

VEHICLE DYNAMICS
EXPO 2007

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**Tuning of the Steering Rack Stability Index for
Hydraulic and Electric Steering Applications**

**Conference
Vehicle Dynamics Expo
9 May 2007 in Stuttgart**

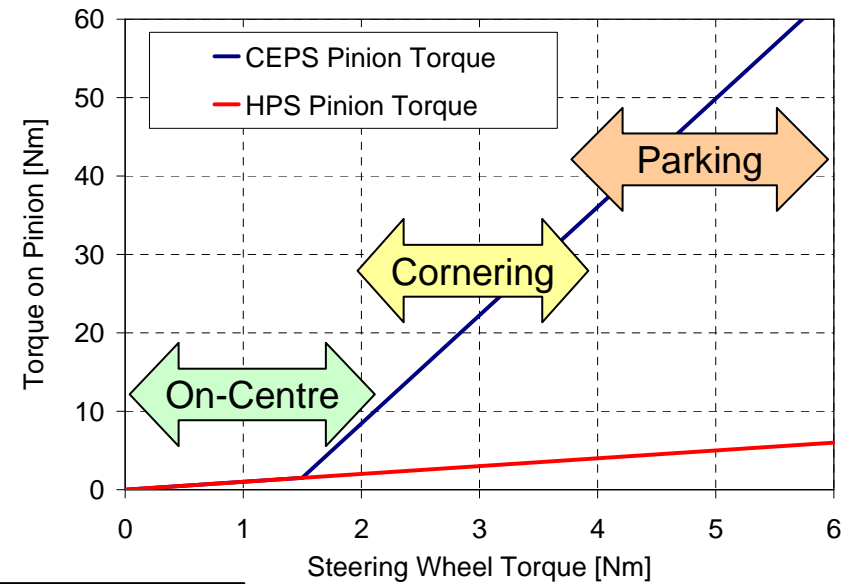
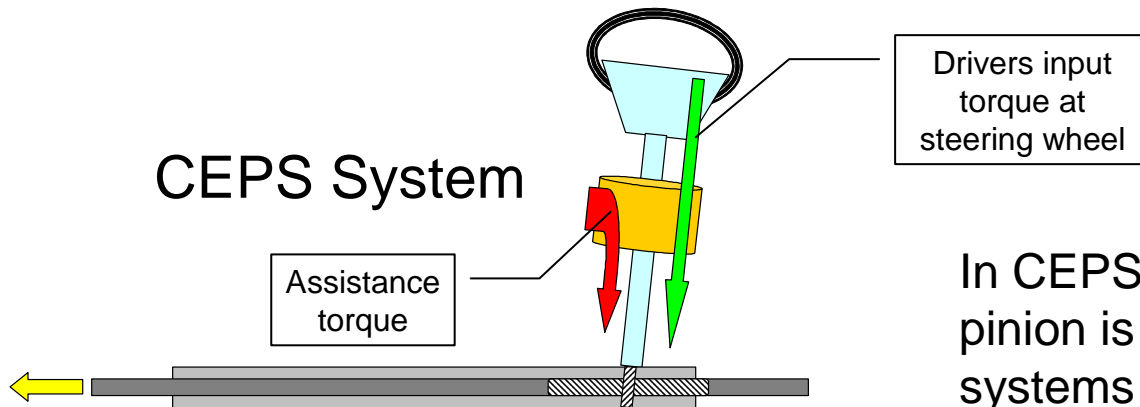
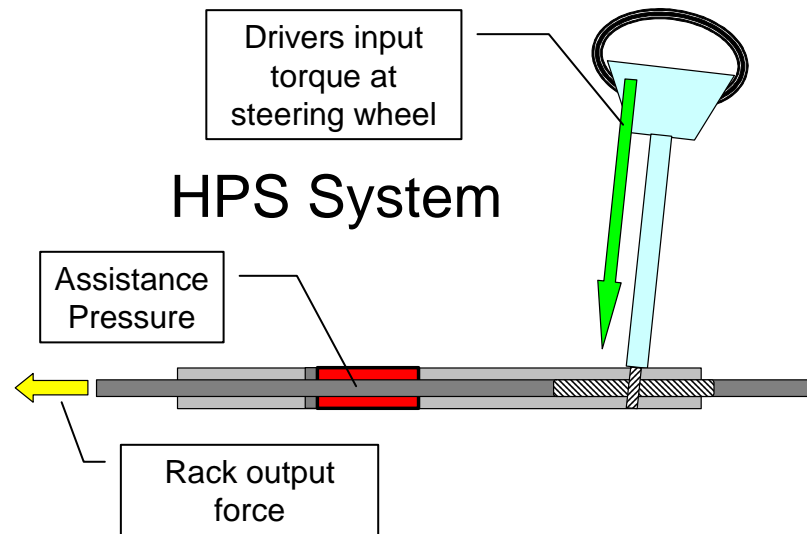
Outline

- Background / motivation for this study
- Analysis methods and results
- Influence of rack stability on steering gear function / vehicle dynamics
- Rack stability index
- Sensitivity study of rack stability
- Conclusion

Background / Motivation

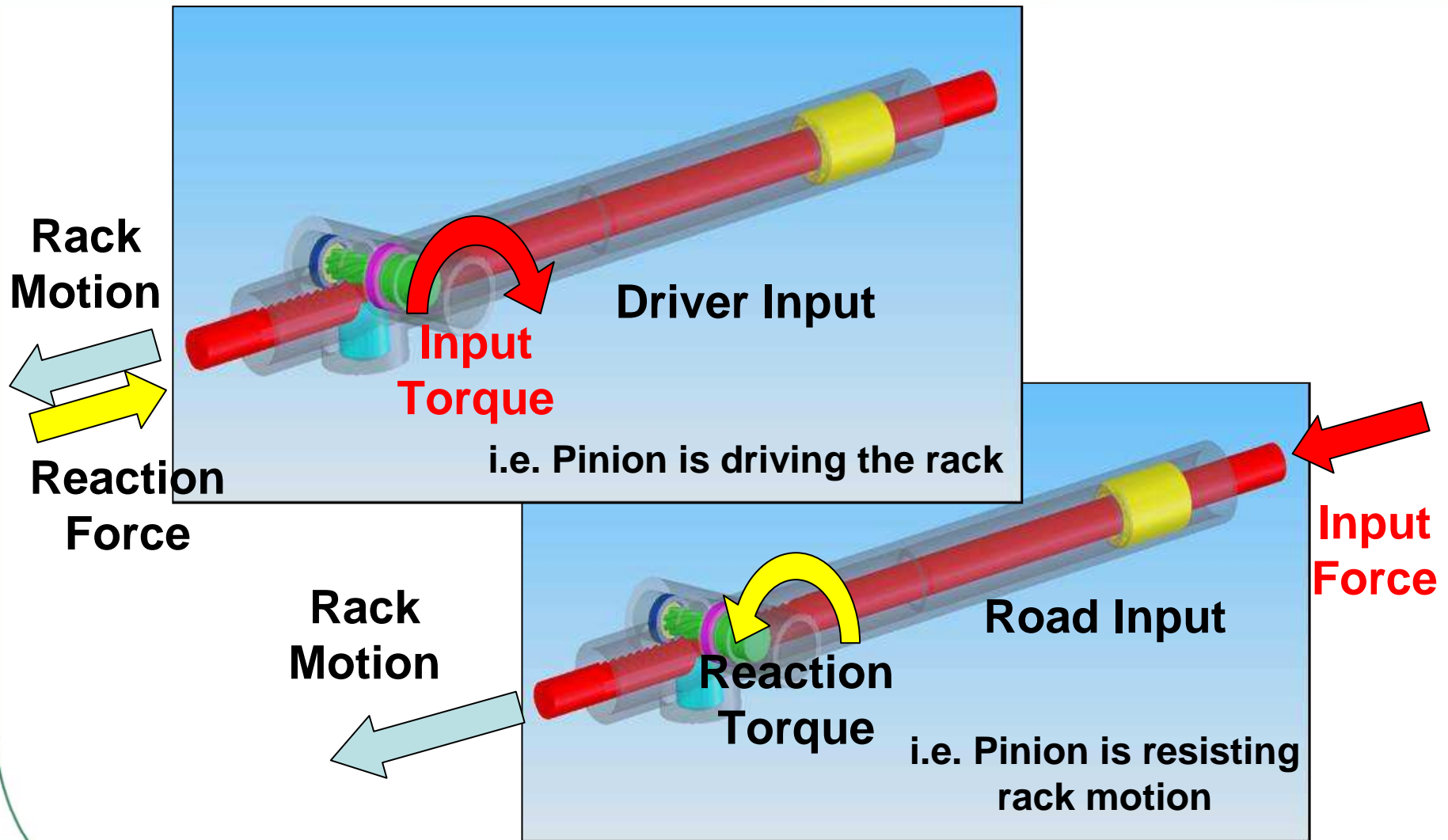
- Trend to change from HPS to EPS
- Delay in widespread acceptance of CEPS;
 - Reported as having poor feel
 - Some noise issues
- Different load conditions with CEPS compared to HPS in gear mesh
- Study conducted on the effect of 3D contact forces operating in gear mesh → results applicable to all types of steering systems

HPS v CEPS Pinion Torque



In CEPS systems torque through the pinion is significantly higher than HPS systems

Definition: Driver Input, Road Input

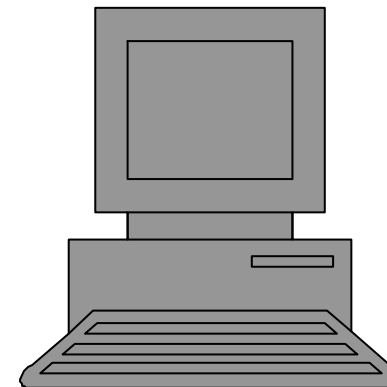
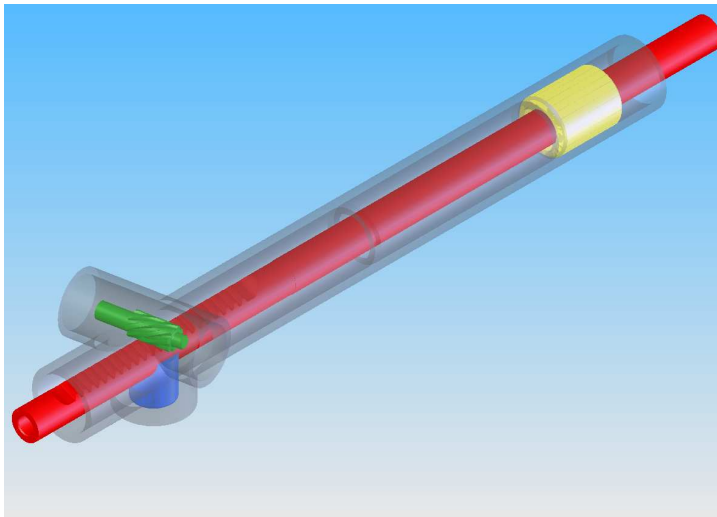


Overview of Study Methods



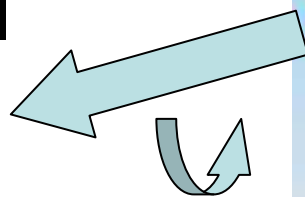
Rack stability has been studied including the effects of the 3D forces acting at the gear mesh using;

- Rig Test
- Simulation with 3D contact forces
- PC program based on a mathematical model



Definition: Rack Roll

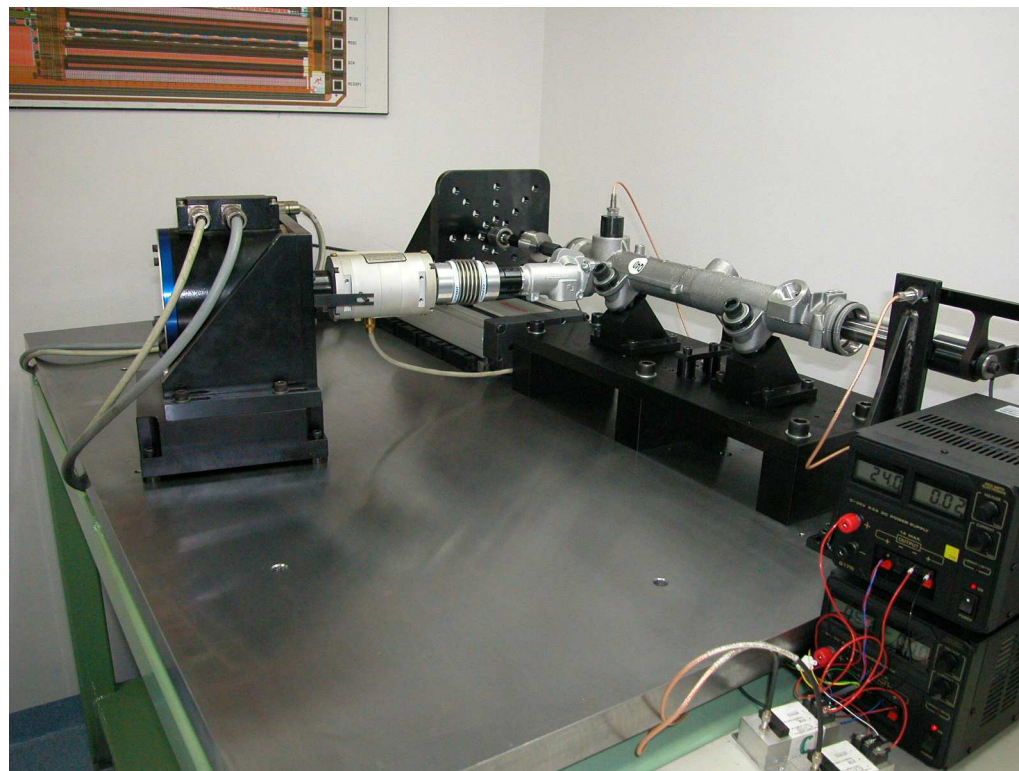
Axis aligned with
direction of rack
travel



