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Appendix A:

- ***Certificate of Conformance for Crossbow Tilt Sensor***

- ***Calibration certificate of Sony Cyber Shot 5 mega pixel Digital Camera***

- ***Calibration certificate of Pentax K10D Digital Camera***

Certificate of Conformance for Crossbow Tilt Sensor

Certificate of Conformance **Crossbow** 2.12

calibration date: 09/11/2002

Calibration Data: Room Temperature

	X Axis	Y Axis
Zero-Angle Voltage	2.527	2.492
Sensitivity	35.003	35.116

Part Number	CXTA02
Serial Number	124759

Options: Regulator

Wiring Diagram:

Color	Function
Red	8 - 30 Vdc
Black	Ground
White	X-Axis
Yellow	Y-Axis

Thank you for choosing a Crossbow sensor. This worksheet is designed to help you get started. Refer to the product data sheet for more complete information.

Definitions

Zero - Angle Voltage : This number is the output voltage (in V) of the sensor on a level surface (zero tilt) measured at the factory on the day of the calibration.

Sensitivity : This number is the sensor's sensitivity in mV per degree.

Technical Support

For further technical assistance, contact Crossbow Technology.

Crossbow Technology, Inc.
41 East Daggett Drive
San Jose, CA 95134
Phone : 408.965.3300
Fax : 408.324.4840
URL : http://www.xbow.com
Email : info@xbow.com

Calibration certificate of Sony Cyber Shot 5 mega pixel Digital Camera

Status Report Tree

PhotoModeler Version: 5.1.0

Project Name: *** Rough Road Profiling ***

Problems and Suggestions (0)
  Project Problems (0)
  Problems related to most recent processing (0)

Information from most recent processing
  Last Processing Attempt: Wed Aug 31 14:39:30 2005
  Status: successful
  Processing Options
    Orientation: off
    Global Optimization: on
    Calibration: on (full calibration)
    Constraints: off
  Total Error
    Number of Processing Iterations: 4
    Number of Processing Stages: 2
    First Error: 0.019
    Last Error: 0.008
  Precisions / Standard Deviations
    Camera Calibration Standard Deviations
      Camera1: SONY
        Focal Length
          Value: 6.118036 mm
          Deviation: Focal: 0.002 mm
        Xp - principal point x
          Value: 2.640445 mm
          Deviation: Xp: 0.001 mm
        Yp - principal point y
          Value: 1.939080 mm
          Deviation: Yp: 0.001 mm
        Fw - format width
          Value: 5.312163 mm
          Deviation: Fw: 2.1e-004 mm
        K1 - radial distortion 1
          Value: 2.806e-003
          Deviation: K1: 4.7e-005
        K2 - radial distortion 2
          Value: 1.253e-004
          Deviation: K2: 5.3e-006
        K3 - radial distortion 3
          Value: 0.000e+000
        P1 - decentering distortion 1
          Value: 1.973e-004
          Deviation: P1: 8.8e-006
        P2 - decentering distortion 2
          Value: 1.761e-004
          Deviation: P2: 9.1e-006

Quality
- Photographs
  - Total Number: 11
    - Bad Photos: 0
    - Weak Photos: 0
    - OK Photos: 11
  - Number Oriented: 11
  - Number with inverse camera flags set: 0
- Cameras
  - Camera1: SONY
    - Calibration: yes
    - Number of photos using camera: 11
- Point Marking Residuals
  - Overall RMS: 0.045 pixels
  - Maximum: 0.389 pixels
    - Point 10 on Photo 1
  - Minimum: 0.040 pixels
    - Point 22 on Photo 11
  - Maximum RMS: 0.189 pixels
    - Point 10
  - Minimum RMS: 0.024 pixels
    - Point 71
- Point Tightness
  - Maximum: 0.00088 m
    - Point 10
  - Minimum: 0.0001 m
    - Point 71
- Point Precisions
  - Overall RMS Vector Length: 0.000151 m
  - Maximum Vector Length: 0.000176 m
    - Point 10
  - Minimum Vector Length: 0.000149 m
    - Point 48
  - Maximum X: 7.23e-005 m
  - Maximum Y: 7.42e-005 m
  - Maximum Z: 0.000144 m
  - Minimum X: 5.17e-005 m
  - Minimum Y: 5.17e-005 m
  - Minimum Z: 0.000127 m

Calibration certificate of Pentax K10D Digital Camera

Status Report Tree

PhotoModeler Version: 5.1.0

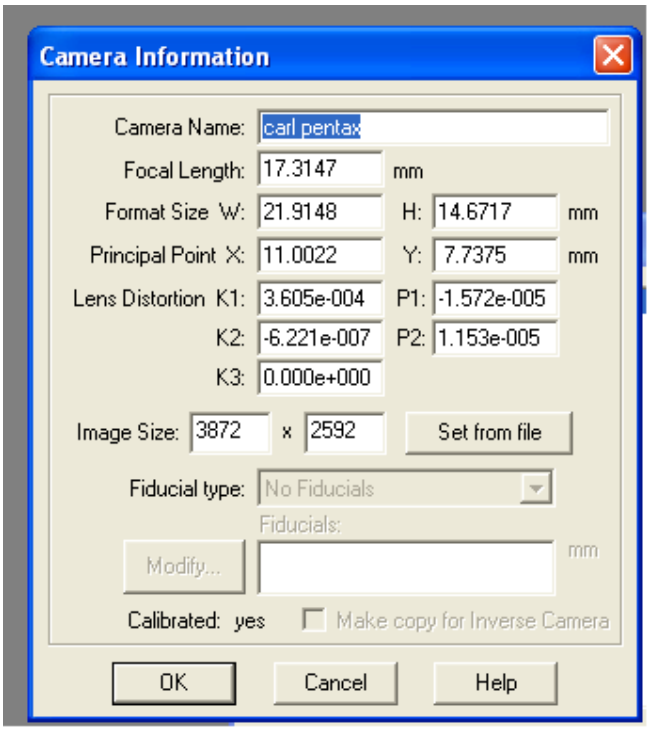
Project Name: *** Project has not yet been saved ***

Problems and Suggestions (1)
  Project Problems (1)
    Problem: A large percentage of your points are sub-pixel marked so it is assumed you are striving for a high accuracy result. The largest residual (Point10 - 3.902977) is greater than 1.00 pixels.
      Suggestion: In high accuracy projects, strive to get all point residuals under 1.00 pixels. If you have just a few high residual points, study them on each photo to ensure they are marked and referenced correctly. If many of your points have high residuals then make sure the camera stations are solving correctly. Ensure that you are using the best calibrated camera possible. Remove points that have been manually marked unless you need them.
  Problems related to most recent processing (0)

Information from most recent processing
  Last Processing Attempt: Tue Jan 15 08:01:21 2008
  Status: successful
  Processing Options
    Orientation: off
    Global Optimization: on
    Calibration: on (full calibration)
    Constraints: off
  Total Error
    Number of Processing Iterations: 4
    Number of Processing Stages: 2
    First Error: 0.119
    Last Error: 0.119
  Precisions / Standard Deviations
    Camera Calibration Standard Deviations
      Camera1: carl pentax
        Focal Length
          Value: 17.314739 mm
          Deviation: Focal: 0.001 mm
        Xp - principal point x
          Value: 11.002161 mm
          Deviation: Xp: 9.4e-004 mm
        Yp - principal point y
          Value: 7.737493 mm
          Deviation: Yp: 9.2e-004 mm
        Fw - format width
          Value: 21.914795 mm
          Deviation: Fw: 2.9e-004 mm
        K1 - radial distortion 1
          Value: 3.605e-004
          Deviation: K1: 1.3e-006
        K2 - radial distortion 2
          Value: -6.221e-007
          Deviation: K2: 9.3e-009
        K3 - radial distortion 3
          Value: 0.000e+000
        P1 - decentering distortion 1
          Value: -1.572e-005

Deviation: P1: 9.5e-007
P2 - decentering distortion 2
Value: 1.153e-005
Deviation: P2: 9.1e-007

Quality
Photographs
Total Number: 12
Bad Photos: 0
Weak Photos: 0
OK Photos: 12
Number Oriented: 12
Number with inverse camera flags set: 0
Cameras
Camera1: carl pentax
Calibration: yes
Number of photos using camera: 12
Point Marking Residuals
Overall RMS: 0.686 pixels
Maximum: 3.903 pixels
Point 10 on Photo 1
Minimum: 0.414 pixels
Point 14 on Photo 12
Maximum RMS: 1.924 pixels
Point 57
Minimum RMS: 0.266 pixels
Point 58
Point Tightness
Maximum: 0.0039 m
Point 10
Minimum: 0.00039 m
Point 58
Point Precisions
Overall RMS Vector Length: 4.67e-005 m
Maximum Vector Length: 5.11e-005 m
Point 2
Minimum Vector Length: 4.54e-005 m
Point 8
Maximum X: 2.58e-005 m
Maximum Y: 2.29e-005 m
Maximum Z: 3.97e-005 m
Minimum X: 1.75e-005 m
Minimum Y: 1.82e-005 m
Minimum Z: 3.62e-005 m


Camera Information
Camera Name: carl pentax
Focal Length: 17.3147 mm
Format Size W: 21.9148 H: 14.6717 mm
Principal Point X: 11.0022 Y: 7.7375 mm
Lens Distortion K1: 3.605e-004 P1: -1.572e-005
K2: -6.221e-007 P2: 1.153e-005
K3: 0.000e+000
Image Size: 3872 x 2592 Set from file
Fiducial type: No Fiducials
Fiducials:
Modify...
mm
Calibrated: yes
Make copy for Inverse Camera
OK
Cancel
Help

Appendix B: Datasheet on S80-MH-5 Data sensor

DATASENSOR

S80L-Y

Distance sensor with laser emission and time of flight measurement

INSTRUCTION MANUAL

CLASS 2 EN 60825-1 (1994)
LASER PRODUCT

CONTROLS

FRONT INDICATORS LED

OUTPUT LED
The yellow LED ON indicates the OR function of the OUT1 and OUT2 outputs (one of the 2 outputs is active).

ALARM LED
The red LED ON indicates the absence of signal.

COMMAND PANEL AND DISPLAY

OUTPUT LED
The yellow LED ON indicates the logic OR function of the two OUT1 and OUT2 outputs (one of the 2 outputs is active).

DISPLAY (4-digit green coloured display)
In the normal mode, the display indicates the detected distance, in millimetres.

OUT1, OUT2 LEDs
The n.1 and n.2 green LEDs ON indicate the activation of the OUT1 and OUT2 outputs.

FAST LED
The n.3 green LED ON indicates the activation of the FAST reading mode (500 Hz).

SET PUSHBUTTON
A pressure on the pushbutton activates the self-setting procedure.
A long pressure on the pushbutton allows the user to access into the mode (FAST or NORM) and delay setting menu.

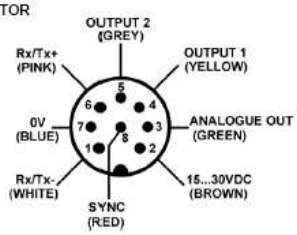
+/- PUSHBUTTONS
A light pressure on these pushbuttons allows the user to run through the menu of the sensor parameters and setting menu.
Moreover, a long pressure allows to change the switching threshold value, as indicated in the "SWITCHING THRESHOLD ADJUSTMENT" paragraph.

INSTALLATION

The sensor can be positioned by means of the three housing's holes using screws (M5x40 or longer) with nuts and washers.
Various orientable fixing brackets to ease the sensor positioning are available (please refer to the accessories listed in the catalogue).
The operating distance is measured from the front surface of the sensor optics.
The M12 connector can be oriented at two different positions (refer to figure).

CONNECTIONS

M12 CONNECTOR

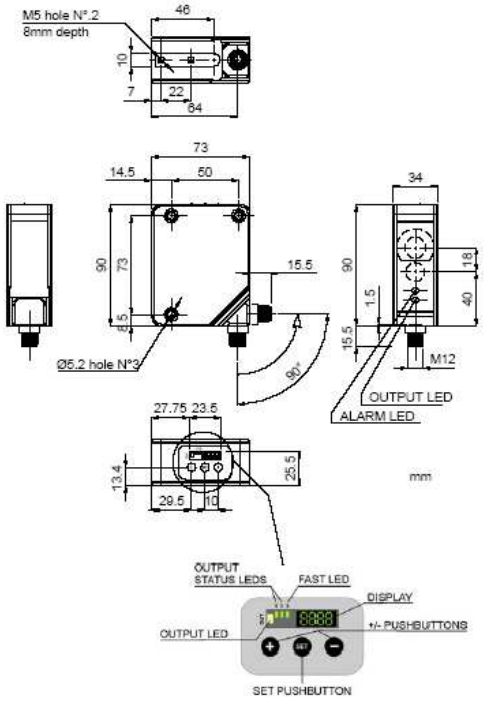


NOTE: the wire colours are referred to the cables manufactured according to the European standard.

