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| Railway Technologies Laboratory |
| Baseline Testing |
| The document summarizes latest Creep-Creepage tests done with Virginia Tech Roller Rig as a means of validation |

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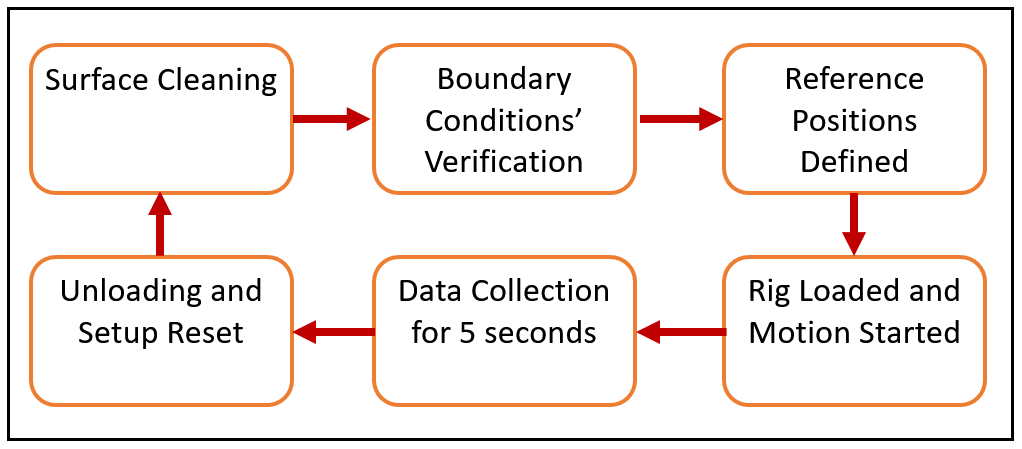
# Current Testing and Methodology

The objective of current testing is to establish baselines for the performance of the Virginia Tech Roller Rig (VTRR). The basic expectation from VTRR is to determine Creep forces while accurately controlling creepages and boundary conditions such as Vertical Load, Angle of Attack, Cant Angle and Lateral Displacement. Keeping this in mind, we designed the following experiments to establish a standard testing and data analysis scheme. The objective is to generate results that are *repeatable* and *reliable.*

## Design of Experiments

The following design of experiment ensures the following points to remove any additional sources of variability:

1. Uniformity of surface conditions at the contact interface
2. Uniformity of boundary conditions
3. Uniformity of terrain characteristics
4. Uniformity of data collection process



We now look at each individual step

### Surface Cleaning - *Ensuring constant surface conditions*

The effect of a third body significantly affects the creep forces at the contact interface. VTRR has two steel wheels rotating against each other at a pre-defined creepage and vertical load. A machining action is thus inevitable and the resulting debris could significantly affect the contact patch behavior thereby introducing a new variable. In order to eliminate that, the wheel and roller surfaces were constantly monitored and cleaned.

### Boundary Conditions’ Verification – *Ensuring constant boundary conditions*

VTRR has six actuators that control Angle of Attack, Cant Angle, Lateral displacement and Vertical Loading. Any deviations in these parameters causes a change in creep-creepage behaviour at the contact patch. Angle of Attack, Cant angles and Lateral Displacement are verified by external sensors which are independent of the actuator feedback. Vertical loading is verified by the force measuring system.

### Reference Position Definition – *Ensuring constant tread and terrain conditions*

Every machined surface has imperfections to some degree such as dents, notches, ovality etc. These imperfections are further aggravated over time especially in cases like VTRR with continuous wear happening due to the machining action. We define same starting and ending points for our servo motion so that the contact interface sees the same terrain over the course of testing. We also define a fixed retraction point for the vertical actuators.

