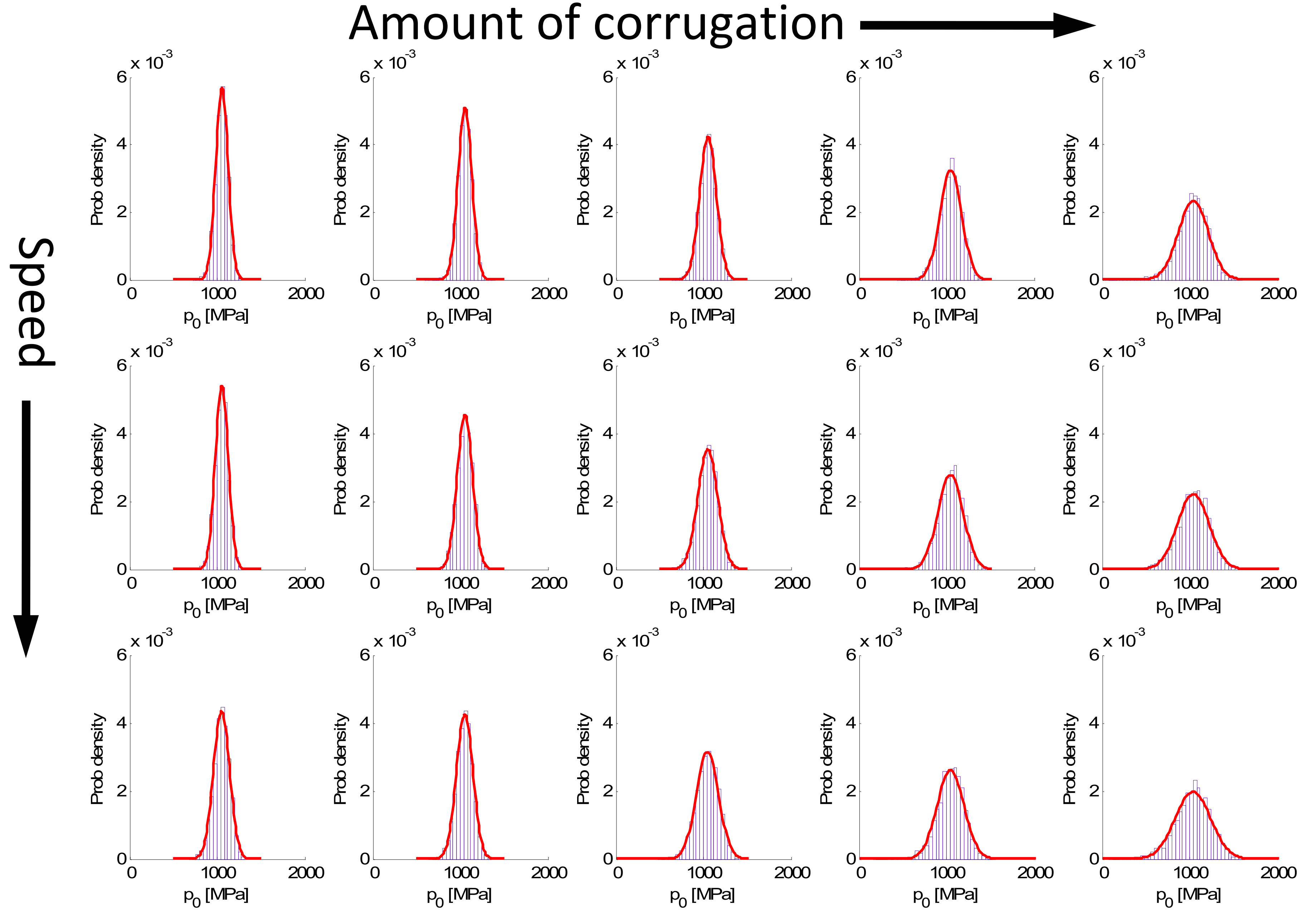
- *A* is the fraction of wheels that during ultrasonic scans, is found to have a defect greater than 1 mm
- The decrease of probability is rapid when *A* decreases below 0.01

Conclusions

- The probability of subsurface fatigue initiation due to material defects in a rolling wheel can be established with relatively easy computations
- Some involved parameters have a very large impact on the results
- To produce accurate results, a determination of the involved parameters is needed
- Truncation of large material defects yields a small effect

Future and ongoing work

- Finding material data for the involved material parameters
- Wheel re-profiling will affect the probability of fatigue initiation, which can be accounted for by modifying the probability density function
- Development of a model for fatigue life estimation
- Including variable contact force due to corrugation


Amount of corrugation
Speed
x 10^-3
Prob density
p0 [MPa]
0
1000
2000
0
2
4
6