TECHNICAL DATA

Power supply:	15 ... 30 Vdc limit values
Ripple:	2 Vpp max.
Consumption (output current excluded):	170 mA max (110 mA @ 24 V)
Outputs:	2 PNP or NPN outputs 30 Vdc max. (short-circuit protection) analogue output with 4-20 mA
Serial interface:	RS485, 9600Bd, 8N1
SYNC input:	PNP
Measurement range:	300 ... 4000 mm (from 90% white to 18% grey) 400 ... 2600 mm (6% black)
Linearity:	0.3% (24Vdc, 25°C, with 90% white target)
Digital resolution:	0.9 mm
Hysteresis:	5 mm (NORM) ; 10 mm (FAST)
Temperature drift:	< 0.6 mm/°C
Output current:	100 mA max.
Output saturation voltage:	≤ 2 V
Response time:	5 ms (NORM) ; 1 ms (FAST)
Switching frequency:	100 HZ (NORM) ; 500 Hz (FAST)
Indicators:	*command panel:* 4-digit display (GREEN), OUTPUT LED (YELLOW) 2 OUT1, OUT2 LEDs (GREEN) FAST LED (GREEN). *indicators LED:* OUTPUT LED (YELLOW) / ALARM LED (RED)
Setting:	SET, +, - pushbuttons
Data retention:	non volatile EEPROM memory
Operating temperature:	-10 ... 50 °C
Storage temperature:	-20 ... 70 °C
Electrical shock protection:	Class 2
Typical spot dimension:	Ø 12 mm at 2 m Ø 20 mm at 4 m
Emission type:	Red laser (665 nm) Class 2 (λ 665 nm) EN 60825-1 (1994)
Ambient light rejection:	According to EN 60947-5-2
Vibrations:	0.5 mm amplitude, 10 ... 55 Hz frequency, for every axis (EN60068-2-6)
Shock resistance:	11 ms (30 G) 6 shock for every axis (EN60068-2-27)
Housing material:	aluminium
Lens material:	Window and lenses in glass
Mechanical protection:	IP67
Connections:	M12-8 pole connector
Weight:	330 g. max.

DIMENSIONS



COMMAND PANEL AND DISPLAY

Appendix C: Blank example of a Road Definition File

```
$-----------------------------------------------------------------MDI_HEADER
[MDI_HEADER]
FILE_TYPE  =  'rdf'
FILE_VERSION  =  5.00
FILE_FORMAT  =  'ASCII'
$-------------------------------------------------------------------------units
[UNITS]
 LENGTH            = 'mm'
 FORCE             = 'newton'
 ANGLE             = 'radians'
 MASS              = 'kg'
 TIME              = 'sec'
$-----------------------------------------------------------------definition
[MODEL]
 METHOD            = '3D'
$-------------------------------------------------------------------------nodes
[NODES]
 NUMBER_OF_NODES    =
{ node   x_value   y_value   z_value }


$-----------------------------------------------------------------offset
[ELEMENTS]
 NUMBER_OF_ELEMENTS    =
{ node_1   node_2  node_3   mu }
```

Appendix D: International Roughness Index plots of profiled terrains

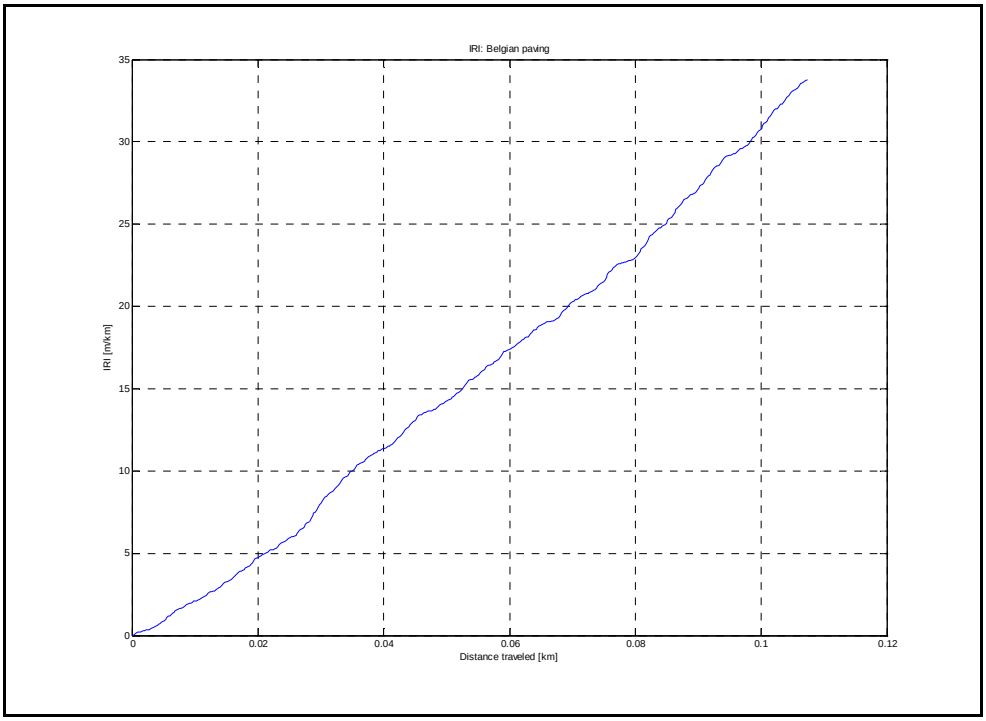


Figure 120: IRI Belgian paving.

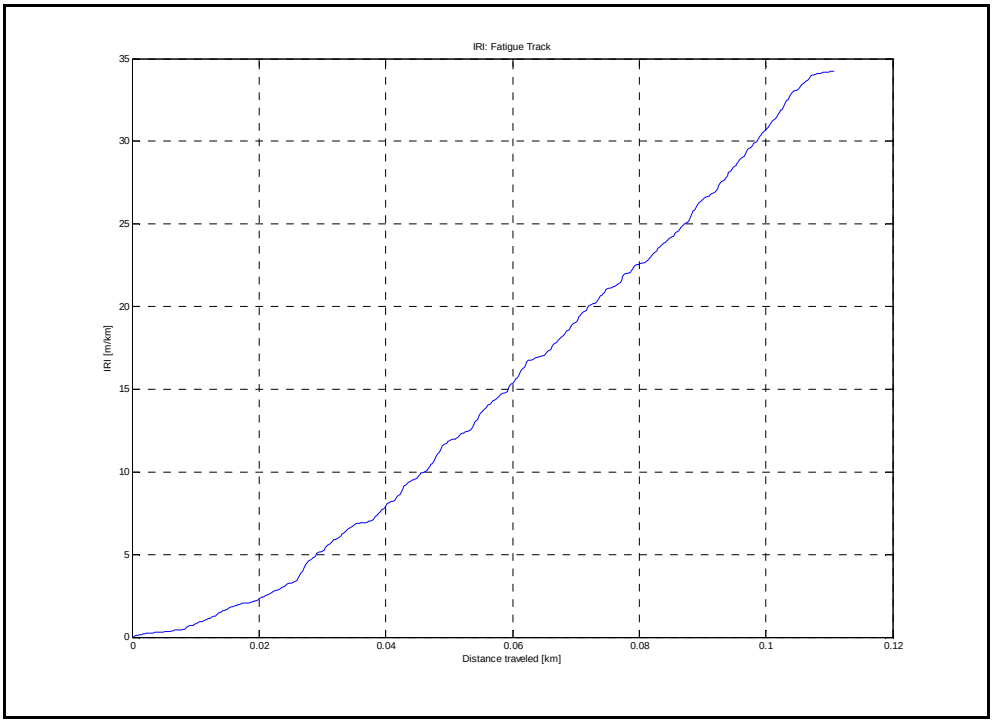


Figure 121: IRI Fatigue Track.

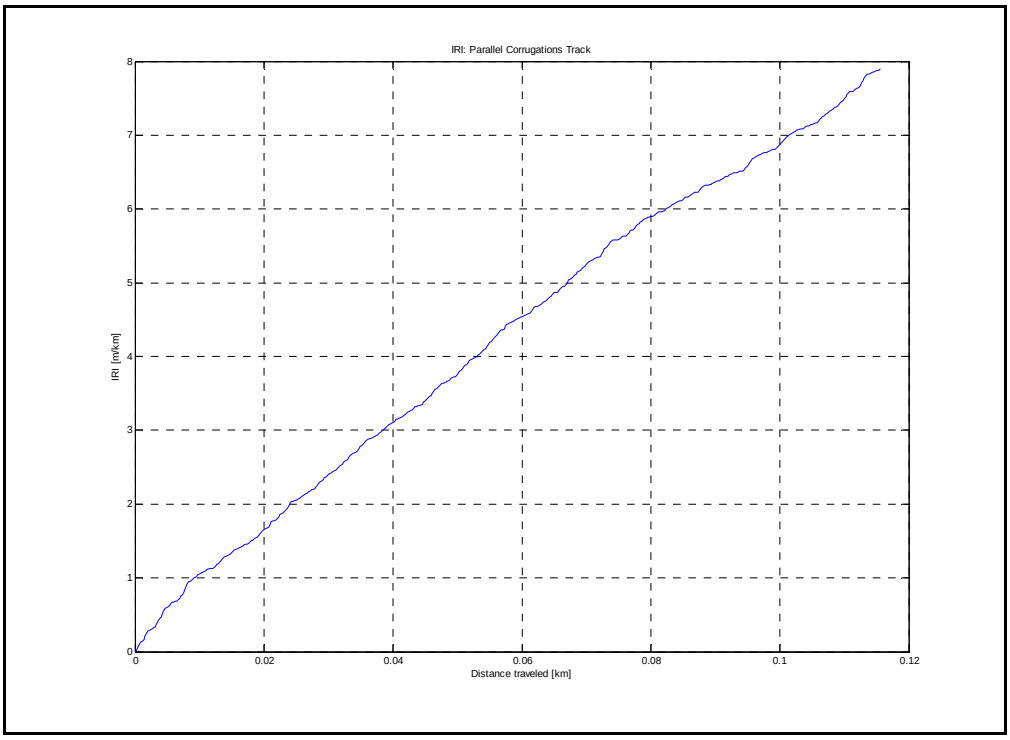


Figure 122: IRI Parallel Corrugations Track.

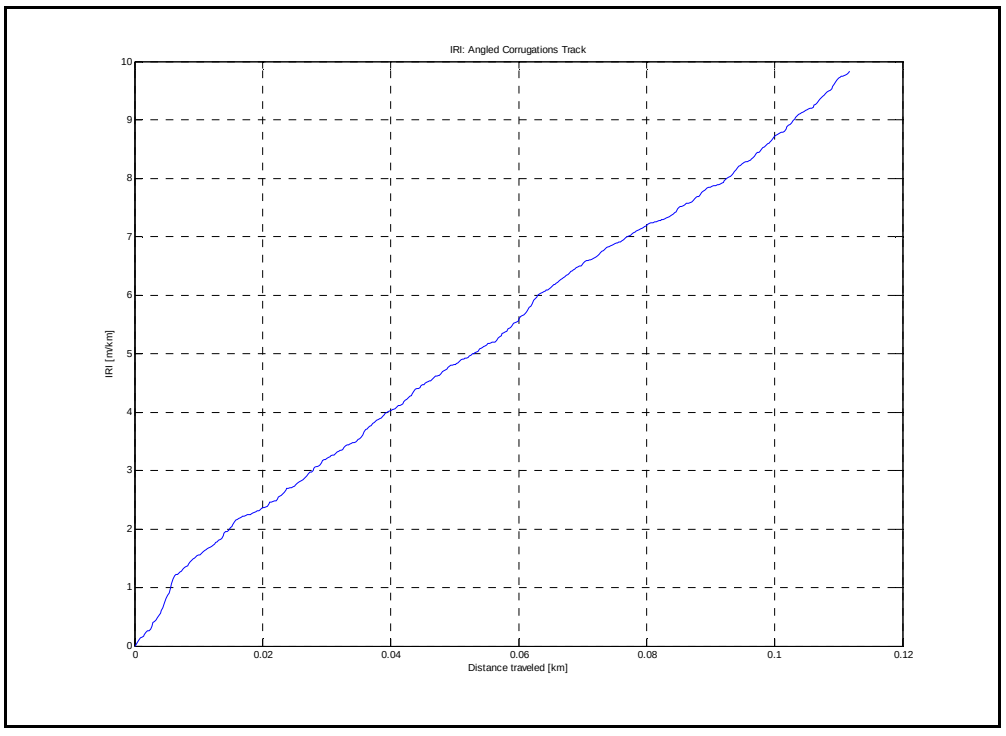


Figure 123: IRI Angled Corrugations Track.