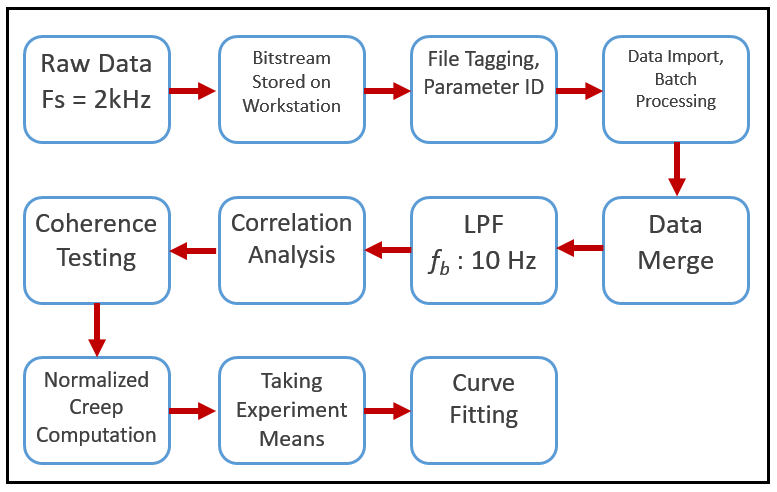
### Loading of Rig and Start of Test

Once the initialization steps are complete, the wheel and roller velocities for the desired creepage is entered in the motion console. Vertical load is applied and the motion is started. All actuators are active and applying forces/moments.

### Data Collection

Constant test data size is necessary for batch post processing of the data. The data collection thus is programmed to cease after five seconds.

## Data Post Processing



### Raw Data Collection

The following table shows the type of data that is queried and the data type:

|  |  |
| --- | --- |
| Query | Data Type |
| Longitudinal Forces | Integer value from -32768 to +32767 |
| Vertical Forces | Integer value from -32768 to +32767 |
| Commanded Wheel Velocity | Integer Value from -220 to + 220 |
| Actual Wheel Velocity | Integer Value from -220 to + 220 |
| Actual Roller Velocity | Integer Value from -220 to + 220 |

This data comes in the form of a stream of bits from sensors and serial connectors interface the data with SynqNET. SynqNET also provides the interface for the workstation to read and send data or commands over to actuators and sensors. The incoming bitstream (ones and zeros) is stored in a volatile cache memory.

### Data storage and Preprocessing

The bitstream in the cache memory is then stored on the workstation in the form of a text file. The file is appropriately named and a separate journal notes the testing parameters that resulted in the data. This raw data is then processed by a MATLAB code which converts the numbers in the text file into data sets like forces and velocities with appropriate human identifiable units.

### Low Pass Filtering

All phenomena of our interest have a frequency much lower than 10 Hz. So a low pass filtering with a break frequency of 10 Hz is desired to filter out the noise and generate better distribution properties.

### Correlation Analysis

Every friction model proposes a direct positive correlation between vertical load and tractive force. We use this property to evaluate the reliability of data. Every sensor has a noise floor which might be at some offset from zero. Therefore if our longitudinal force readings are dominated by the noise floor, then the mean of the data would be non-zero even if the actual forces are zero.

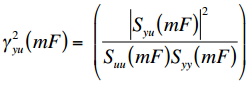
In order to verify that the incoming data is not junk, we do a correlation analysis as the primary test on the data to verify that the longitudinal force data is indeed correlated with vertical load data. Data failing this test are not taken up for creep-creepage curve generation. Correlation Analysis is done by:

1. Generating a linear trend line between longitudinal and vertical forces.
2. Computing the goodness of fit criteria: *R2* value and RMSE
3. Computing the slope of the trend line
4. Data not adhering to the set threshold are disregarded for further analysis.

### Coherence Testing

Coherence is a very common signal processing concept which tell us whether a particular time series is coherent with another time series. Controls community uses this criterion to determine whether the output is caused by the input signal or noise dynamics of the control. This is a secondary test on our data to further verify the validity of the data considered. If the data is coherent in the frequency range of our interest, then we can trust the data or else we have to disregard it.

The formula for coherence is given by:



Strong Coherence values are those above 0.9. They indicate a strong correlation between input data (Vertical Force) and output data (Longitudinal force). Data dominated by the noise floor would have a weak coherence.

