CHAPTER IV

PRELIMINARY TEST

The preliminary test was carried out in real driving environments. Few simple test runs were performed at Somboon Group's factory. Somboon Group is a manufacturer of vehicle parts, including leaf springs. Six rides were performed on roads within the factory and some section of Bangna-Trad road. Data was collected by the accelerometers mounted at various positions of a test vehicle and the visual ride events were also recorded by a video camera attached at the rear glass behind passenger seat. The measured data were processed both in time domain and frequency domain. The application of ride comfort evaluation suggested by ISO 2631 was applied and finally found that the calculated results agree with the data collected from each transducer.

4.1. Objective

1. To study and practice the ride comfort measurement, preparation and settings of the test instruments.

2. To collect the acceleration data and relevant information and bring to an analysis. The results from the application of ride comfort evaluation standard, ISO 2631 was examined and discussed.

3. To gain knowledge from real experiments and test environments in order to improve and adjust the test structure for further investigation.

4.2. Test Instruments

1. One six-axis accelerometer (Crossbow Technology MNAV Series)
2. Accelerometers (KYOWA Electronic Instruments Co., Ltd.), one of three-axis typed (20 G) and four single axis typed (10 G)
3. A data logger (KYOWA Electronics Instruments Co., Ltd.)
4. A video camera and a set of the vacuum suction holder arm

4.3. Tested Vehicle

The test vehicle for the investigation was TOYOTA CAMRY 2002 whose details are given in table 4-1

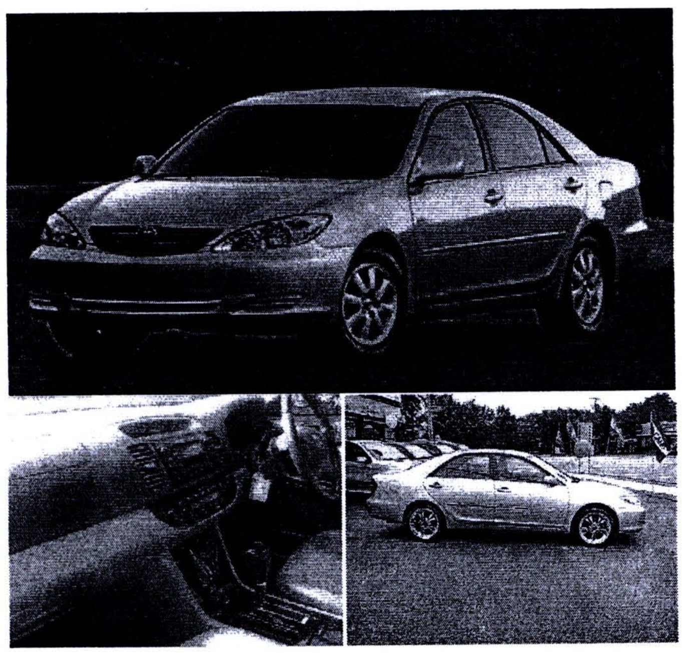


Fig.4-1 The tested vehicle used in the investigation

Model	CAMRY 2.4Q
Gear system	Automatic
Engine cc	2,400
Engine type	4 cylinders DOHC 16 valves
Steering	rack and pinion PAS
Doors	4
Width (mm)	1,810
Length (mm)	4,825
Height (mm)	1,500
Weight (Kg)	1,460

Table 4-1 Technical information of the tested vehicle

4.4. Sensors positioning

1. The six-axis (Cross bow) accelerometer was attached to the floor and the three-axis typed (Kyowa) was secured on the top of it. The position was at the back of the driver's seat (Fig.4-2(a)).

2. Four remaining accelerators which are single axis typed were mounted at four locations outside cabin to measure acceleration in vertical direction. The positions are at the top of shock-absorber (Fig.4-2(b) left top/FRT), the right front of the car (Fig.4-2(b) right top/FRB), the right corner on the floor inside the rear trunk(Fig.4-2(b) left bottom/ RRT), and the rear right location near the wheel (Fig.4-2(b) right bottom/RRB).

