

PROBLEM—Rail corrugation is a highly undesirable track surface wear pattern that induces undesirable vibrations and noise in railway systems. It costs the railway industry around 5-20% of total maintenance costs per year.

SOLUTION—Develop models to predict corrugation growth, and validate these findings with field testing and experimental testing in the laboratory.

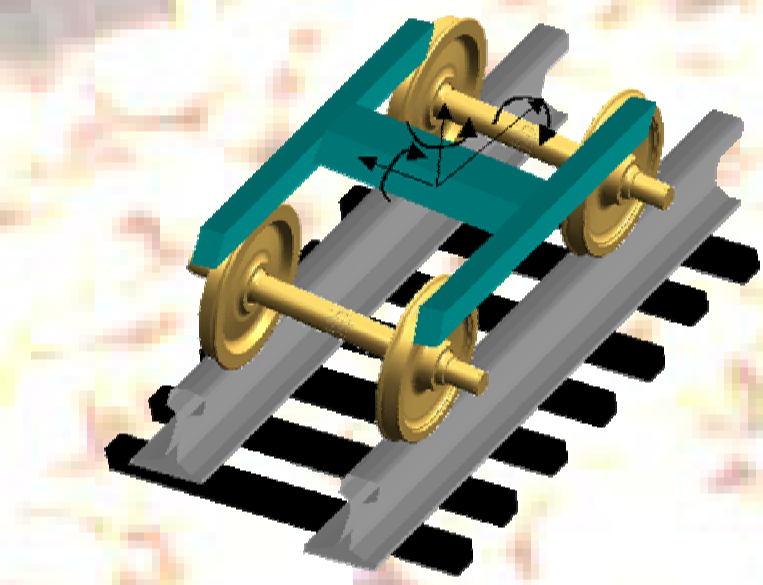
Theoretical Models

Experimental Validation

Numerical Model

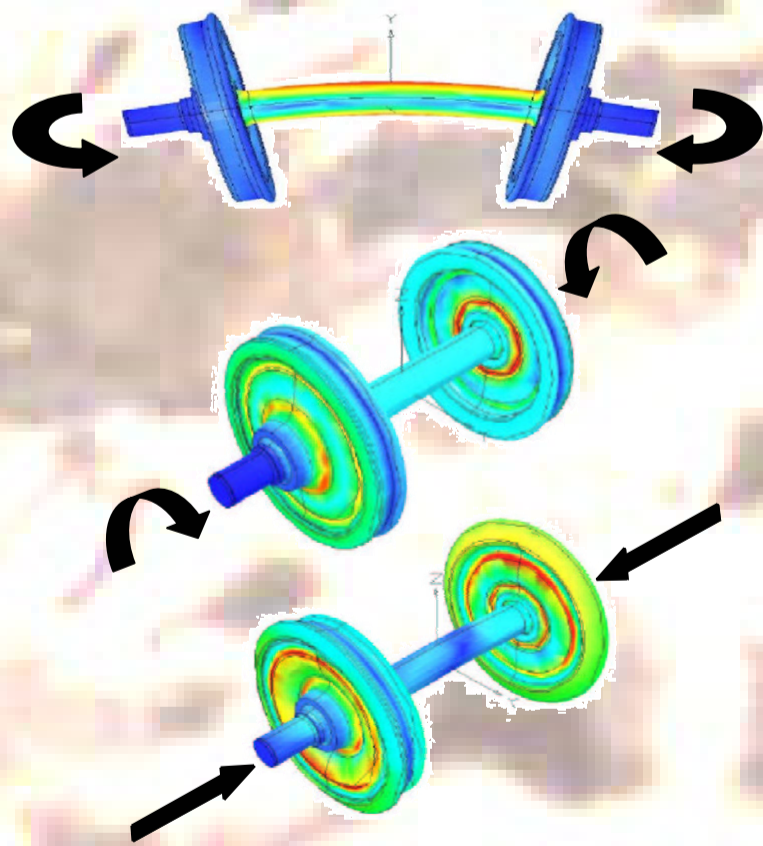
Numerical solution employing a modal description of perturbation of steady cornering