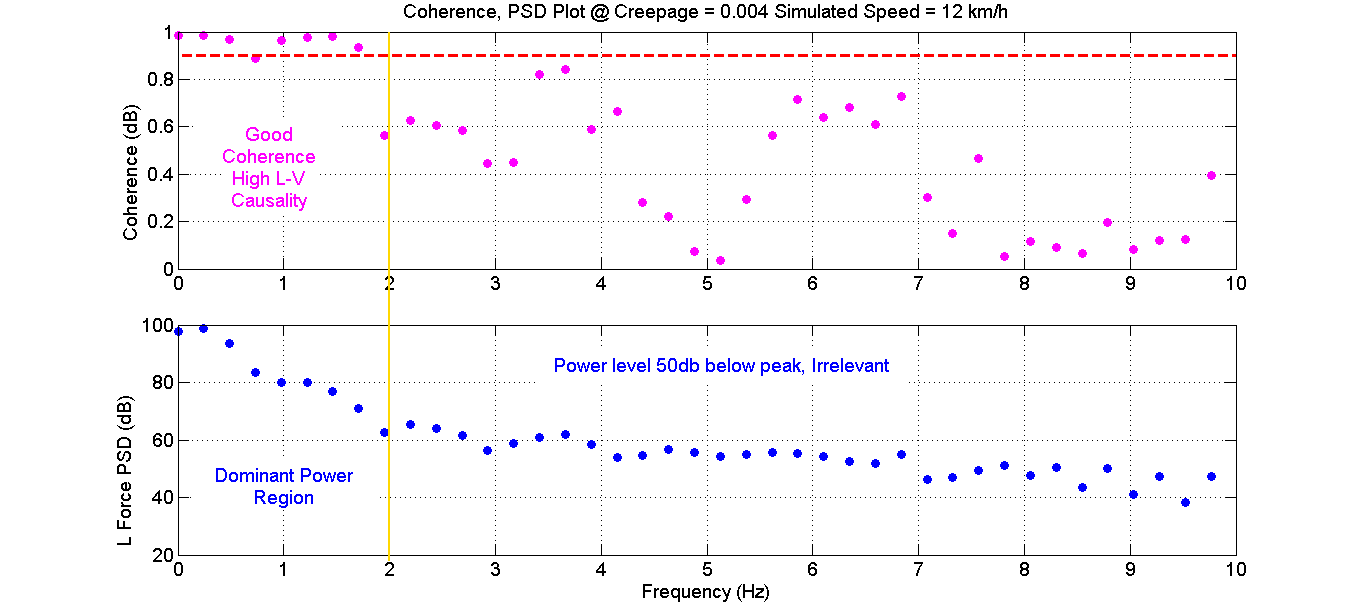


Figure 1 Strong Coherence Data – Accepted for Curve Plotting

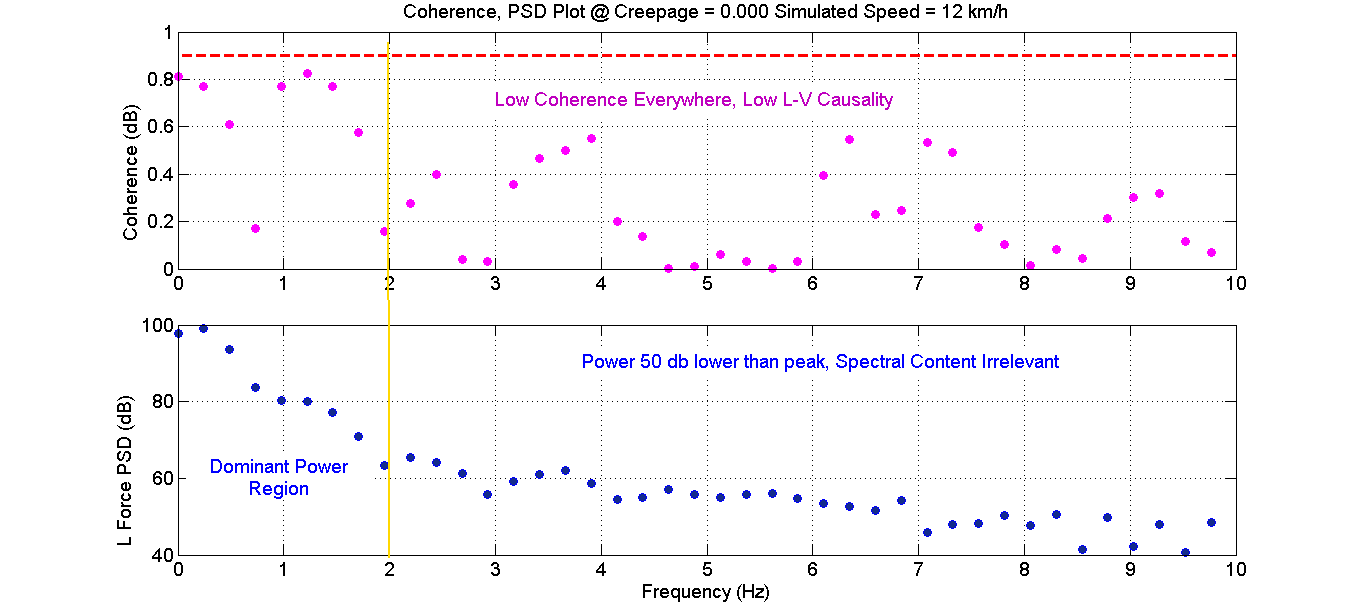


Figure 2 Weak Coherence Data - Rejected for Curve Plotting

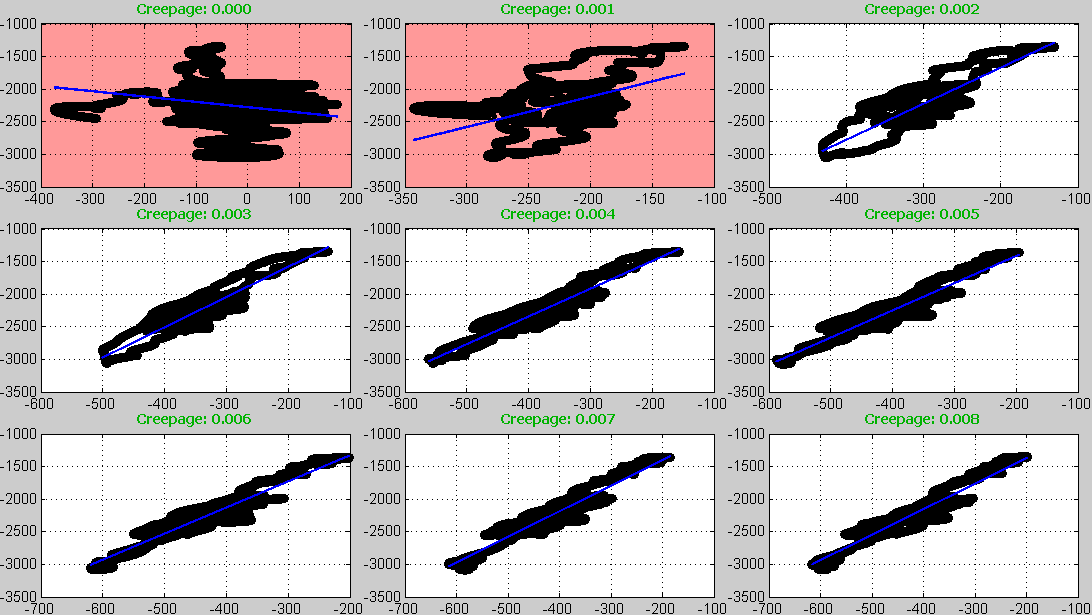


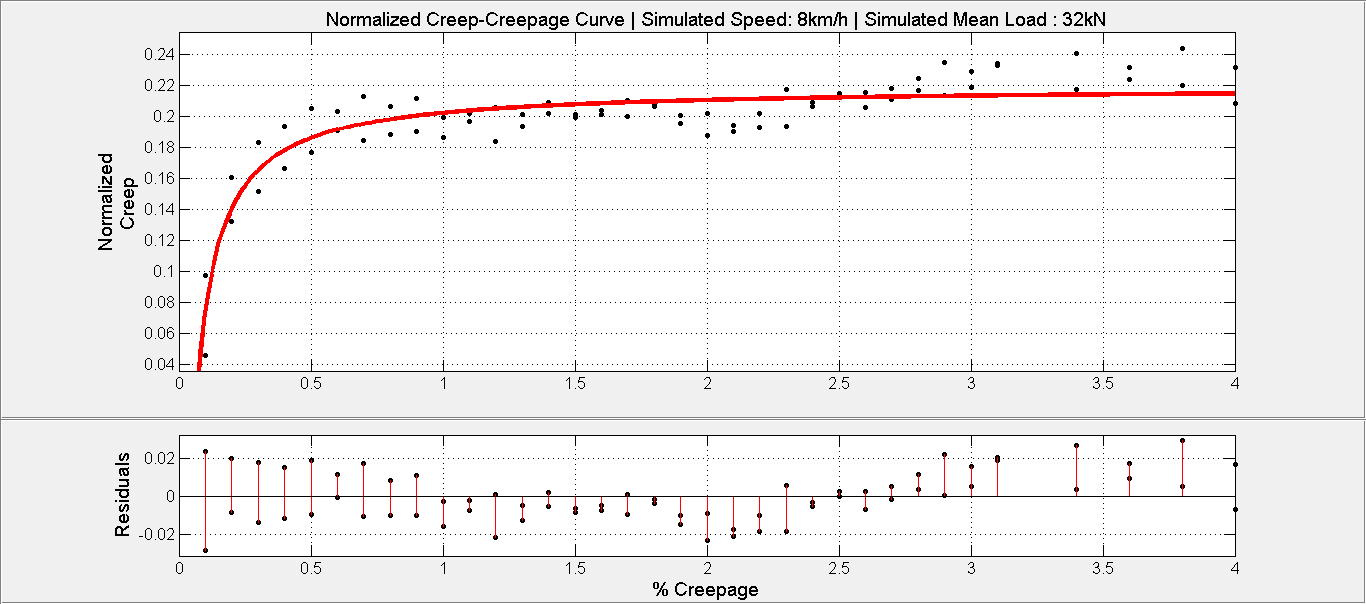
Figure 3 Correlation Testing, Dataset – 1, Speed - 8 km/h, Load - 32 kN, Red plots indicated rejected data

### Normalized Creep Computation

While reporting creep-creepage curves, it’s a standard practice among researchers to report creep values *normalized* by the vertical force so that the general phenomena is visualized. Once the data passes the reliability checks, the vertical and longitudinal force arrays are divided and normalized creep is computed. This is done for the whole experiment, hence a five second data has approximately 10,000 normalized creep data points.

### Taking experiment means and generating the Creep-Creepage curve.

For all the normalized creep data sets as obtained in the previous step, we take means of those data sets. A scatter plot of all such mean points is created and a rational fit is done so as to generate a best fit curve. The goodness of fit is evaluated and if determined satisfactory, the curve is accepted. If not, then further analysis relating to outliers is done and such points are removed so as to generate a satisfactory fit with minimal dispersion.



# Creep-Creepage curve dependence on base speed

After establishing a definitive design of experiment for the creep-creepage curve generation, we add a third dimension and investigate the effects of base speed on the creep-creepage phenomena. The results are as shown

# Summary of Experiments

We use a Completely Randomized Design of Experiment (CRD) to determine the creep-creepage curve. Appropriate steps are taken to ensure that final creep-creepage curve is not biased on data but is indicative of the actual physics at the contact interface. In just about three months of time, the Roller Rig has generated a Creep-Creepage curve that is reliable, repeatable and consisten with the established physics.