Rack roll, rotation
about axis

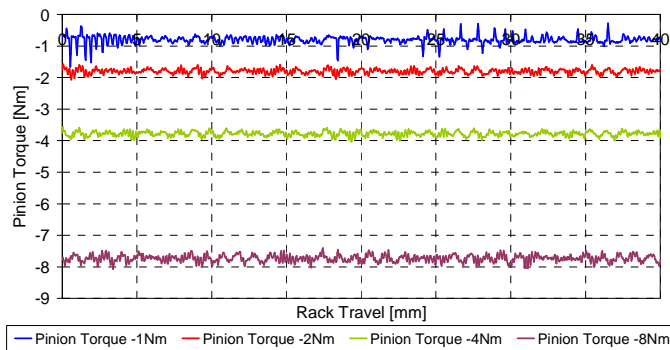
Rack Stability Test Rig

Steering Gear Test Rig constructed for validation of steering gear simulation model

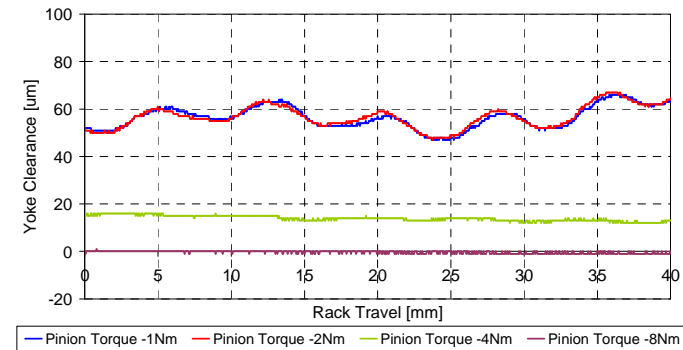


Rack Stability Test Rig Results, Driver Input

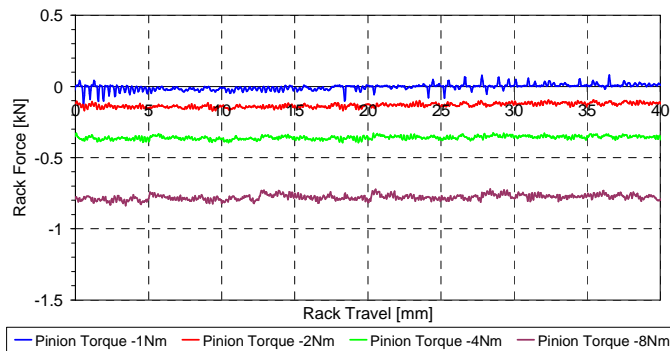
Rack Travel v Pinion Torque



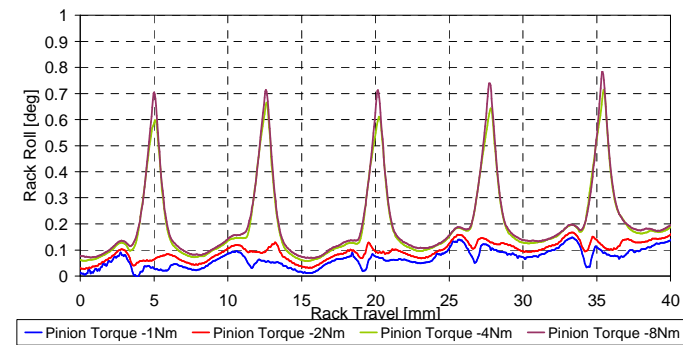
Rack Travel v Yoke Clearance



Rack Travel v Rack Force

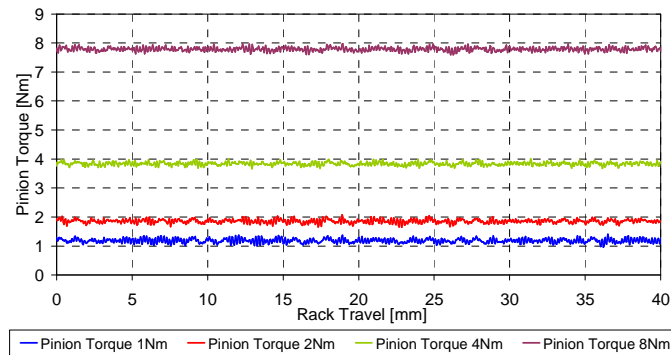


Rack Travel v Rack Roll

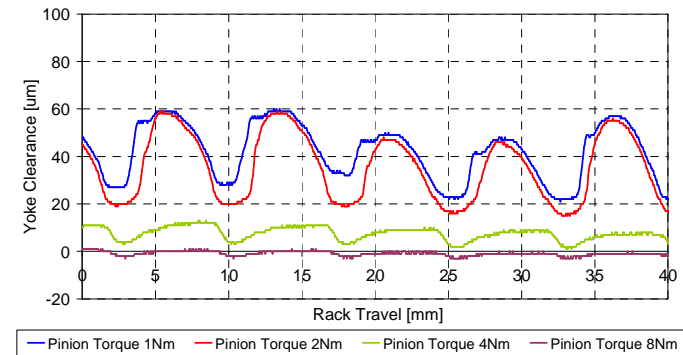


Rack Stability Test Rig Results, Road Input