Bogie Frame—Rigid with degrees of freedom as shown



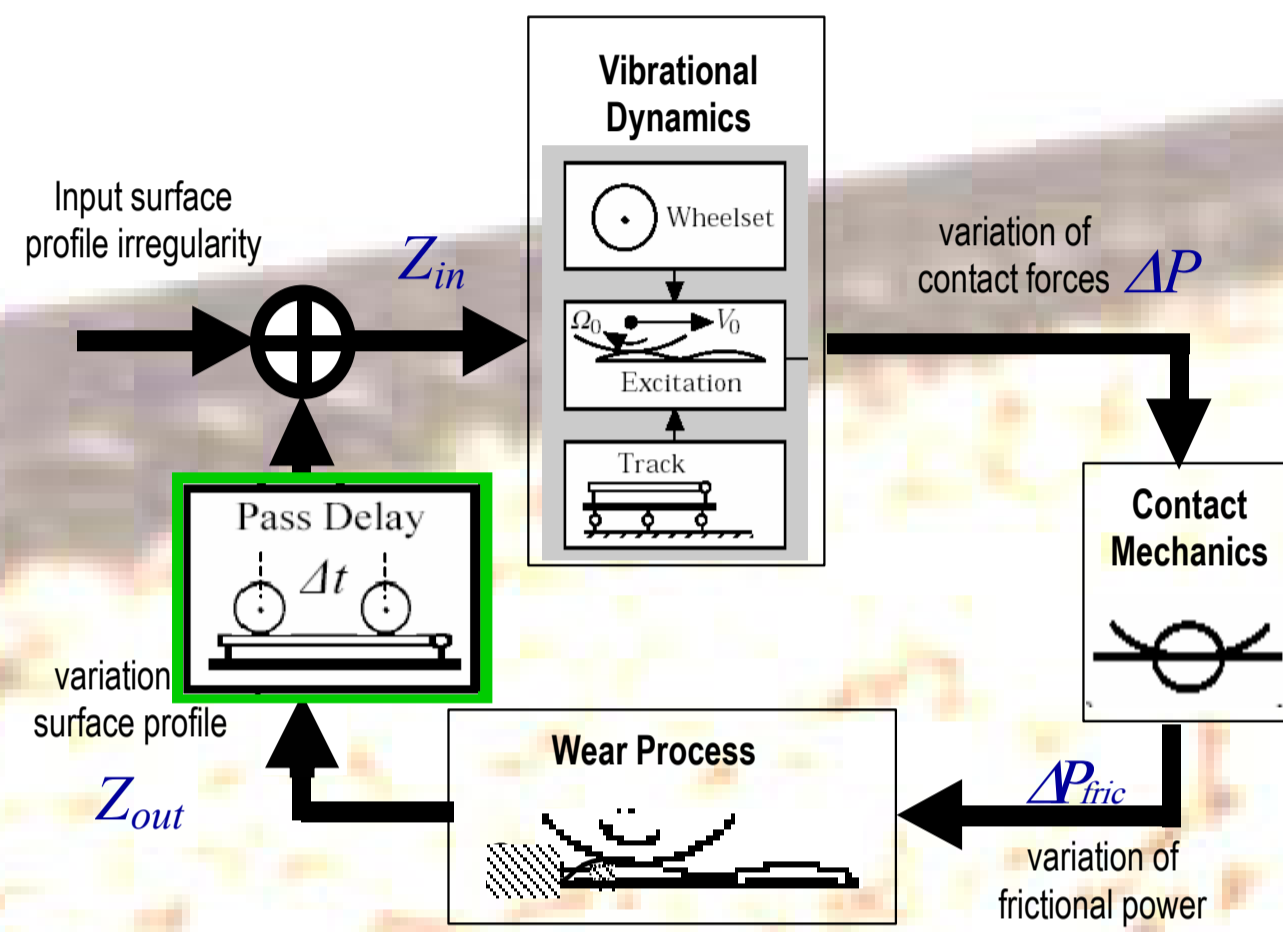