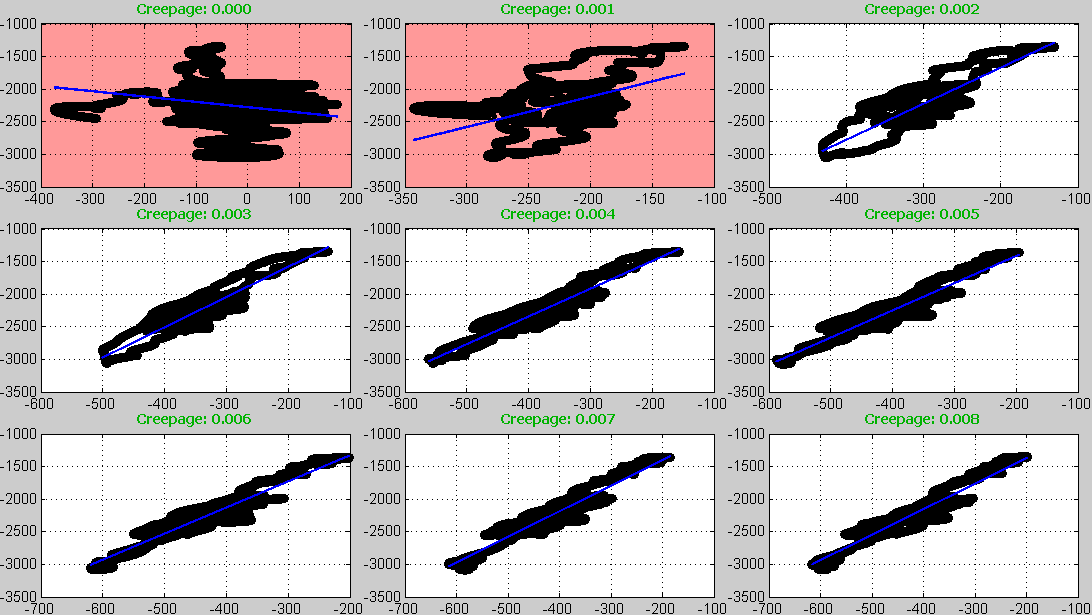
# Future Tasks

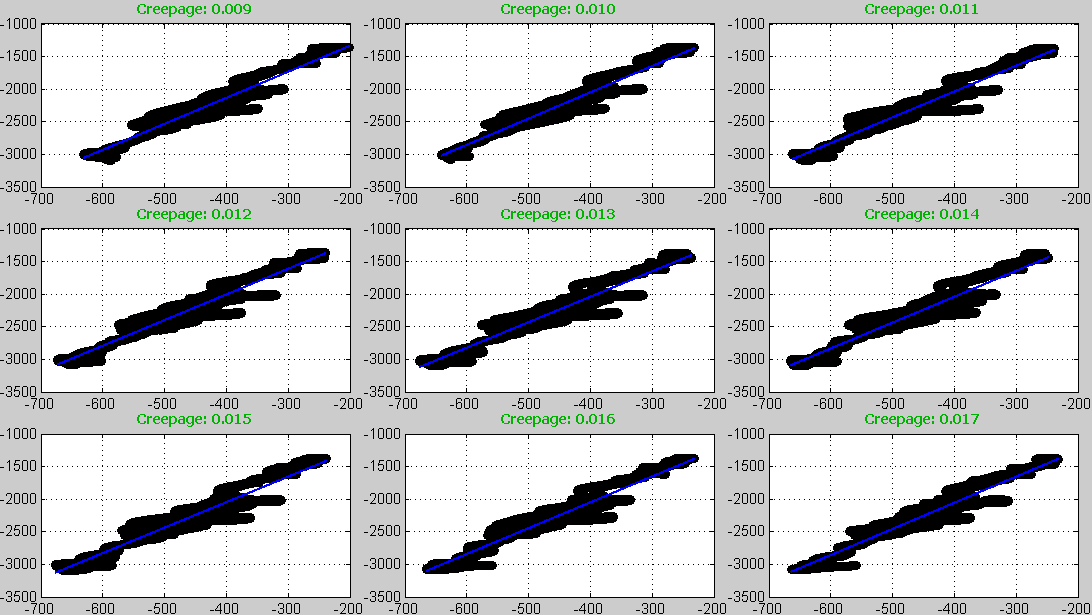
1. Investigate and quantify error dynamics of the Roller Rig
2. More data points to be collected while examining the effects of:
   1. Cant Angle
   2. Angle of Attack
   3. Vertical Load
   4. Base Speed
3. Implementing automated motion routines to speed up the data collection.
4. Building upon the existing signal processing framework to extract more information from data.