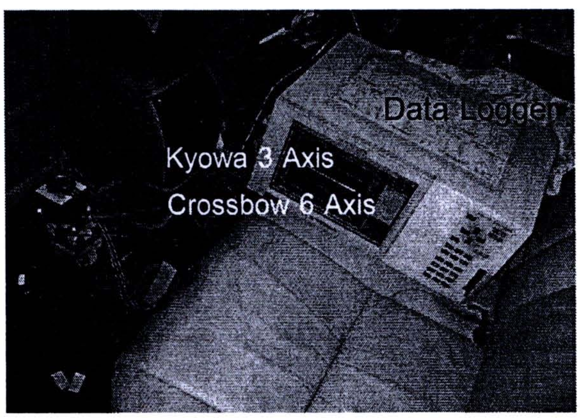


Fig.4-2(a) Position of sensors installed within a cabin

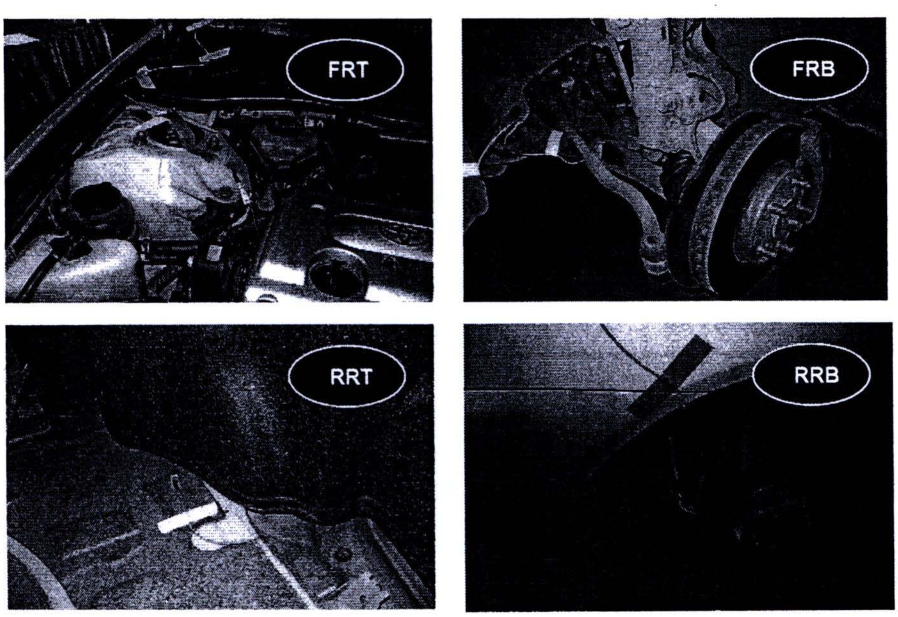


Fig.4-2(b) Positions of sensors installed outside a cabin

3. A set of video camera and holder arm was attached to the rear glass within the cabin to record visual ride events that were experienced by a driver and passengers.

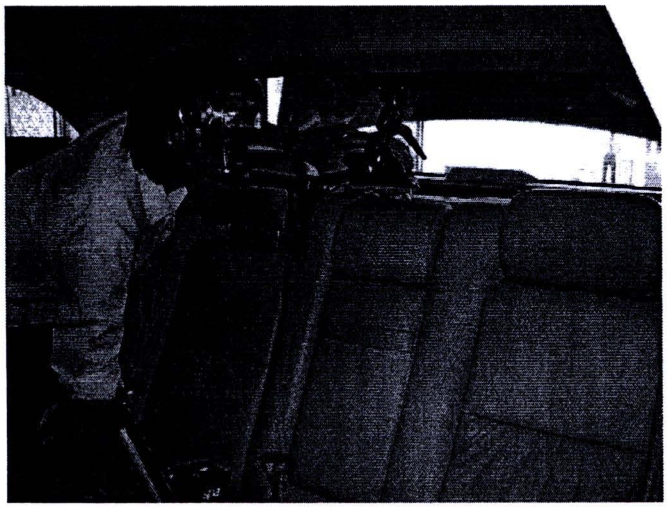


Fig.4-2(c) Attachment of a video camera

4.5. Testing Locations

The locations of testing are the road sections within Somboon Group's factory and Bangna-Trad Road, Km 5th to Km 7th. The graphical illustration of the test tracks are given in topic 4.7.

4.6. Driving Conditions

The driving situations are varied from straight track, curve, to road bumps, potholes, lids of water draining pipes, road gaps, etc.

4.7. Procedure

The investigations were performed by one driver and three passengers traveling in a car with a set of transducers. Six rides with multiple measurements were made. The floor accelerations in three orthogonal axes were collected by Kyowa (three-axis) and X-BOW (six-axis) accelerometers, the later one also measured the other rotational velocities, i.e., roll, pitch, and yaw. Four single-axis accelerometers were measuring the vertical accelerations at the different positions of a traveling vehicle. During the rides, the driving environment was captured by a video camera from the rear glass position. The data collected by crossbow sensor was saved in a notebook and the other ones need to send signals into a data logger. The data collection for all sensors was started to record at the same time. The six-axis accelerometer was measuring with the sampling frequency of 50 Hz while the three-axis accelerometer was measuring with the sampling frequency of 200 Hz. Six test rides were performed on six road section with different scenario. The description and graphical illustrations are given below,

Case 1: Direct track driving over a road bump at speed 20 Km/hr within the factory's area

Case 2: One round completed driving around the factory at speed 30 Km/hr

Case 3: One round completed driving around the factory over lids of water draining pipes

Case 4: Direct track driving on Bangna-Trad road section between Km 15^{th} to a petrol station at speed 80 Km/hr

Case 5 : Driving on Bangna-Trad road section between the petrol station at speed 50 Km/hr, turning back at U-turn and increasing speed to 100 Km/hr

Case 6: Driving over rough surface road track outside the factory's area at speed 20 Km/hr

