

Complementary data to the main paper, published in the proceedings of
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Experimental study of ground vibrations induced by Brussels IC/IR trains in their neighbourhood

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As for other disciplines of engineering, ground vibrations induced by railway traffic are more and more studied by simulation. However, as validation can only be performed by measurements, there is still a need in experimental results. The proceeding paper presents a synthesis of the experimental data collected in the context of the implementation of the new RER network in the Brussels Capital Region. The paper first presents the three in situ tests that have been carried out along the line L161, in order to determine the track and soil characteristics. The soil configuration (number and characteristics of the layers) is obtained with the help of the impact of falling mass. Seismic refraction test is used, coupled with the fitting of a finite/infinite element model, for the damping. The track dynamic parameters are obtained by tuning experimental receptances with numerical ones, with the help of a track/soil model, based on the finite element approach. The second part consists in the analysis of the horizontal and vertical ground vibrations measured during the passage of domestic trains (AM96, AM86, AM80 or AM75) at various speeds (from 40 to 120 km/h). In order to compare the levels and to have a global view, various indicators are used as the peak particular velocity and the time-average velocity, associated to the standard evaluation of the risk of building failures and human exposure in buildings respectively. These results show that the ground vibrations amplitude depends on various factors: soil configuration, train type and speed, direction of measurement, track quality. In a particular case, a local defect (rail joint) induces large deformation on the soil. This report is complementary of the main paper, giving all the measurements in a detailed form.

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This companion report presents all the measured vibratory data obtained for three sites in the region of Brussels: Watermael (site 1 and 2) and Ottignies. Figure 1.1 presents an overview of the railway track for the two locations (sites 1 and 2 of Watermael consist of the same track).



(a) Watermael



(b) Ottignies

Figure 1.1: Investigated sites in the Brussels Region Network

Each chapter focuses on one investigated site, presenting all the measurement performed during the passing of domestic trains. The position of the sensors and the relevant dimensions are also given. Four kinds of magnitude are emphasized, for each investigated distance x_R from the track:

- the time history of the horizontal $v_x(t)$ and $v_y(t)$ and vertical $v_z(t)$ vibrations,
- the frequency content $v_i(f)$ associated on each curve ($i = x, y$ or z),
- the time-average velocity $v_{i,rms}(t)$,
- the spectrogram $v_i(t, \omega)$, useful to describe to time evolution of the spectral content.

The analysis and the conclusion can be found in the main paper.

Measurement in Watermael (site 1)

Train type	Track	Speed [km/h]	# carriages
AM75	A	115	3×4
AM80	B	80	2×3
AM96	A	125	2×3
HLE27+M4	B	80	$1 + 9$
AM96	B	120	4×4
AM80	B	100	2×3
AM96	B	115	4×3
HLE27+M4	B	120	$1 + 9$
AM75	A	110	2×4
AM80	B	80	2×3
AM80	B	90	2×3
HLE27+M4	B	120	$1 + 9$
AM96	A	110	3×3
AM96	B	90	4×2
AM75	B	115	4
HLE27+M4	B	120	$1 + 6$
AM75	B	85	4