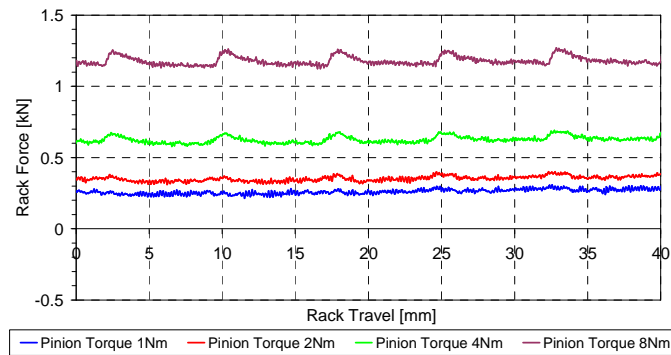
Rack Travel v Pinion Torque



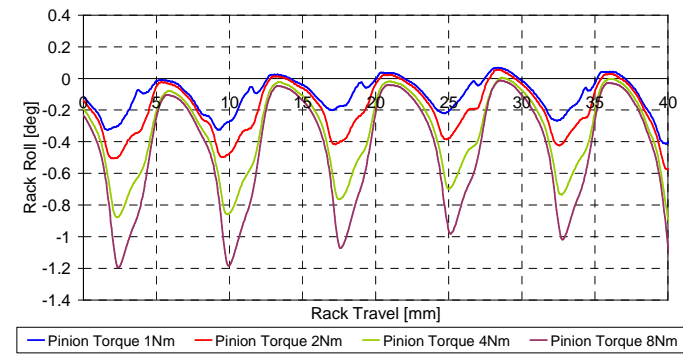
Rack Travel v Yoke Clearance



Rack Travel v Rack Force

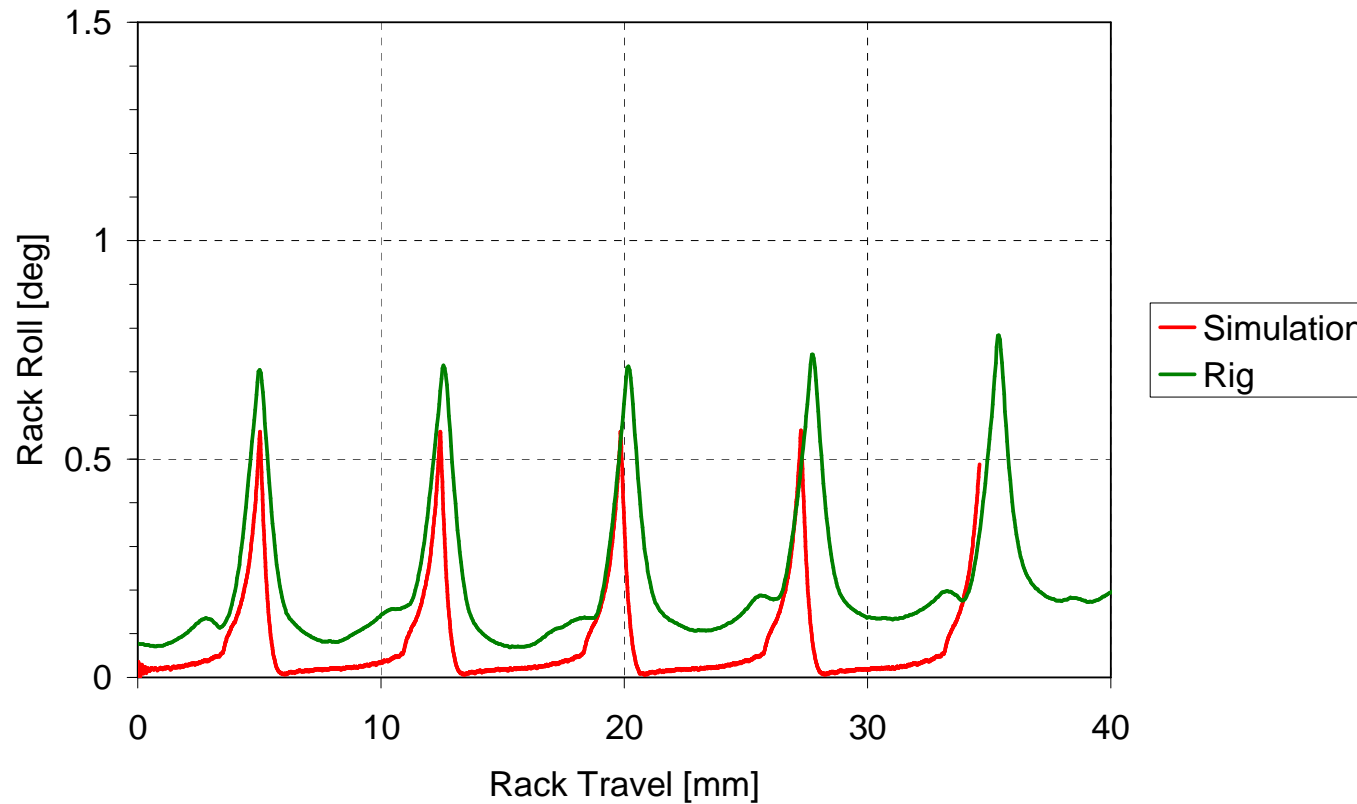


Rack Travel v Rack Roll

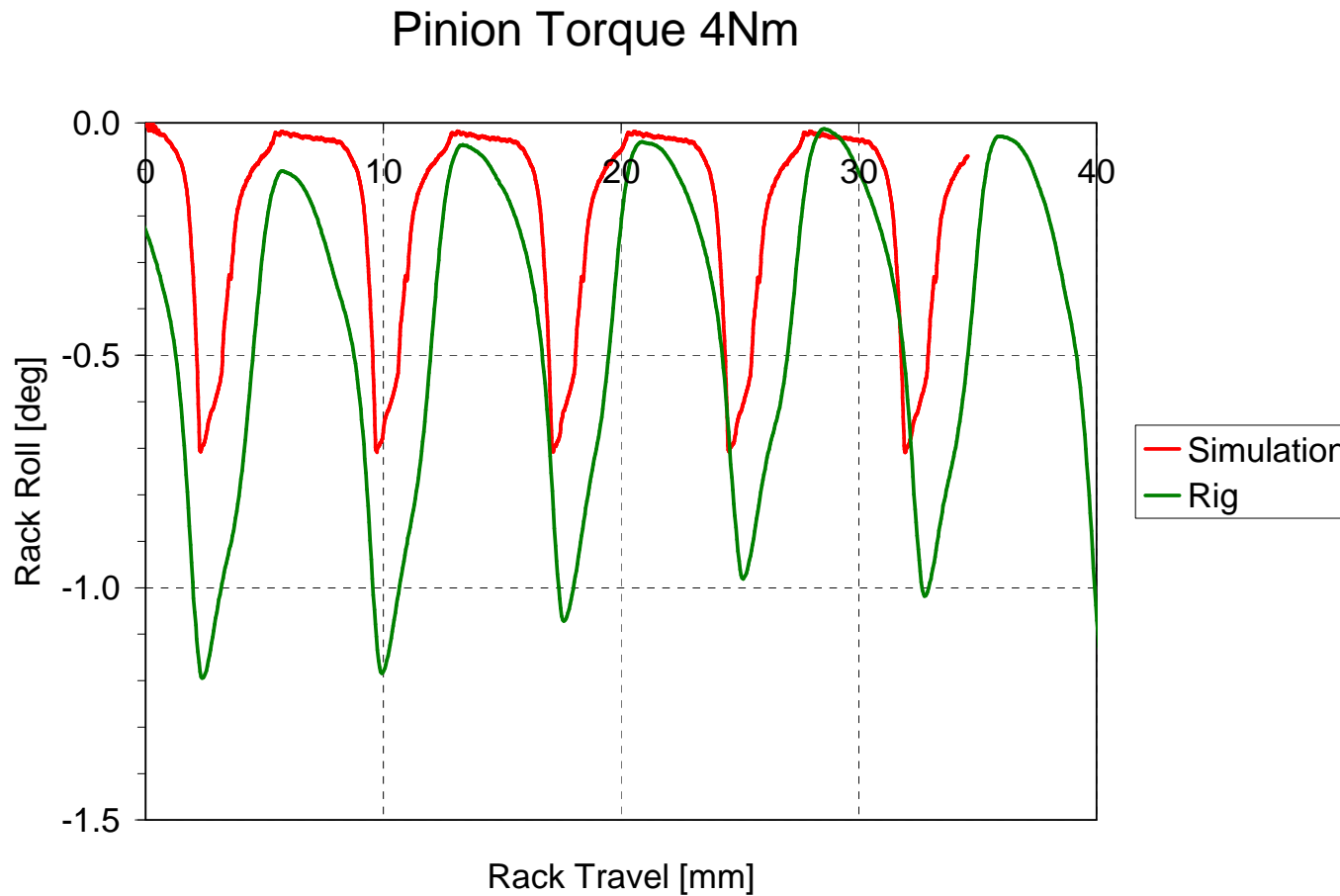


Simulation and Rig Results, Driver Input

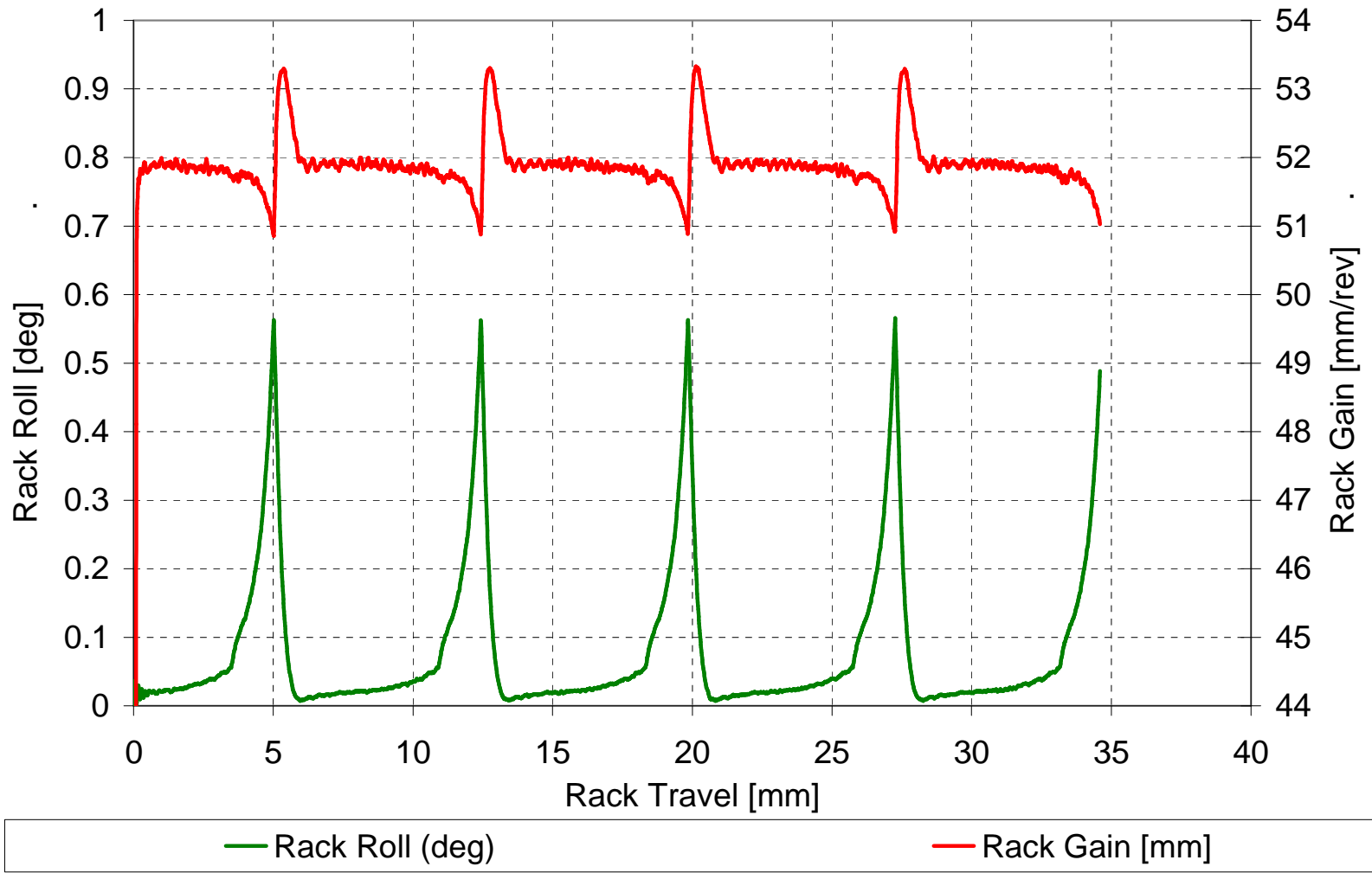
Pinion Torque 4Nm



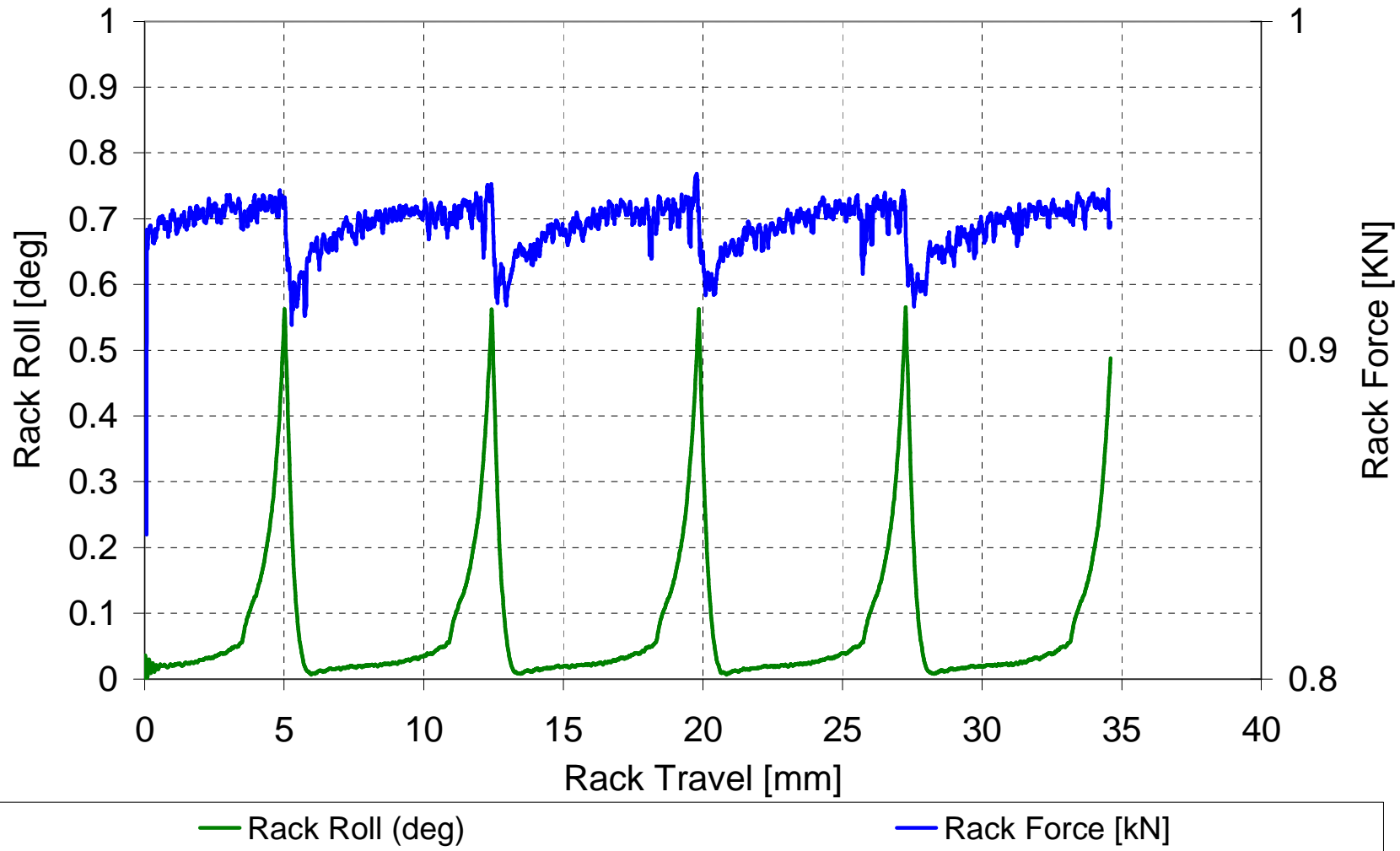
Simulation and Rig Results, Road Input



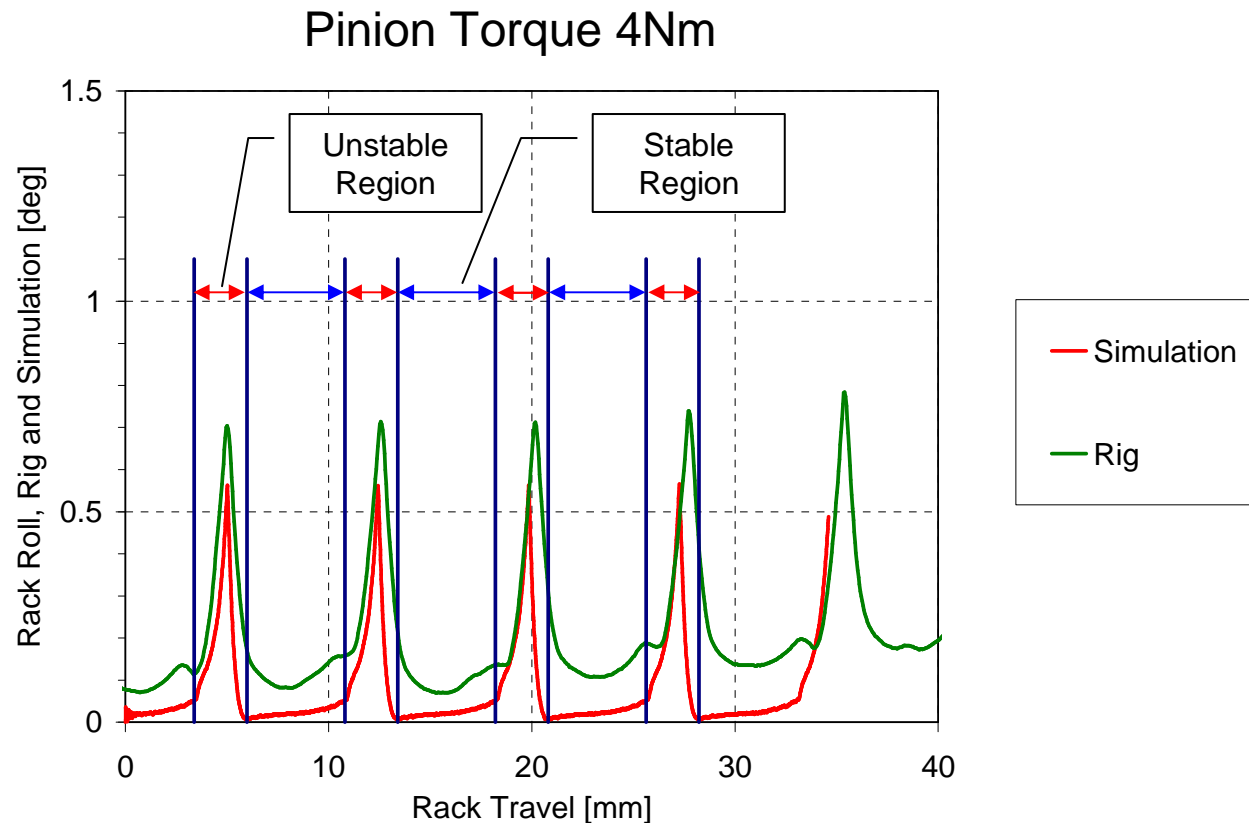
Rack Roll and Rack Gain Transmission Errors