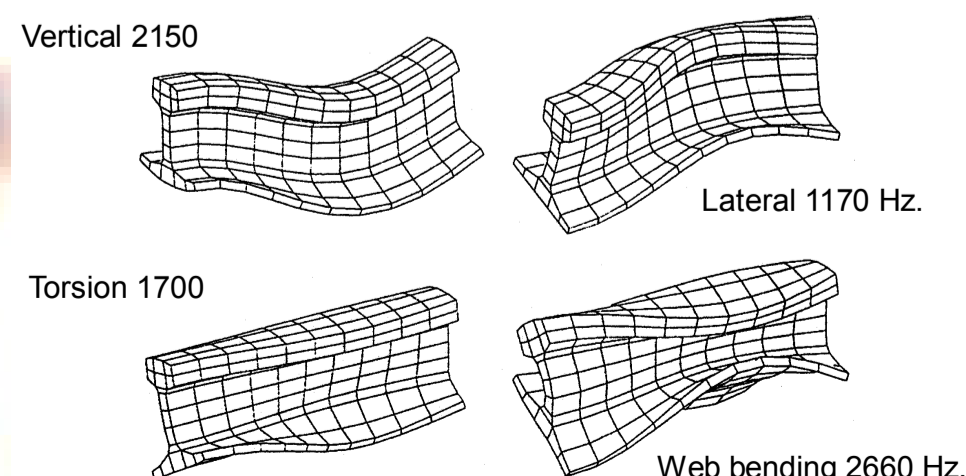
5-mode Wheelset Model