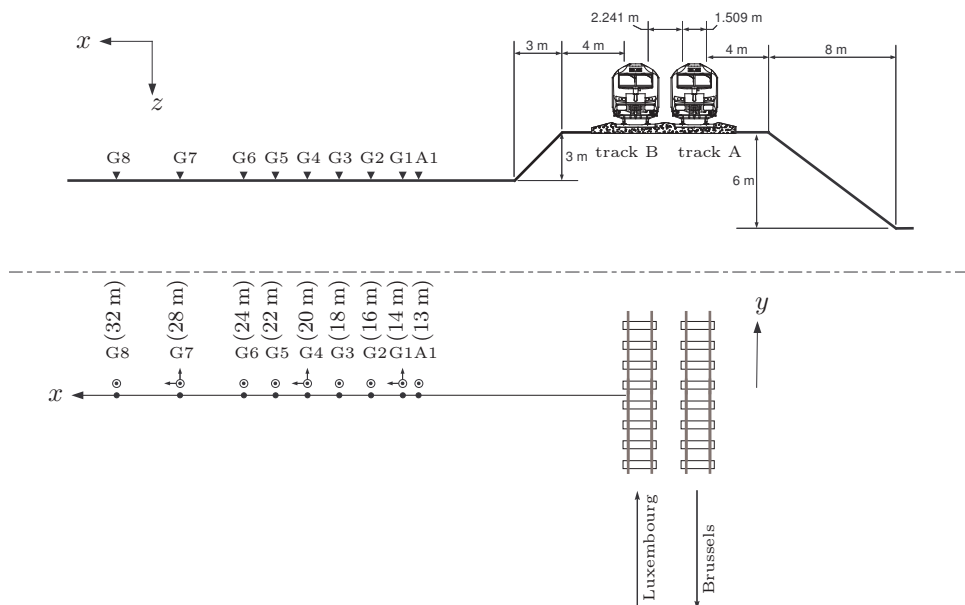


Figure 2.1: Located measurement points and review of all the train passing

2.1 AM75 unit at 115 km/h

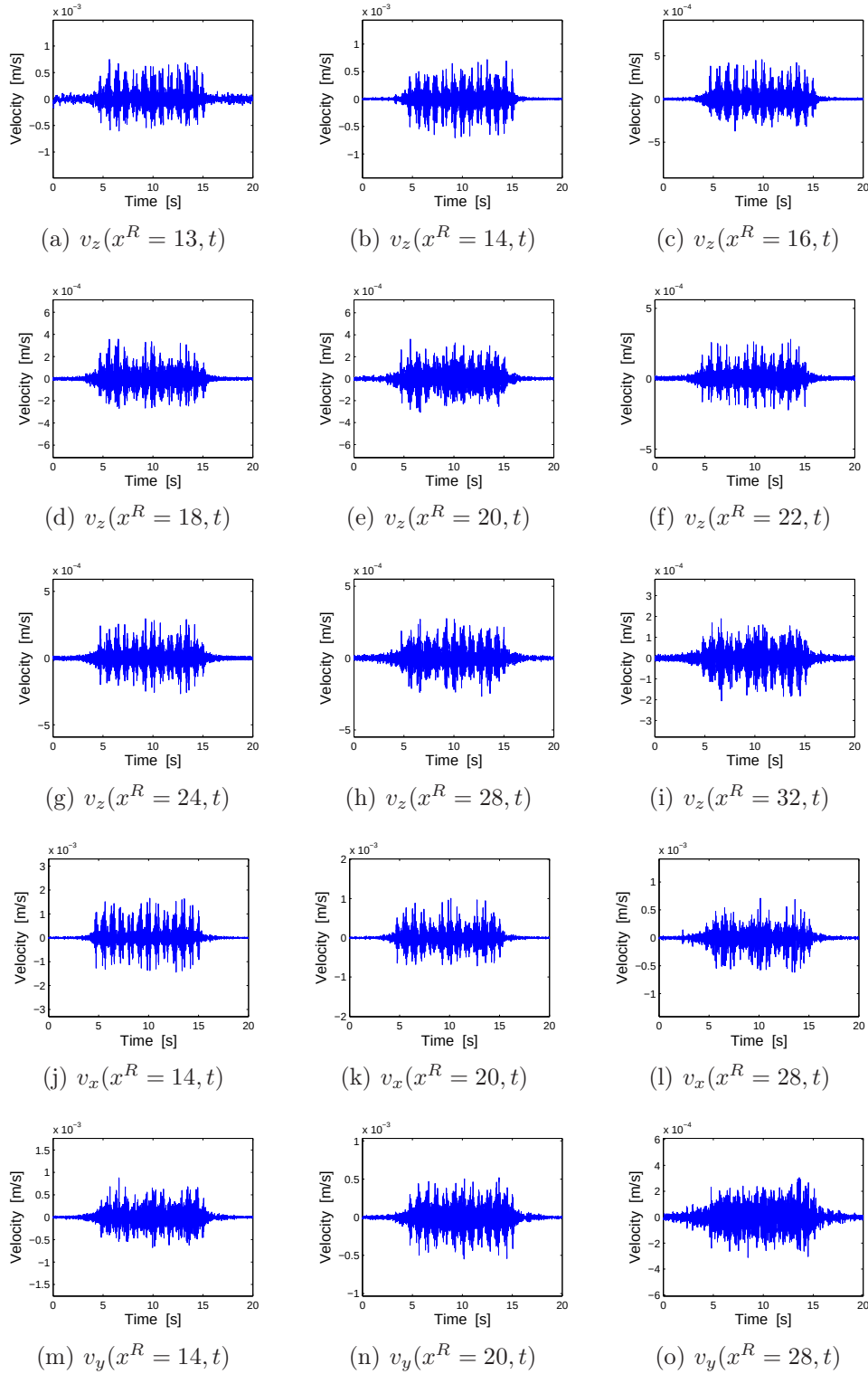


Figure 2.2: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 115 km/h

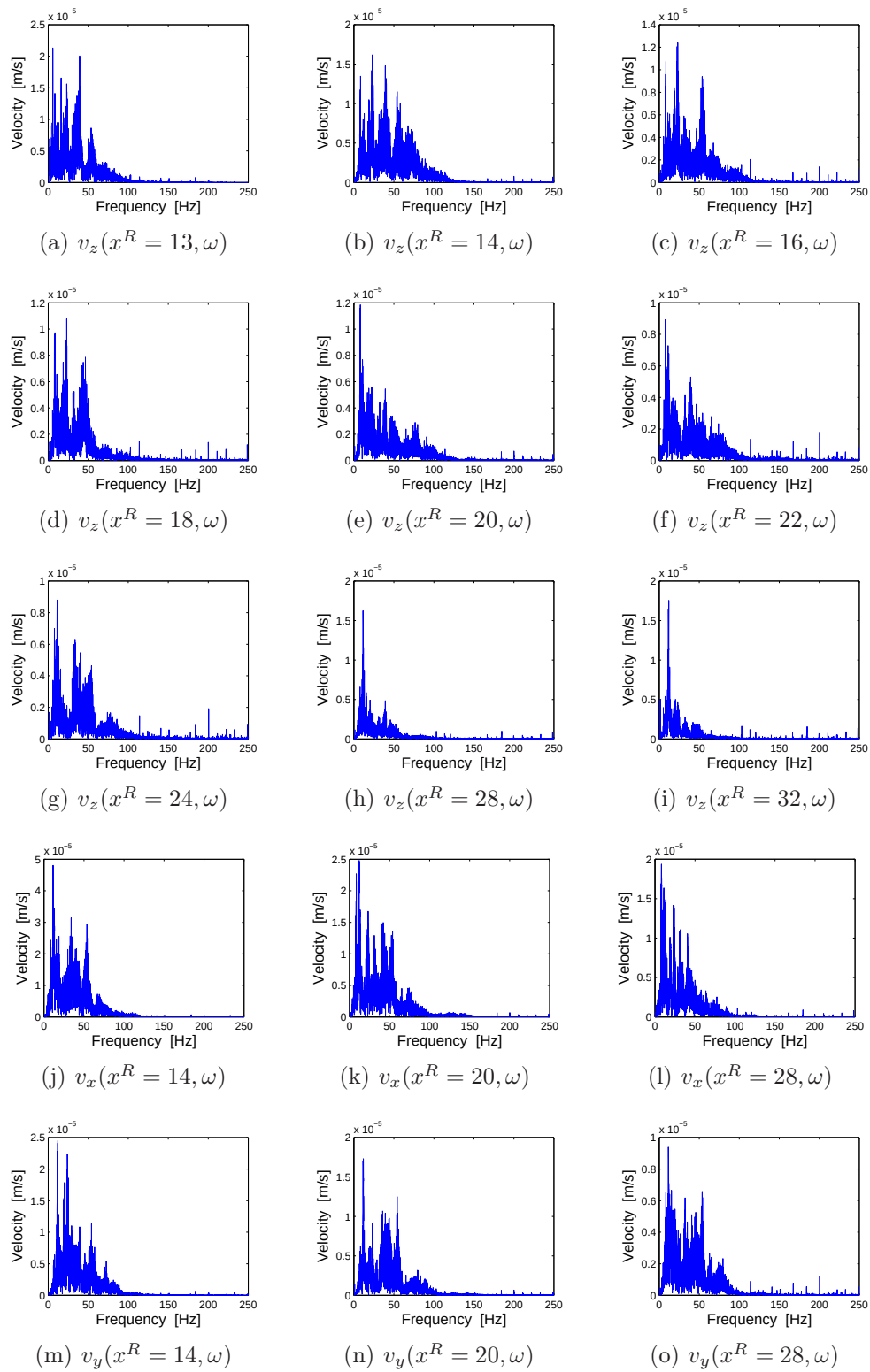


Figure 2.3: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 115 km/h

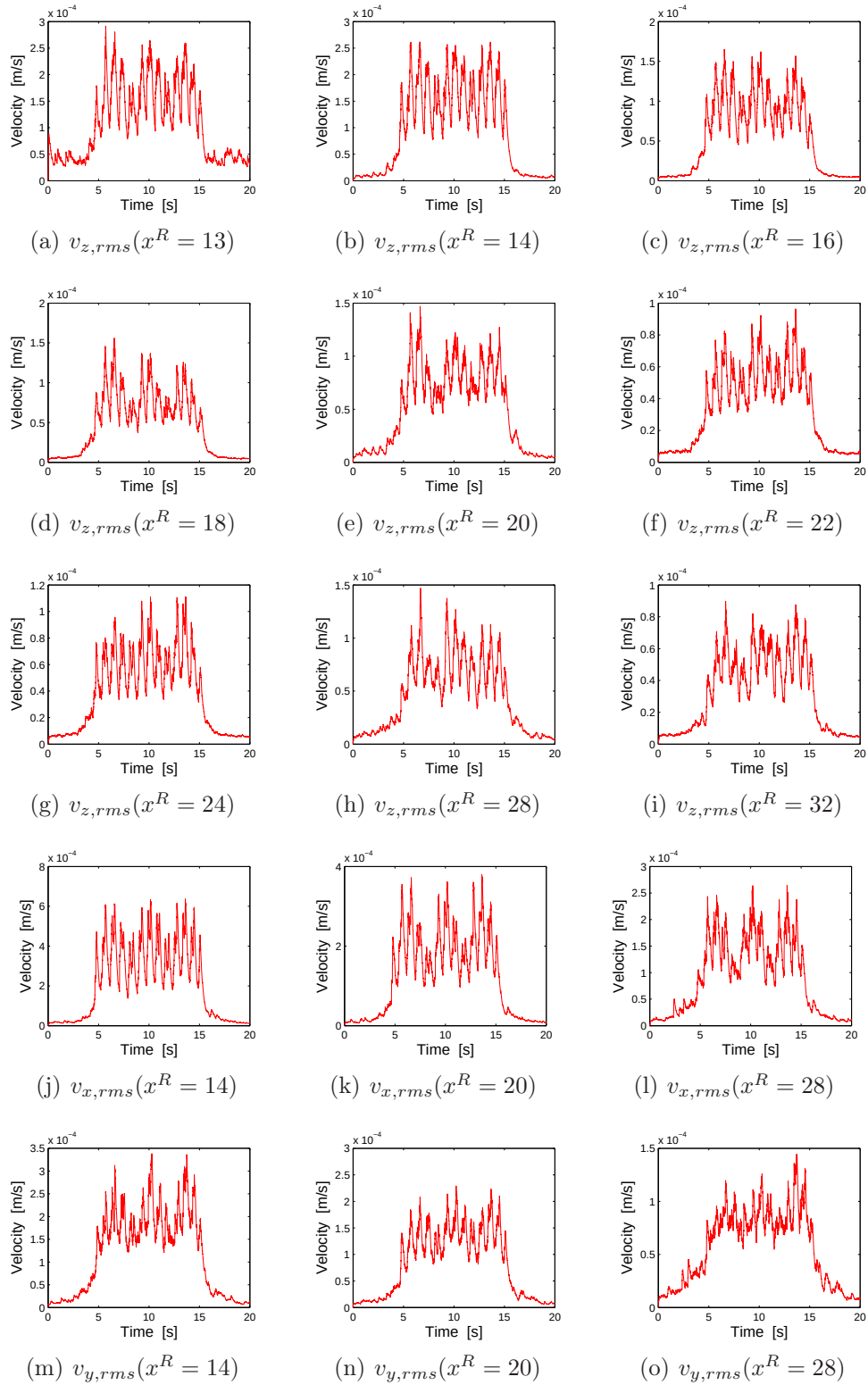


Figure 2.4: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 115 km/h

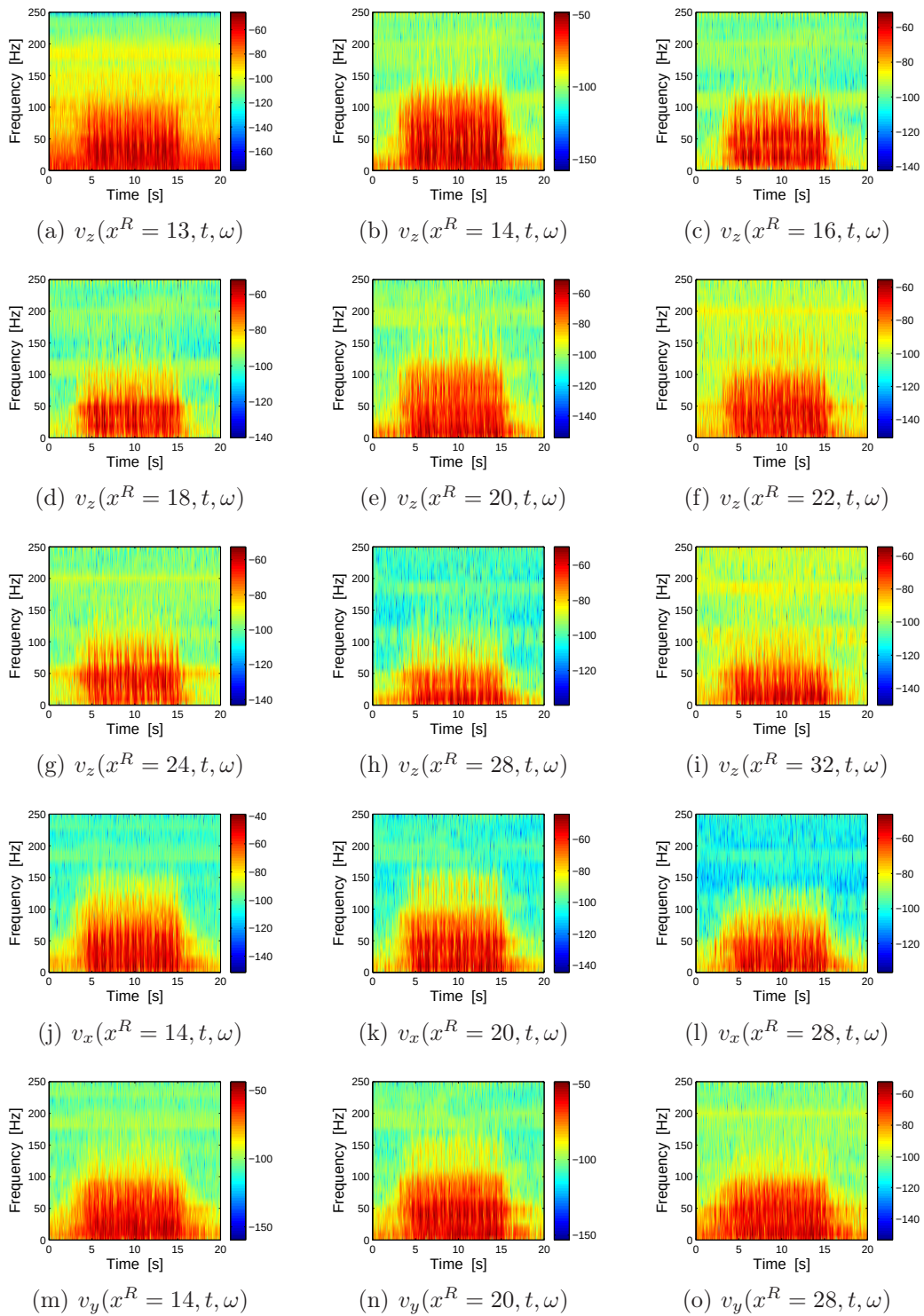


Figure 2.5: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 115 km/h

2.2 AM80 unit at 80 km/h

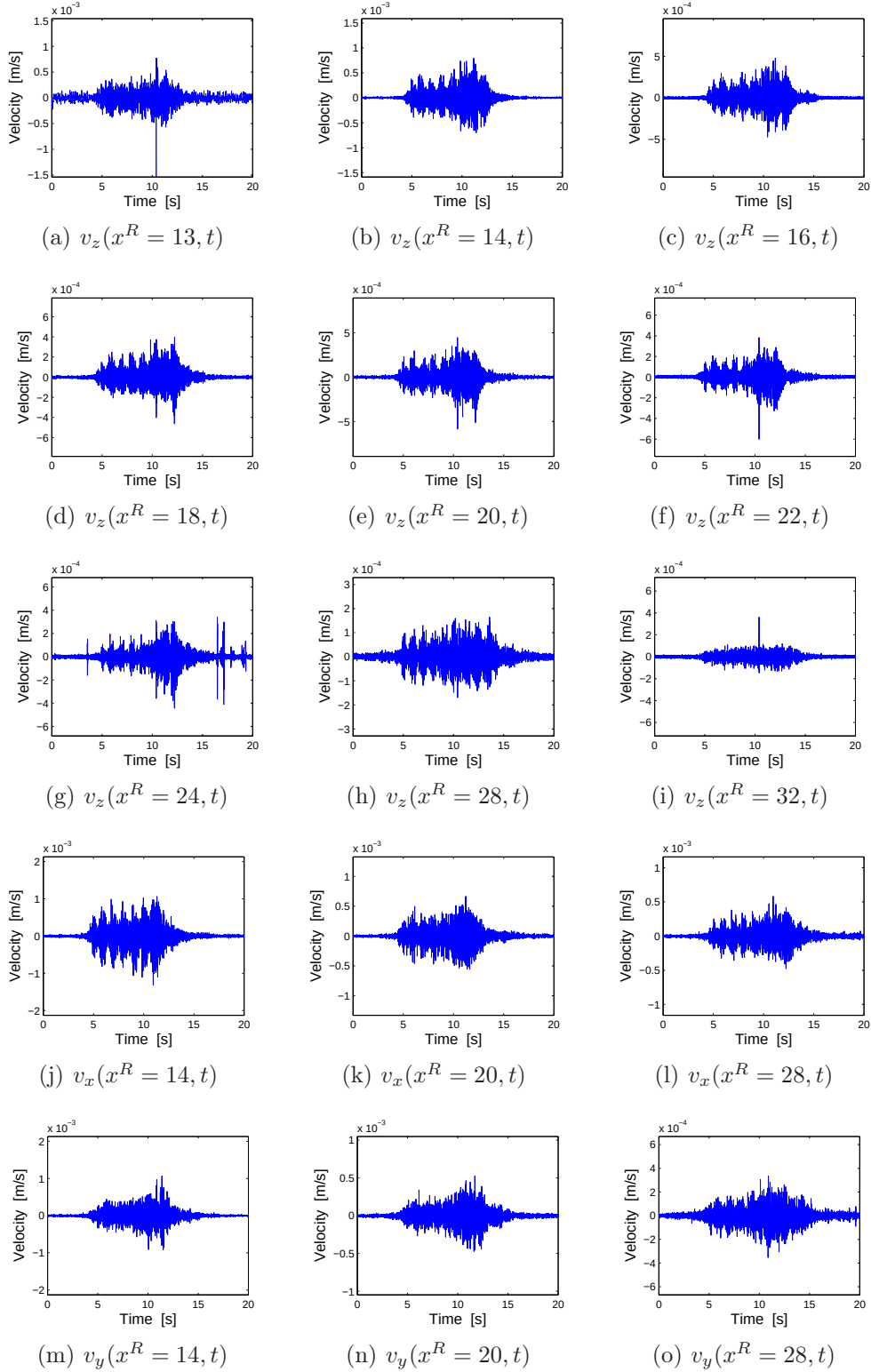