Rack Roll and Rack Output Force Variation

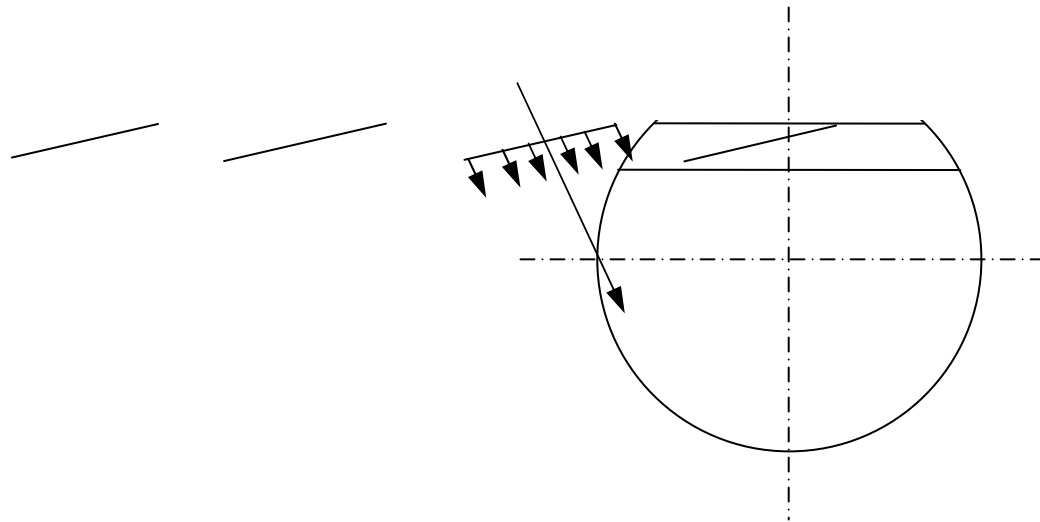


Identification of Stable and Unstable Regions



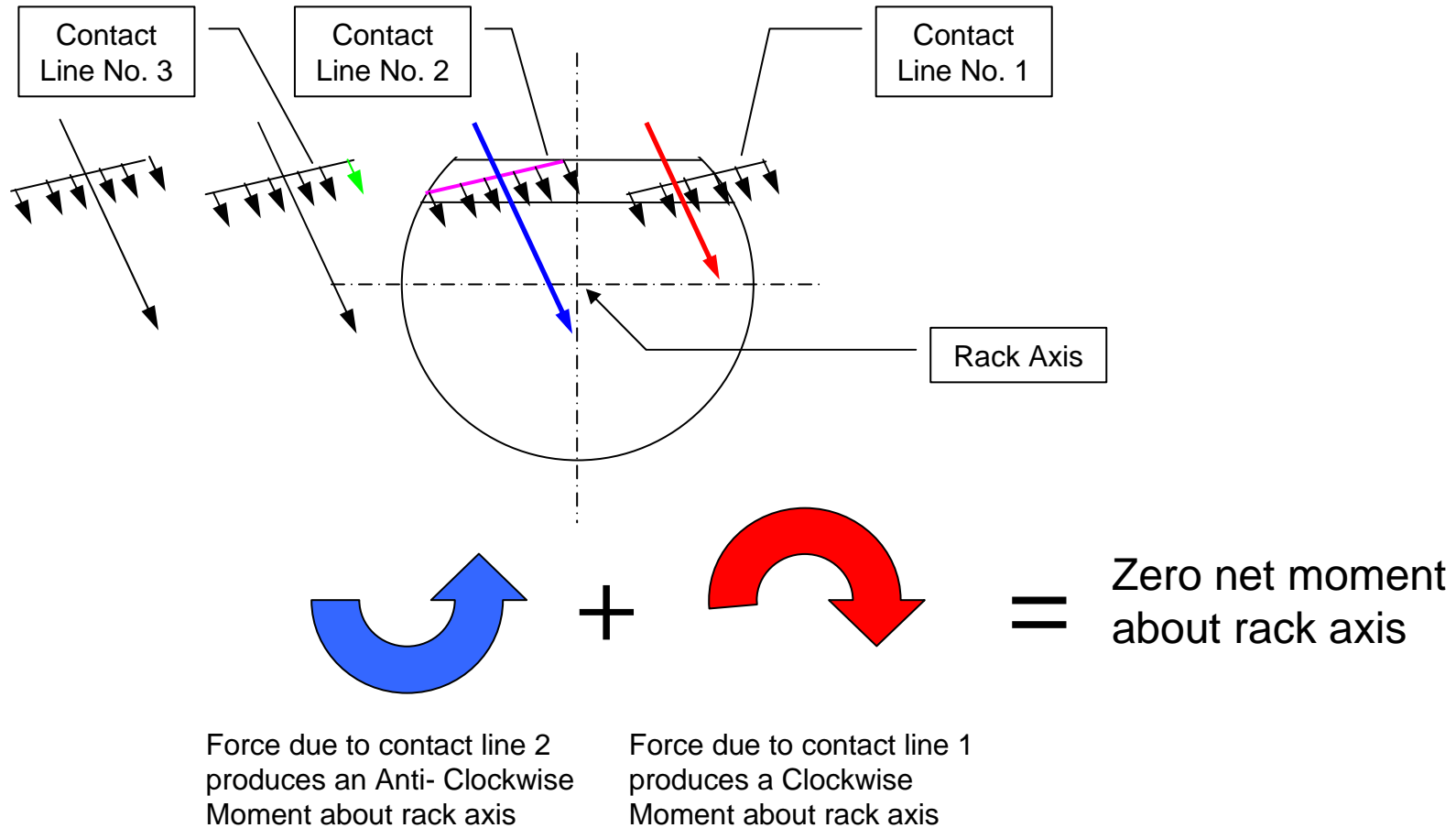
Task, develop an algorithm to predict stable and unstable regions as part of gear mesh design!

Contact Line Movement

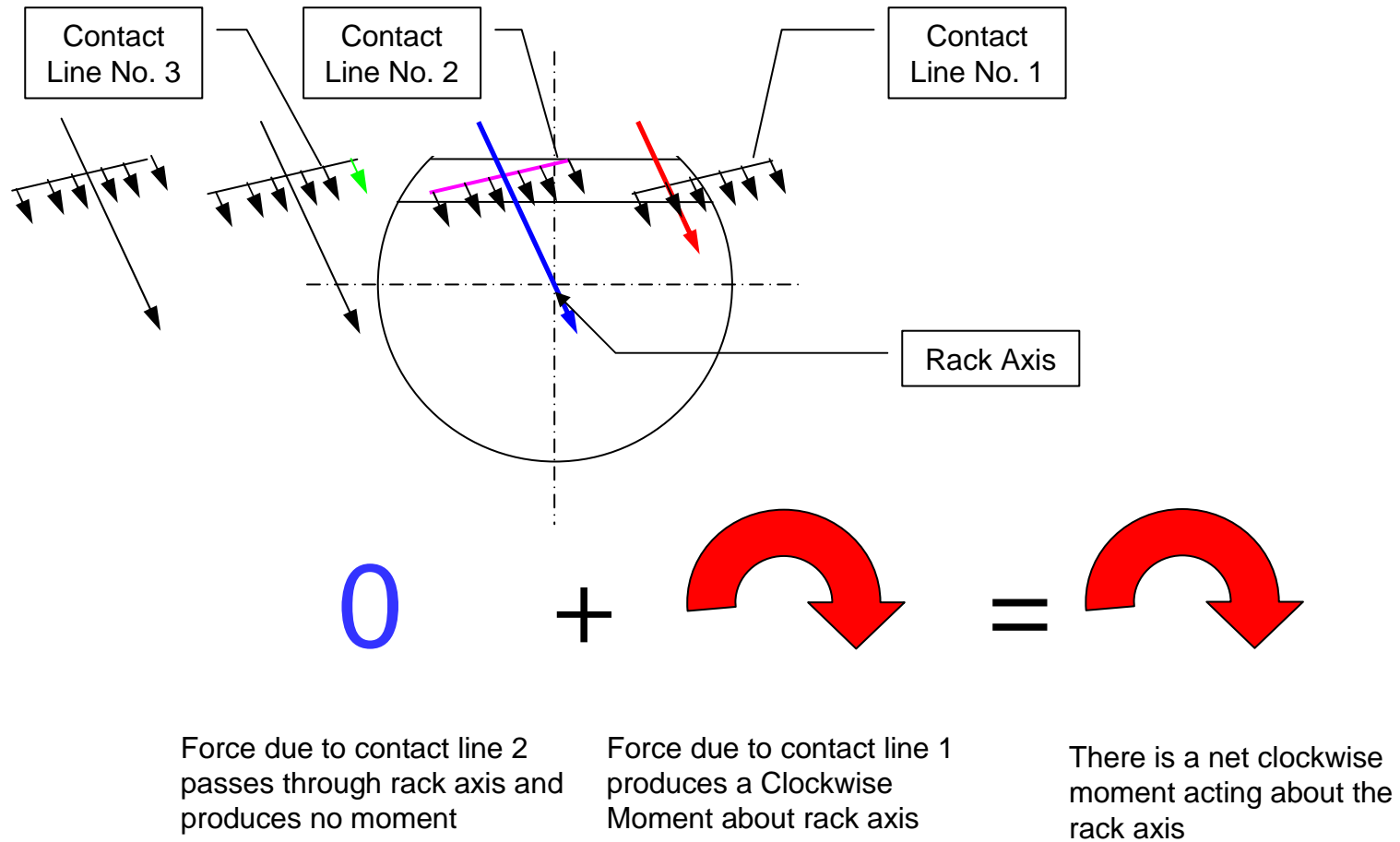


The pinion is driving the rack into the slide, hence the contact lines appear to move across the page