2 x bending
2 x torsion
1 x axial



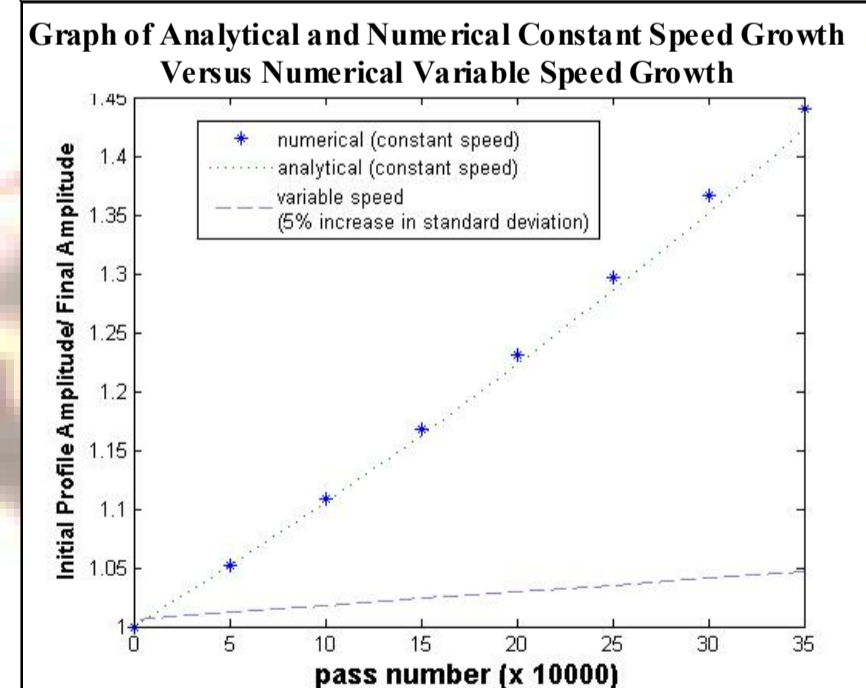
Rail Modes of Vibration

Significant above 1 kHz, especially laterally



Parameter Description	Change in Growth rate ^(%)
Steady wear parameter (k_0)	+10%
frictional traction ratio ($Q/\mu P_c$)	+20%
friction coefficient $\{Q/\mu P \text{ const}\} (\mu)$	+20%
Standard deviation of vehicle speed	-10%,-5%
Standard deviation of sleeper spacing	-2%,+10%
Nominal wheelset load $\{Q/\mu P \text{ const}\} (P_c)$	+5%,+2%
Rail mass per unit length (m_R)	-5%,+1%
Sleeper spacing (L)	-20%,+20%
Pin-Pin modal mass (M_1)	0%,-5%
Rail radius of curvature (R_R)	-4%,-2%
Rail 2 nd moment of area (J_2)	+5%,-5%