Figure 2.6: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 80 km/h

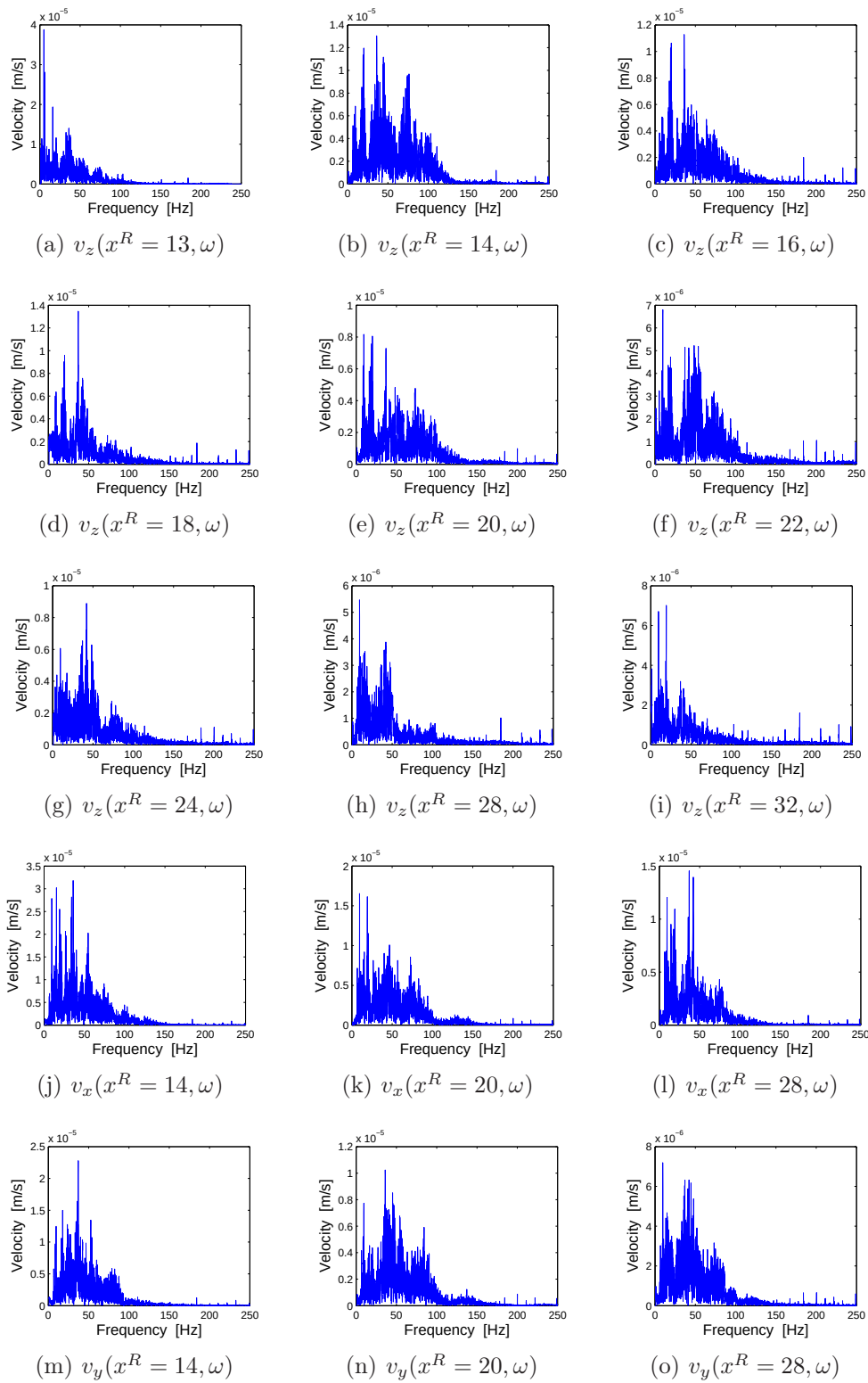


Figure 2.7: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 80 km/h

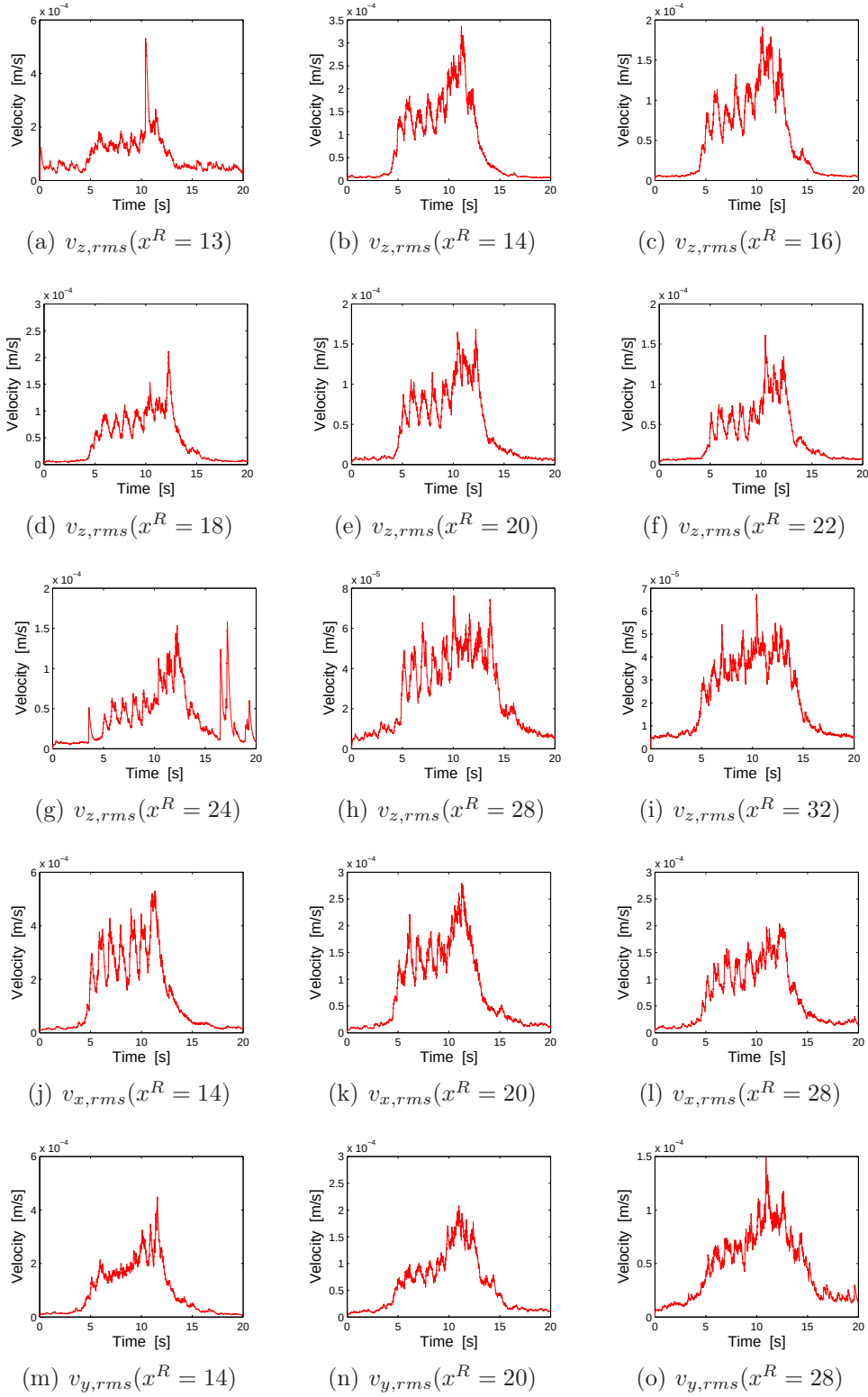


Figure 2.8: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 80 km/h

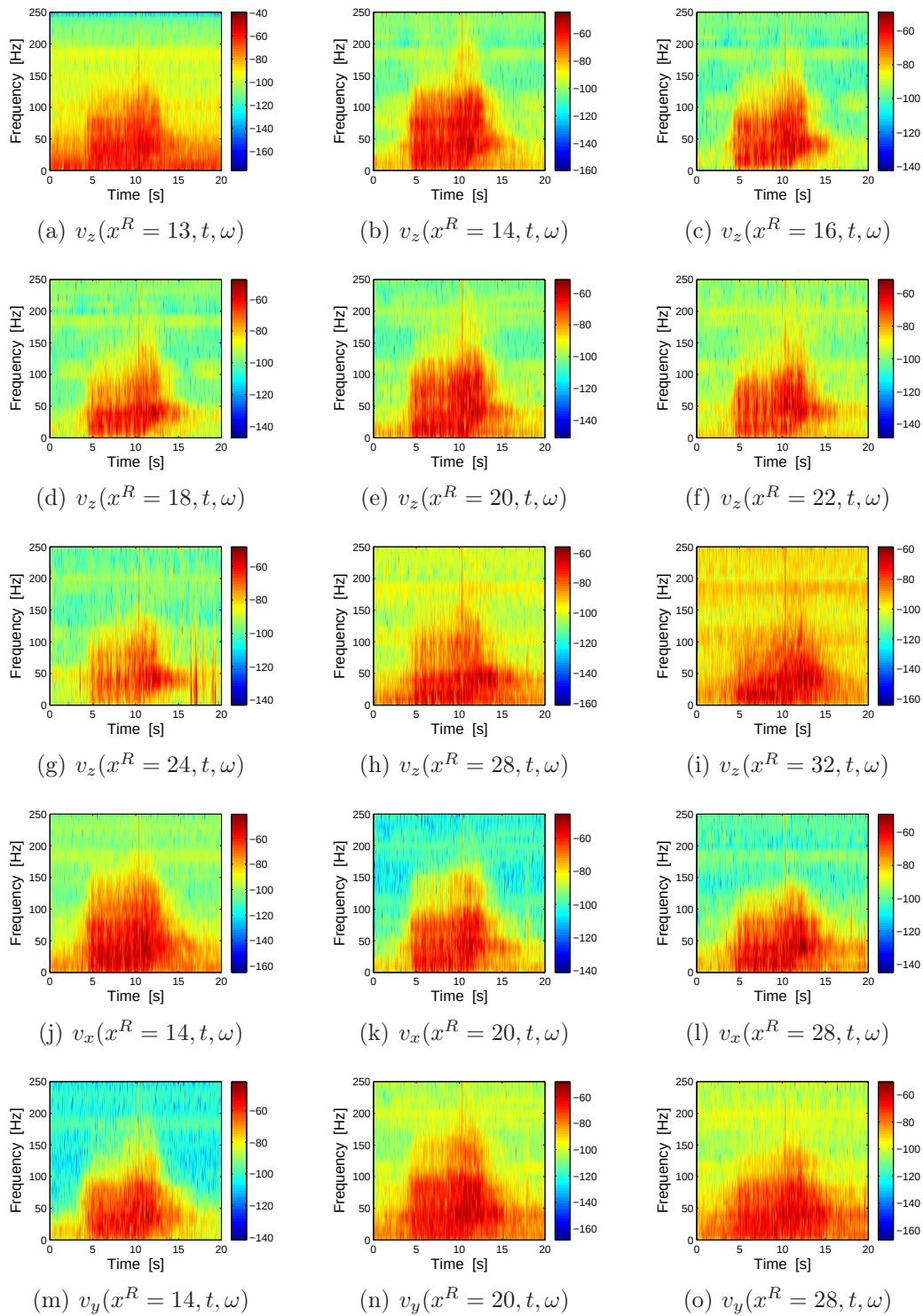


Figure 2.9: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 80 km/h

2.3 AM96 unit at 125 km/h

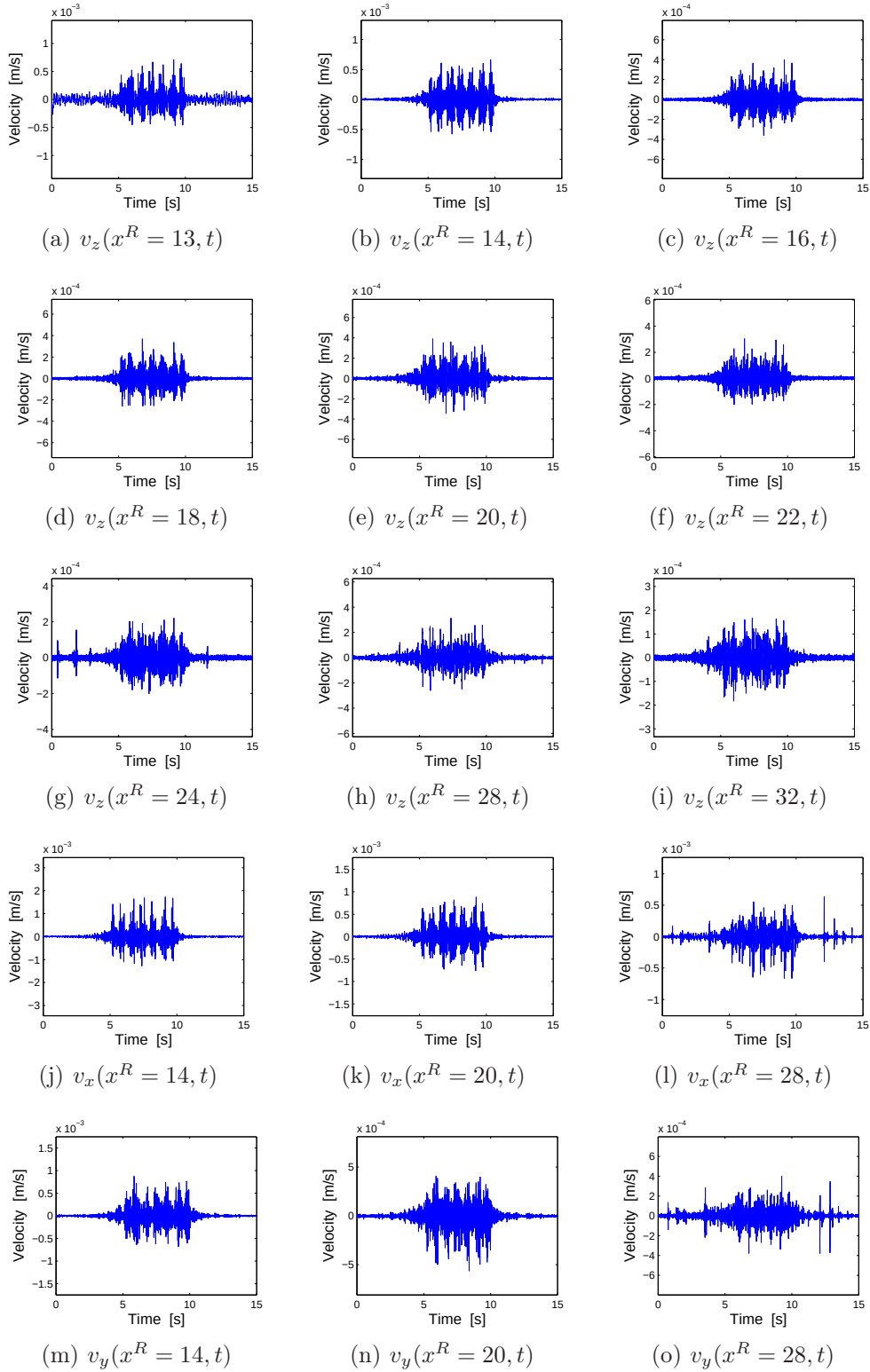


Figure 2.10: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 125 km/h

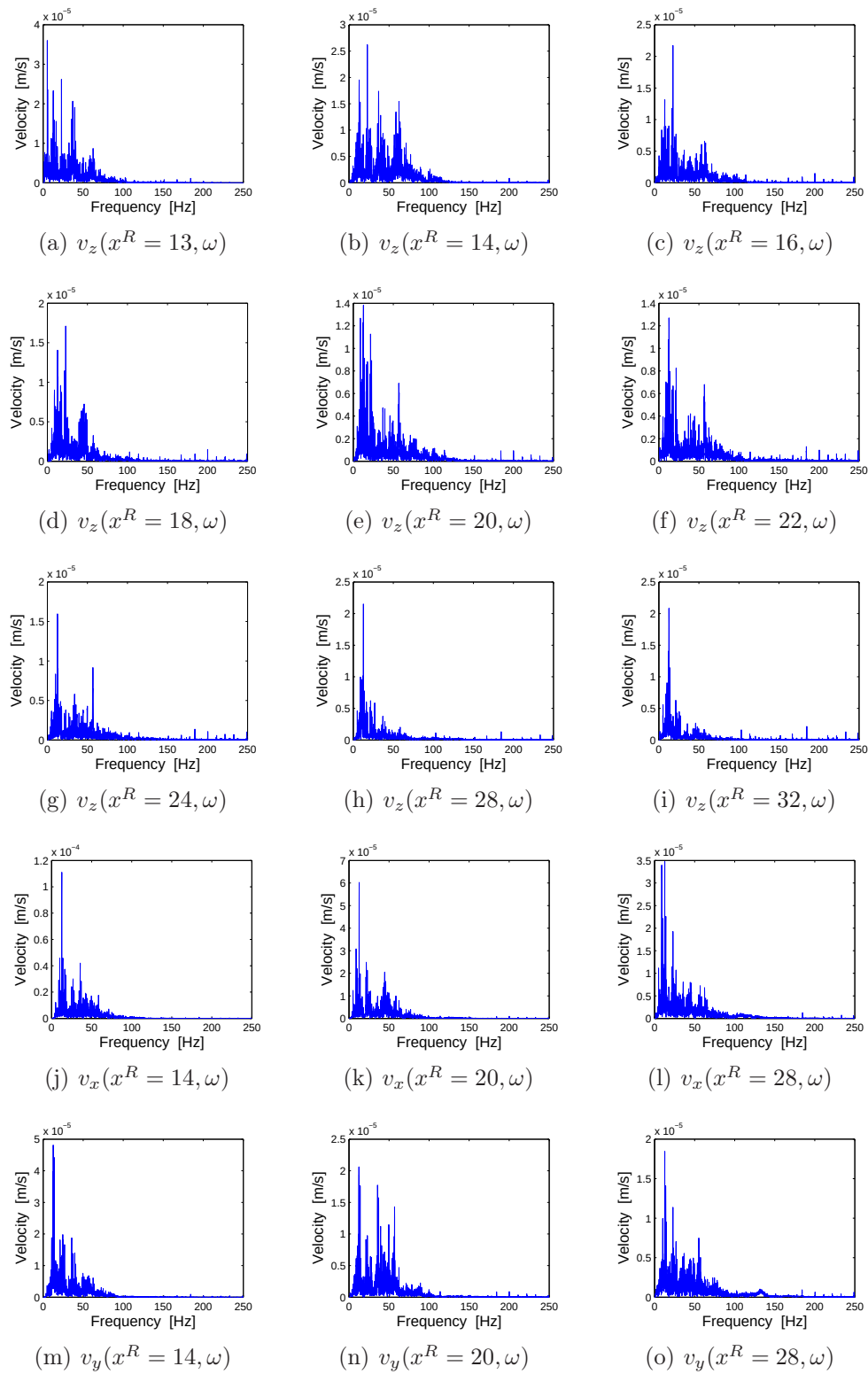