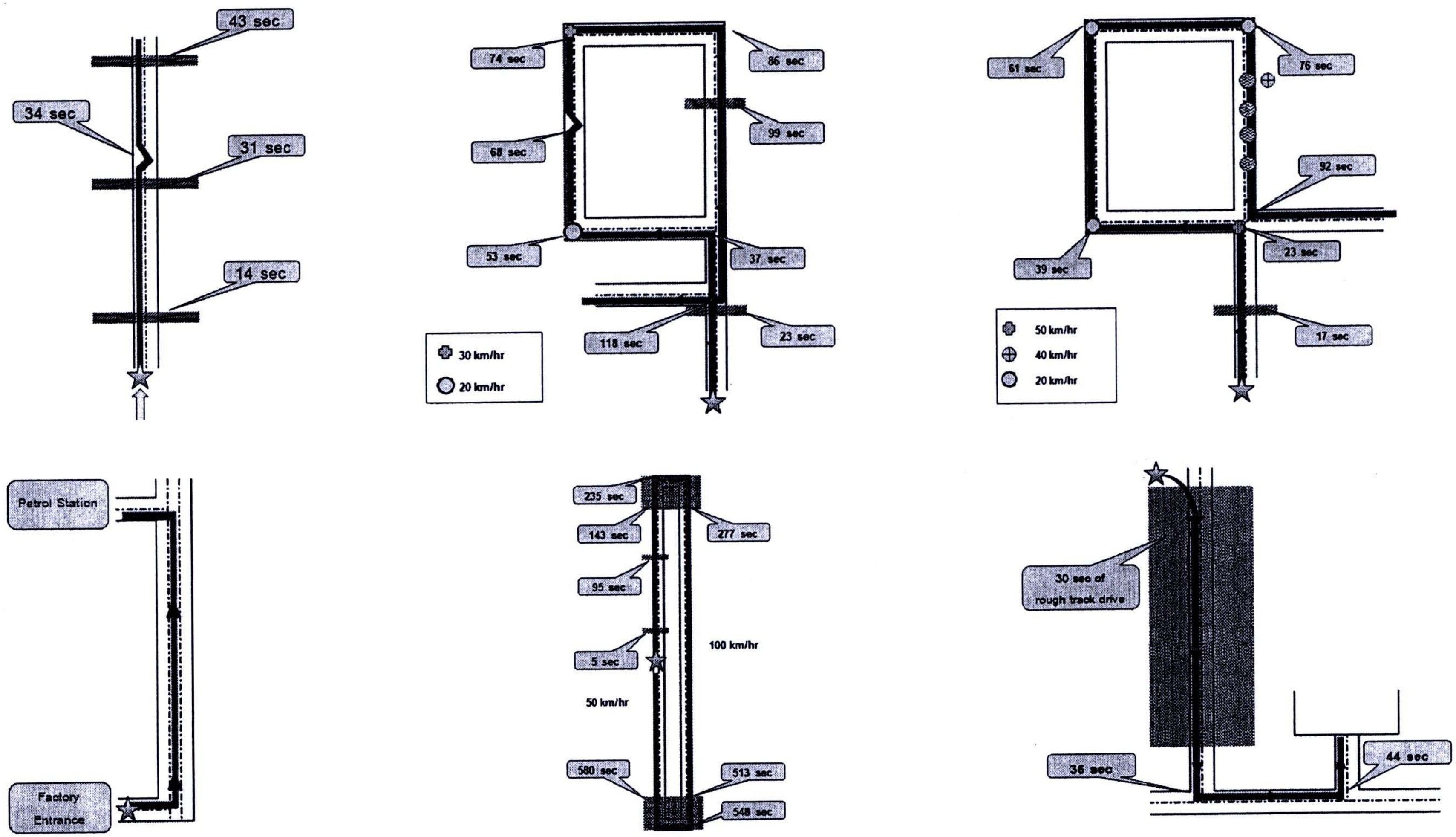


Fig.4-3 Different driving situation of test tracks

4.8. Data Analysis

The analysis of the data includes time domain and frequency domain analysis, which were performed on MATLAB program.

4.8.1. Time Domain Analysis

In this category, the raw data imported were displayed by a plot over time. This method allows the interpreter to notice the amplitude and direction of the acceleration over time. The method of interval root mean square was also employed by taking the group of data of the interested interval. It provides better information with ease of comparison. However, this approximation method can lead to error if the resolution of the data interval is not small enough. For the analysis of the reported results of this study, the raw data was divided into 100 intervals for the interval root mean square method.

4.8.2. Frequency Domain Analysis

Data analysis in frequency domain was performed by mean of PSD method which is based on Fast Fourier Transform (FFT) operation. This analysis allows the interpreter to see the components contained in a measured signal at different frequencies. For this study, the Periodogram technique was employed to estimate the average PSD of signals by Discrete Fourier Transform (DFT), using number of DFT at 1,024 and 256 points.

4.9. Results

For all sensors, acceleration data in time domain agree well with the ride event and the floor acceleration measured from different sensors were the same in all cases. In term of ride comfort evaluation, the frequency weighting technique and method to calculate the average ride comfort were applied to measured data. The results of the weighted RMS acceleration in each directions obtained from a six-axis accelerometer, both translational (A_{wx} , A_{wy}, A_{wz}), rotational (R_{wx} , R_{wy}, R_{wz}), and the total combination of multi axial (A_v) are shown in table 4-2. The approximated level of ride comfort/ discomfort are represented by the letters a, b, c, d, and e which represents the level of comfort as "not uncomfortable", "a little uncomfortable", "fairy uncomfortable", "uncomfortable", and "very uncomfortable", respectively. The results show that the amount of overall vibrations calculated from ISO evaluation method agree with the ride events and conditions of road surface in different cases.

4.9.1. <u>Results of Time domain Analysis</u>

From the comparison of the average root mean square values of the acceleration signals obtained from the X-BOW (six-axis) and Kyowa (three-axis) sensors, in case of direct track driving over a road bump at speed 20 Km/hr within the factory's area (case1) and case6 which was driving over rough surface road track outside the factory's area at speed 20 Km/hr, it is found that the RMS accelerations of case1 in fore-and-aft, lateral, and vertical directions from both sensors tend to agree with each other. The graphs shown in Fig.4-4(a) are the plots of raw data against time and the plots of 100-interval RMS acceleration over time of case1 while Fig.4-4(b) are those of case 6. The results from both sensors show good agreement in the same manner, i.e., they possess the highest peaks at the same point of time. For example in case1, the highest peaks for all three directions appeared at the 14^{th}, 31^{st}, and 43^{th} second which were at the time of driving over a road bump. In case 6, it is found that the maximum swing appeared at the time interval from the first second to the 30^{th} second which was at the time of driving over rough surface road. At the 36^{th} and 44^{th}, the car was turning left, so that the graph posses the high amplitude in positive-lateral direction as shown in Fig.4-4(b).

When considering rotational accelerations; i.e., roll, pitch and yaw, obtained from X-BOW(six-axis) sensors for case1 and case2 as shown in Fig.4-5, it is found that the graphs of roll for both cases possess the highest swing, the lower are in pitch and the lowest are in yaw directions. In case 2, the graphs swing with larger amplitude than those of case 1. From the graph of yaw in case 2, the amplitude tends to increase towards positive direction at the time when the car was turning left (the 37^{th} second). At the 53th, 74th, 86th,and 118th, the graph exhibits in similar manner but in opposite direction as the car was turning right.