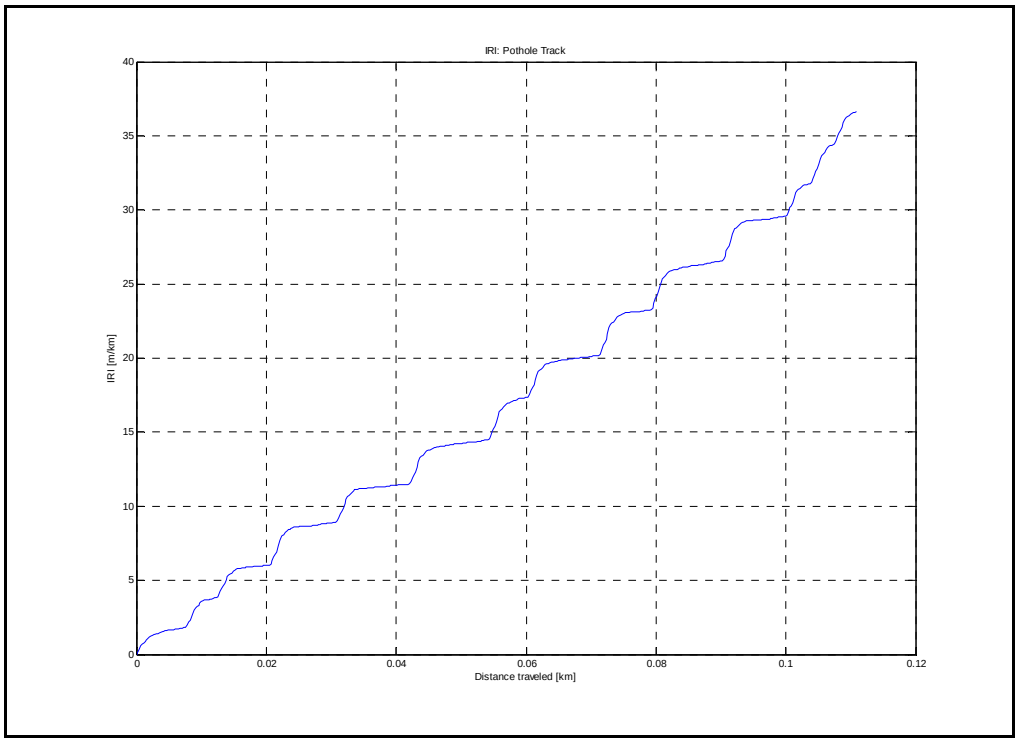


Figure 124: IRI Pothole Track.

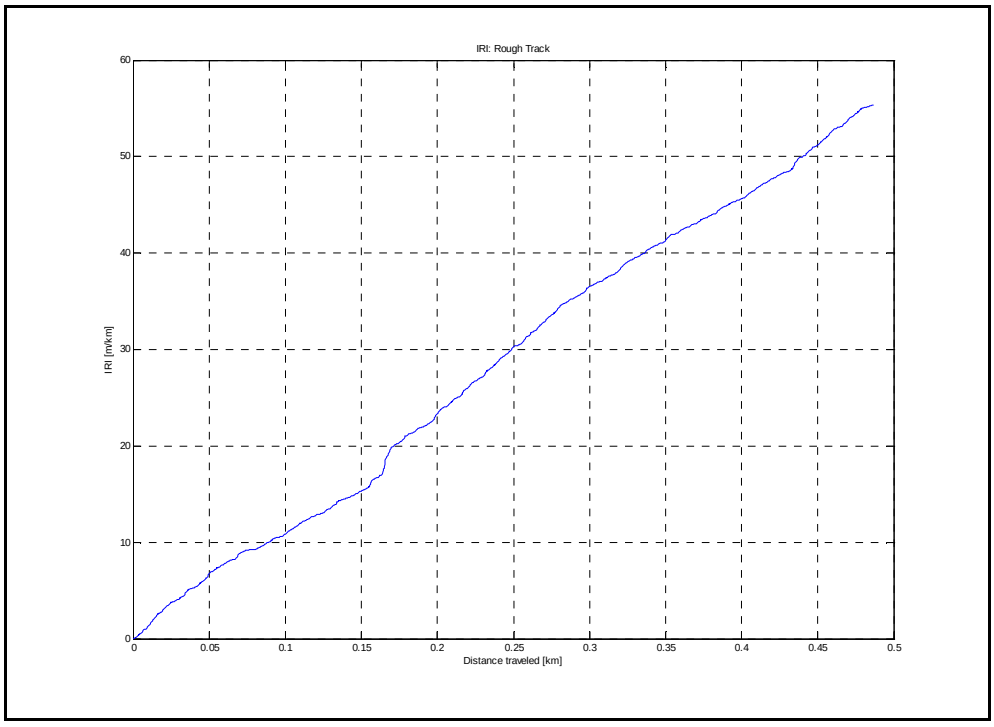


Figure 125: IRI Rough Track.

Appendix E: Weighted FFT from the Simulation and Land Rover data

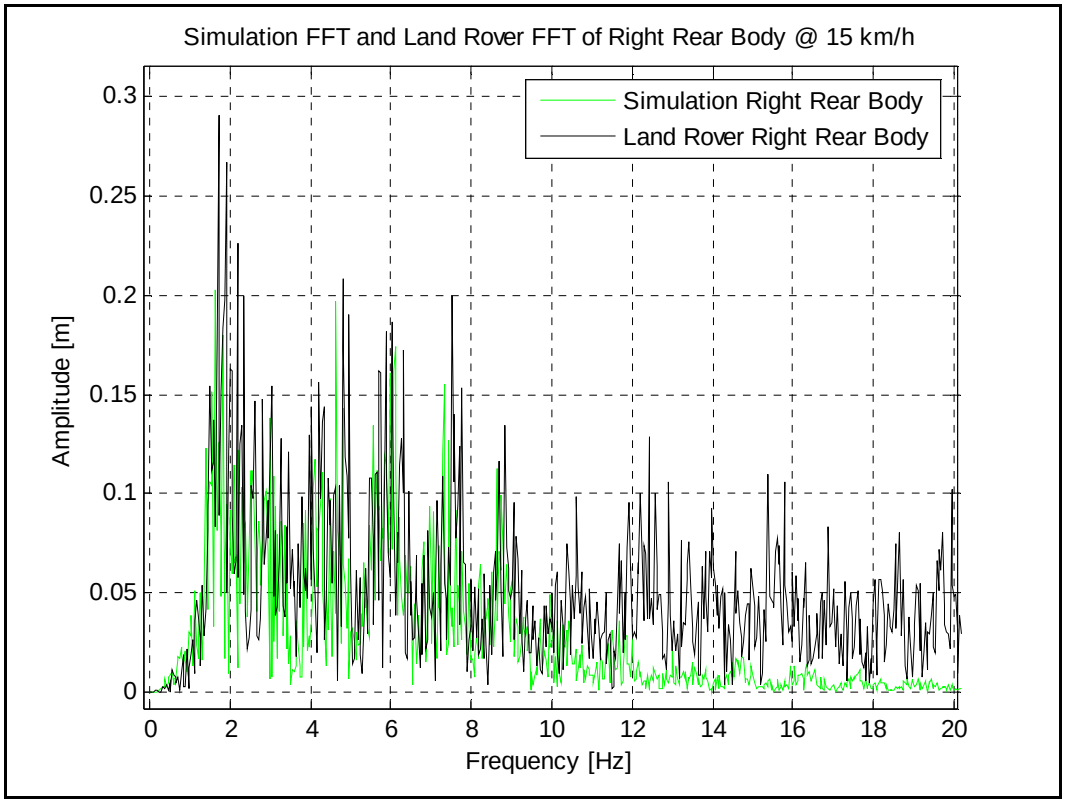


Figure 126: Weighted FFT from the Simulation and Land Rover data @ 15km/h.

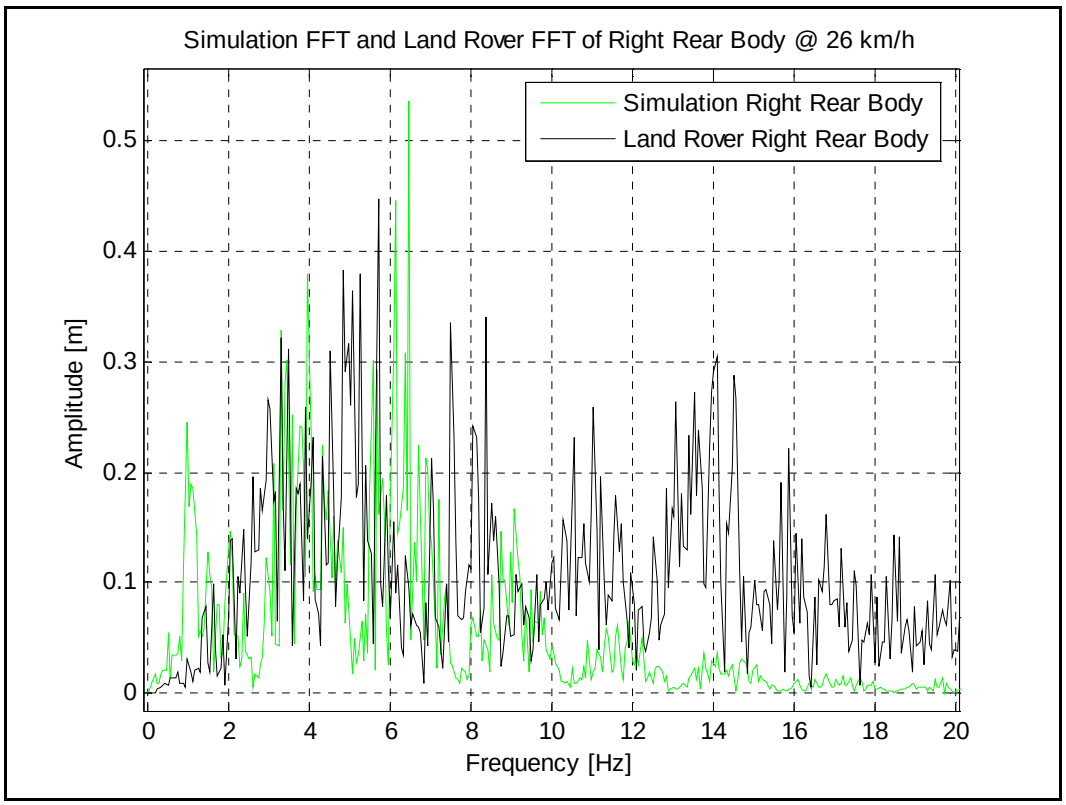


Figure 127: Weighted FFT from the Simulation and Land Rover data @ 26km/h.

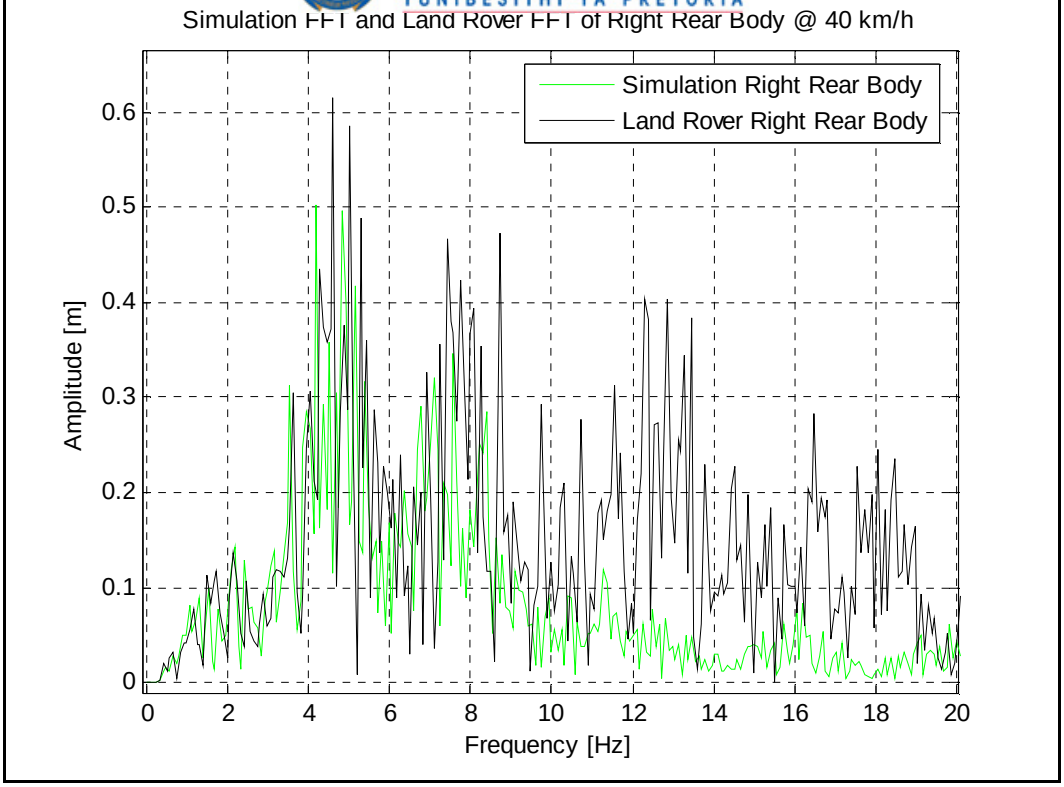


Figure 128: Weighted FFT from the Simulation and Land Rover data @ 40km/h.