Figure 2.11: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 125 km/h

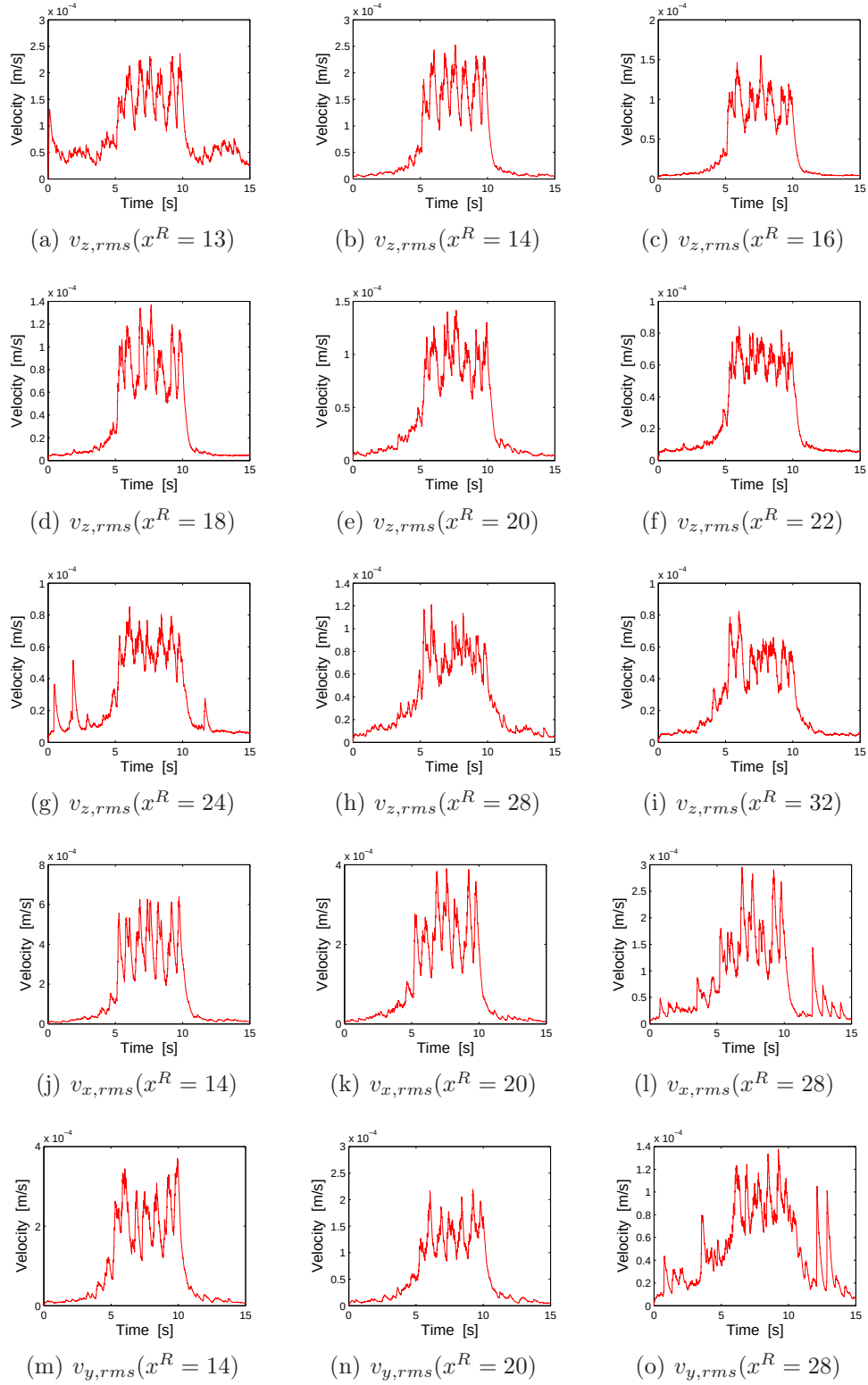


Figure 2.12: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 125 km/h

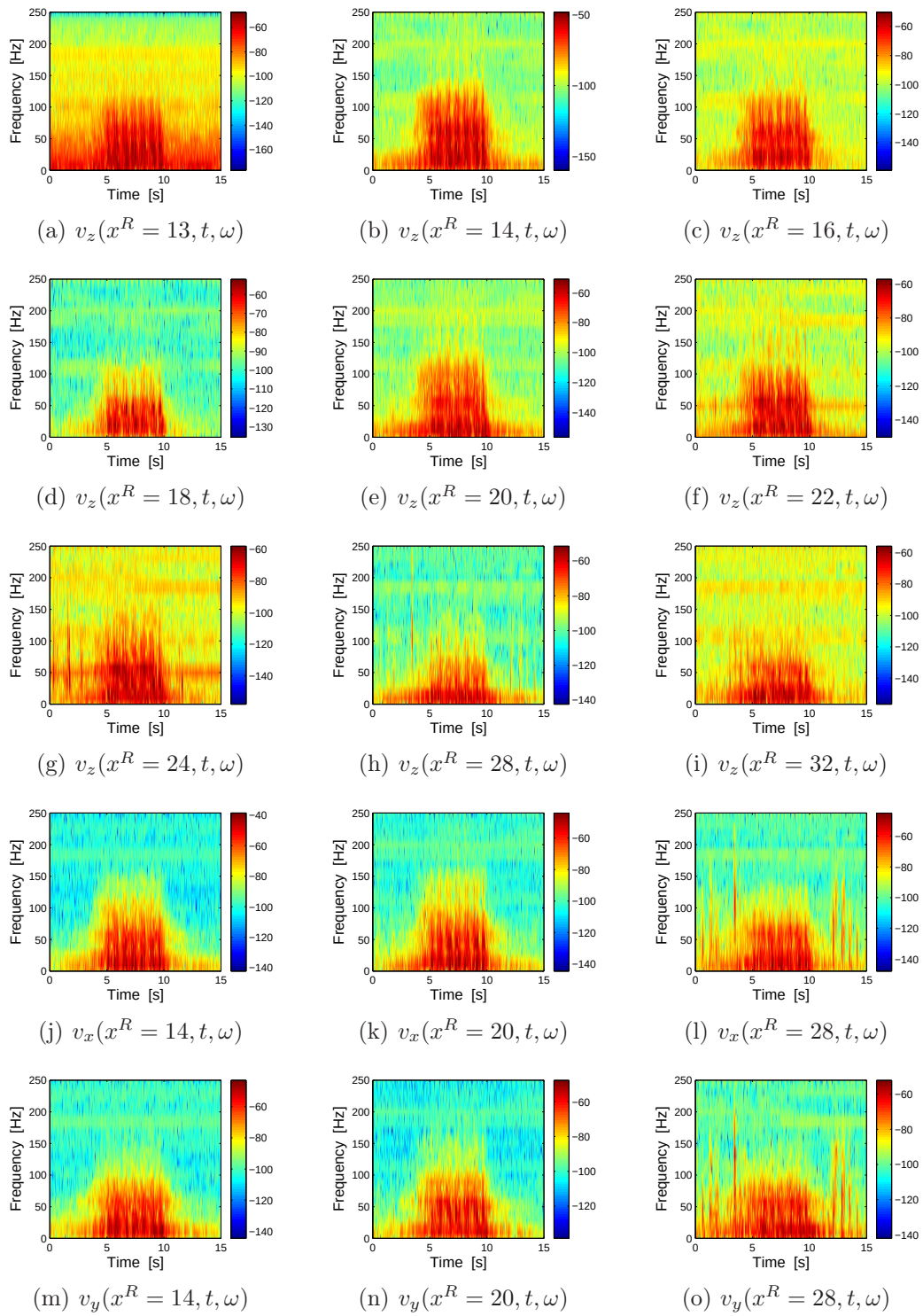


Figure 2.13: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 125 km/h

2.4 M4 railcar at 80 km/h

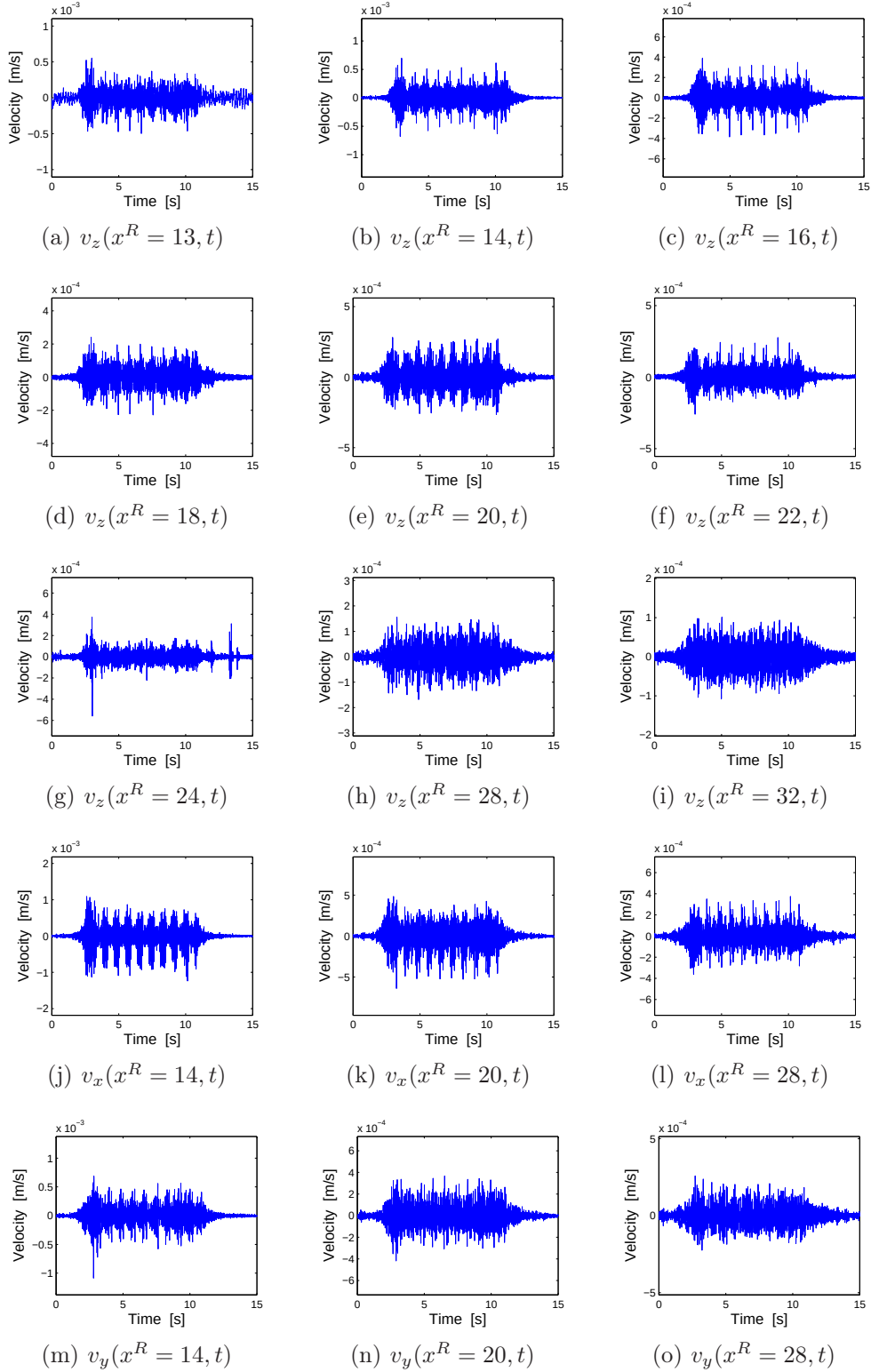


Figure 2.14: Time history of the vertical and horizontal velocities measured in free field during the passage of a M4 railcar at 80 km/h

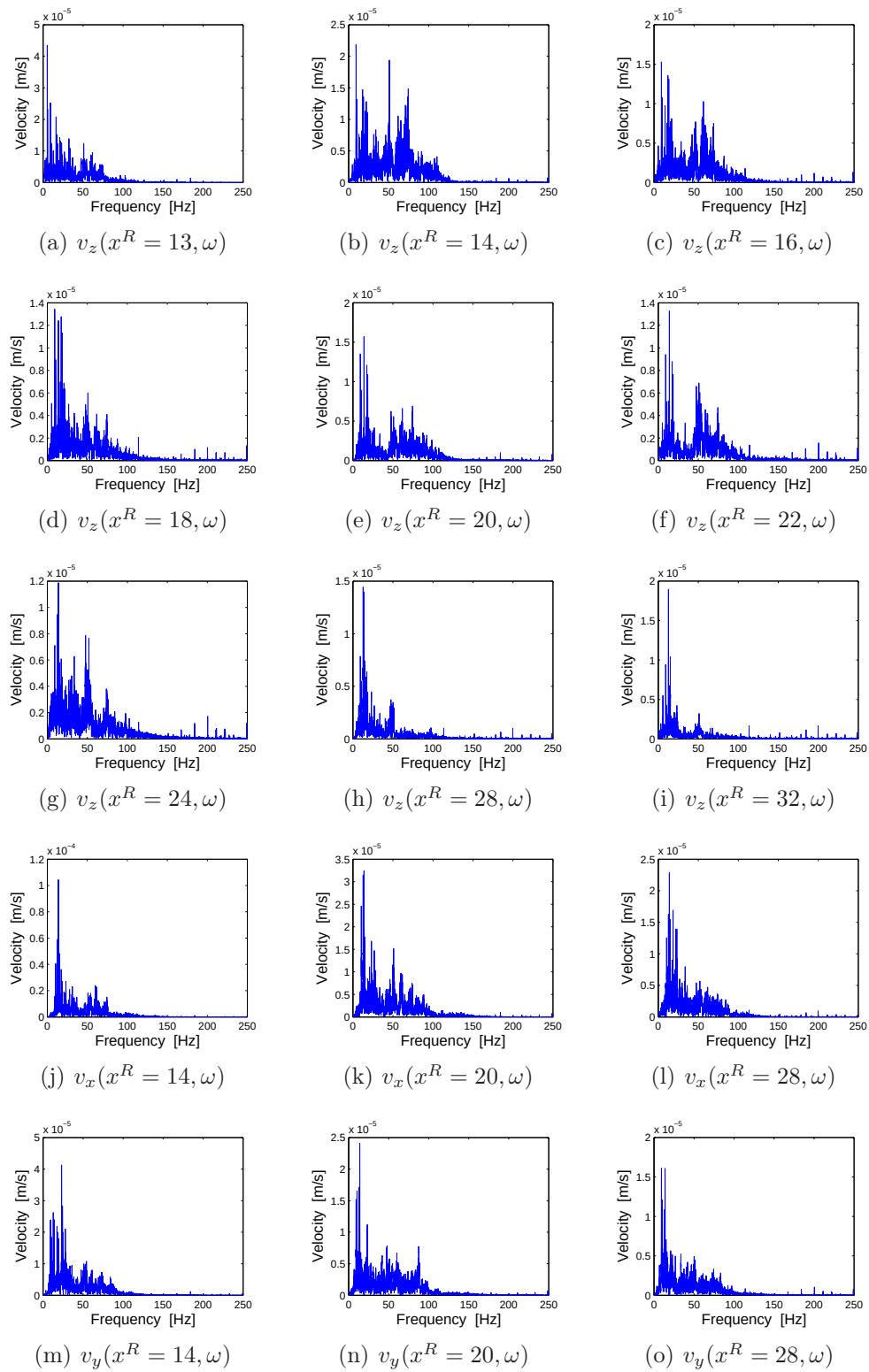


Figure 2.15: Spectral content of the vertical and horizontal velocities measured in free field during the passage of a M4 railcar at 80 km/h