The comparison was also made between the acceleration signals obtained from the other four single-axis accelerometers which were attached at four different positions outside a cabin and the signals obtained from X-BOW and Kyowa sensors which were attached at the positions within a cabin. All measured signals result in the same consequences, i.e., they possess the highest peak at the same point of time when the car was moving over a road bump as shown in Fig.4-6. The acceleration signal obtained from the sensor attached at the rear right back (RRB) of the test vehicle seems to exhibit the highest amplitude, among the results measured from the sensors at the other positions

4.9.2. Results of Frequency domain Analysis

In the frequency analysis, PSD results of the acceleration signals obtained from X-BOW and Kyowa sensors tend to agree with each other for both case 1(smooth track) and case6 (rough track) although the sampling frequencies of the two sensor are different. PSD results of the acceleration signals obtained from single-axis typed accelerometers for case 1 which is a smooth track exhibit the highest peak at the frequency around 10 Hz which is the natural frequency of wheel or unsprung mass, especially when road inputs are similar to white noise. It can be obviously seen from the signals measured at the FRB and RRB positions (see Fig.4-7).

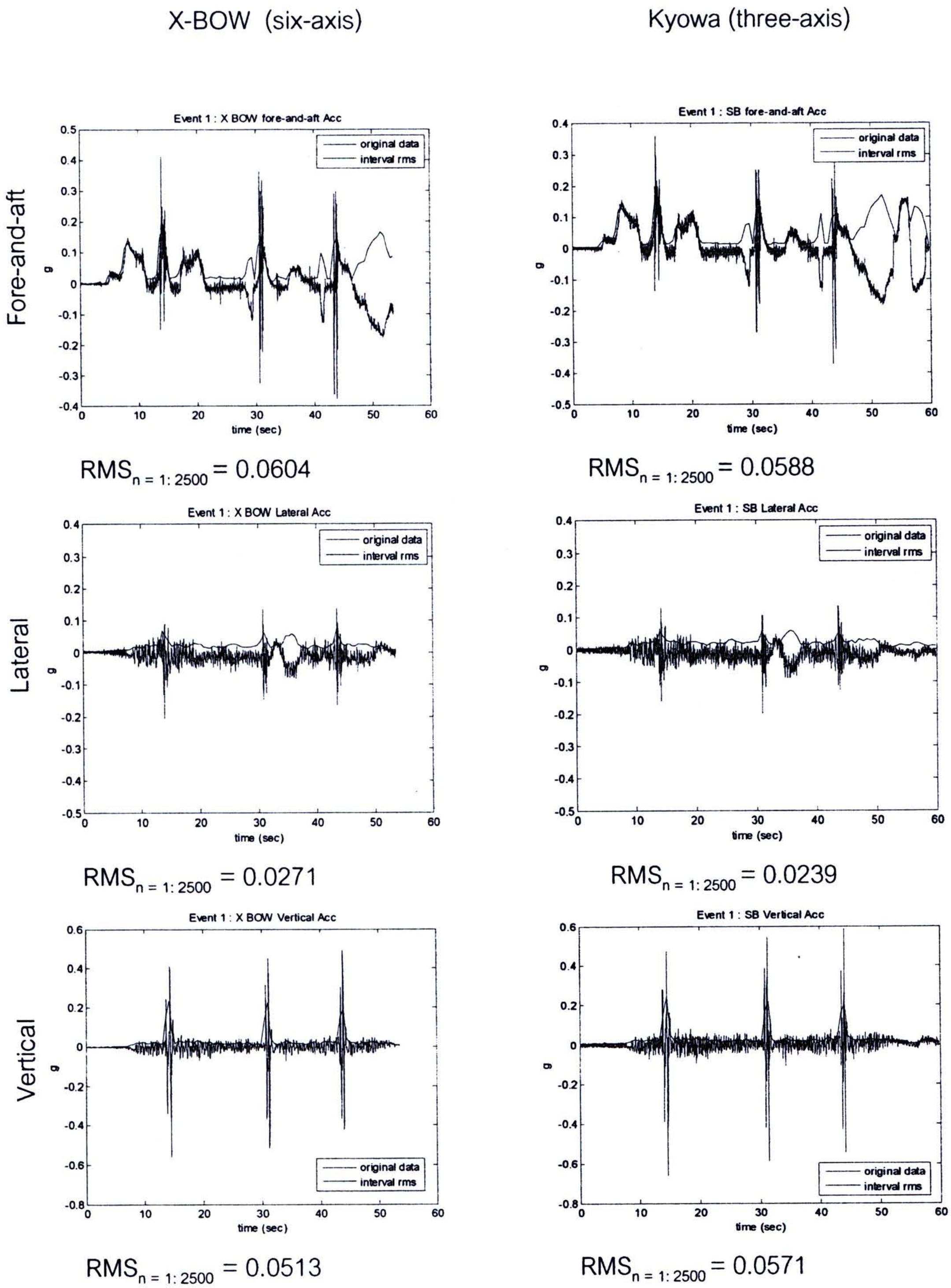
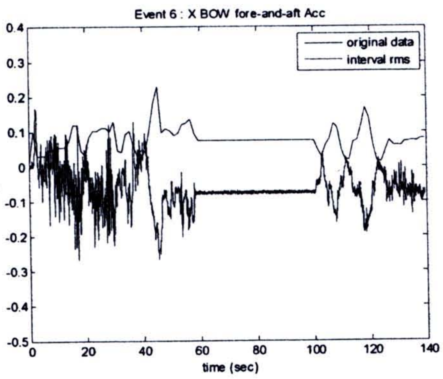