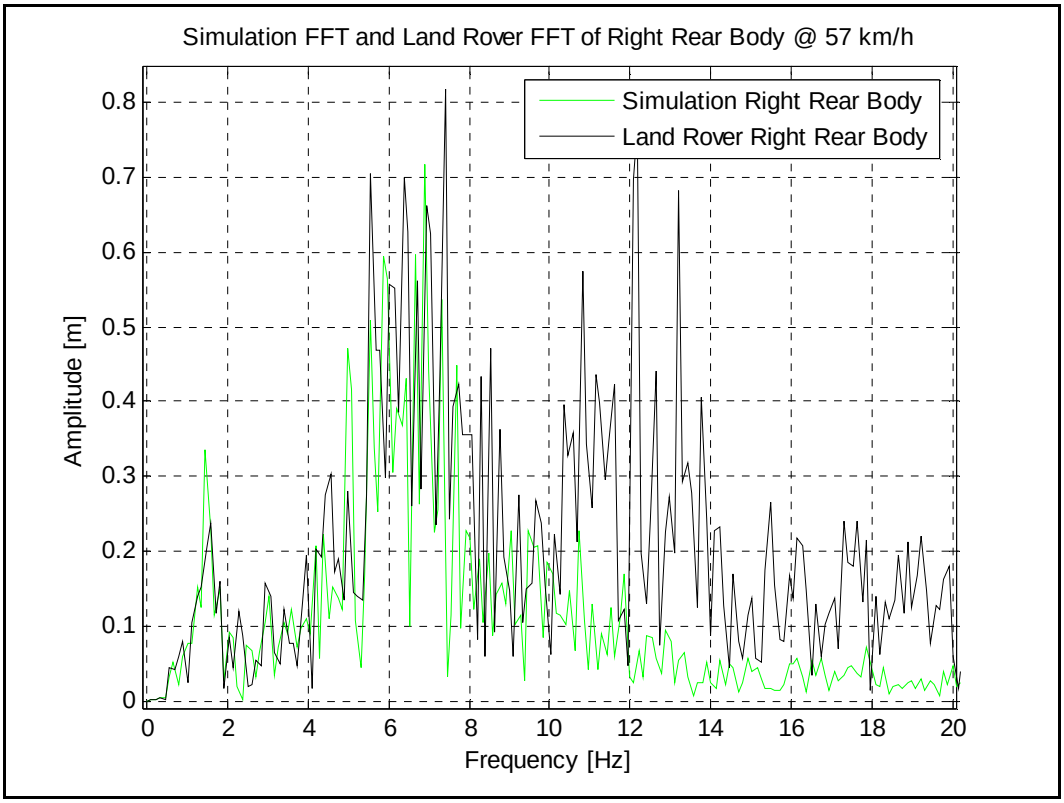


Figure 129: Weighted FFT from the Simulation and Land Rover data @ 57km/h.

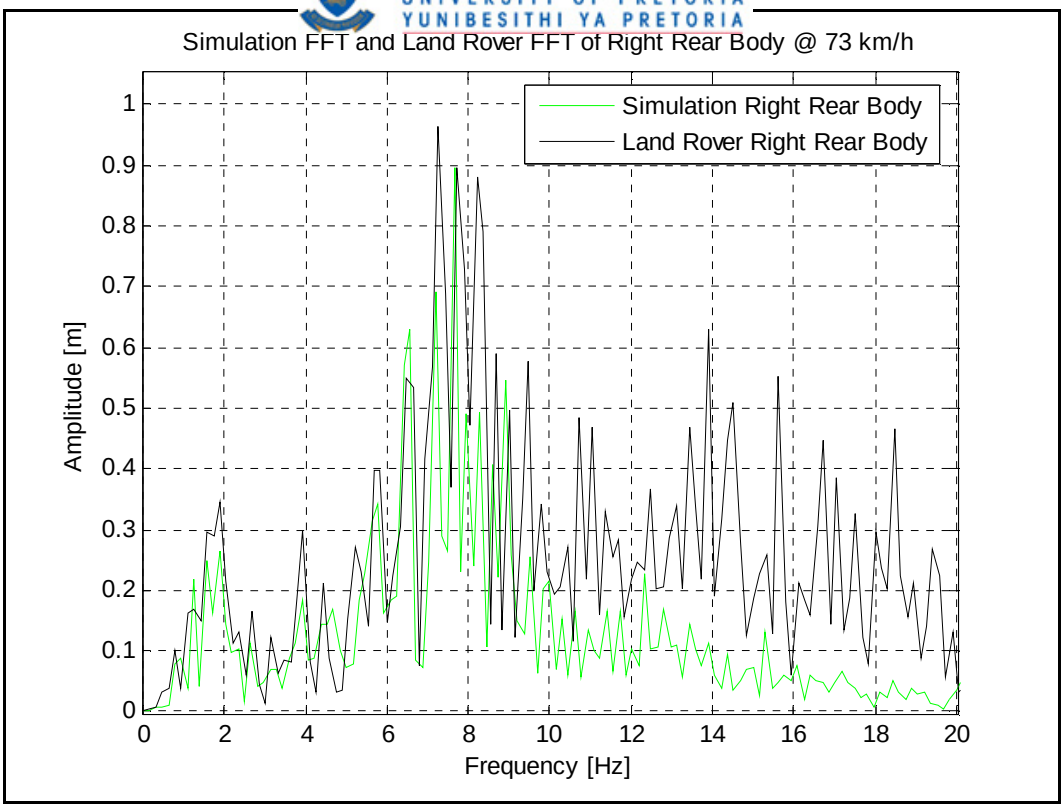


Figure 130: Weighted FFT from the Simulation and Land Rover data @ 73km/h.

Appendix F: Filtered vertical accelerations from simulations and Land Rover data

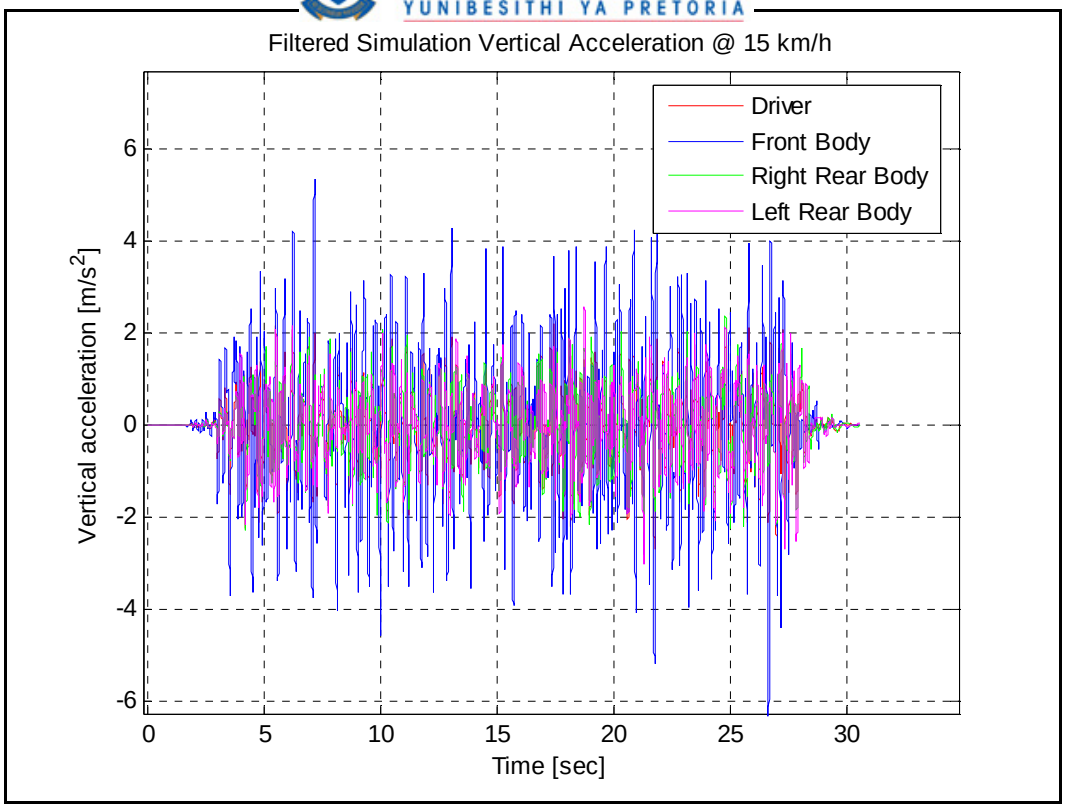


Figure 131: Simulation vertical accelerations @ 15km/h.

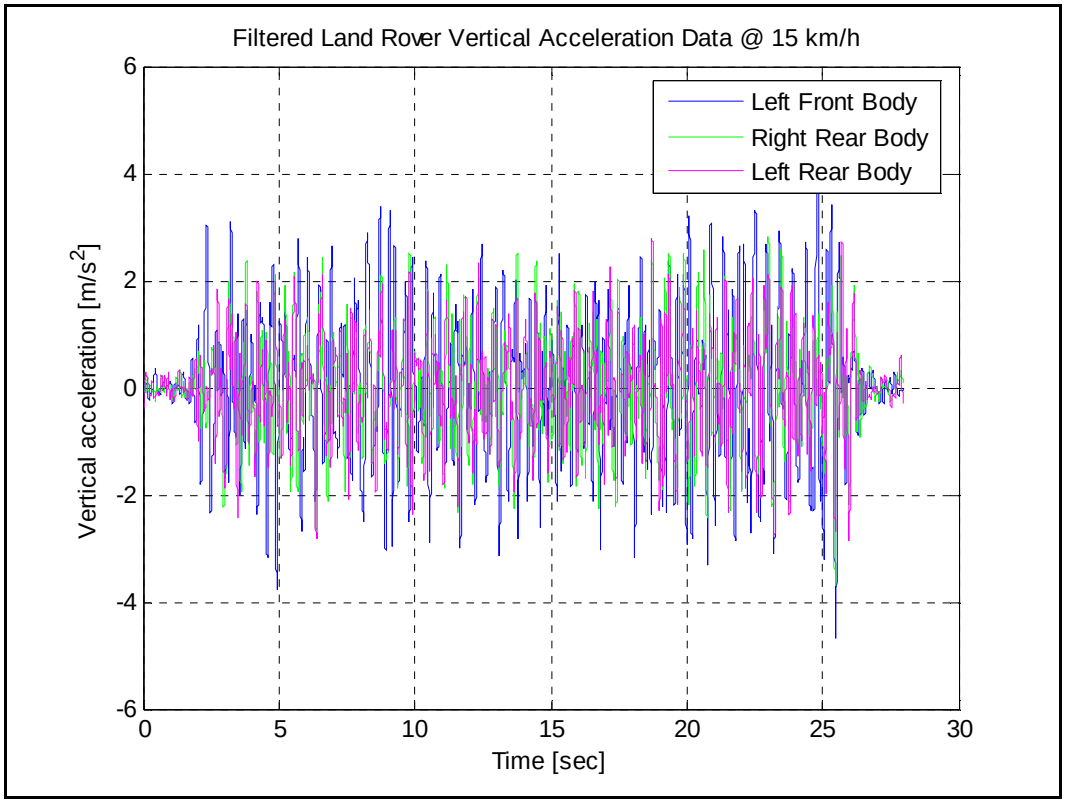


Figure 132: Land Rover vertical accelerations @ 15km/h.