Wheel radius of curvature (R_w)	-4%,-2%
Wheelset mass (m_w)	+5%,-1%
Pin-Pin modal damping ratio (ζ_1)	-1%,-5%
Contact modal damping ratio (ζ_c)	-10%,0%

* Notes: 1. Change in growth rate, G_{ri} , due to a +10 percent change in parameter.
2. Two results refer to low and high frequency modes respectively (ie $i=1,2$)



Analytical Model

Stability analysis of a simplified 2DOF model based on a feedback interaction of primary components.

$$\left| Z_{out_i} / Z_{in_i} \right| = 1 + G_{ri} \approx e^{G_{ri}}$$

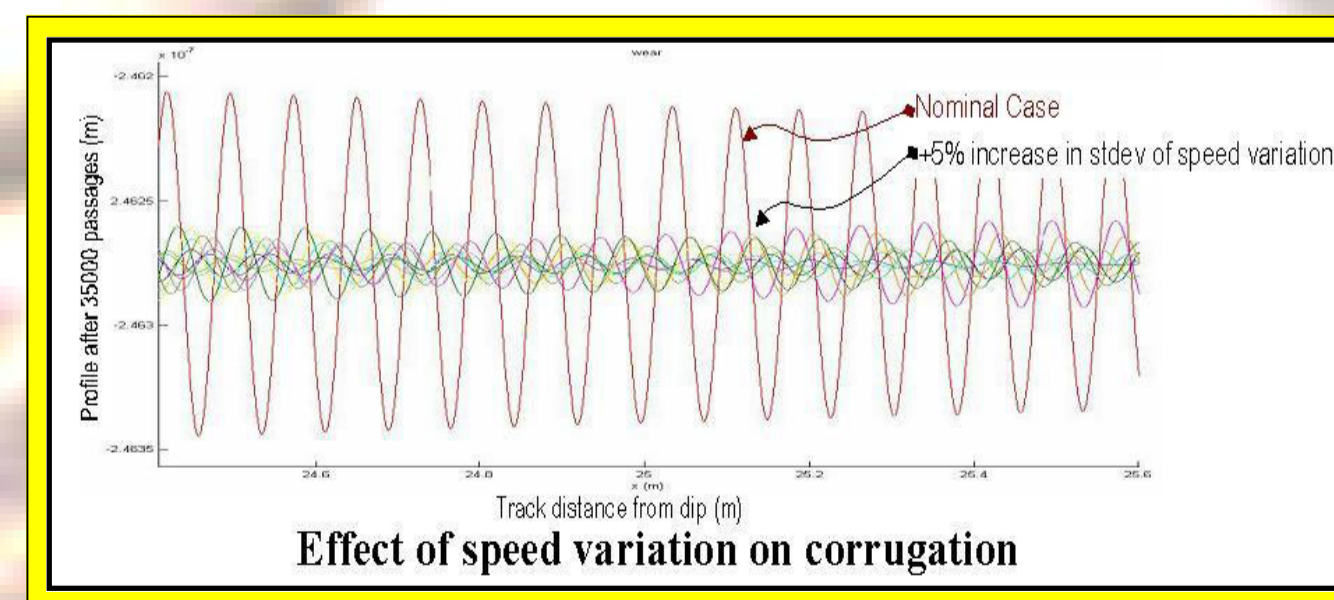
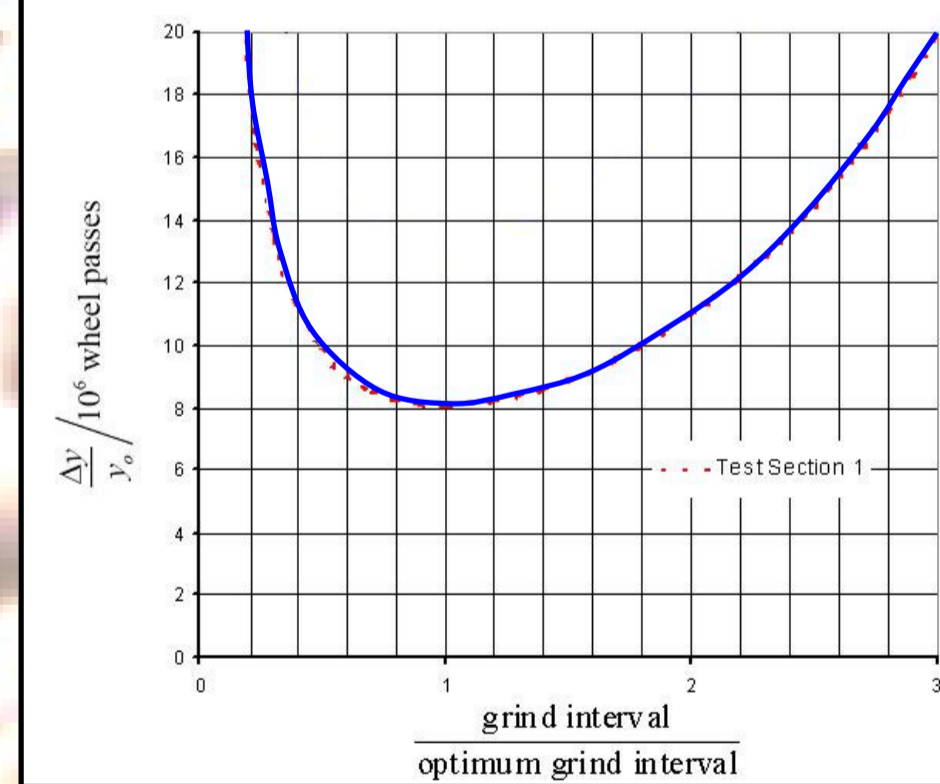
$$G_{ri} \approx K_b \left(1 + \frac{K_{ct}}{4\zeta_i(1+\zeta_i)} \right)$$