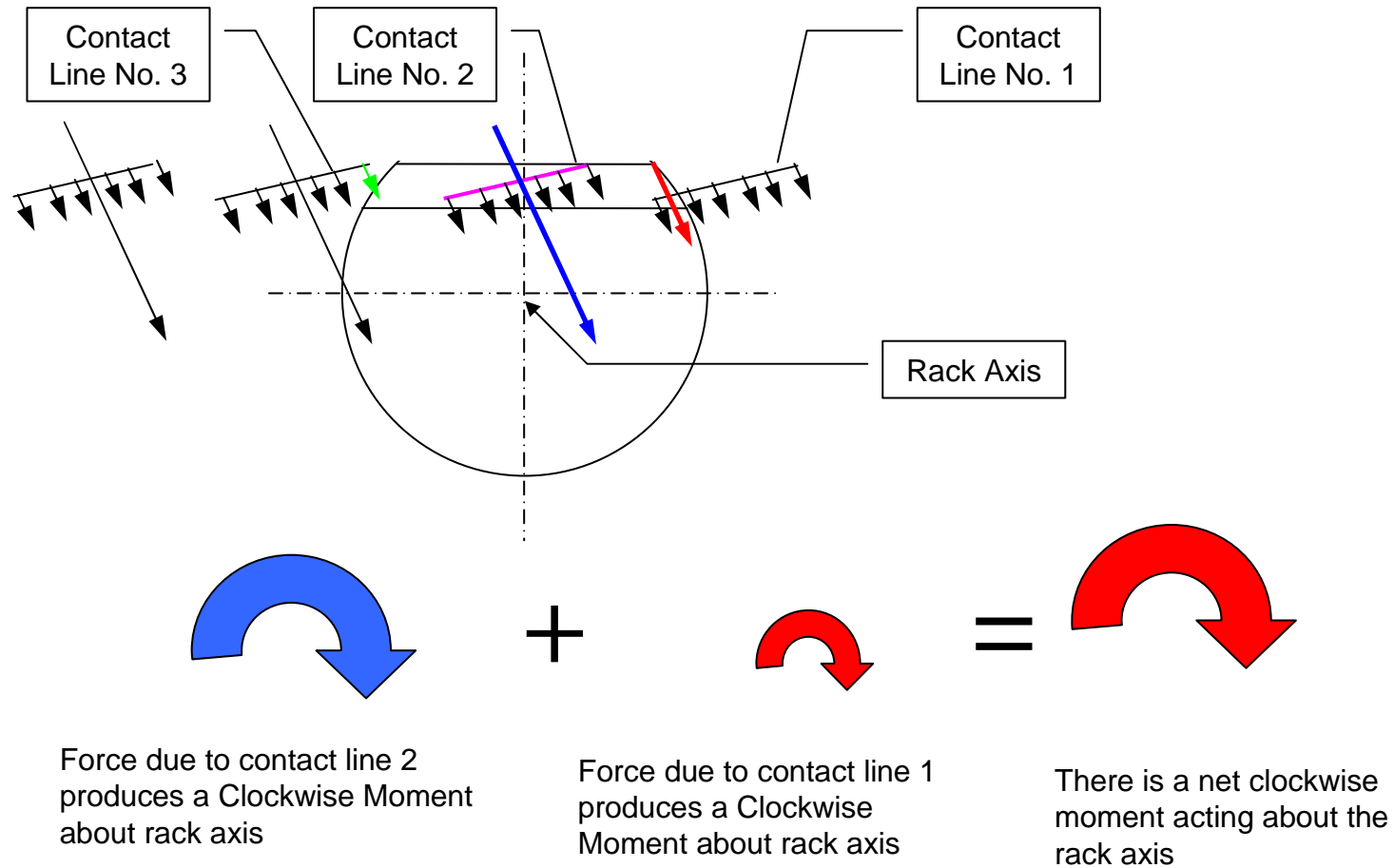
Contact Line Location, Stable



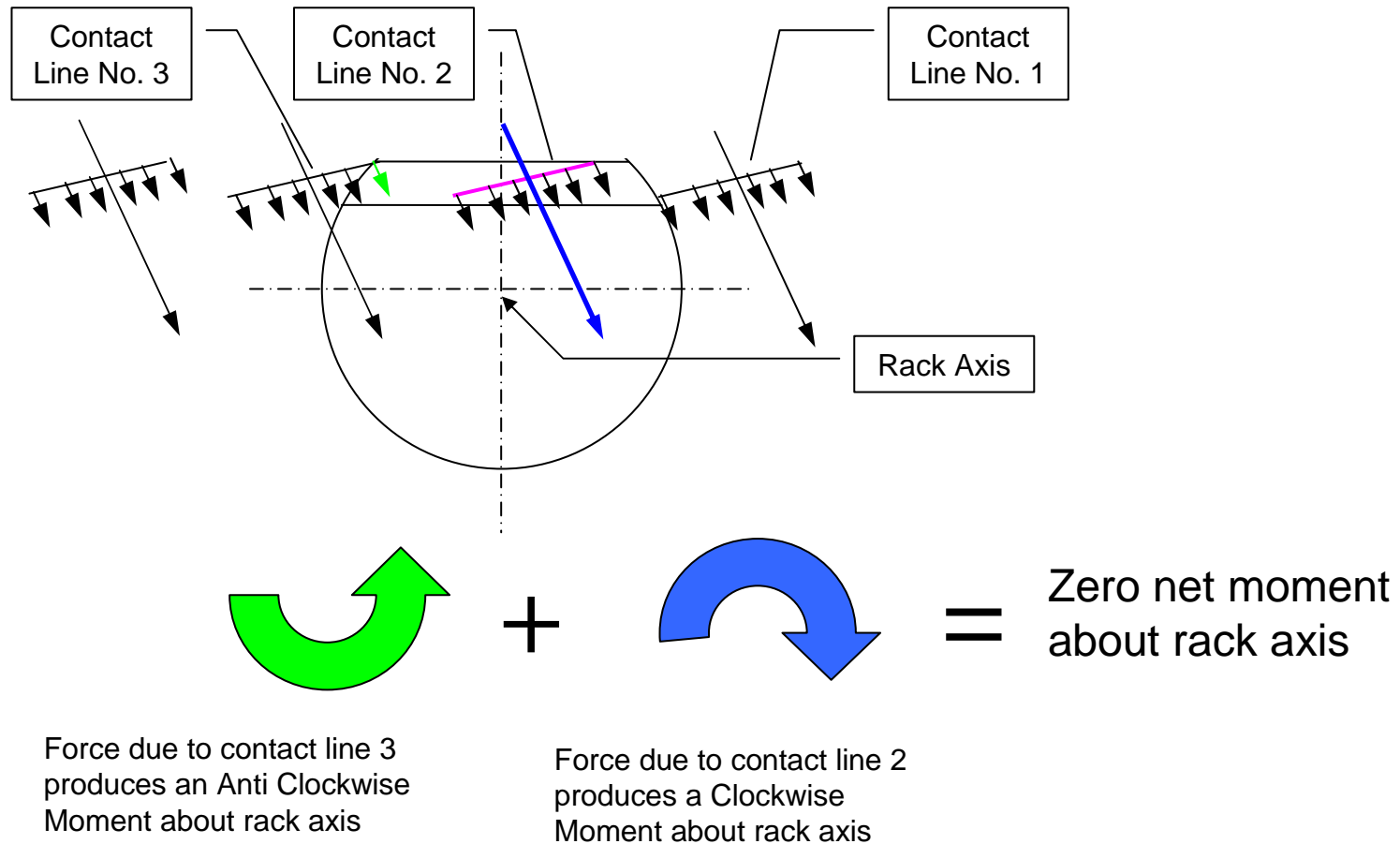
Contact Line Location, Start of Unstable Region



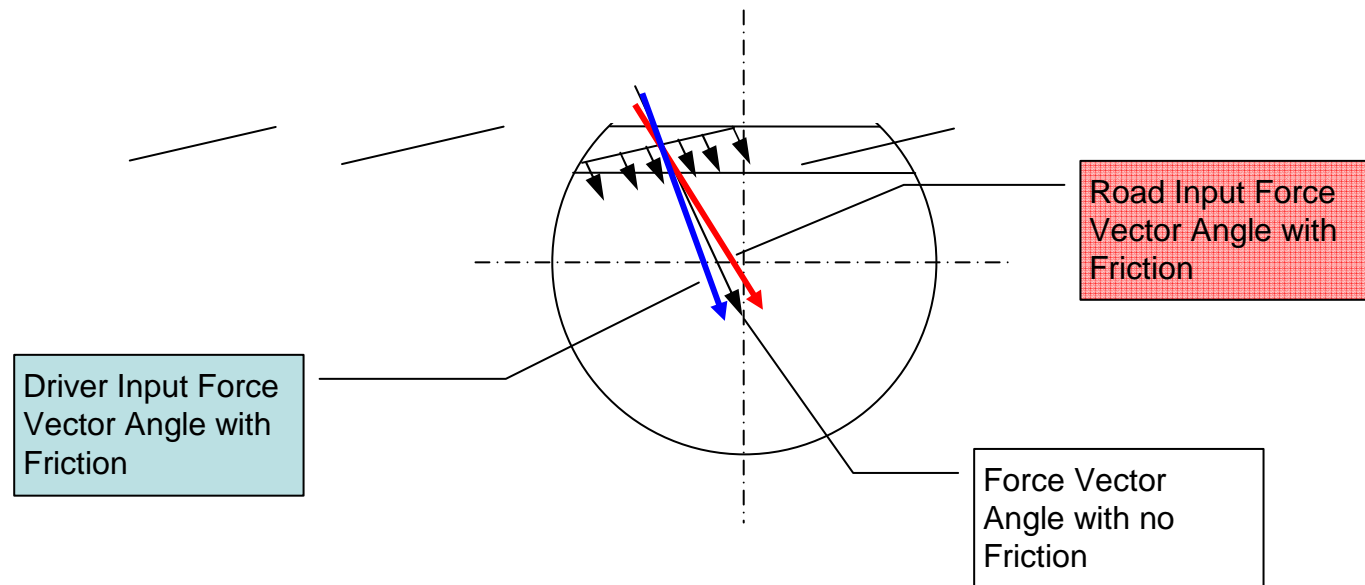
Contact Line Location, Middle of Unstable Region



Contact Line Location, End of Unstable Region

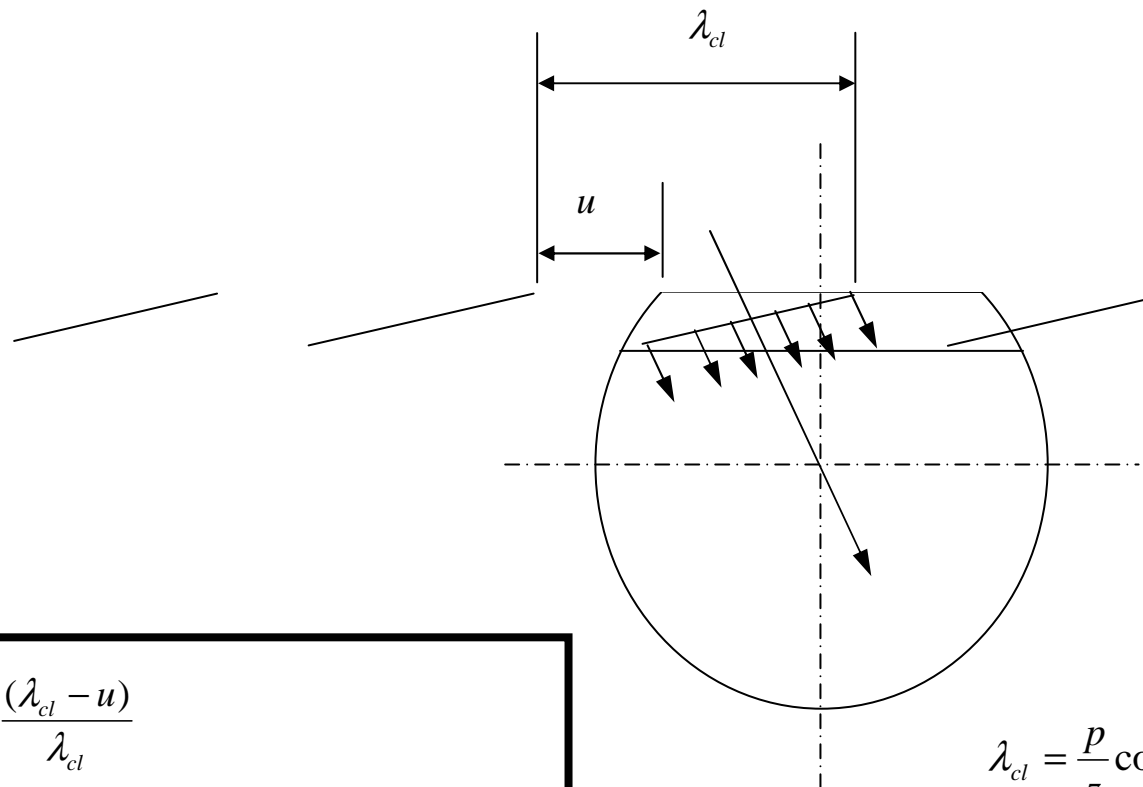


Addition of Friction to Model



Friction changes the angle of the force vector from the contact line.
Result mesh more stable for driver inputs and less stable for road inputs.

Stability Index Calculation



$$SI = \frac{(\lambda_{cl} - u)}{\lambda_{cl}}$$

Where.

SI Stability Index
 λ_{cl} contact line wave length (mm)
 u length of unstable region (mm)

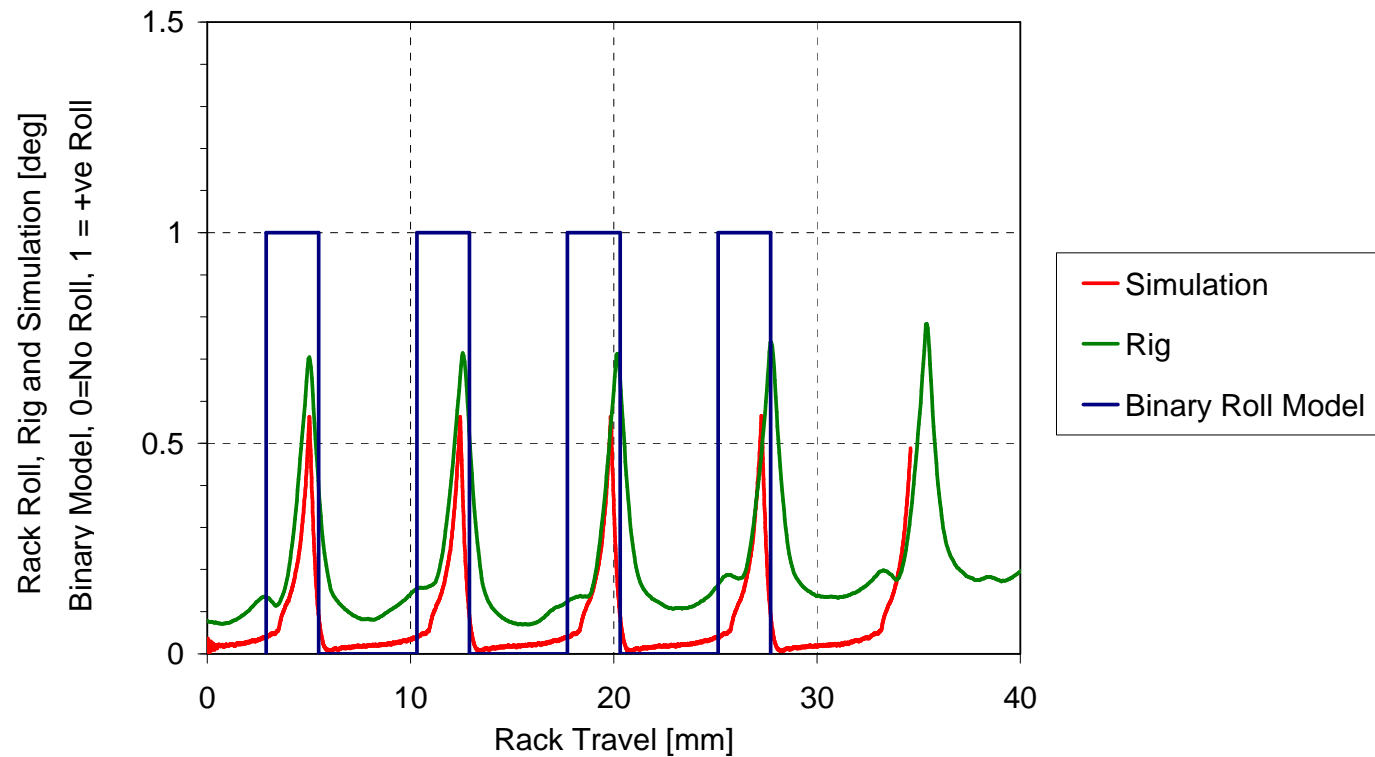
$$\lambda_{cl} = \frac{p}{z} \cos \Sigma$$