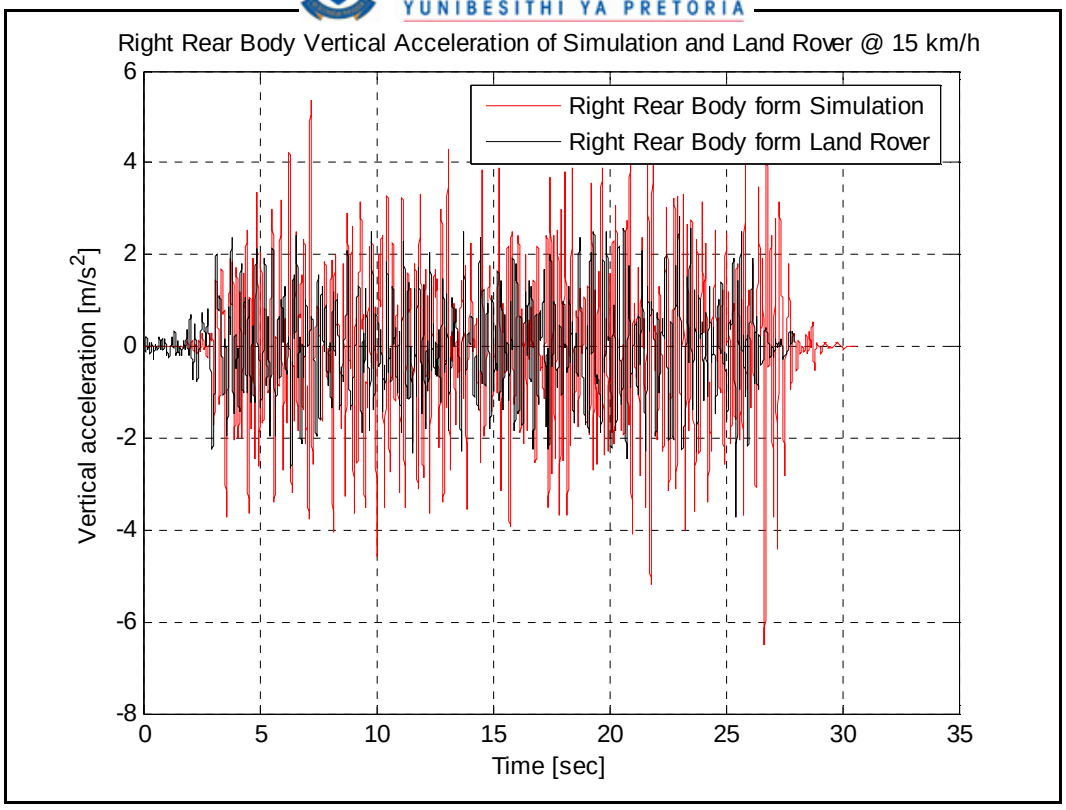


Figure 133: Right Rear Body vertical accelerations from Simulation and Land Rover @ 15km/h.

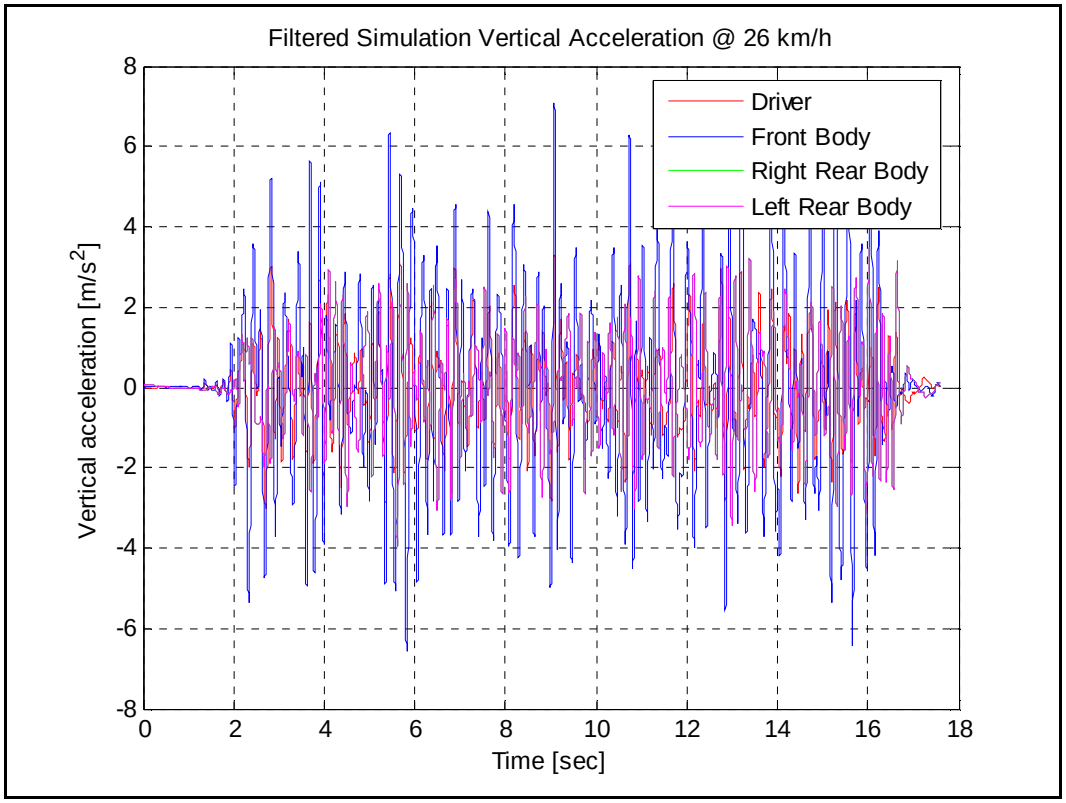


Figure 134: Simulation vertical accelerations @ 26km/h.

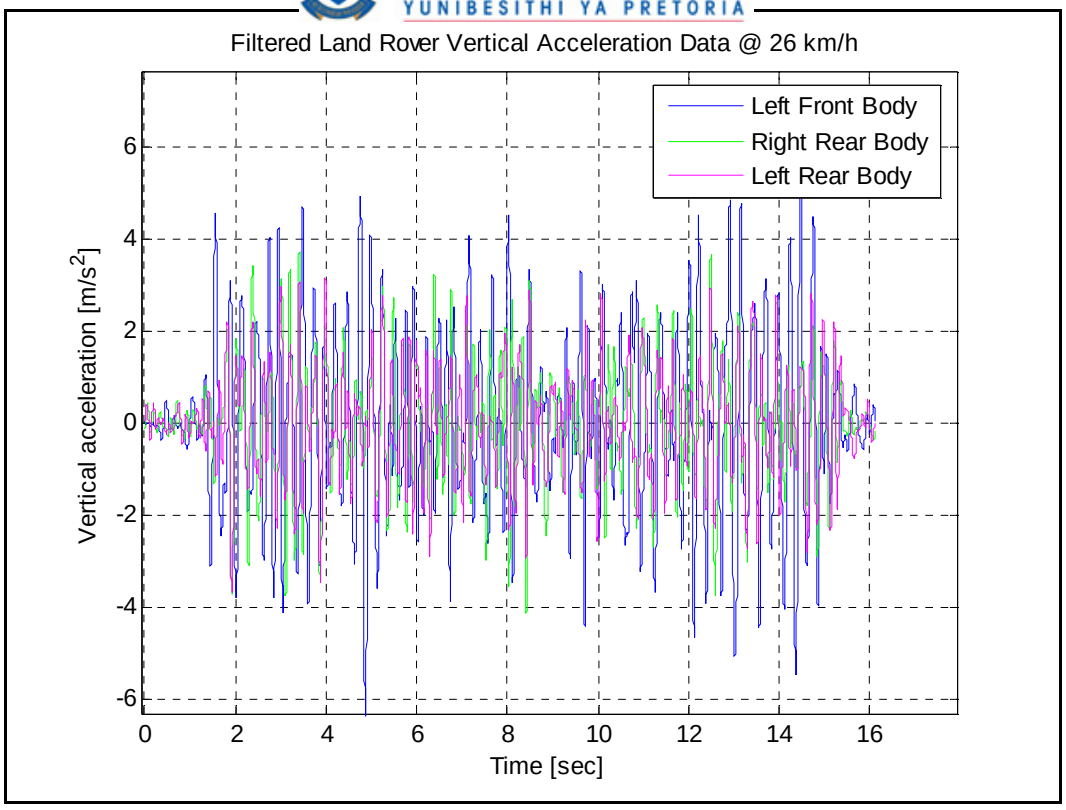


Figure 135: Land Rover vertical accelerations @ 26km/h.

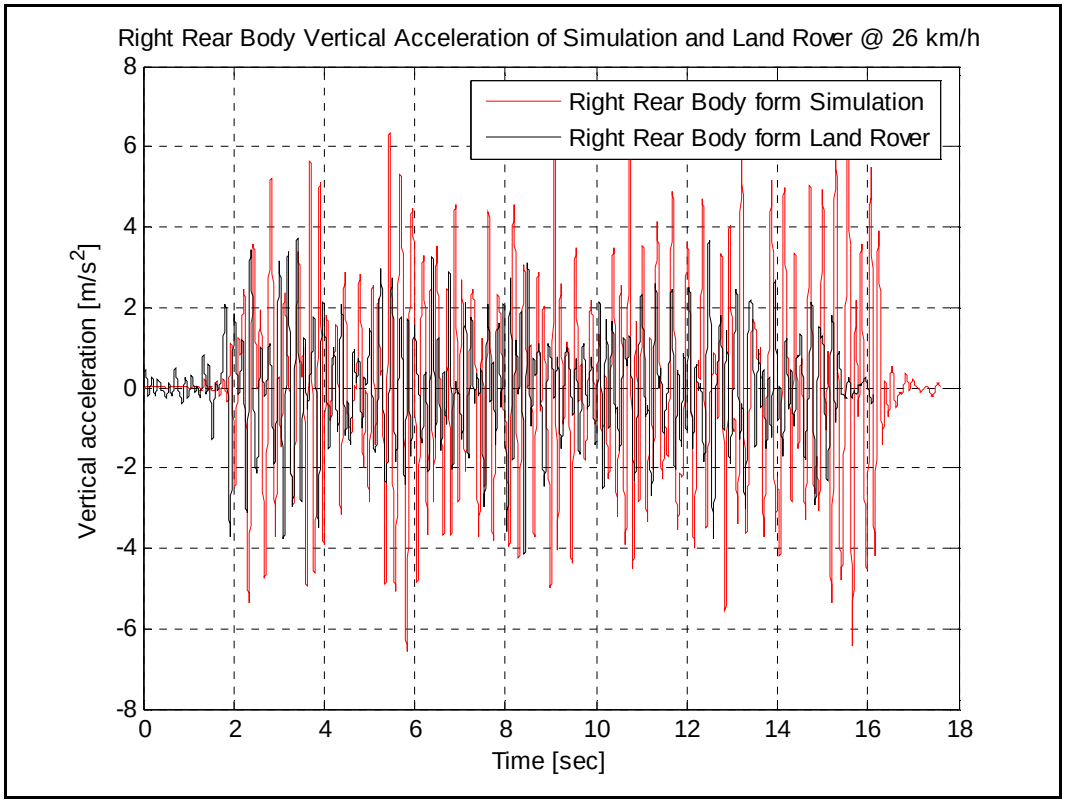


Figure 136: Right Rear Body vertical accelerations from simulation and Land Rover @ 26km/h.

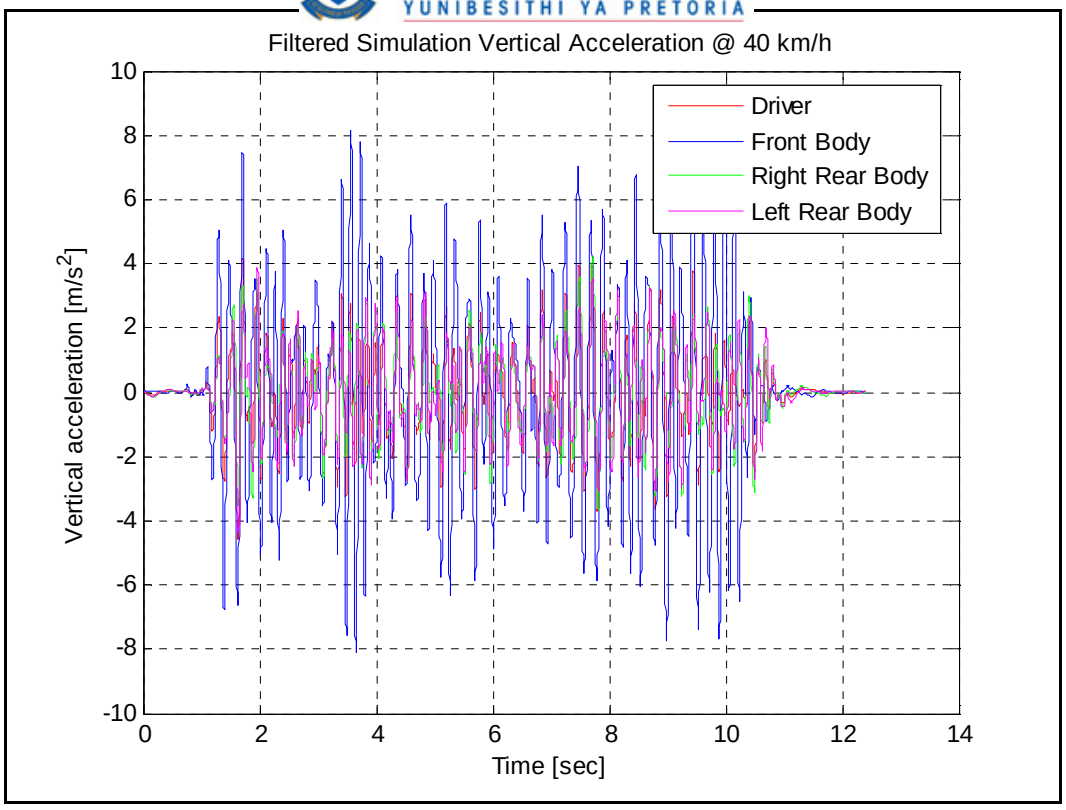


Figure 137: Simulation vertical accelerations @ 40km/h.