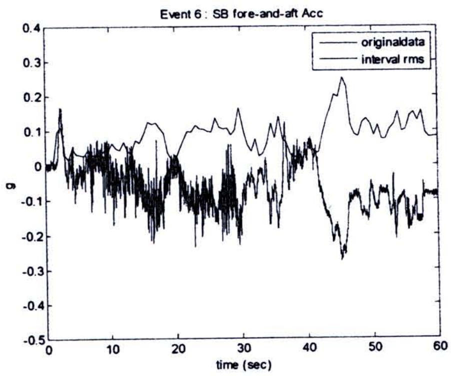
Fig.4-4(a) Acceleration results of driving situation case1 captured by two different sensors installed within a cabin

X-BOW (six-axis) | Kyowa (three-axis)

Fore-and-aft

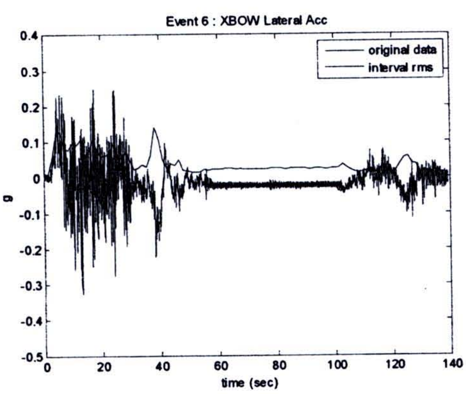


$RMS_{n\,=\,1:3000} = 0.0948$

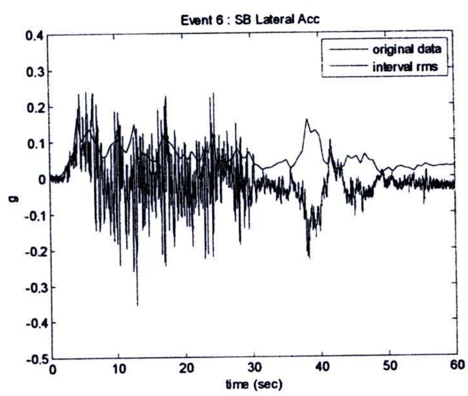


$RMS_{n\,=\,1:3000} = 0.0953$

Lateral

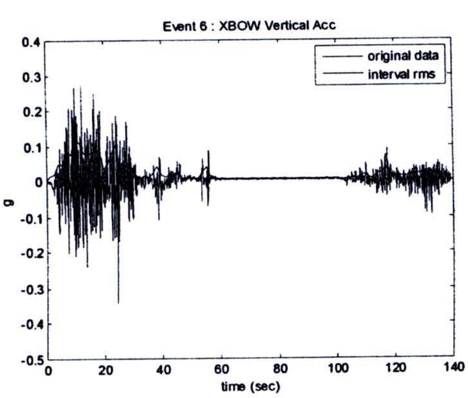


$RMS_{n\,=\,1:3000} = 0.0670$

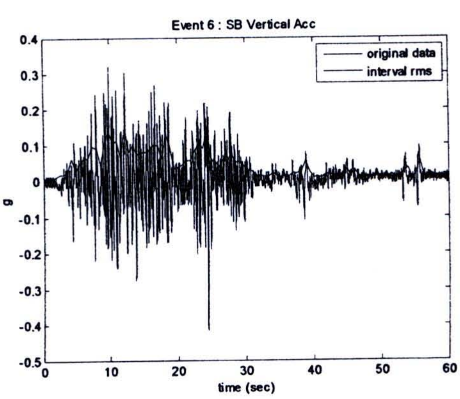


$RMS_{n\,=\,1:3000} = 0.0675$

Vertical



$RMS_{n\,=\,1:3000} = 0.0526$



$RMS_{n\,=\,1:3000} = 0.0581$

Fig.4-4(b) Acceleration results of driving situation case6 captured by two different sensors installed within a cabin