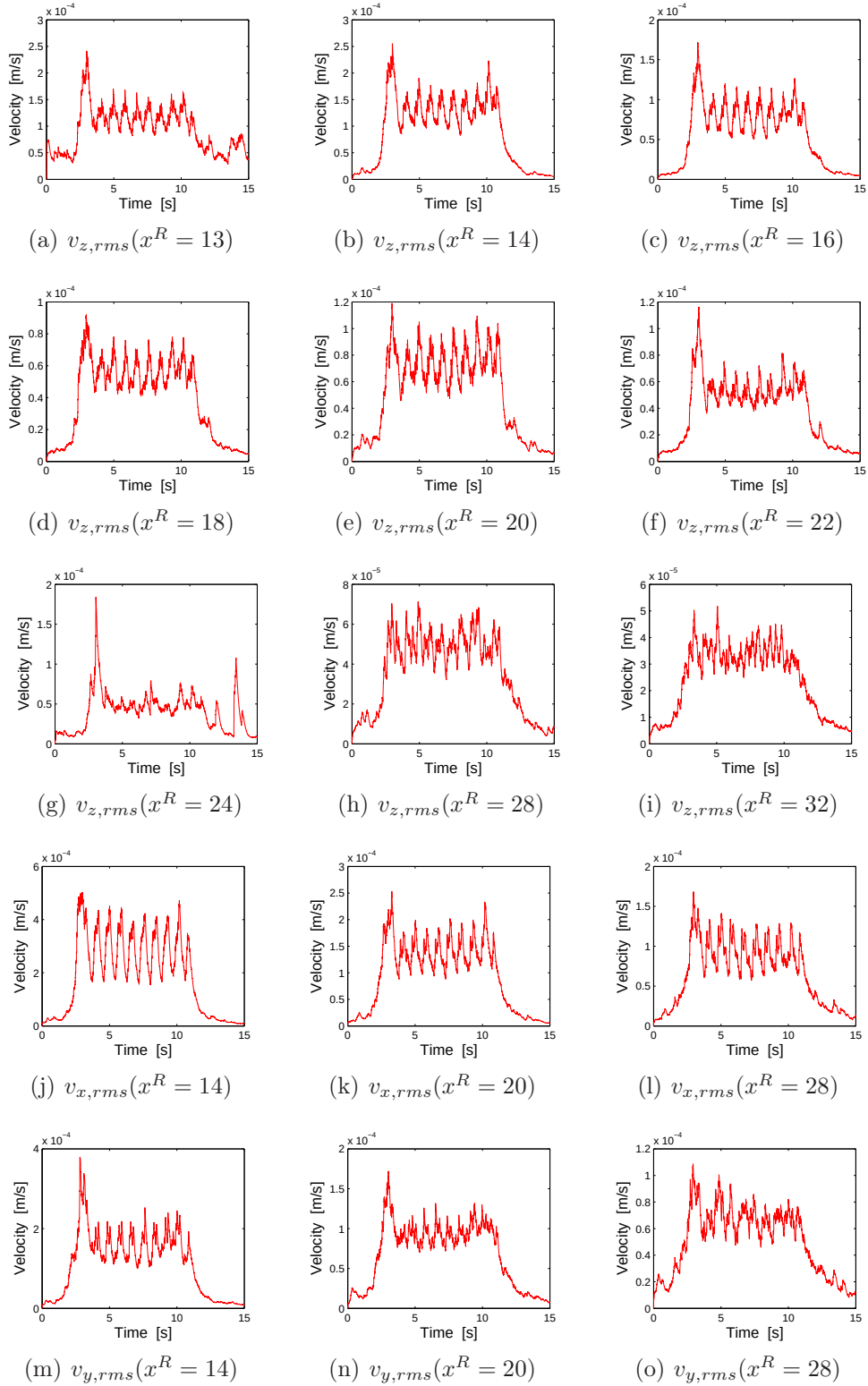


Figure 2.16: Time-average of the vertical and horizontal velocities measured in free field during the passage of a M4 railcar at 80 km/h

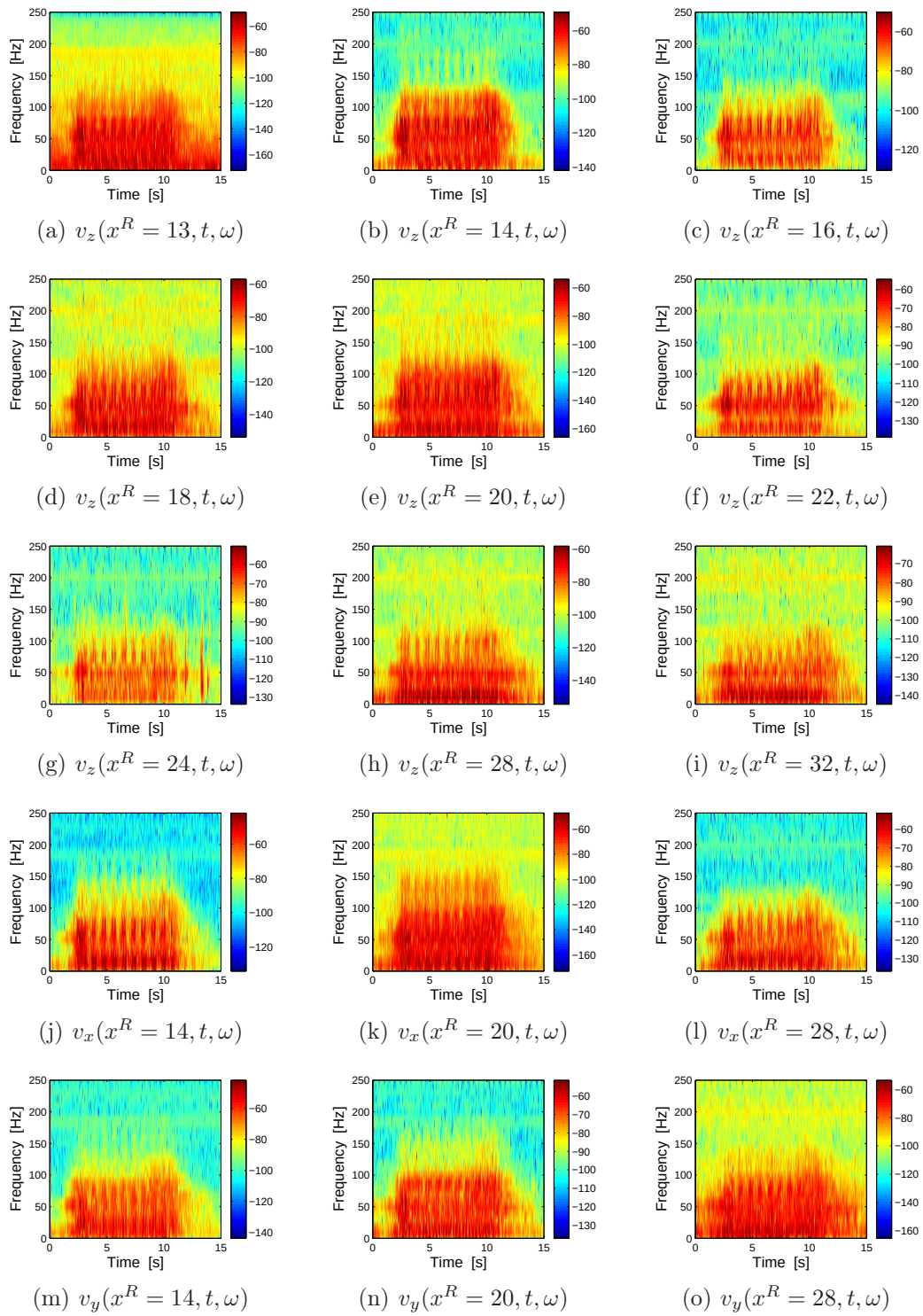


Figure 2.17: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of a M4 railcar at 80 km/h