Modal sensitivity of wheel/rail relative displacement to a change in input wear

Sensitivity of wear variations to wheel/rail contact deflection variations

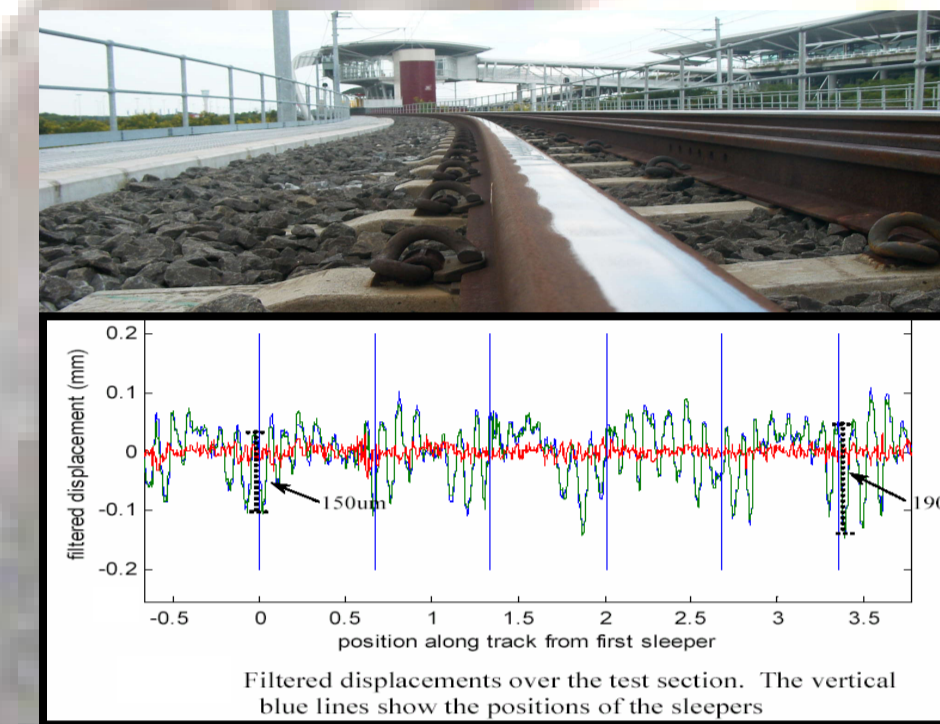
Modal damping constant

Optimum Grind Interval Results



Field Testing

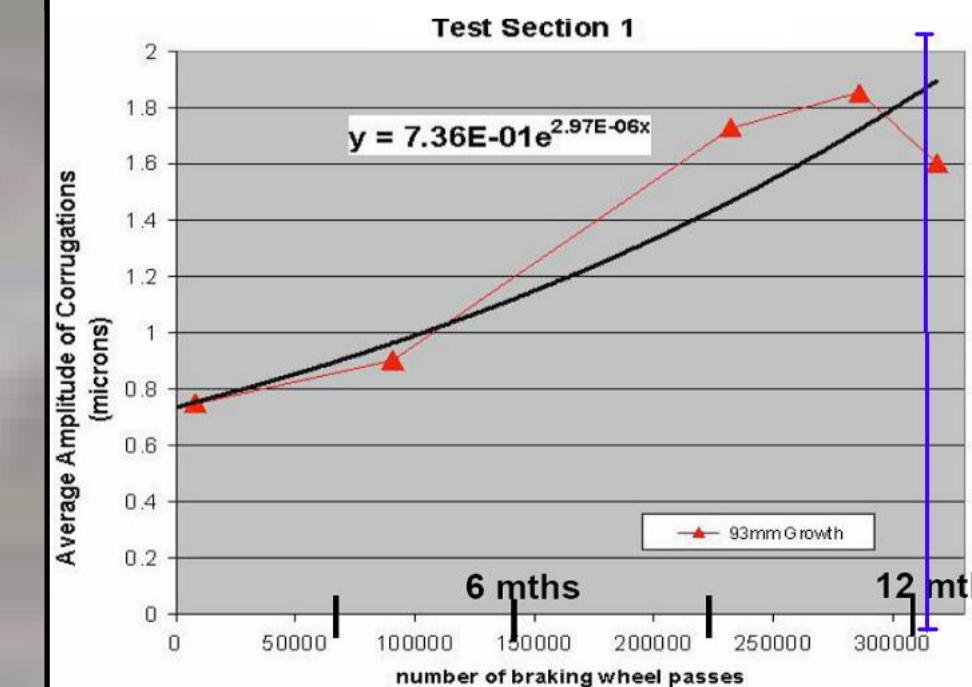
Extensive field testing of corrugation growth to validate numerical and analytical growth predictions.