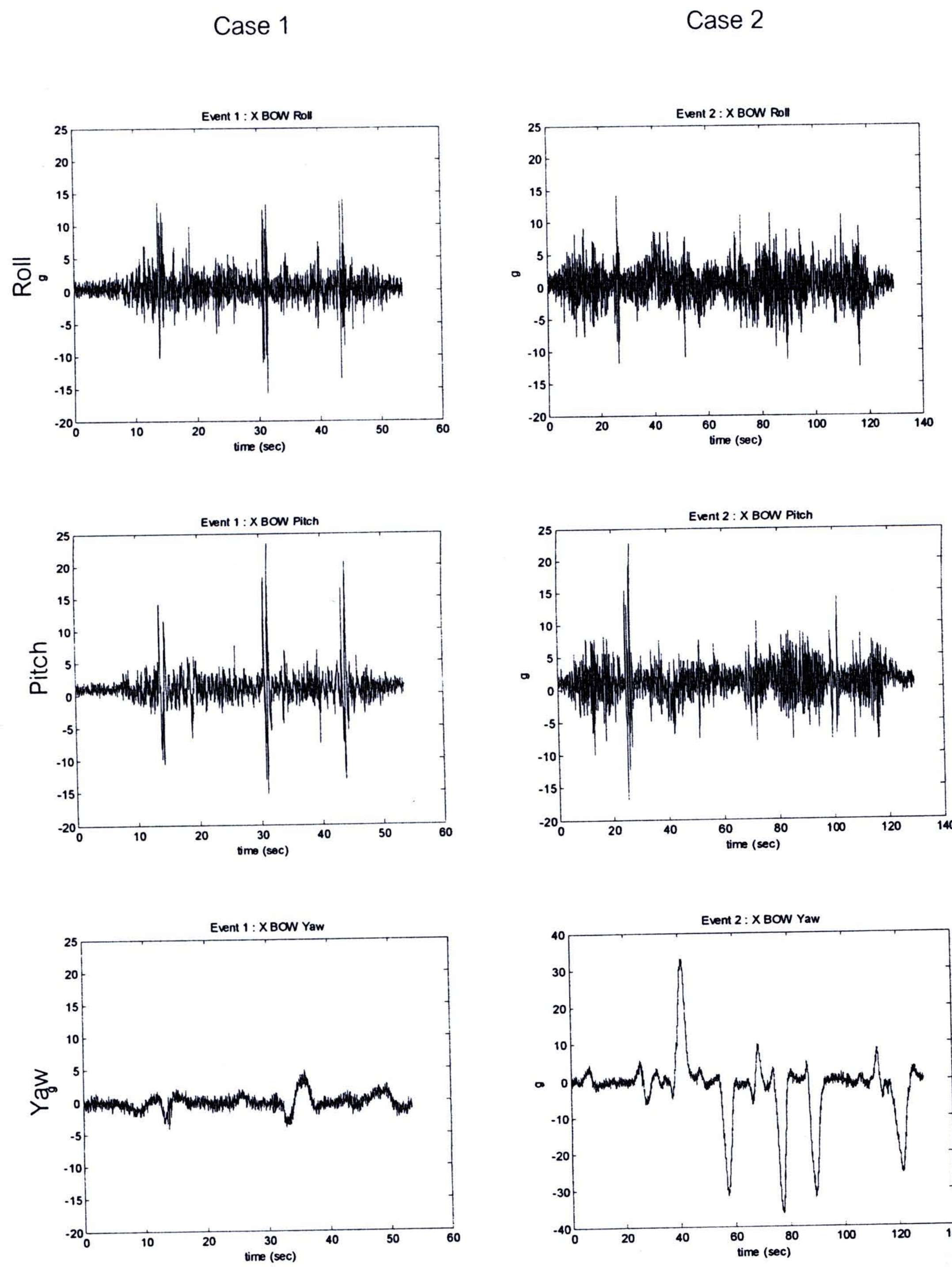


Fig.4-5 Rotational acceleration results of driving situation case 1 and case 2 captured by X-BOW (six-axis) sensor

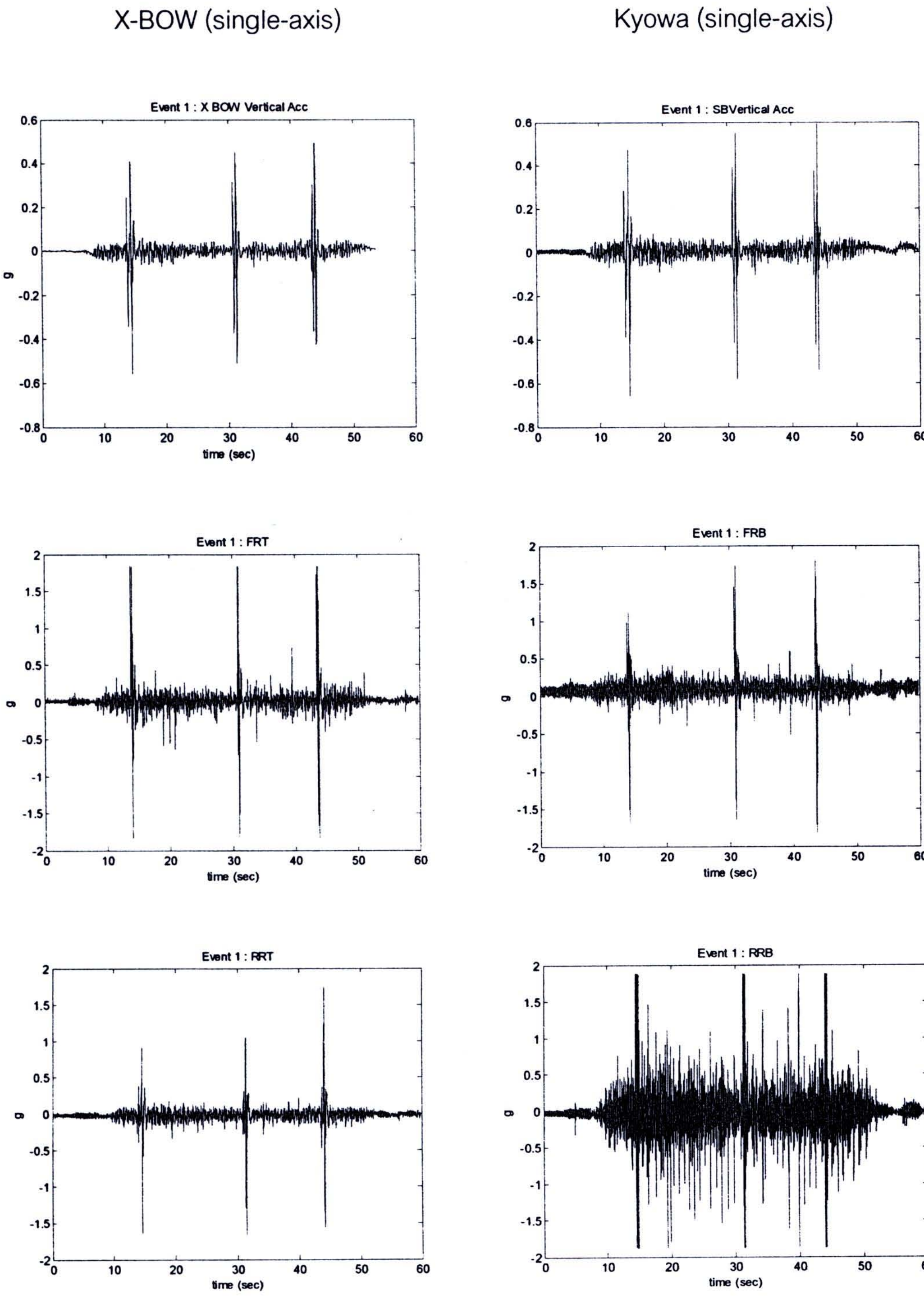


Fig.4-6 Vertical acceleration results of driving situation case 1 captured by two different sensors installed outside a cabin