Where.

p lead of helix on pinion (mm)
 z number of teeth on pinion
 Σ installation angle of pinion (deg)

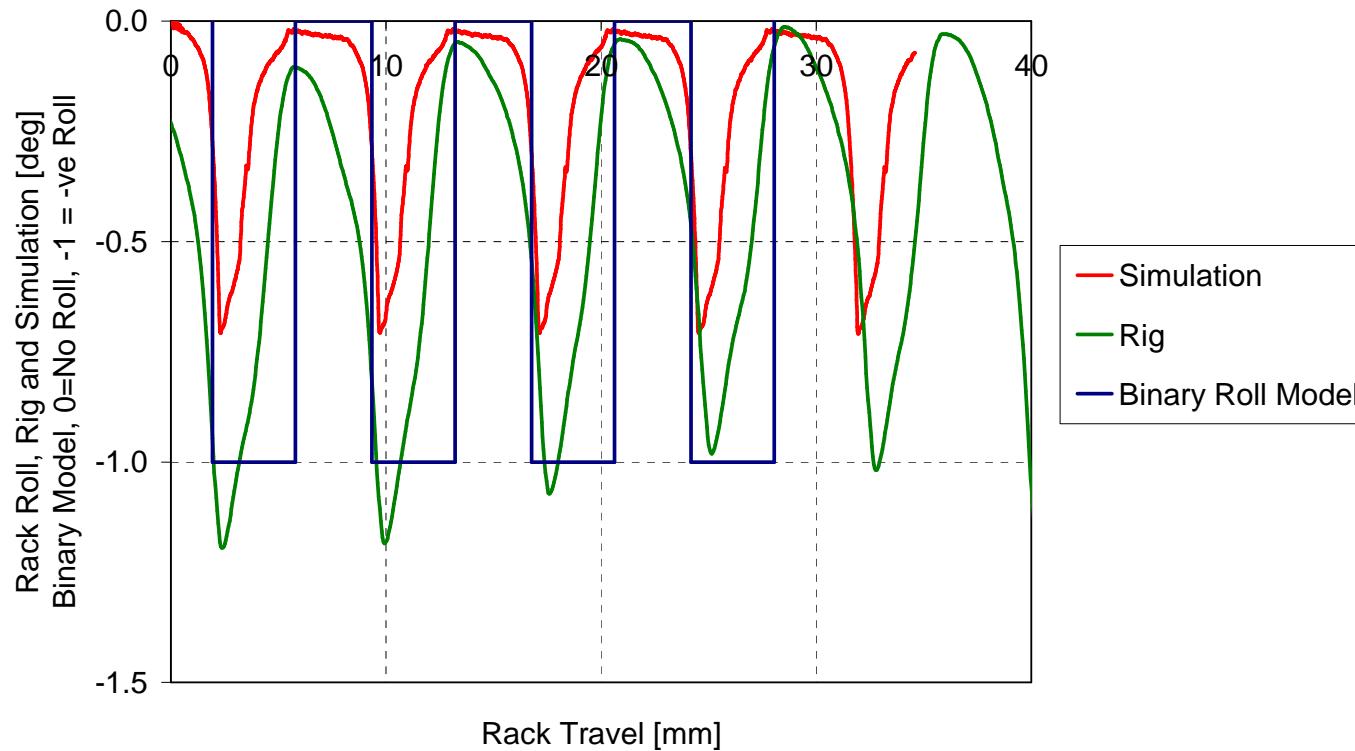
Rack Stability Binary Model, Driver Input

Pinion Torque 4Nm



Rack Stability Binary Model, Road Input

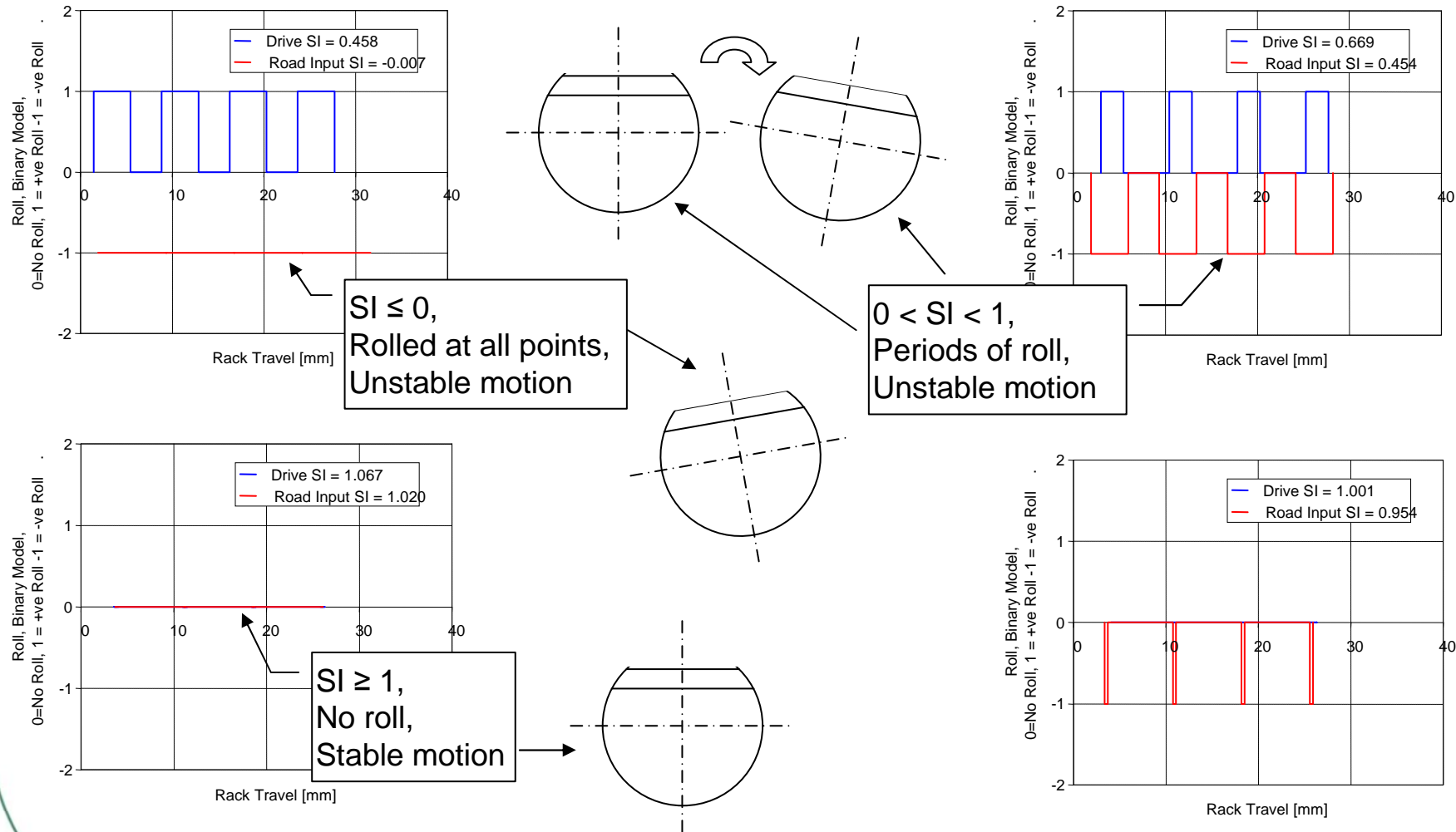
Pinion Torque 4Nm



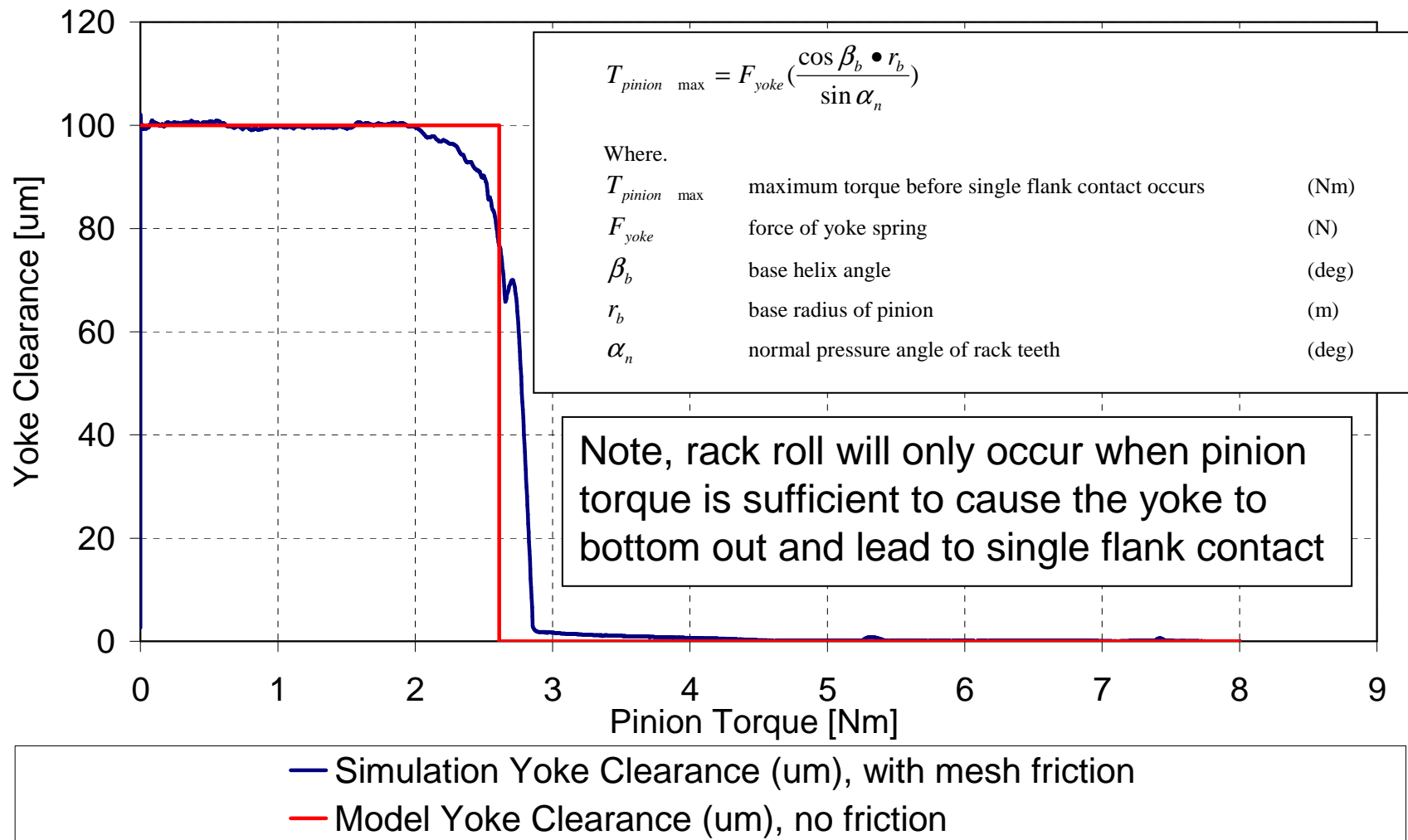
Interpretation of Stability Index (SI)

- $SI \leq 0$, rack rolled at all locations
- $0 < SI < 1$, periods of stable motion and unstable motion, the higher the number the greater percentage of stable motion
- $SI \geq 1$ stable for all locations
- SI in drive mode is greater than road input due to friction direction
- Can be stable in drive and unstable for road input