Measuring Corrugations



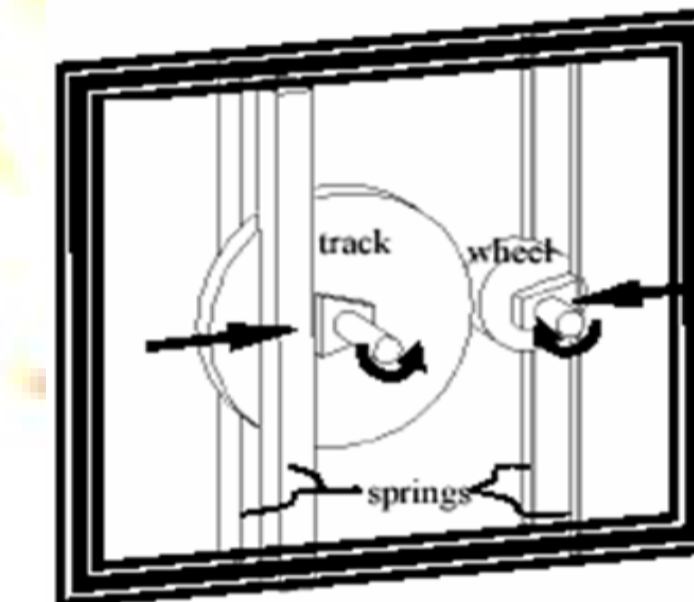
Field Growth results with Optimum Grind Interval



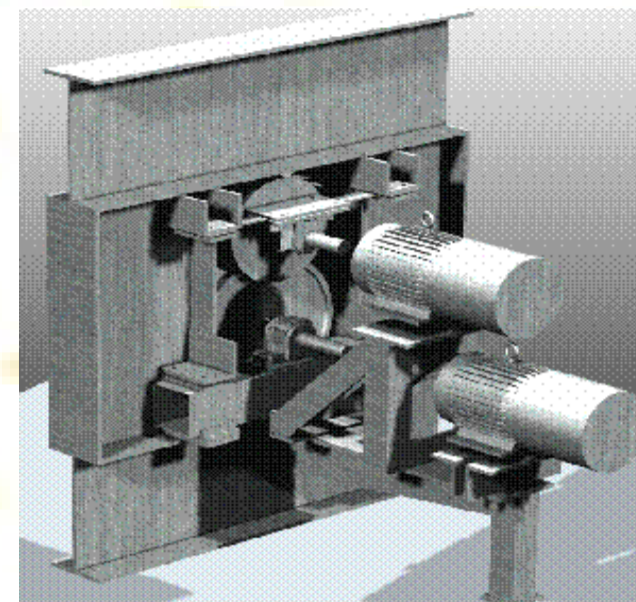
Test Rig

Design and manufacture of an experimental test rig to recreate rail corrugation.

Test Rig Concept



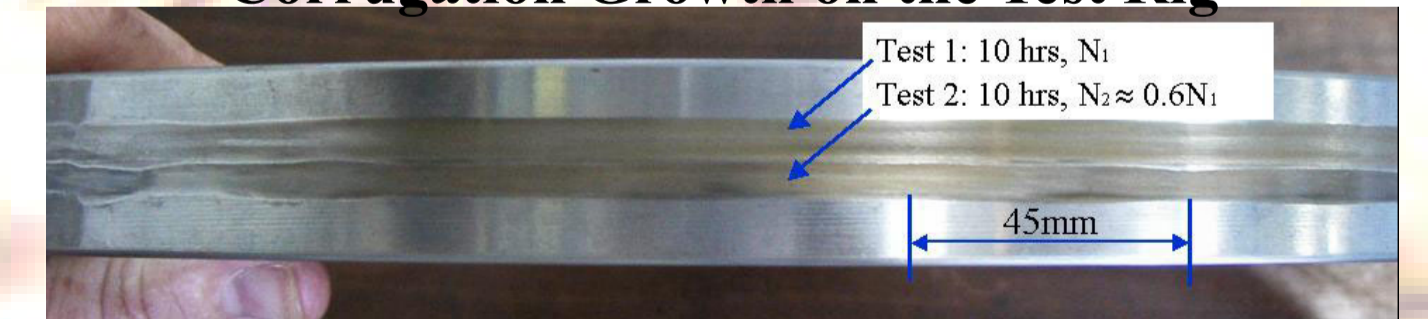
Test Rig Design



Rail Corrugation Test Rig



Corrugation Growth on the Test Rig



OUTCOMES—

- Application of this new insight in the form of a corrugation growth estimator system.
- Development of a control system for the mitigation of rail corrugation, using growth estimator technol-

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