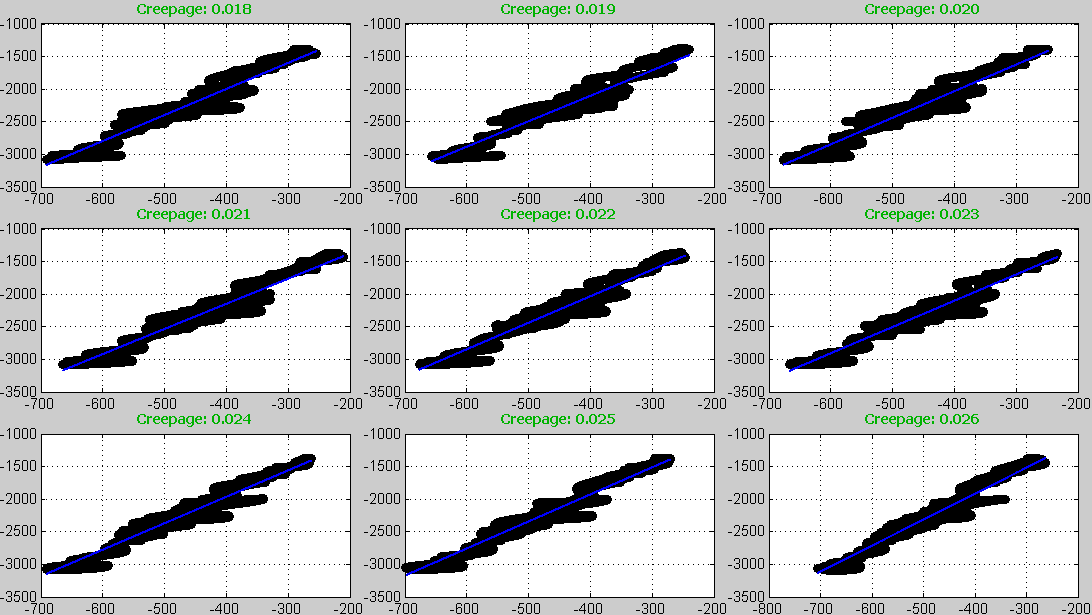
Appendix

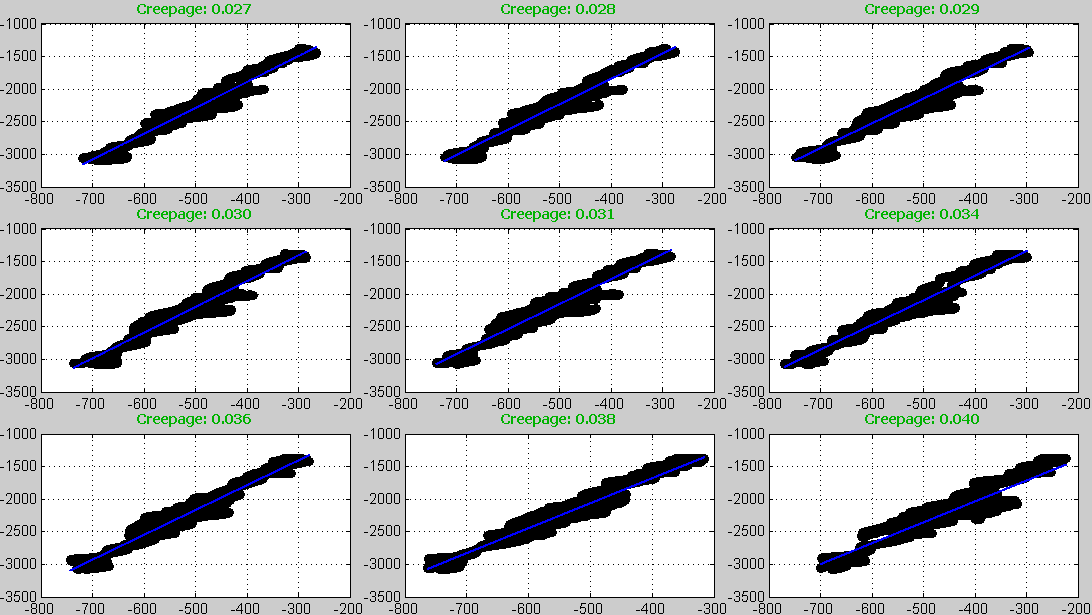
# Simulated Speed : 8km/h | Simulated Load: 32 kN | Dataset: 1

## Correlation Testing Data









## Coherence Testing Data