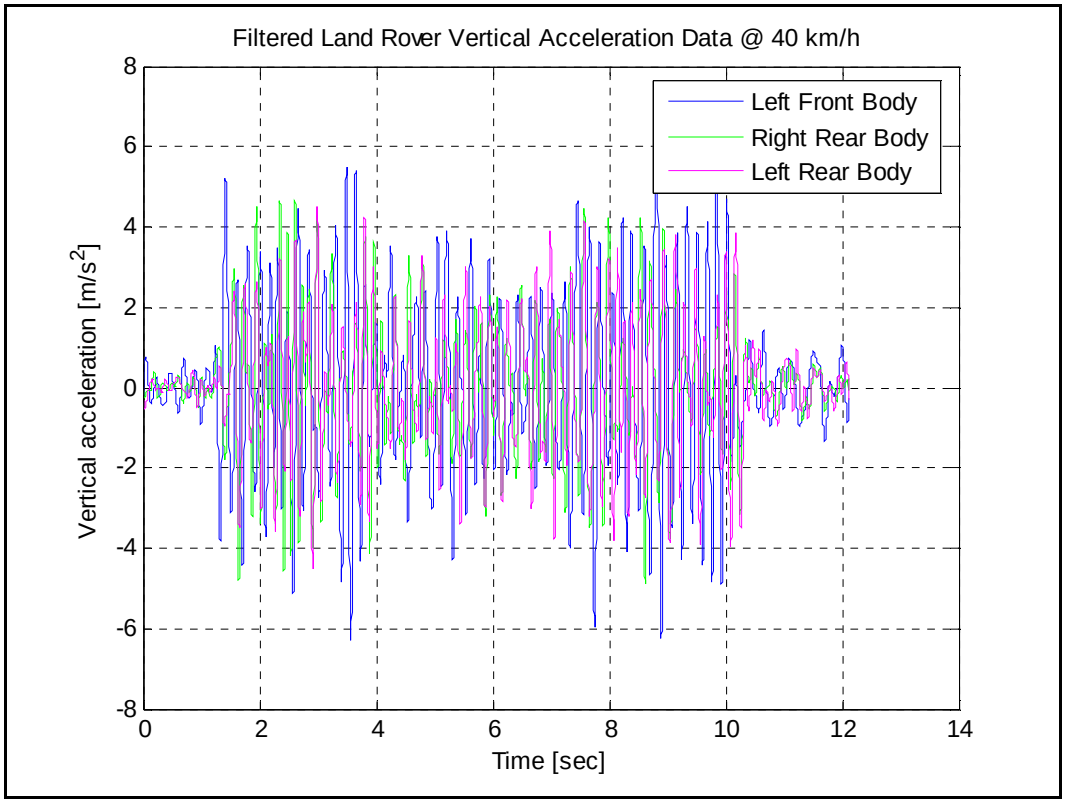


Figure 138: Land Rover vertical accelerations @ 40km/h.

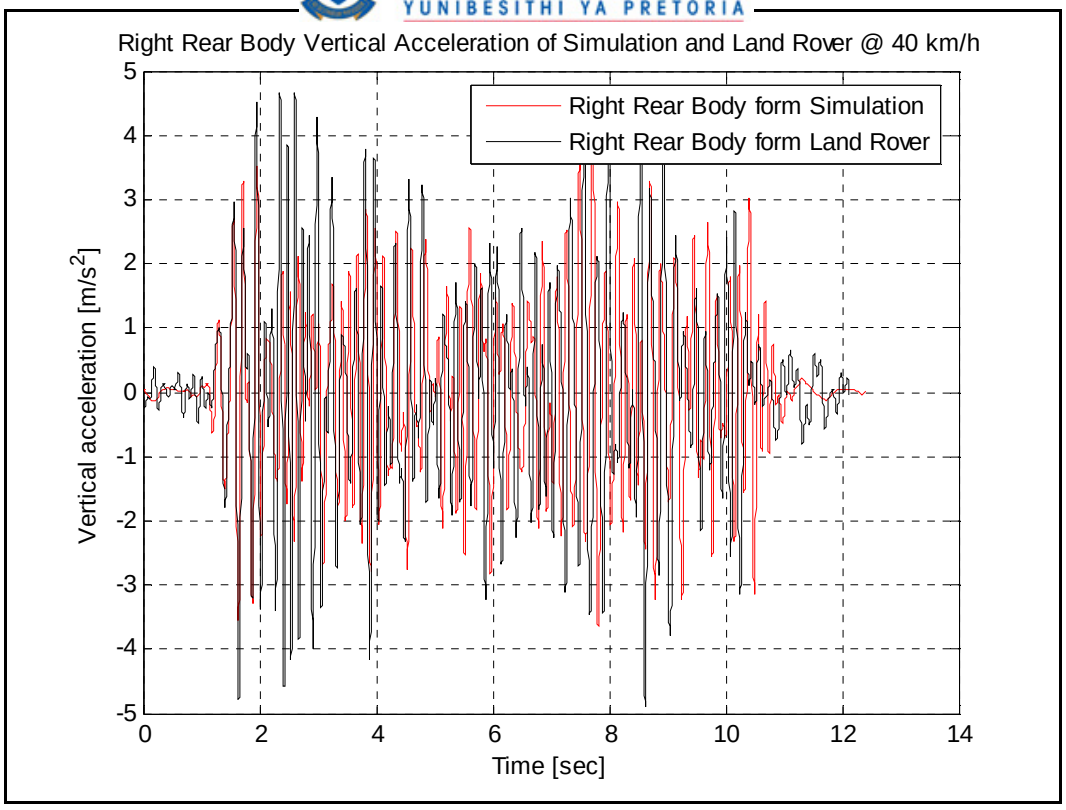


Figure 139: Right Rear Body vertical accelerations from simulation and Land Rover @ 40km/h.

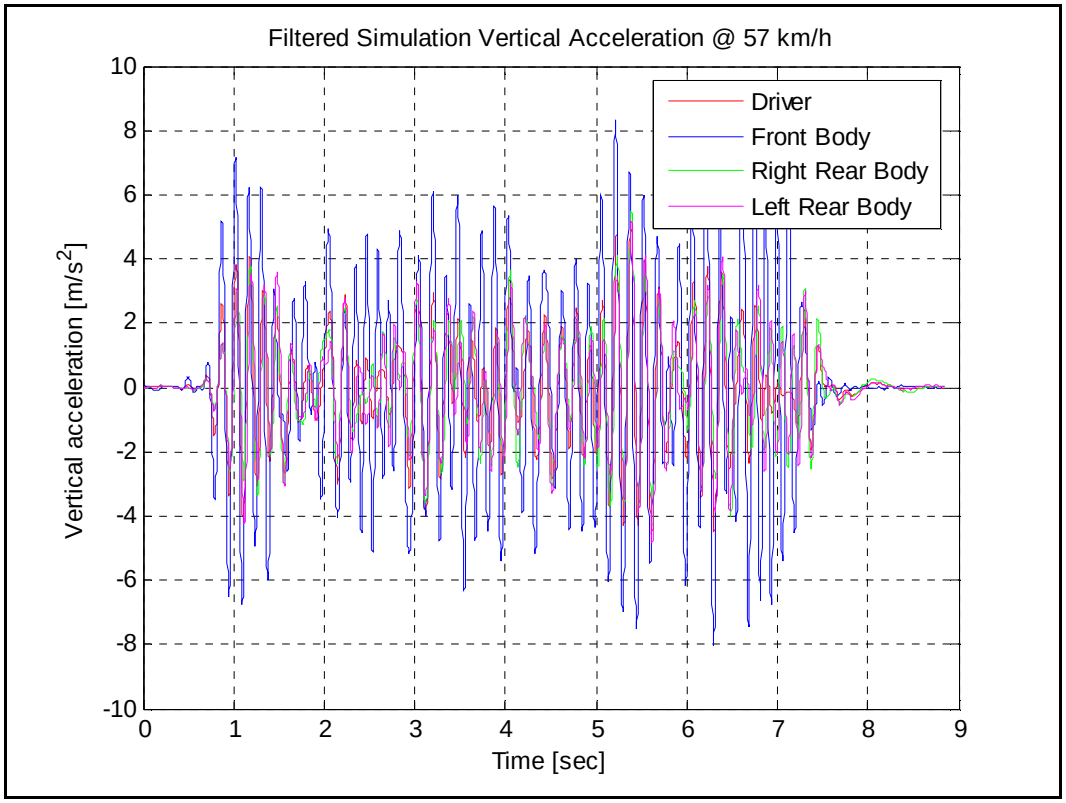


Figure 140: Simulation vertical accelerations @ 57km/h.

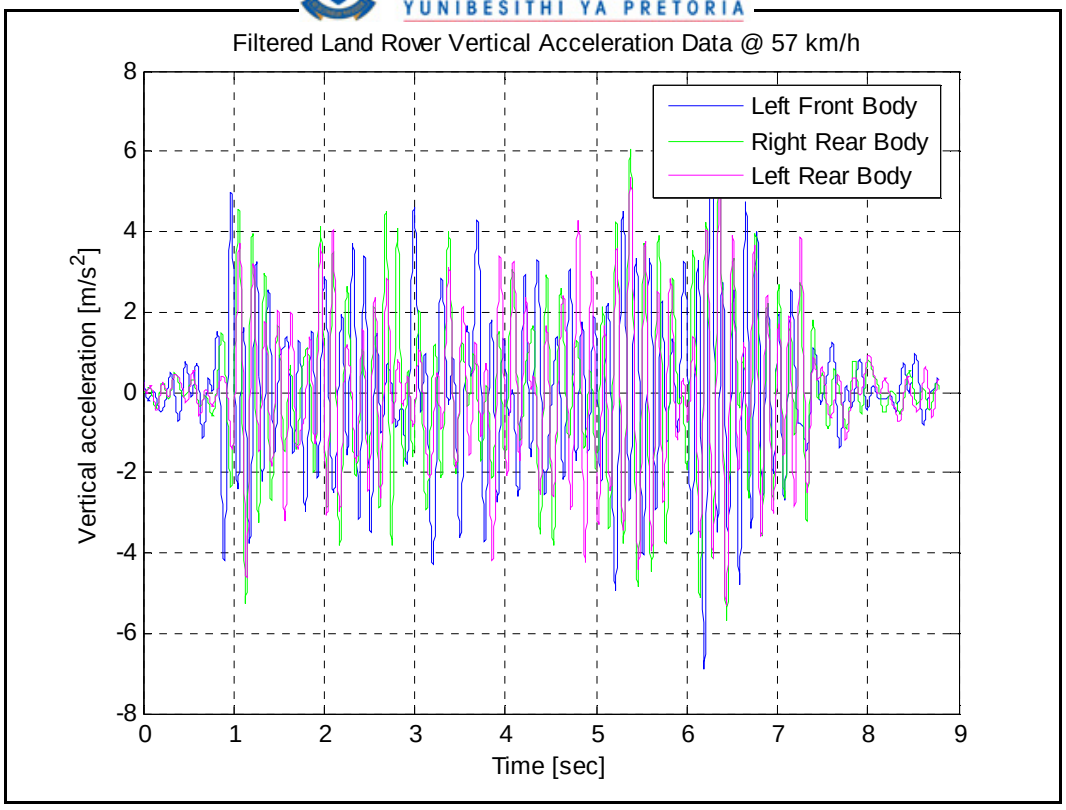


Figure 141: Land Rover vertical accelerations @ 57km/h.