2.5 AM96 unit at 120 km/h

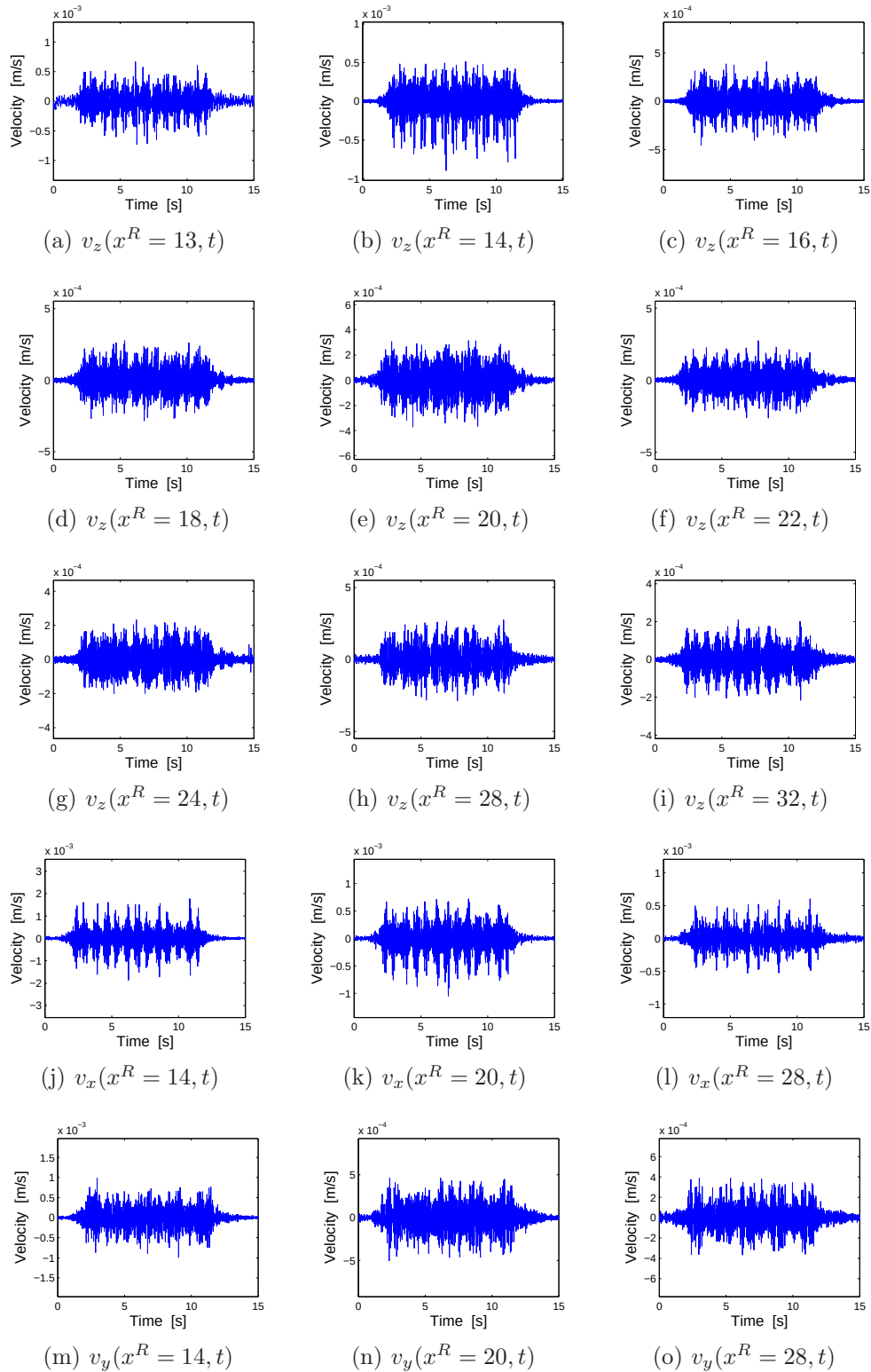


Figure 2.18: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 120 km/h

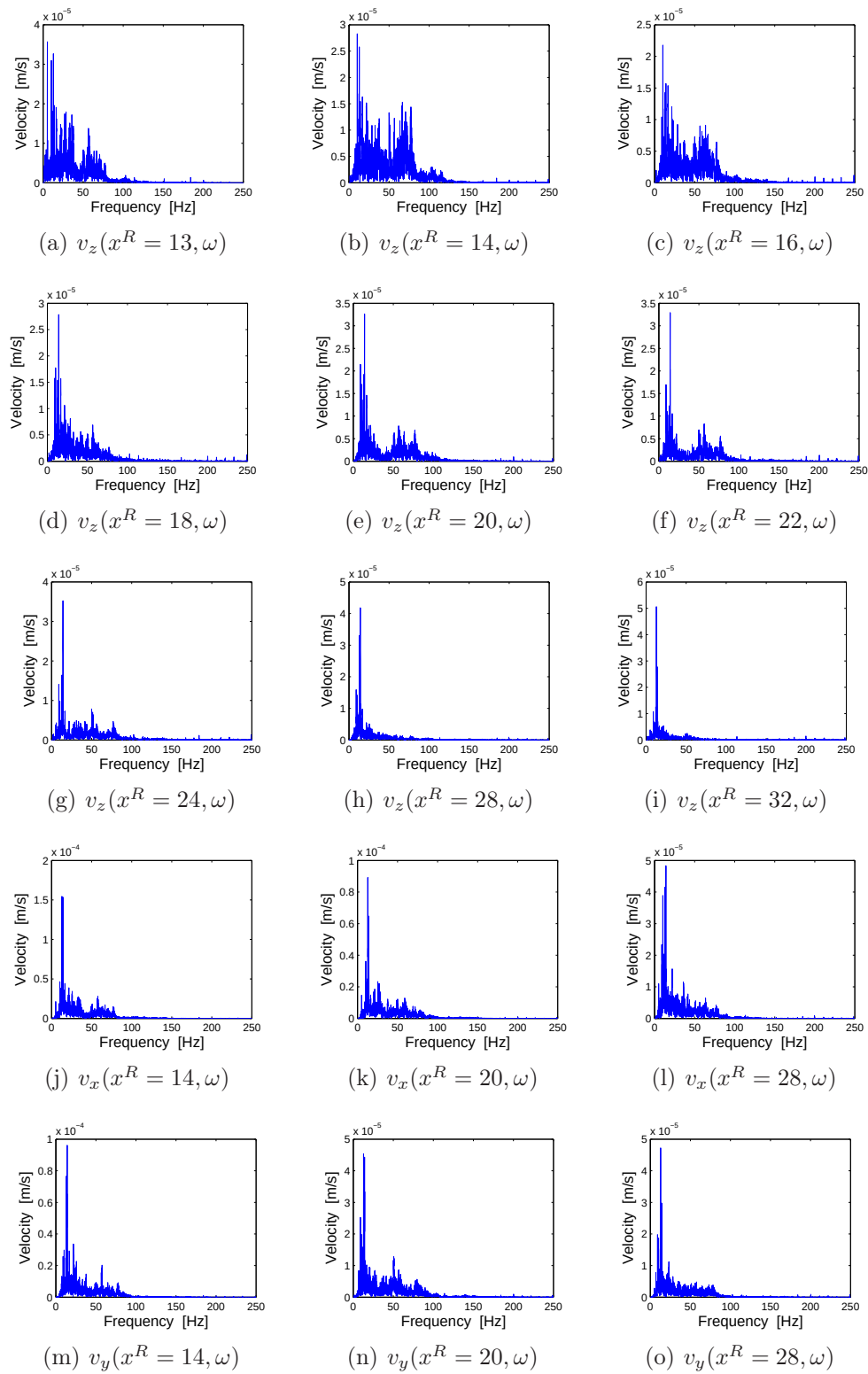


Figure 2.19: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 120 km/h

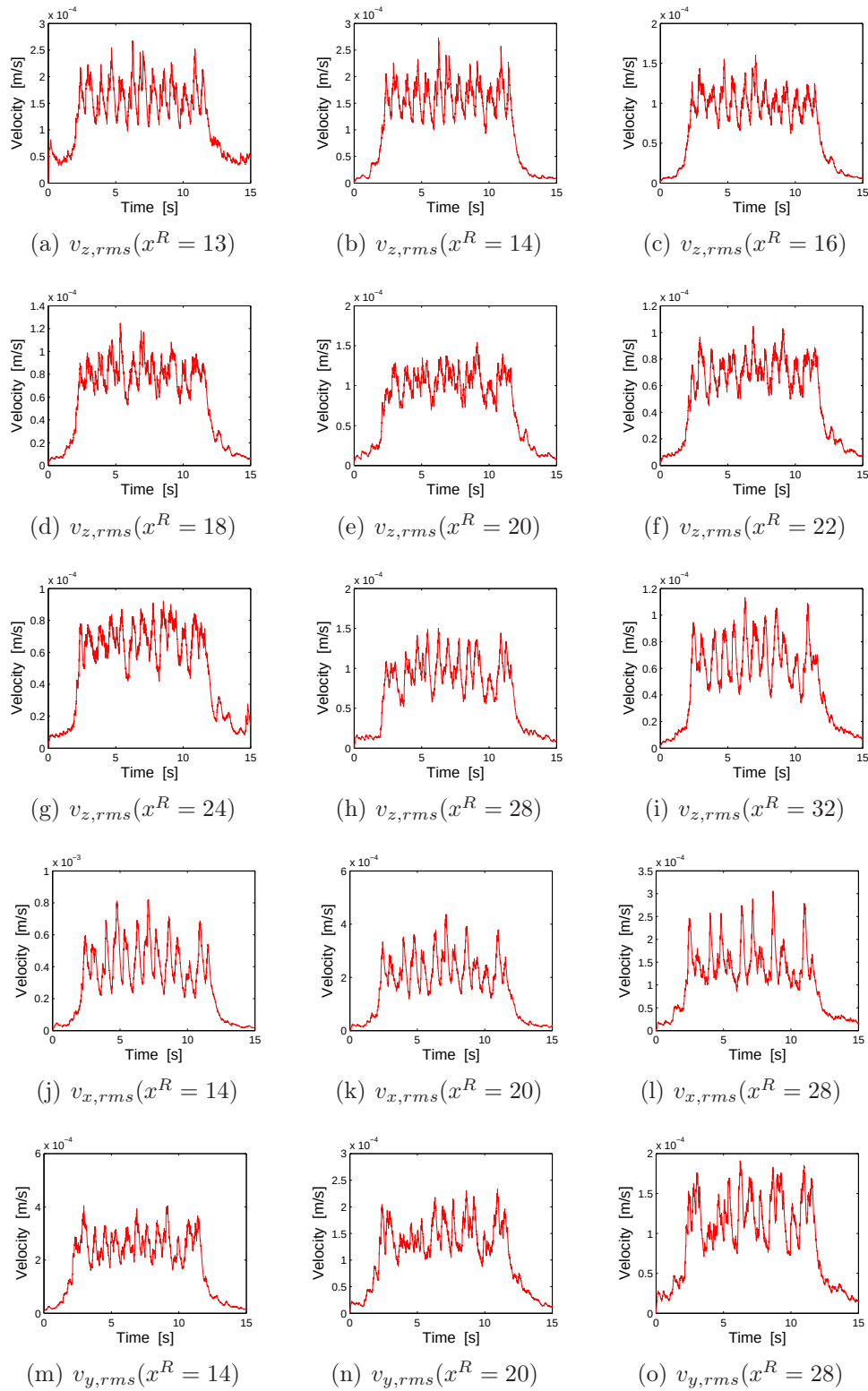


Figure 2.20: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 120 km/h

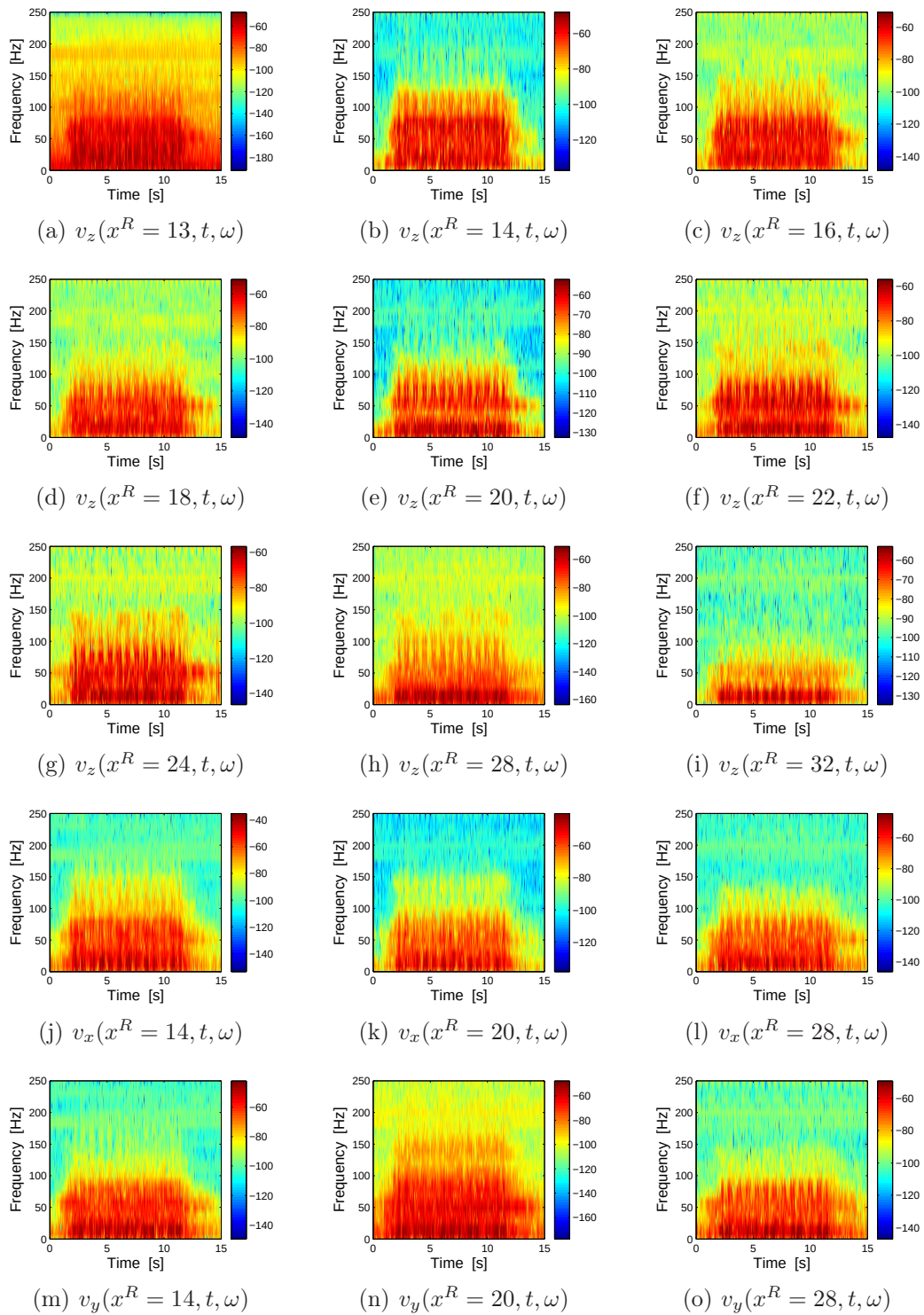


Figure 2.21: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 120 km/h

2.6 AM80 unit at 100 km/h

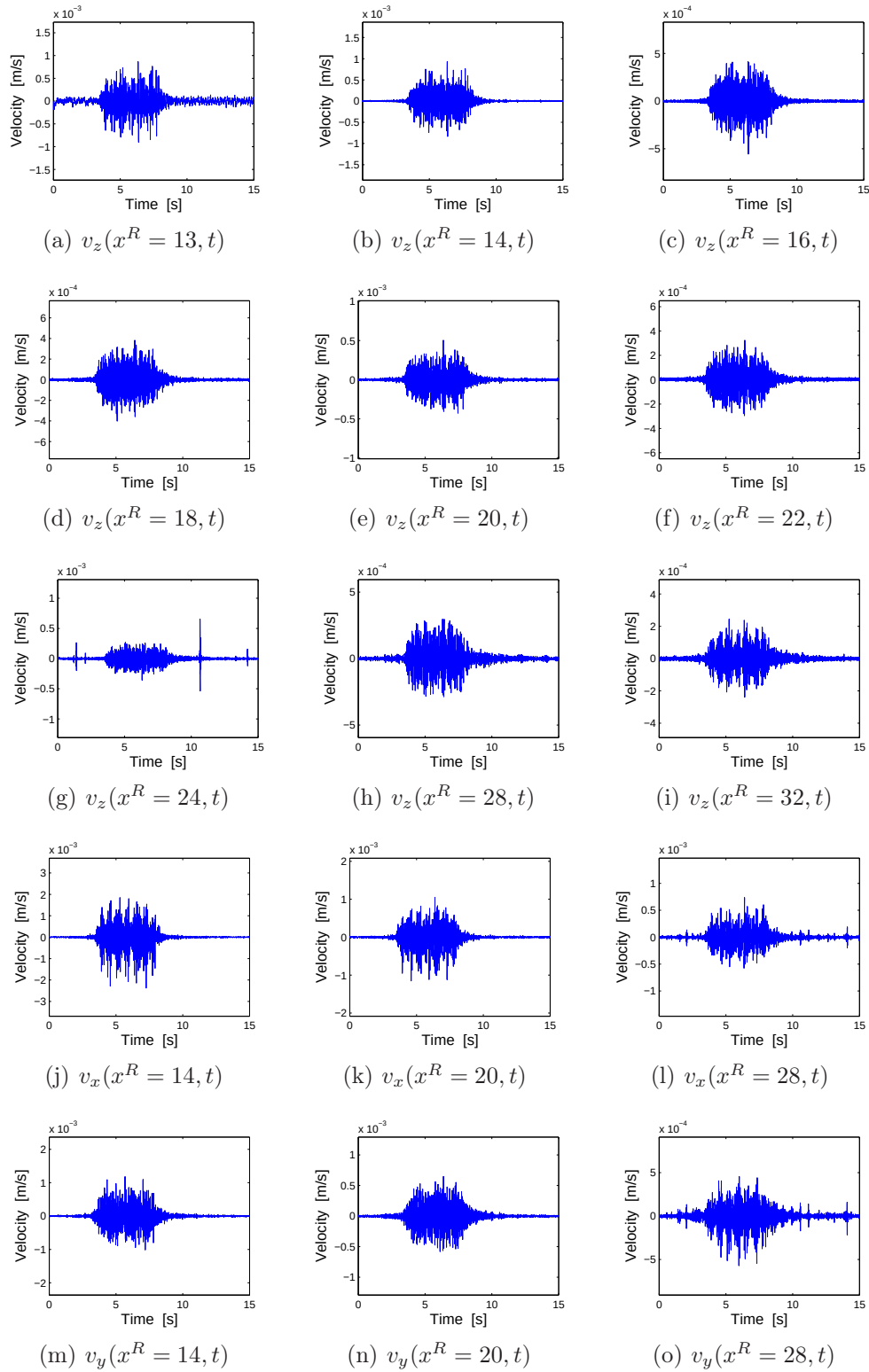


Figure 2.22: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 100 km/h