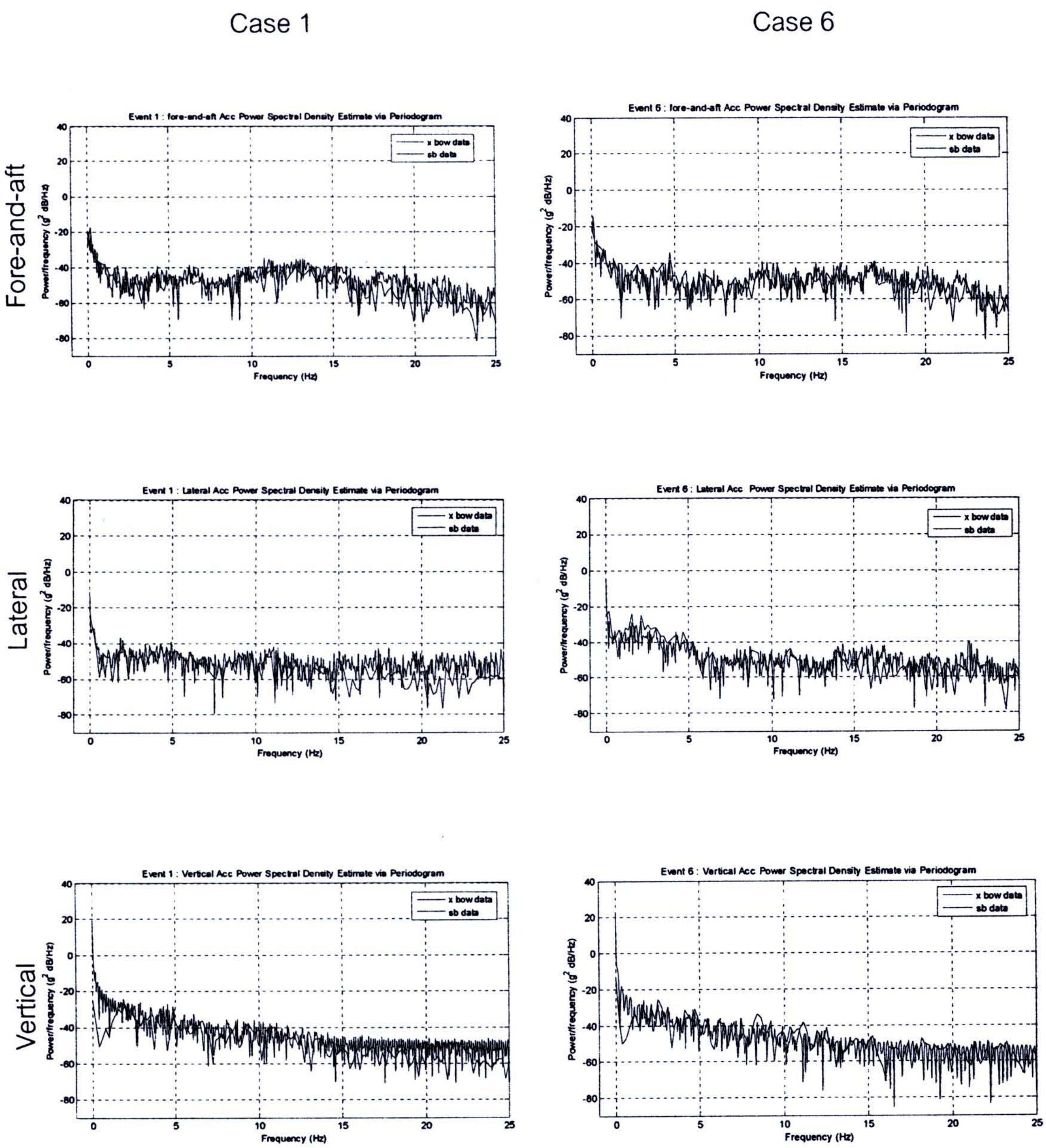


Fig.4-7 PSD results of acceleration spectra for driving situation case1 and case6 captured by two different sensors installed within a cabin

4.9.3. Results of Frequency Weighting Analysis

In the frequency weighting analysis, data of interests from six ride for both translational and rotational cases were randomly selected. All criteria can be divided in to new seven sub-cases as the following,

1. Driving over the smooth track within the factory.
2. Driving over the track with some obstacles, including
    2.1. Road bumps
    2.2. Lids of water drain pipes
3. Driving over rough surface track
4. Driving over real road sections outside the factory with various speed of
    4.1. speed 50 Km/hr
    4.2. speed 80 Km/hr
    4.3. speed 100 Km/hr

The calculated weighted RMS accelerations for all cases above are reported in Table 4-2 and Fig.4-8. When the total vibration values (a_v) are considered, the highest one is found to be in case 2.1 which was calculated from data obtained from the case of driving over a road bump. It is also found in this case that the weighted RMS of vertical acceleration (a_{wz}) is highest among other cases. In the third case, the total value was calculated from data obtained from the case of driving over rough road surface. The weighted RMS values of the lateral (a_{wx}), vertical (a_{wz}), and roll acceleration (R_{wy}) are higher than those of the other cases, but the total vibration value is close to that of the case 2.1 with the same level of comfort (very uncomfortable), according to ISO 2631-1 standard. In case 1, whose data obtained from the case of driving over a smooth track within the factory, the total weighted value is close to that of the case 4.1 which is a smooth drive over real road section outside the factory at speed 50 km/hr with the same comfort level (a little uncomfortable).