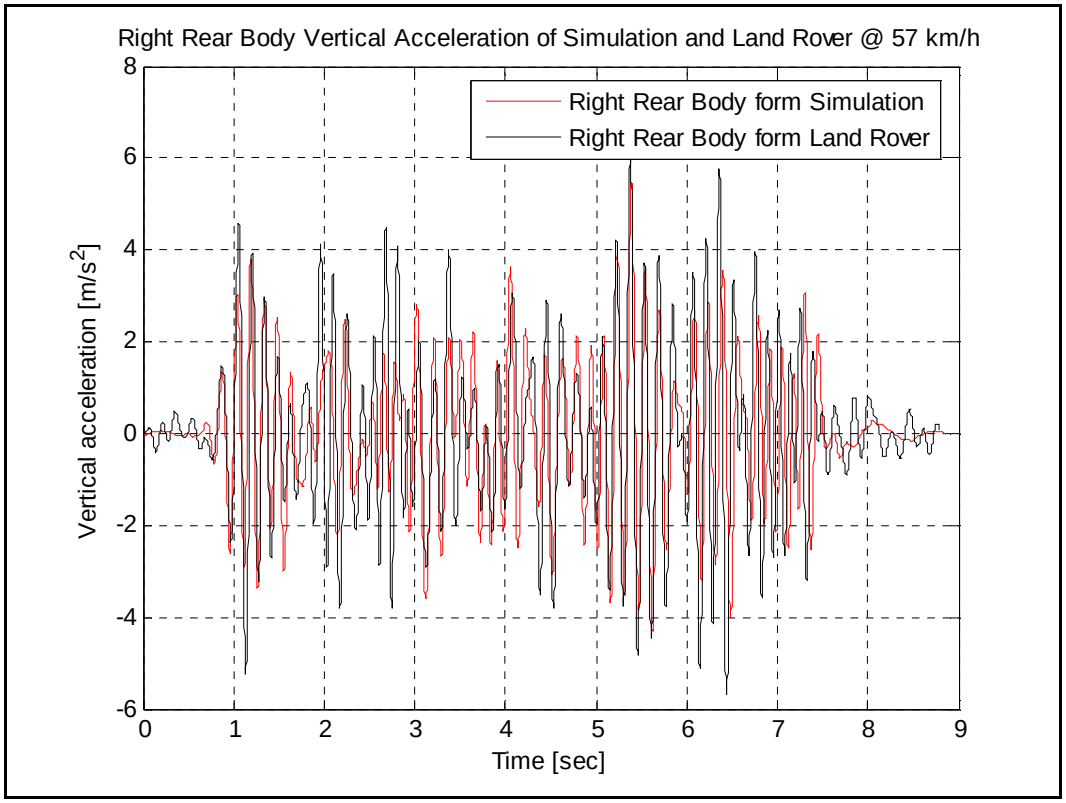


Figure 142: Right Rear Body vertical accelerations from simulation and Land Rover @ 57km/h.

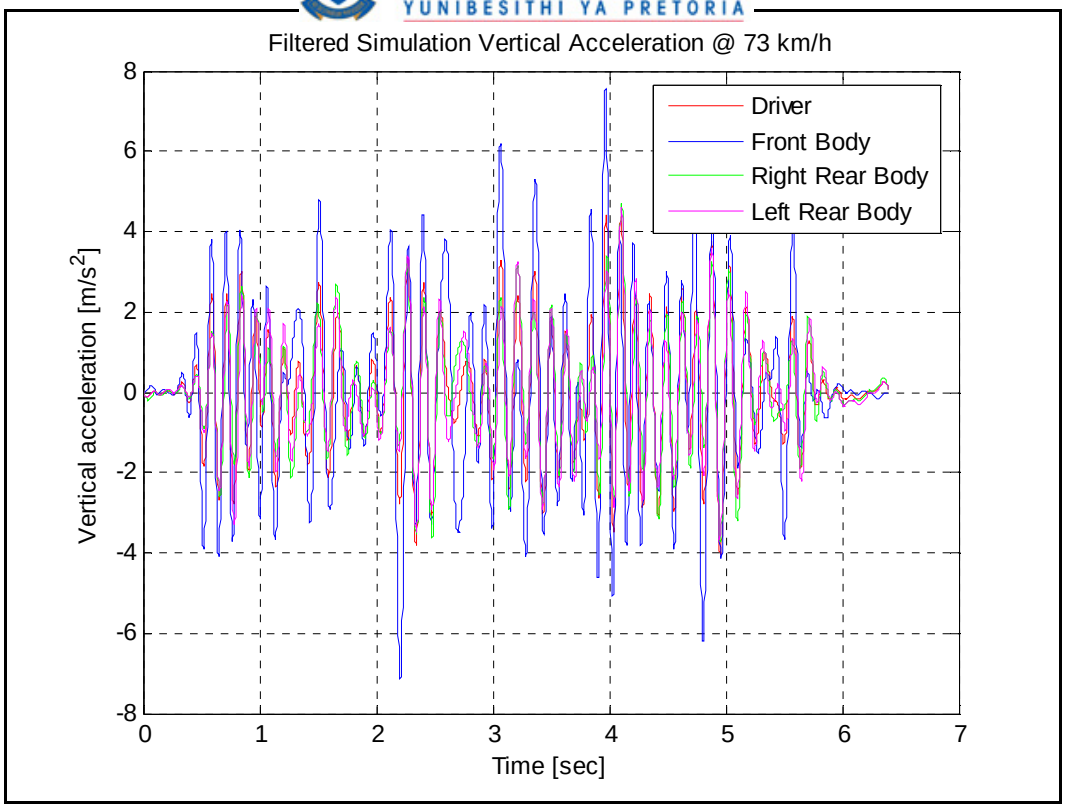


Figure 143: Simulation vertical accelerations @ 73km/h.

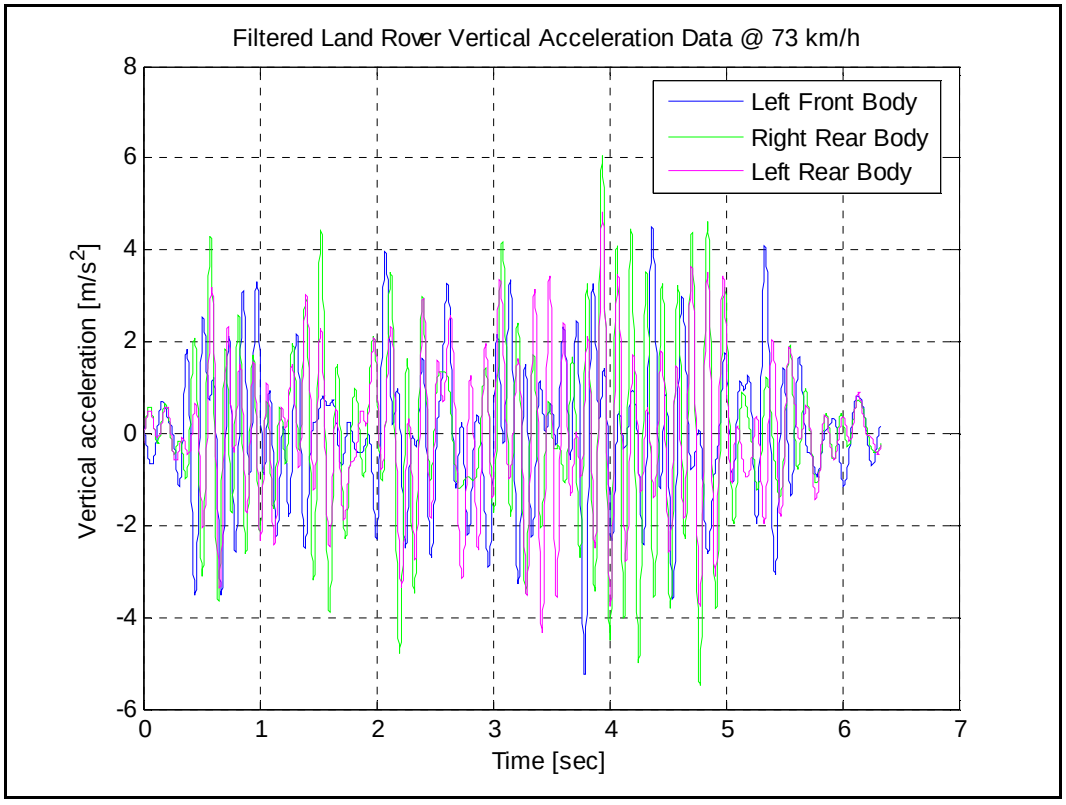


Figure 144: Land Rover vertical accelerations @ 73km/h.

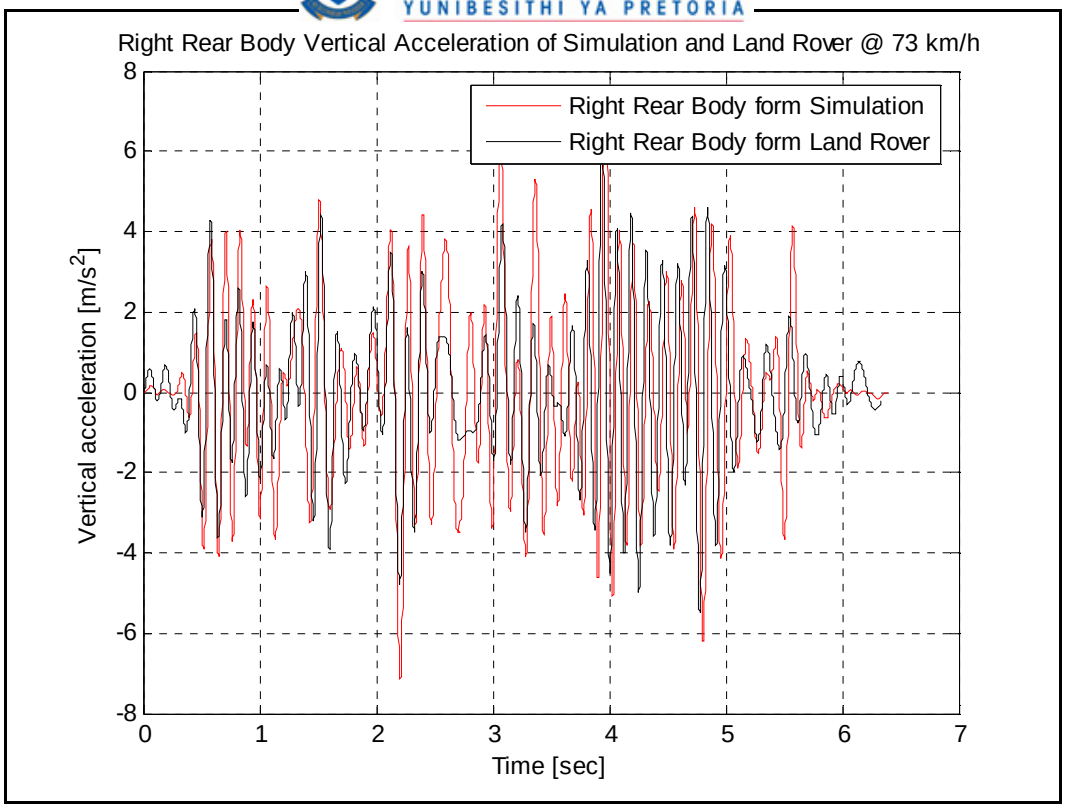


Figure 145: Right Rear Body vertical accelerations from simulation and Land Rover @ 73km.