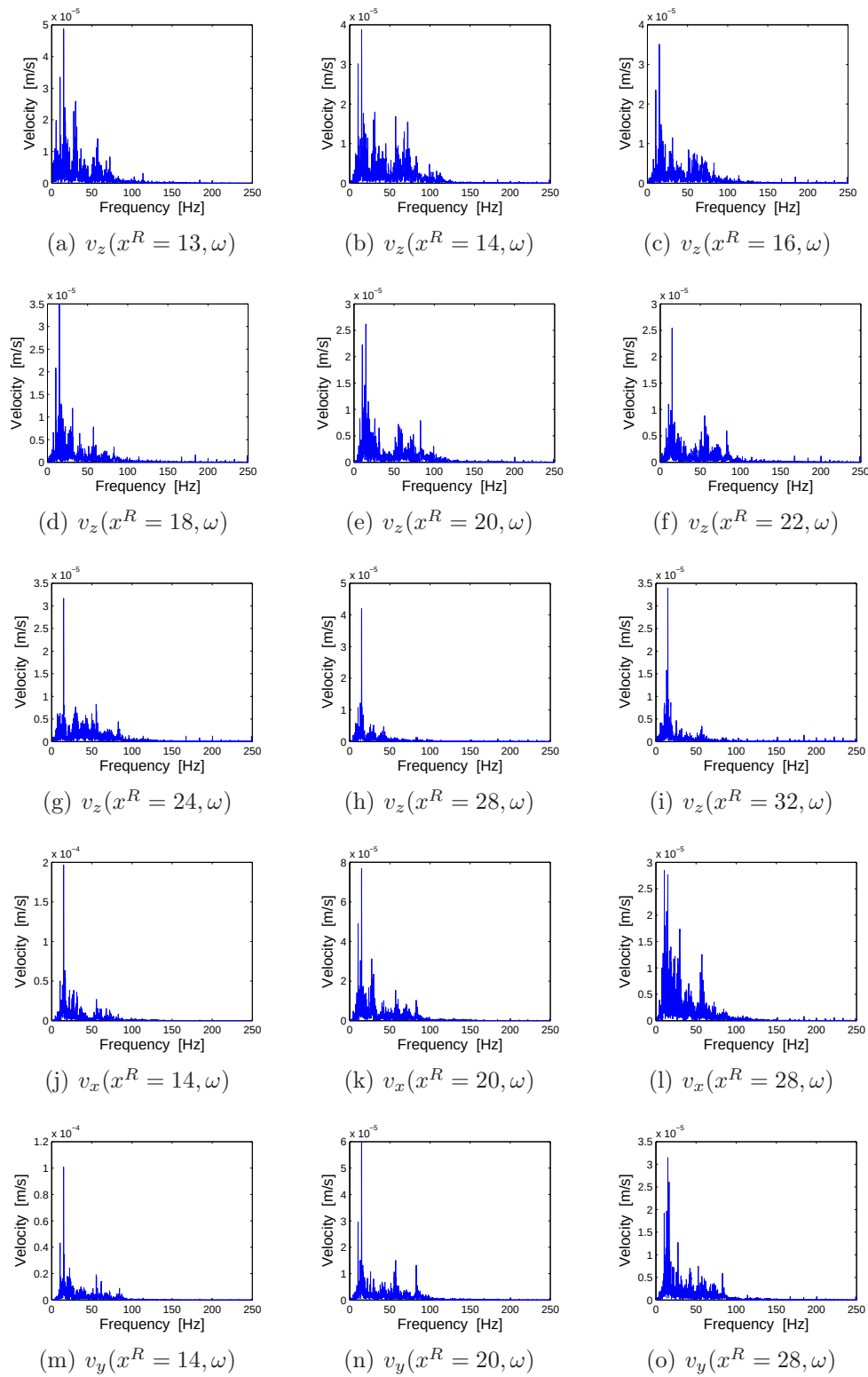


Figure 2.23: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 100 km/h

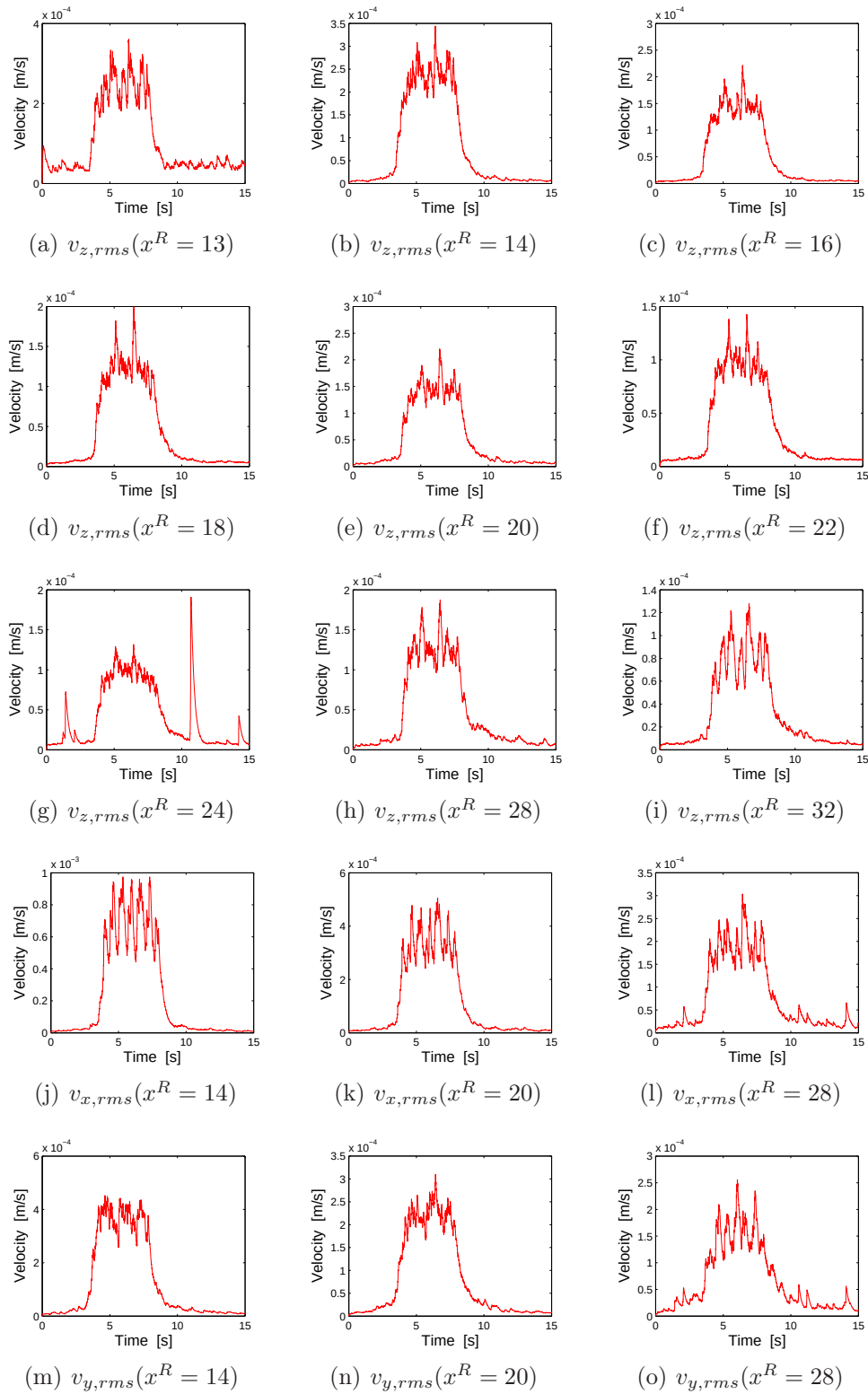


Figure 2.24: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 100 km/h

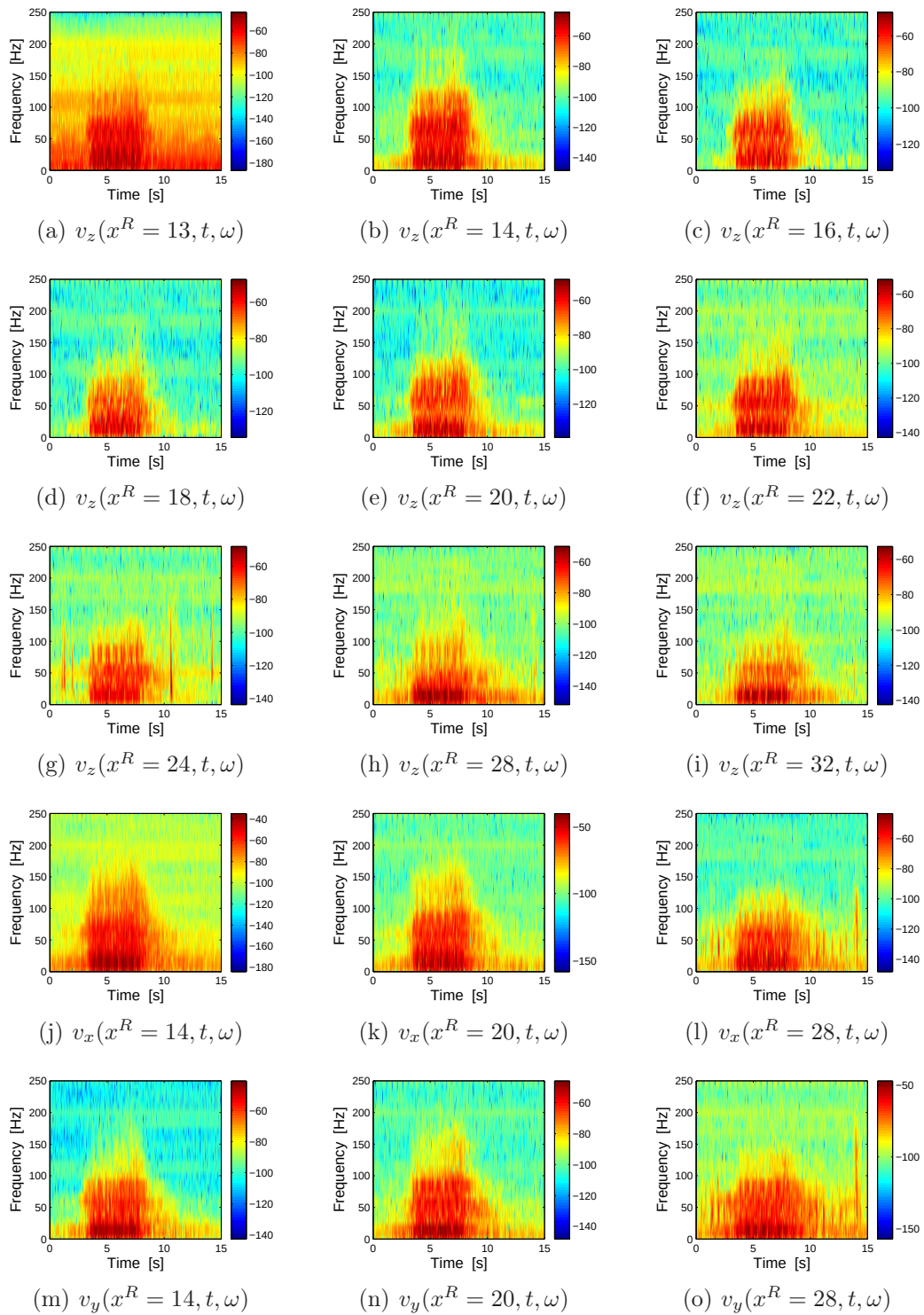


Figure 2.25: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 100 km/h

2.7 AM96 unit at 115 km/h

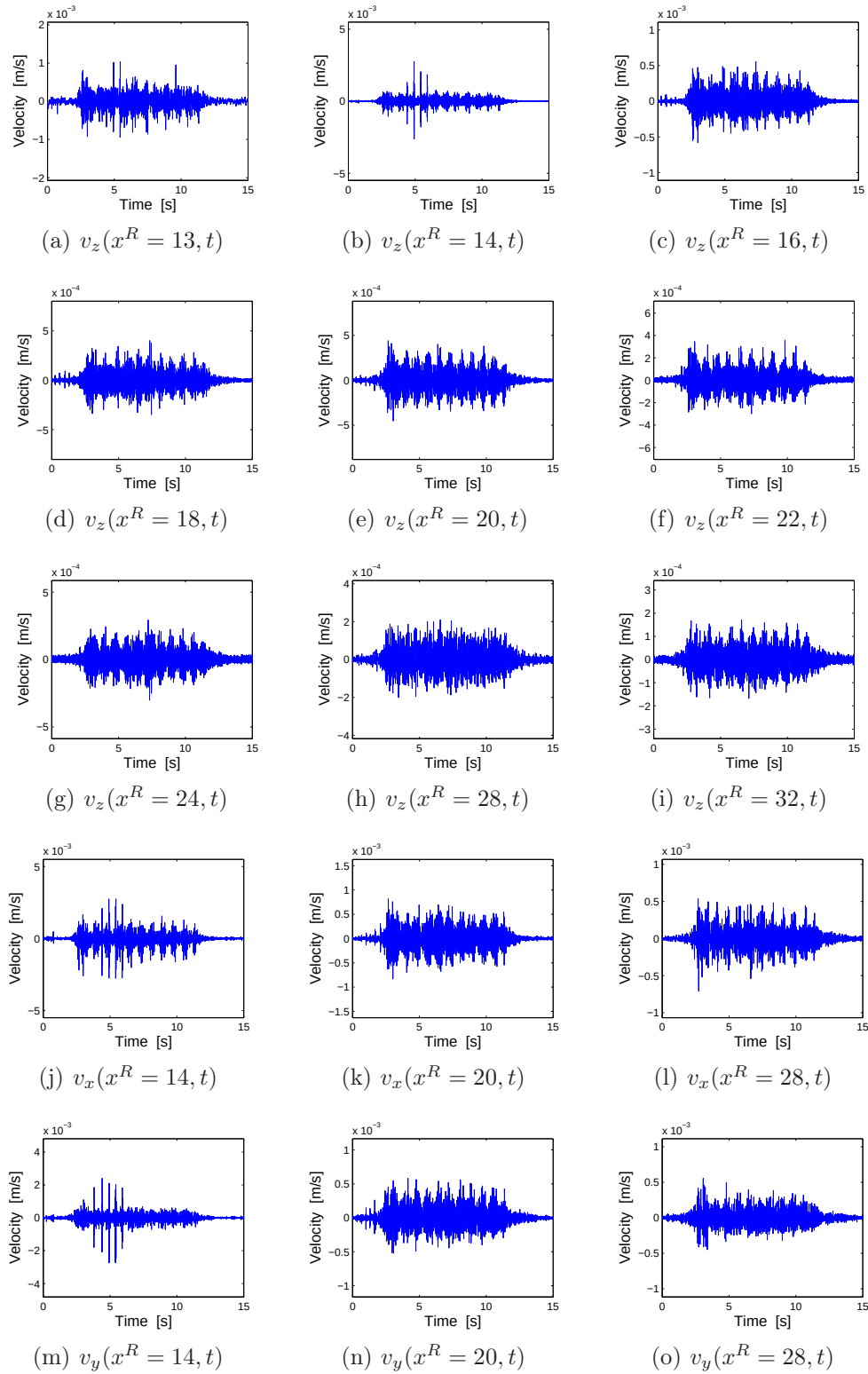


Figure 2.26: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 115 km/h

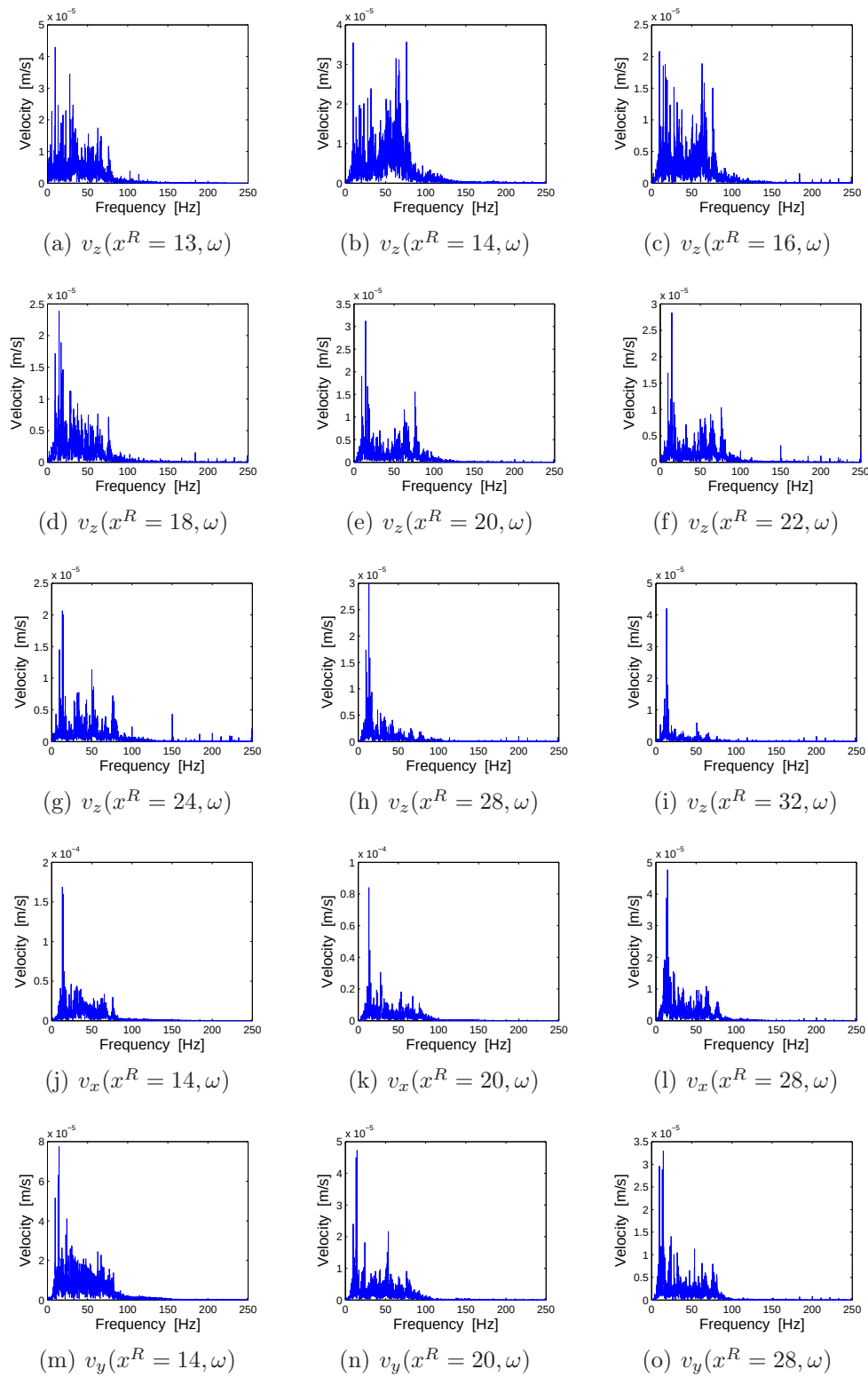


Figure 2.27: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 115 km/h