case	Weighted r.m.s. translational acceleration (m^2/sec)			Weighted r.m.s. rotational acceleration (m^2/sec)			Vibration total value (m^2/sec)		
	a_{wx} (lateral)	a_{wy} (fore-and-aft)	a_{wz} (vertical)	R_{wx}	R_{wy}	R_{wz}	a_{vl} (linear)	a_{vr} (rotational)	a_v (total)
1.	0.1411	0.3217	0.2394	0.0929	0.1765	0.0243	0.4251	0.1174	0.4410 (b)
2.1	0.3027	0.7291	1.5813	0.3584	0.1818	0.0471	1.7674	0.1837	1.7770 (e)
2.2	0.3779	0.1954	0.6580	0.1760	0.4678	0.0563	0.7836	0.3032	0.8402 (d)
3.	0.9457	0.3569	0.8107	0.5103	1.5184	0.0747	1.2957	0.9782	1.6235 (e)
4.1	0.2488	0.3198	0.1913	0.0793	0.0739	0.0431	0.4480	0.0570	0.4517 (b)
4.2	0.1970	0.1792	0.6009	0.1361	0.3429	0.0263	0.6572	0.2229	0.6940 (c)
4.3	0.1691	0.3132	0.3836	0.1259	0.2453	0.0248	0.5233	0.1626	0.5480 (c)

Table 4-2 The weighted RMS accelerations results

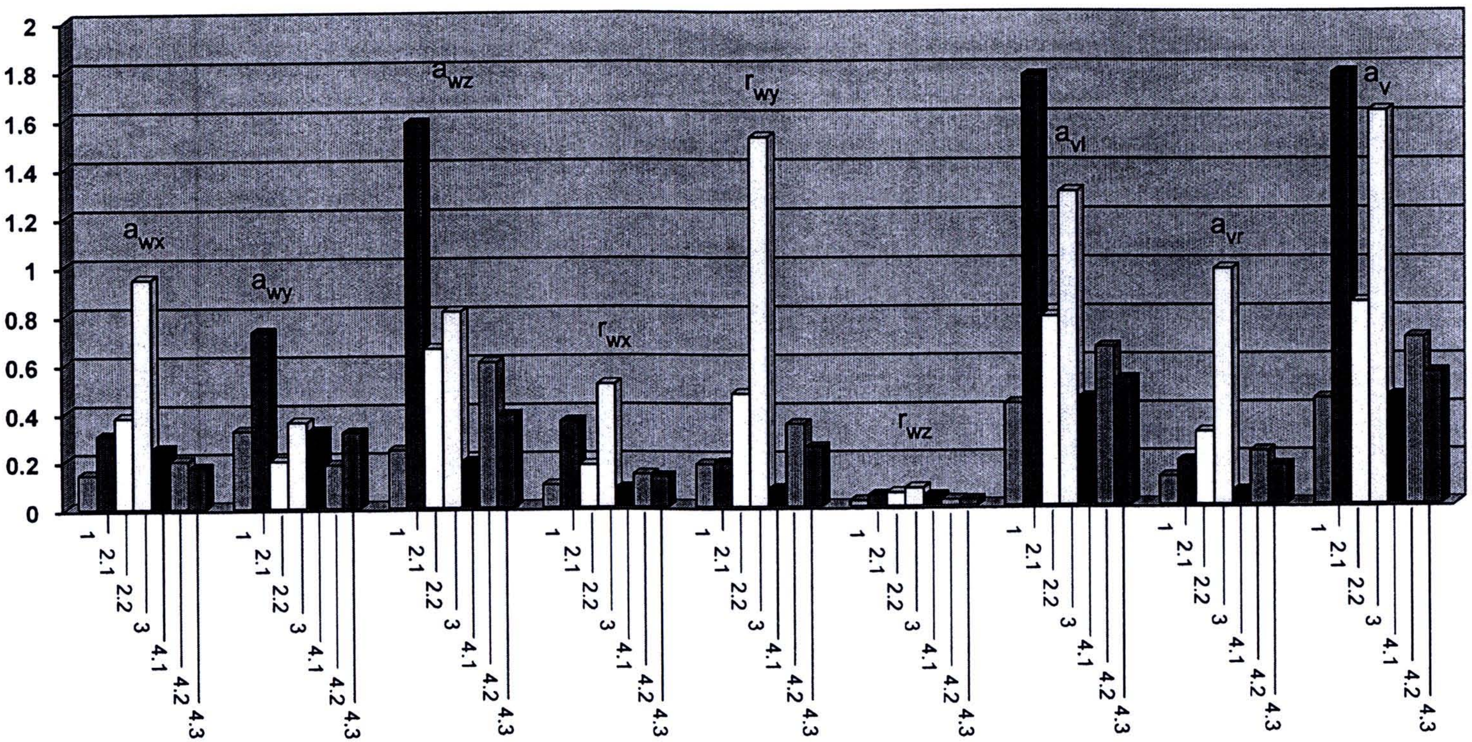


Fig.4-8 graphic results of weighted RMS accelerations

4.10. Conclusions and Further Recommendations

The results show good agreements between acceleration data and ride events/road conditions. However, there were few mistakes occurring during the investigation such as mispositioning of the accelerometers attached to the floorboard, due to difficulty in mounting process. The comparable data from different sensors should be collected at the same sampling frequencies and should be at least 160 Hz to give PSD spectra in the frequency range of 1-80 Hz which is the important range for ride comfort analysis, recommended by ISO standard. From the analysis in frequency domain, the PSD results could not be interpreted clearly as may be because of the road tracks surfaces were not different enough. The results obtained from the frequency weighting analysis shows good agreement with the acceleration signals and real driving events so that the application of ISO in term of comfort evaluation is found to be effective and reasonable. However, the reported results are based on one evaluation method only. The application of the other alternative methods such as VDV (Vibration Dose Value) should be applied and compared the results among each other.