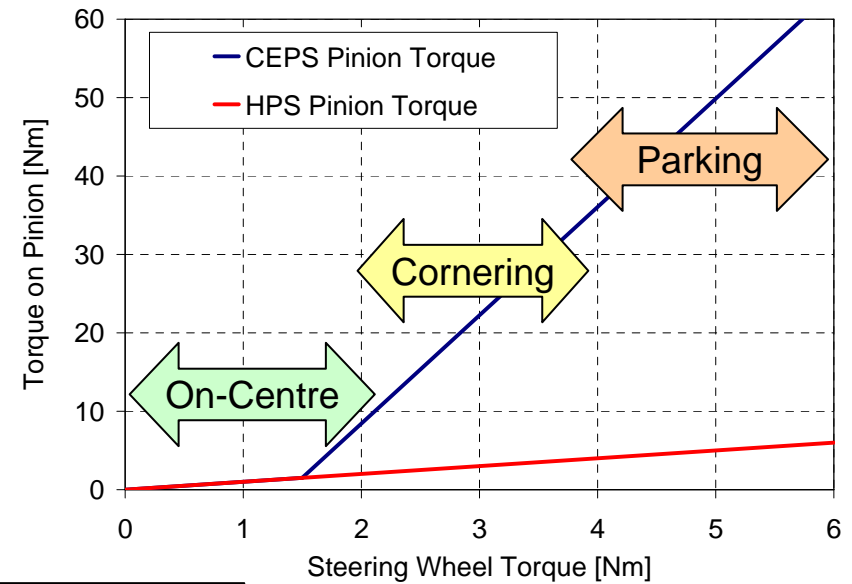
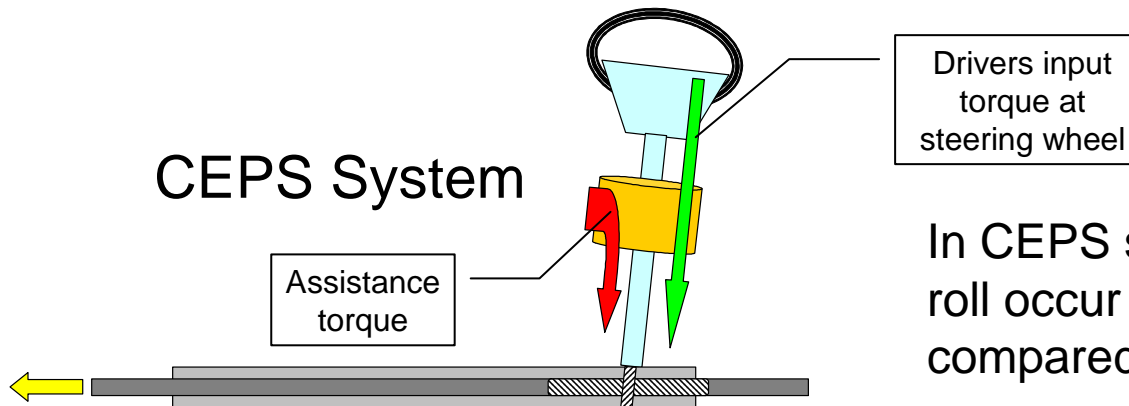
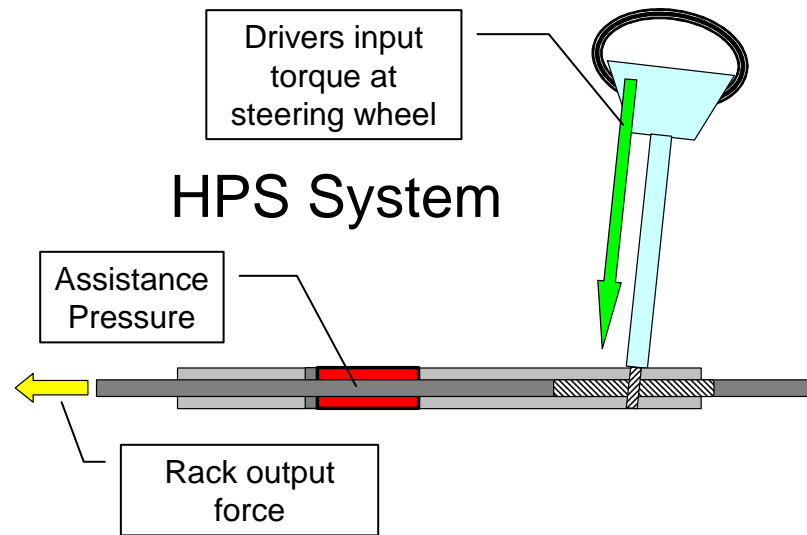
Stability and Prediction of Stable and Unstable Regions



Dual to Single Flank Torque



HPS v CEPS Pinion Torque

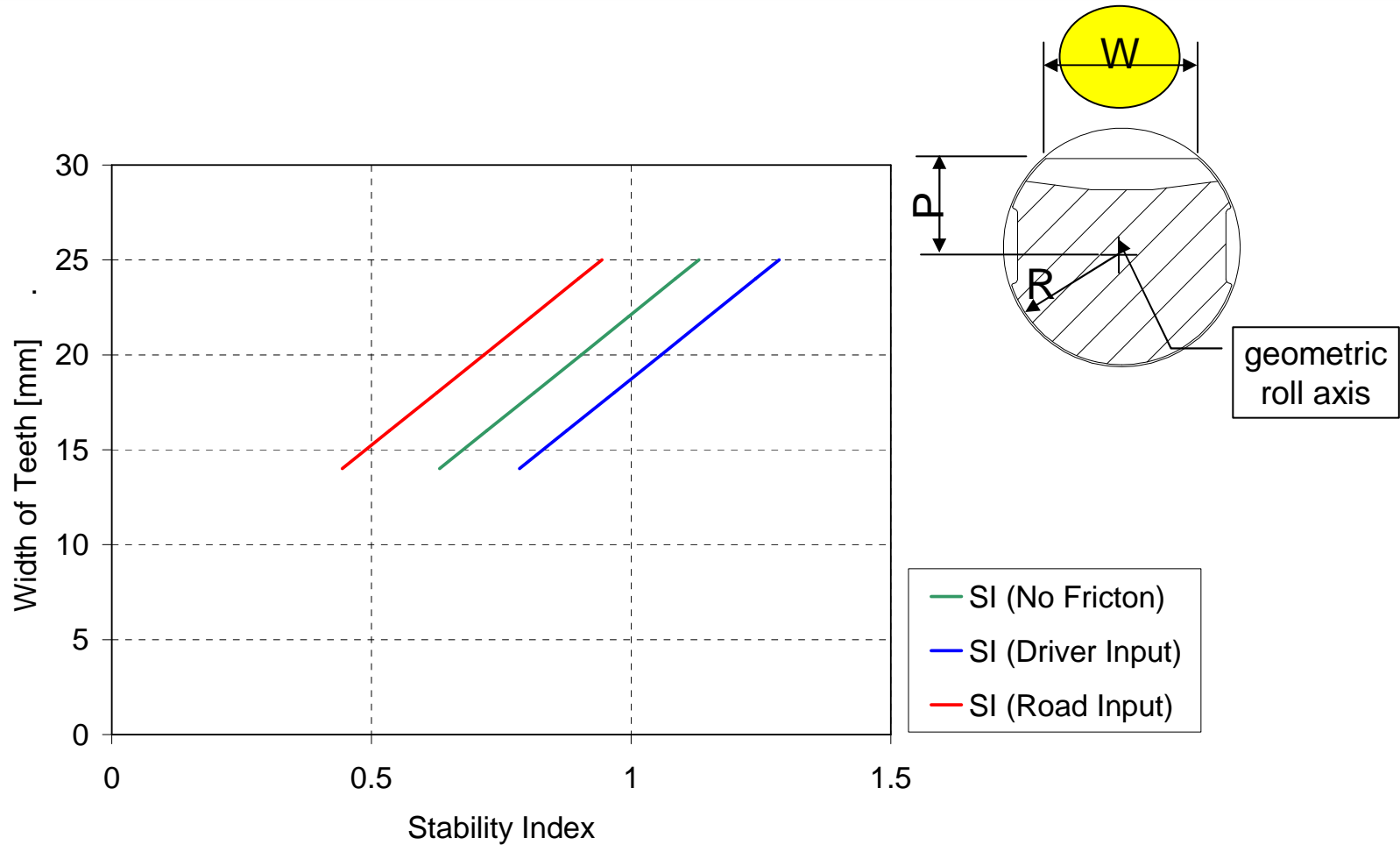


In CEPS systems potential for rack to roll occur during low level cornering, compared to parking conditions for HPS

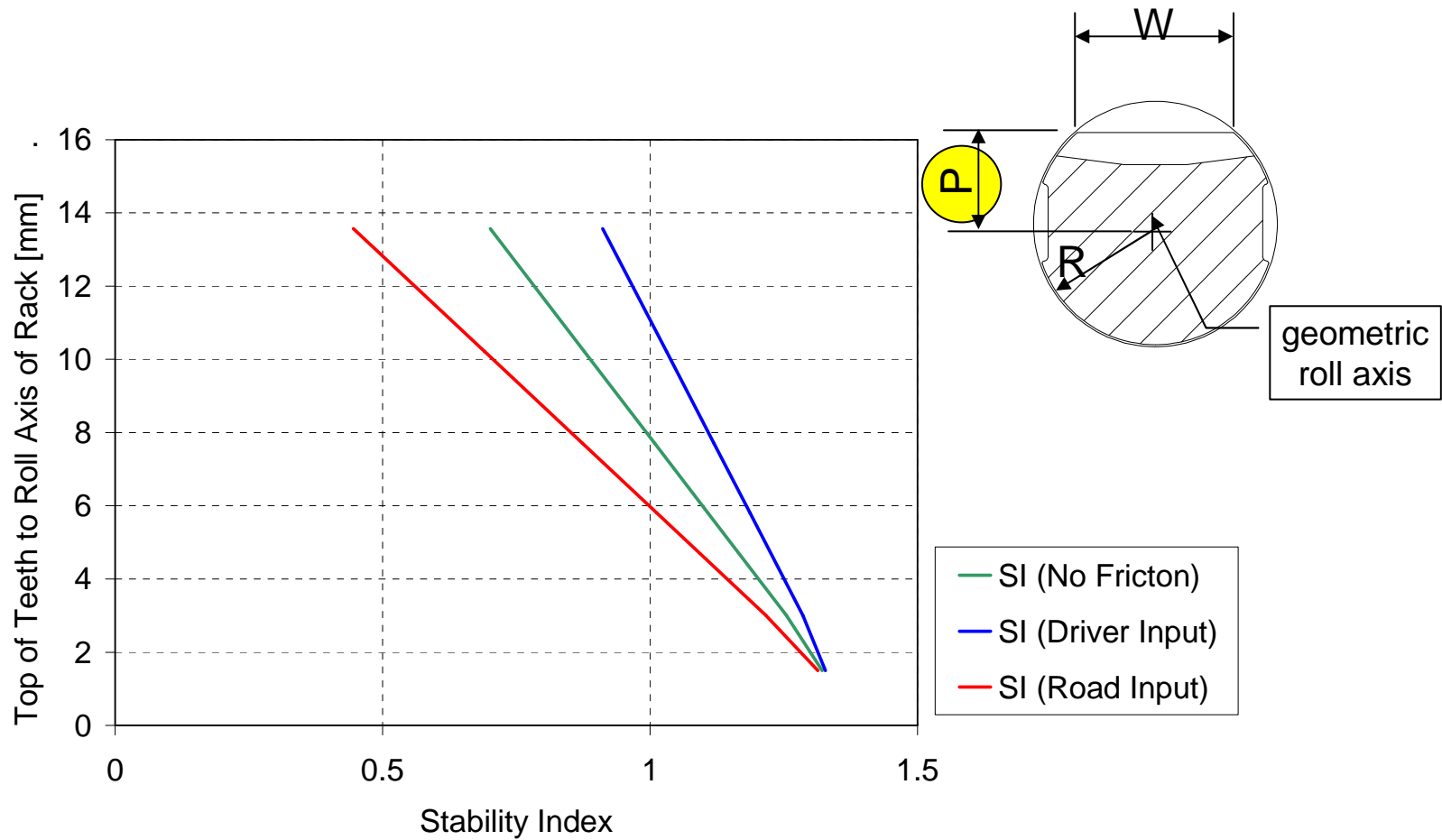
Parameters which influence SI

Parameter	SI Increased by;
Width of rack teeth (W)	Increasing teeth width
Top of teeth to roll axis of rack (P)	Reducing this distance
Normal pressure angle of rack teeth	Increasing normal pressure angle
Skew angle	Reducing the skew angle
Mesh Friction	SI for driver input is increased by increasing friction, but this will reduce road input SI
Yoke clearance	Reducing yoke clearance
etc...	