Appendix G: 8 Hz Low Pass Filtered Fast Fourier Transforms of Simulations and Land Rover Vertical Accelerations

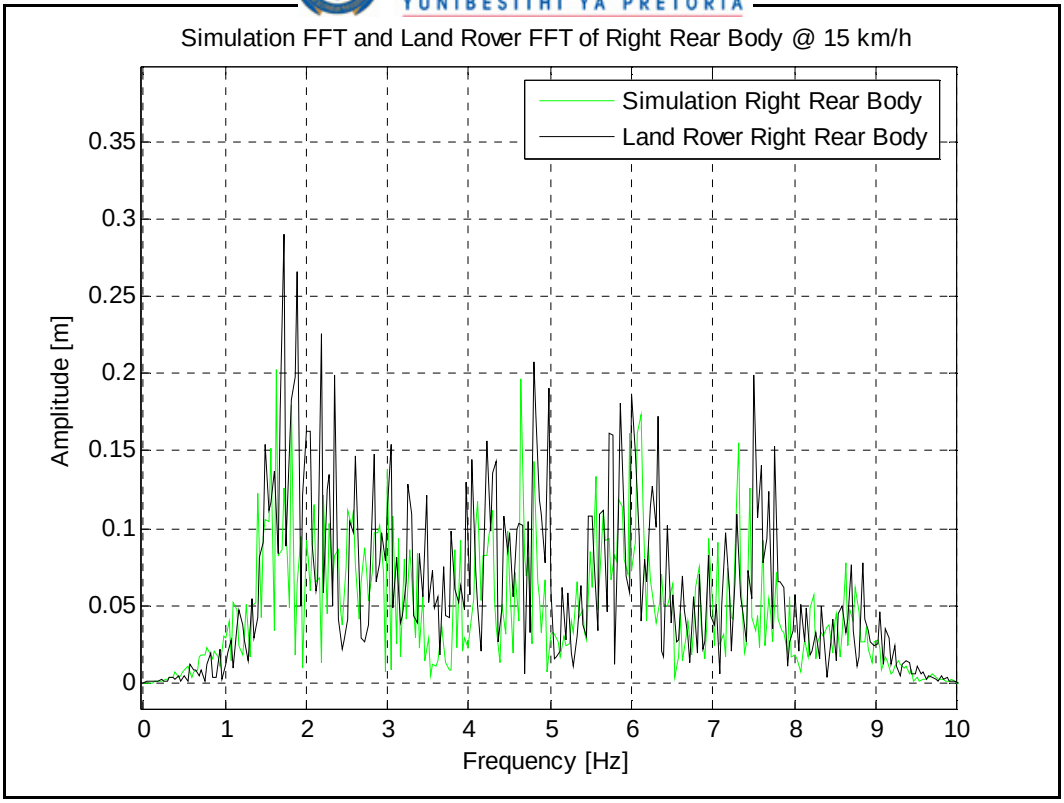


Figure 146: Filtered FFT of vertical accelerations @ 15km/h

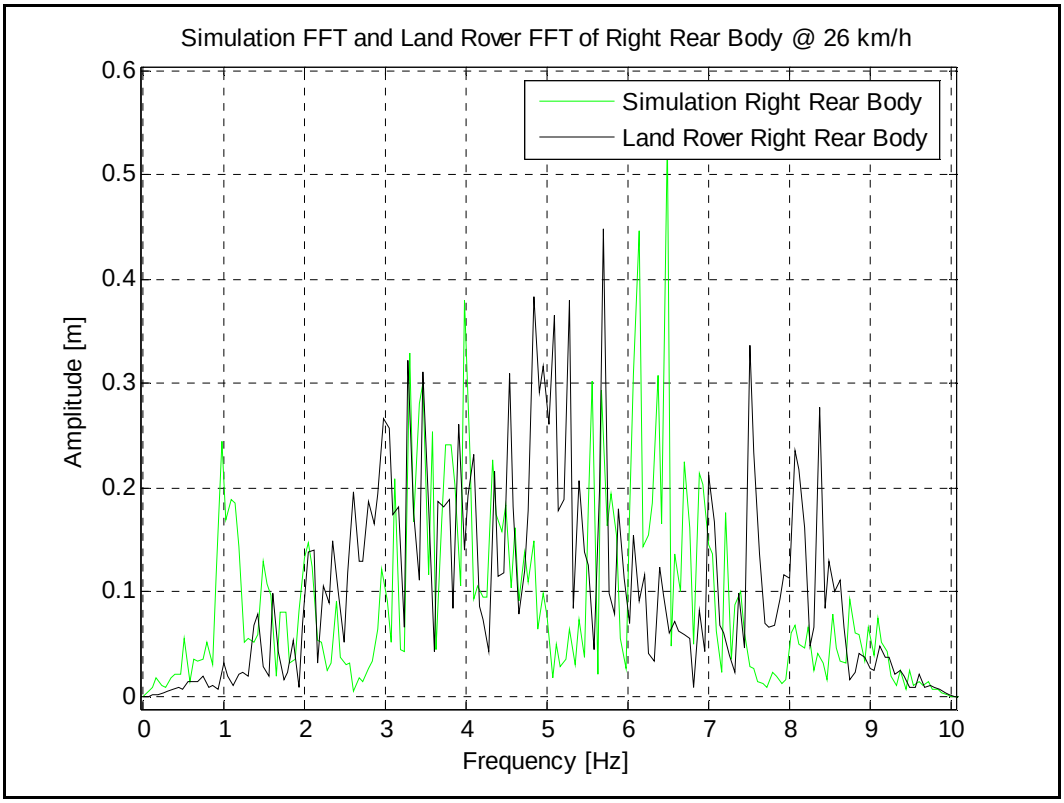


Figure 147: Filtered FFT of vertical accelerations @ 26km/h.

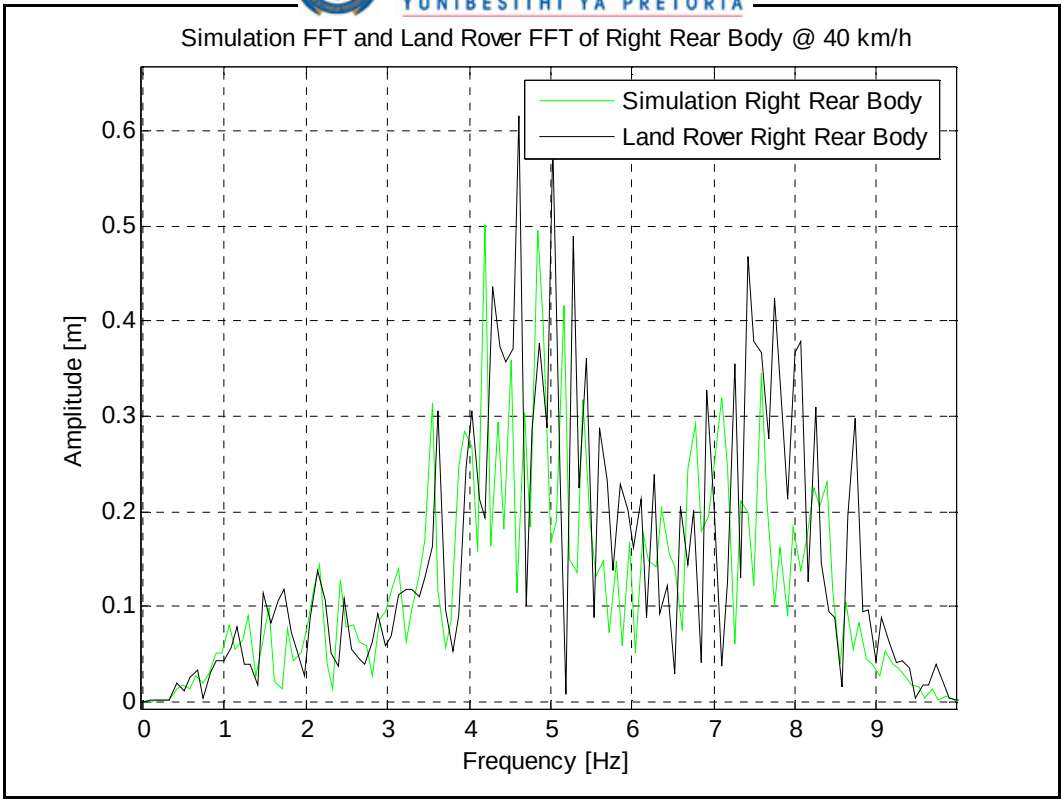


Figure 148: Filtered FFT of vertical accelerations @ 40km/h.

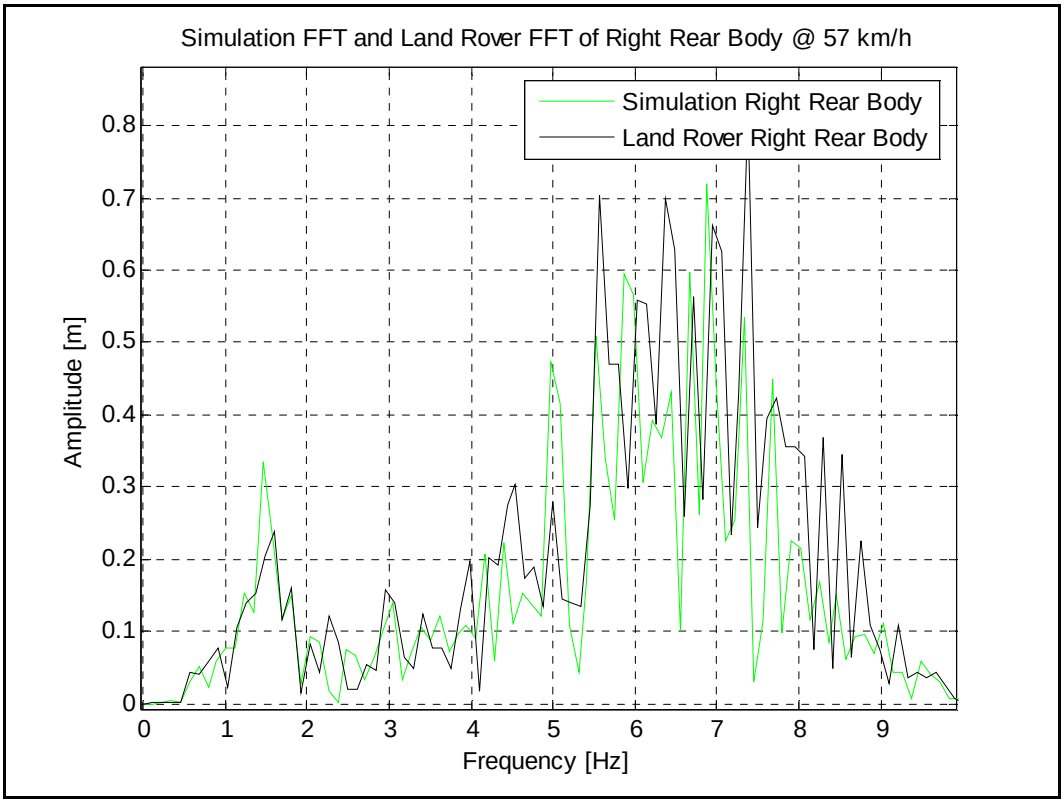


Figure 149: Filtered FFT of vertical accelerations @ 56km/h.

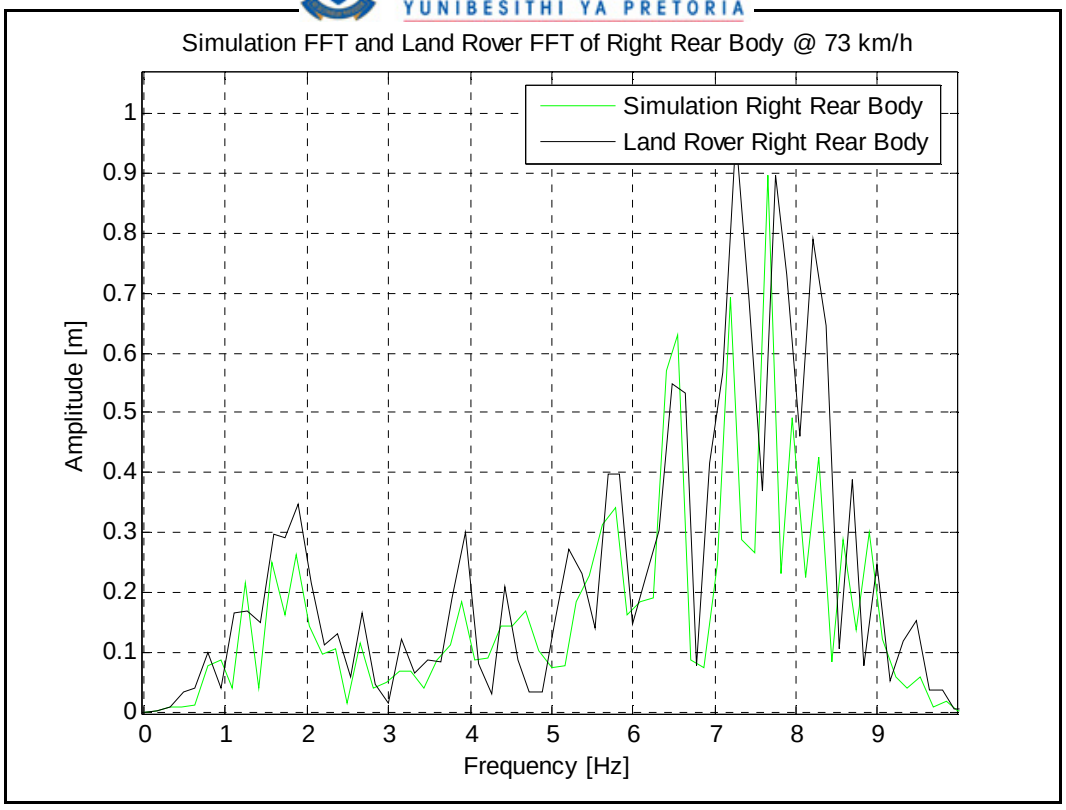


Figure 150: Filtered FFT of vertical accelerations @ 73km/h.