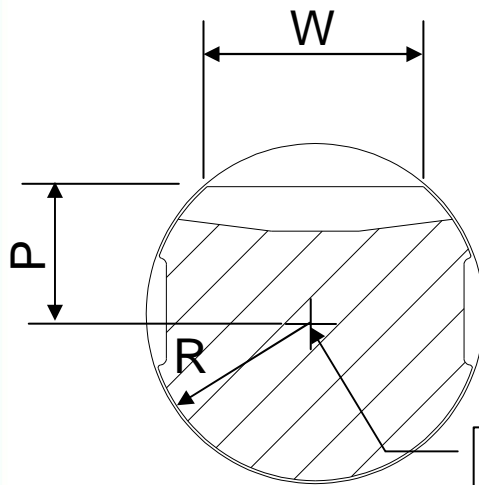
Parameters which influence SI



Parameters which influence SI

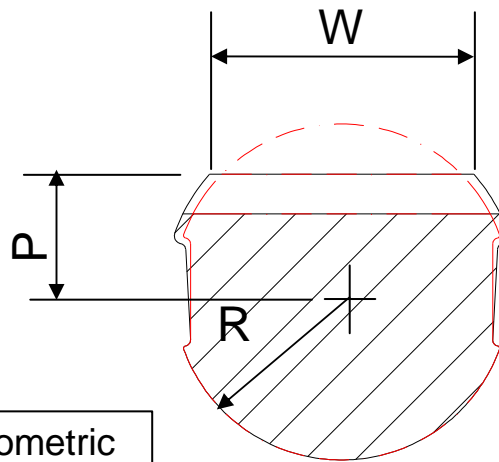


Parameters which influence SI, Rack Section



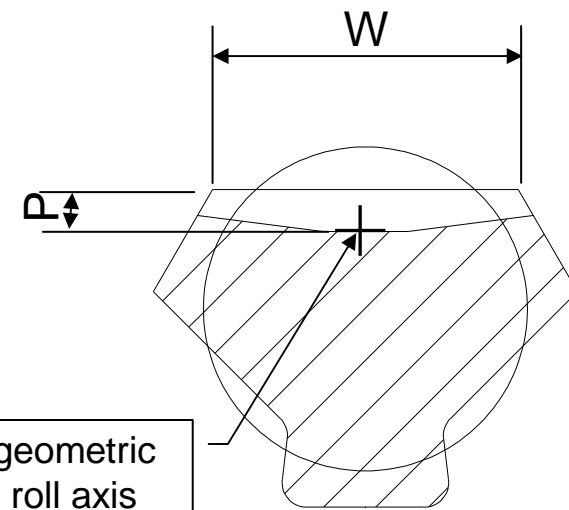
D Rack

As 'P' is increased 'W' is decreased, further reducing the SI



Modified D Rack

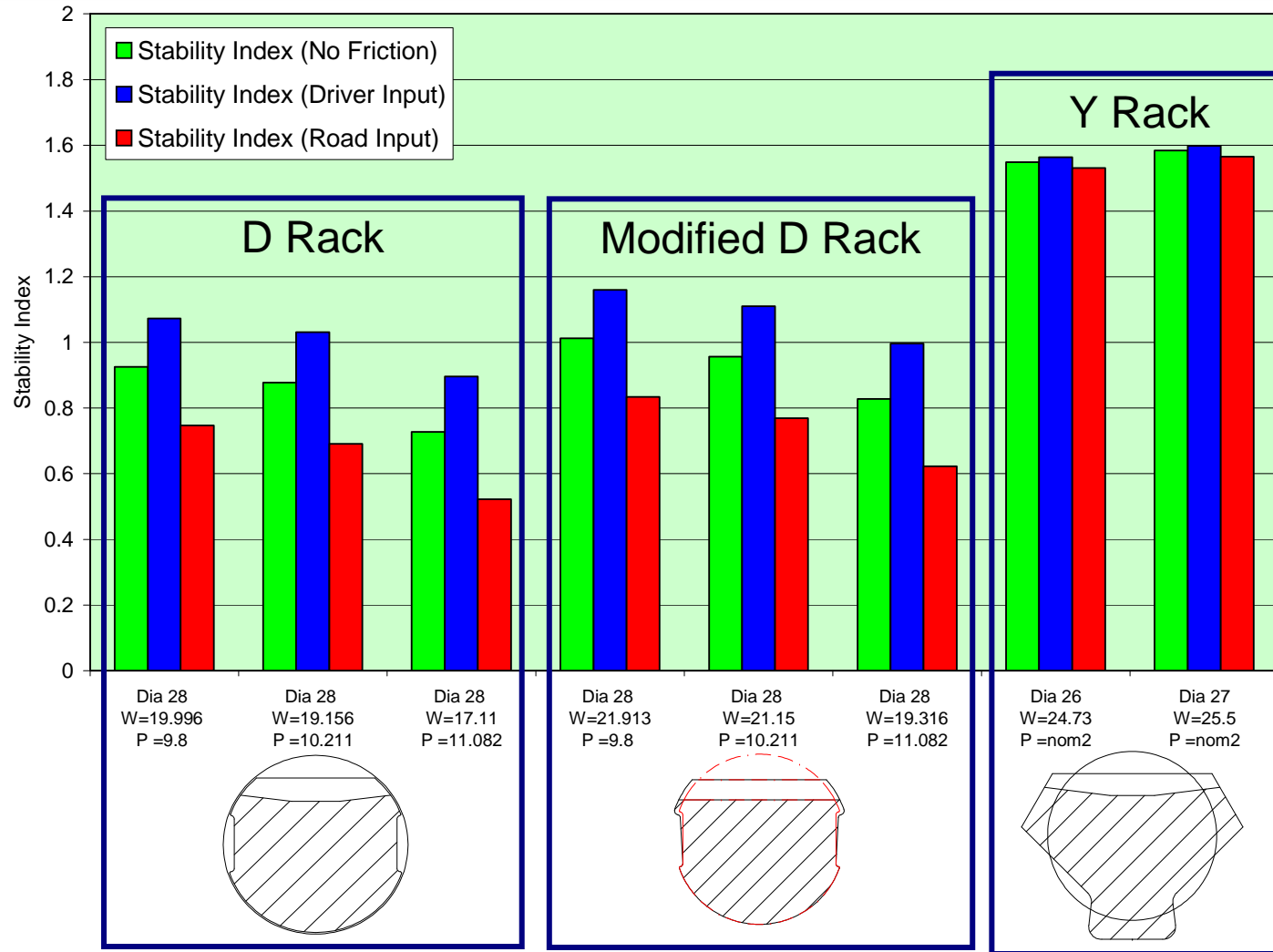
As 'P' is increased 'W' can be adjusted slightly, to improve SI compared to base D rack design



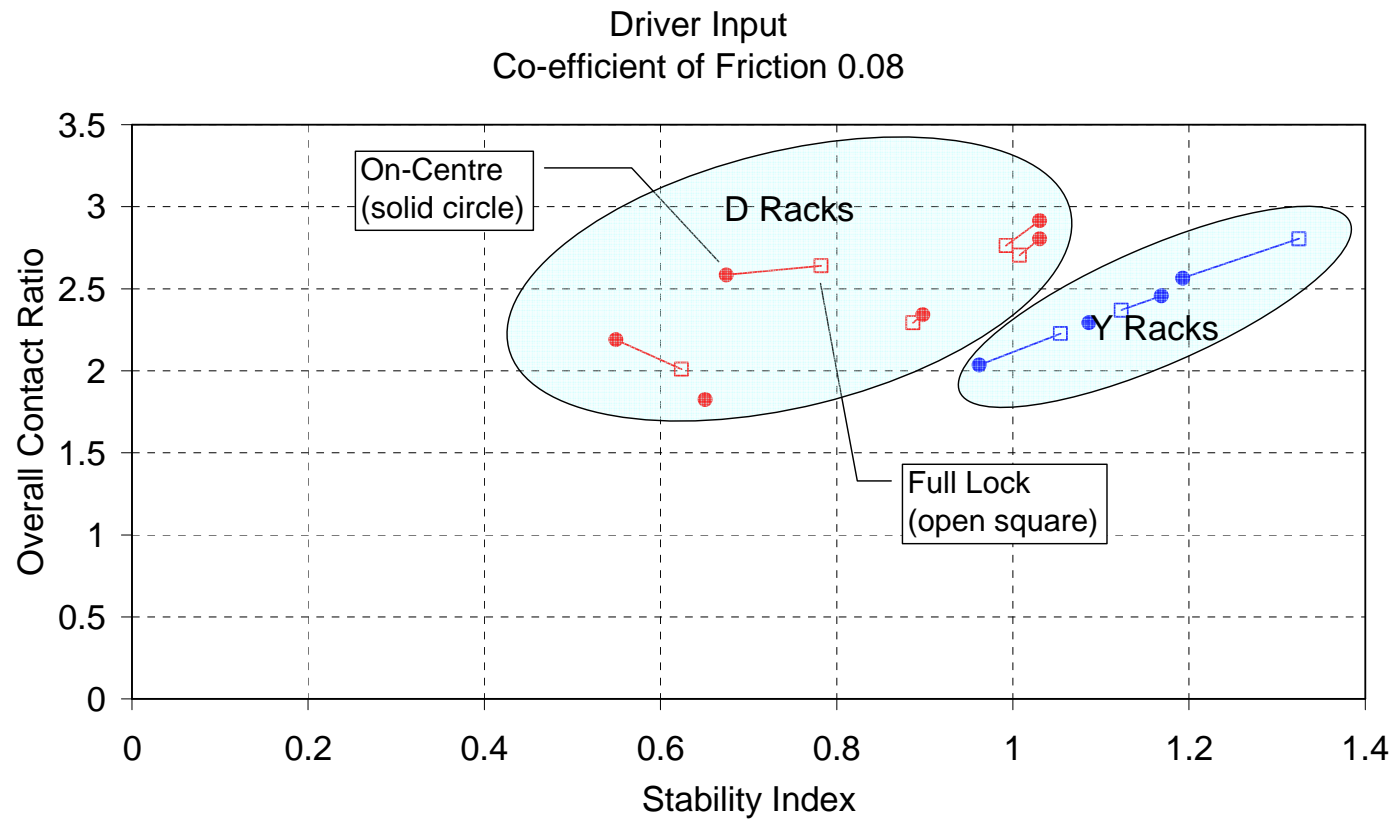
Y Rack

'P' is relatively small and 'W' is relatively large and independent of 'P' hence the SI is relatively high

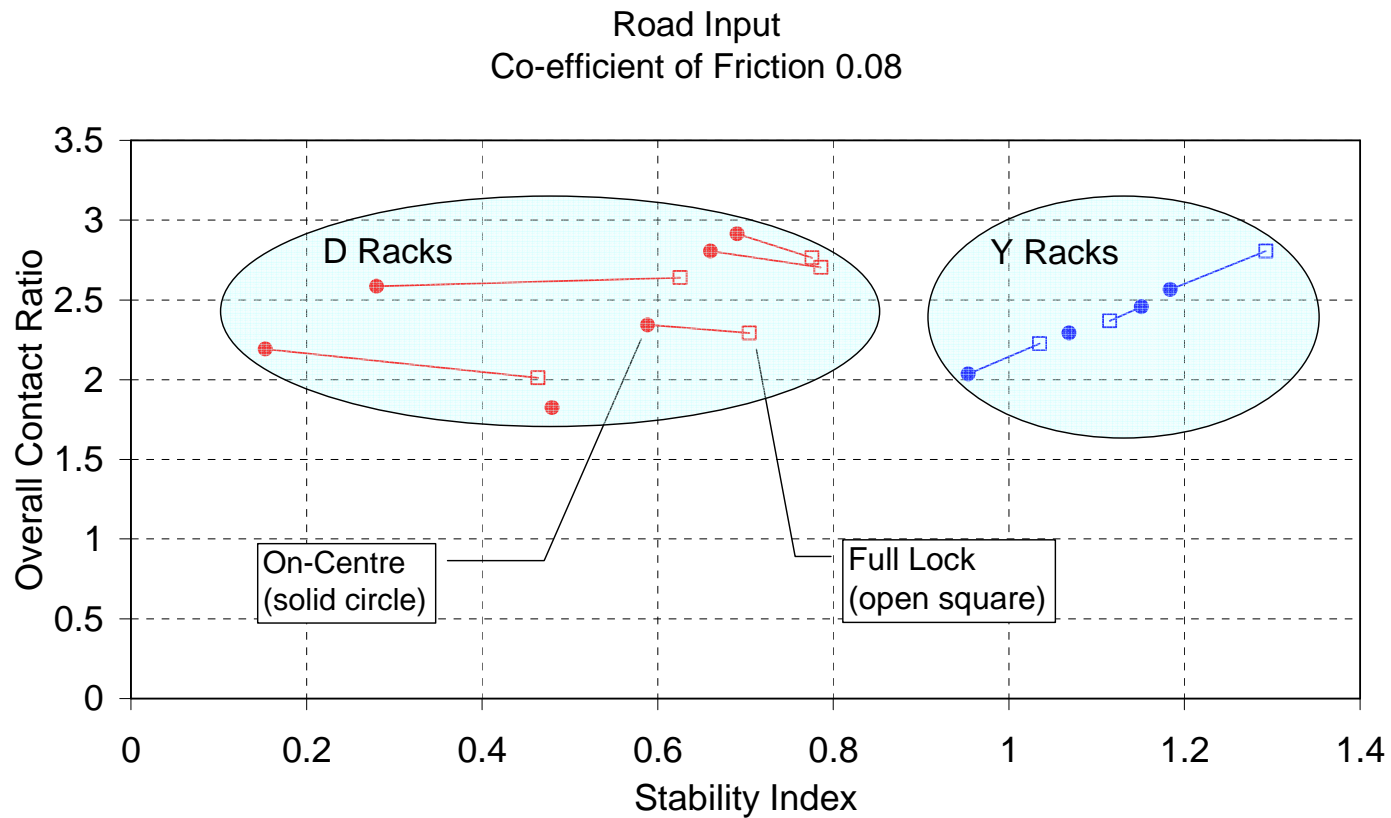
SI Case Study



SI v Contact Ratio



SI v Contact Ratio



SI and Steering Gear Function

A low stability index can lead to;

- Rack gain transmission errors
- Change in rack output force from
 - Rack gain transmission errors
 - Variation in mesh efficiency
- Wedging of rack teeth into pinion
- Reduction in contact area → increased tooth stress

Conclusion

- Unstable racks can degrade steering gear function
- The stability index is a useful tool to predict if a rack will be unstable
- Gear mesh and rack section design are factors in the calculation of the stability index
- Wider teeth → more stable design, but can have a weight and cost penalty
- Y racks are a more robust design to achieve a high stability index