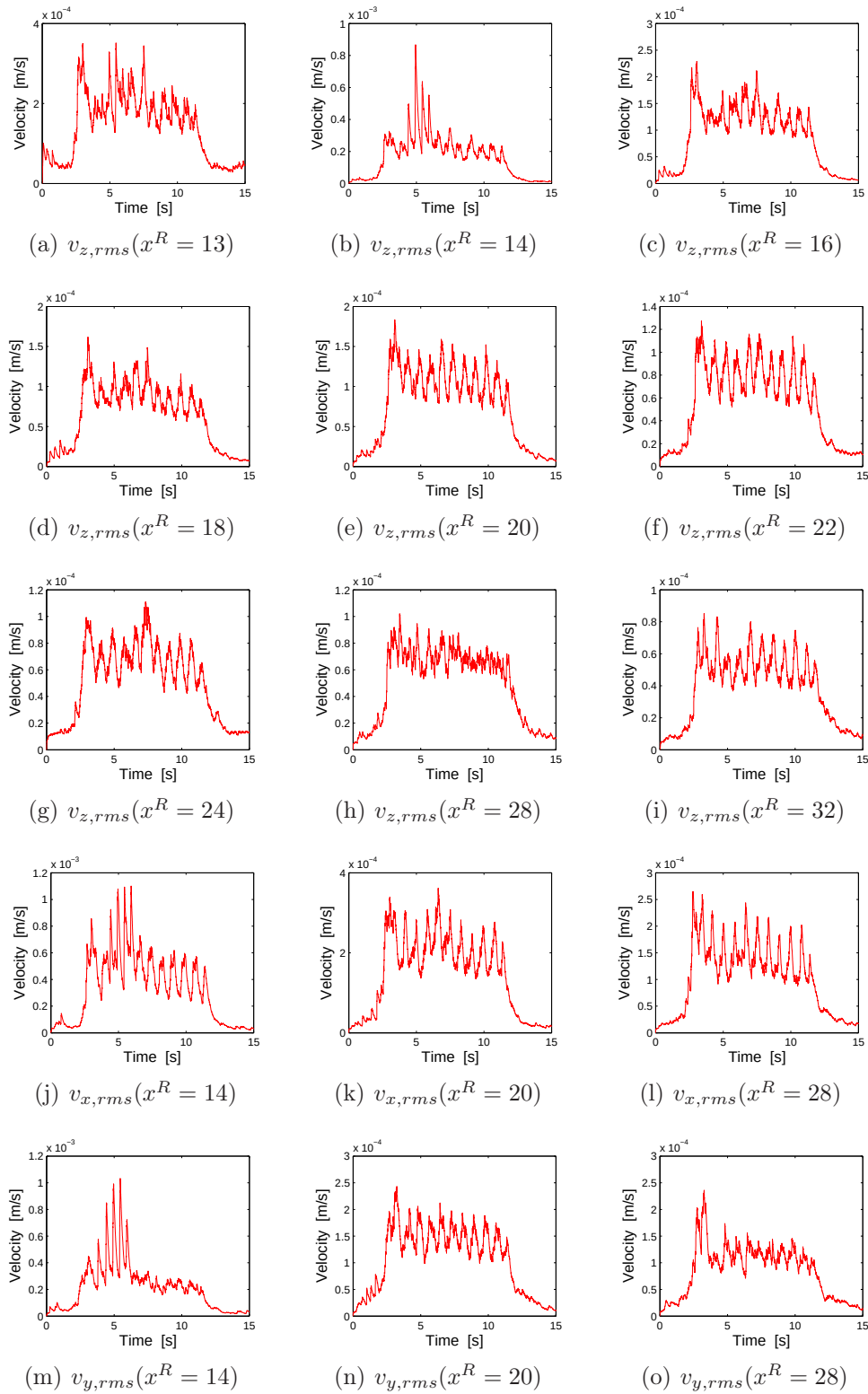


Figure 2.28: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 115 km/h

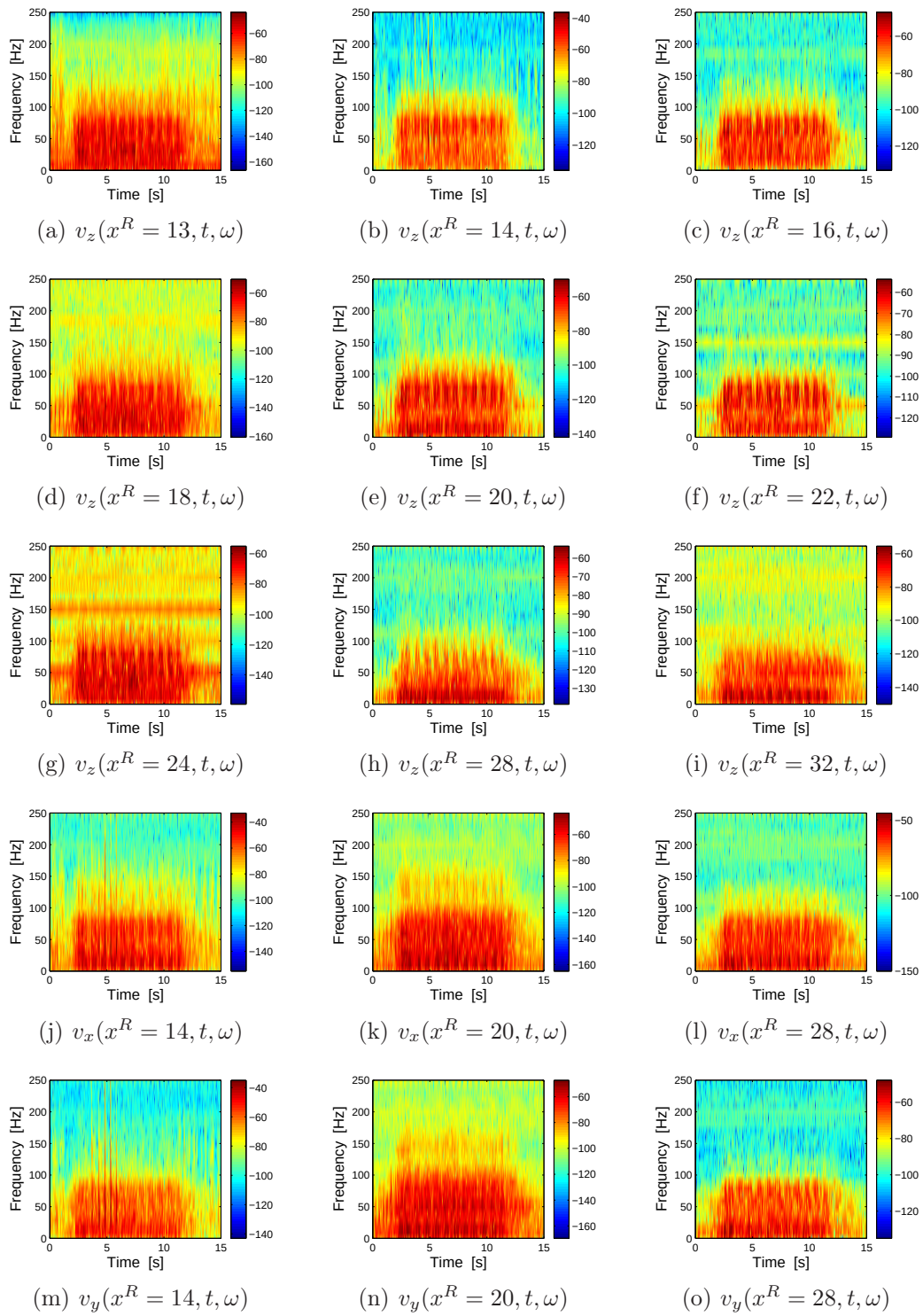


Figure 2.29: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 115 km/h

2.8 M4 railcar at 120 km/h

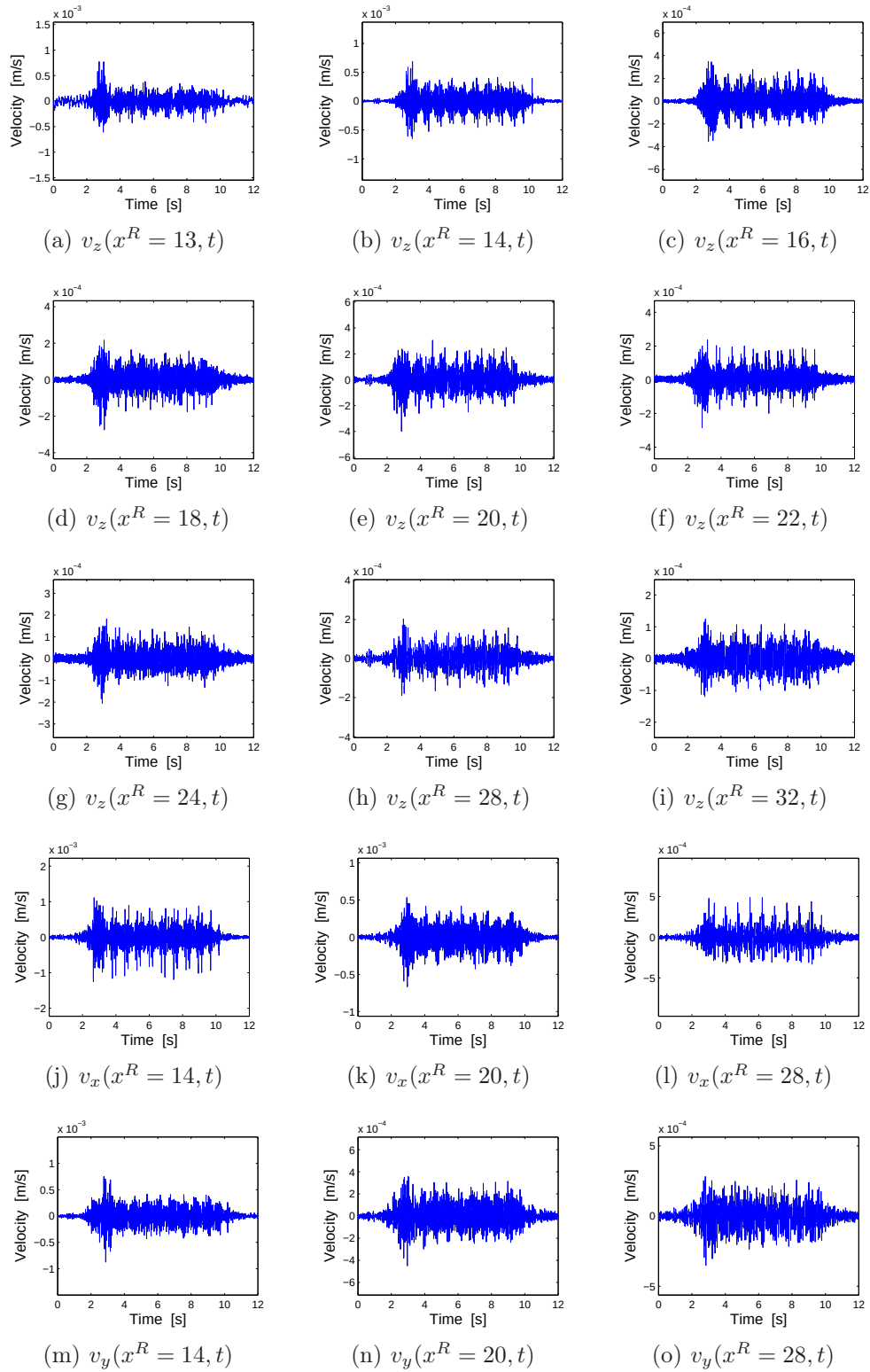


Figure 2.30: Time history of the vertical and horizontal velocities measured in free field during the passage of a M4 railcar at 120 km/h

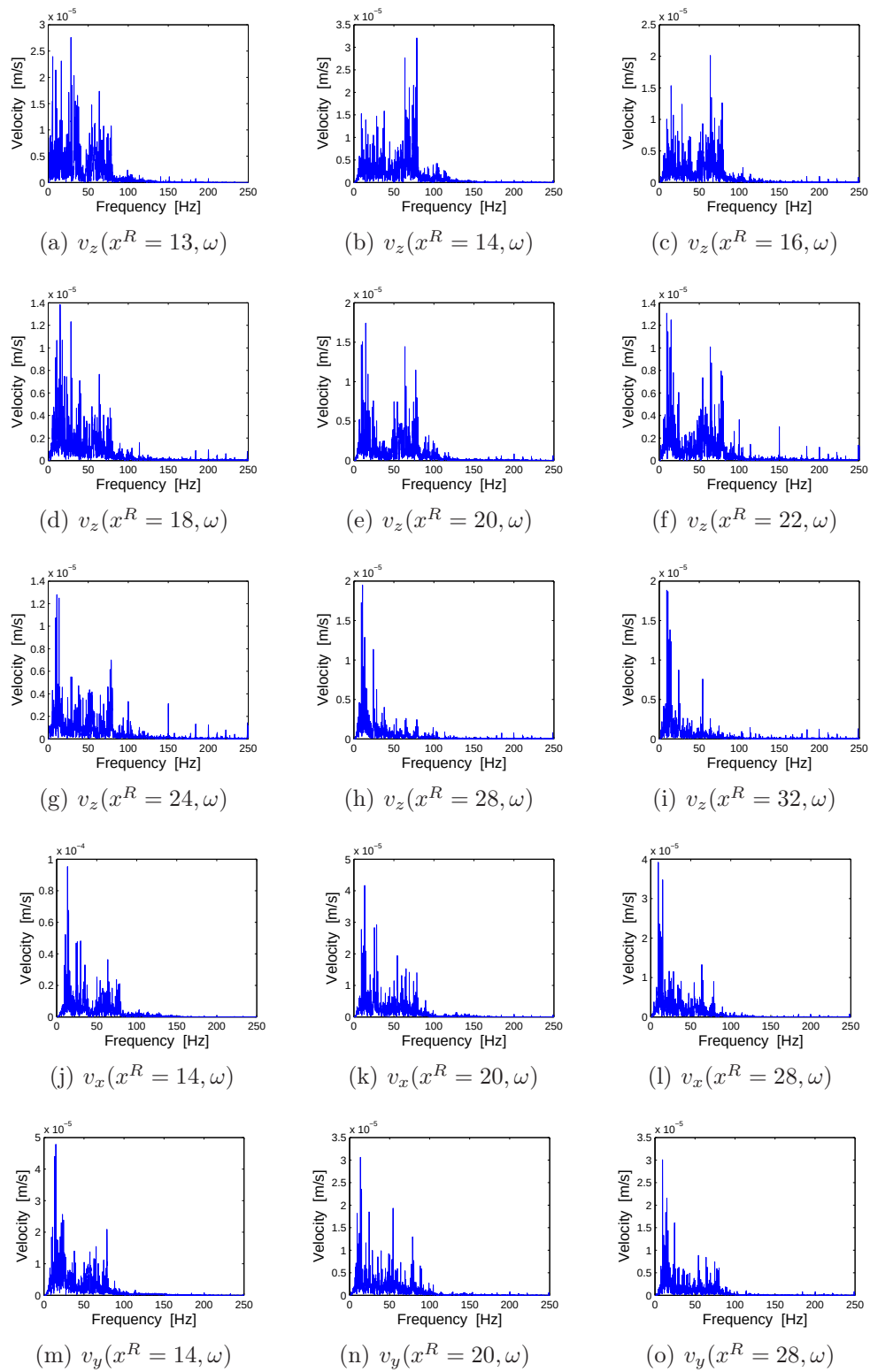


Figure 2.31: Spectral content of the vertical and horizontal velocities measured in free field during the passage of a M4 railcar at 120 km/h

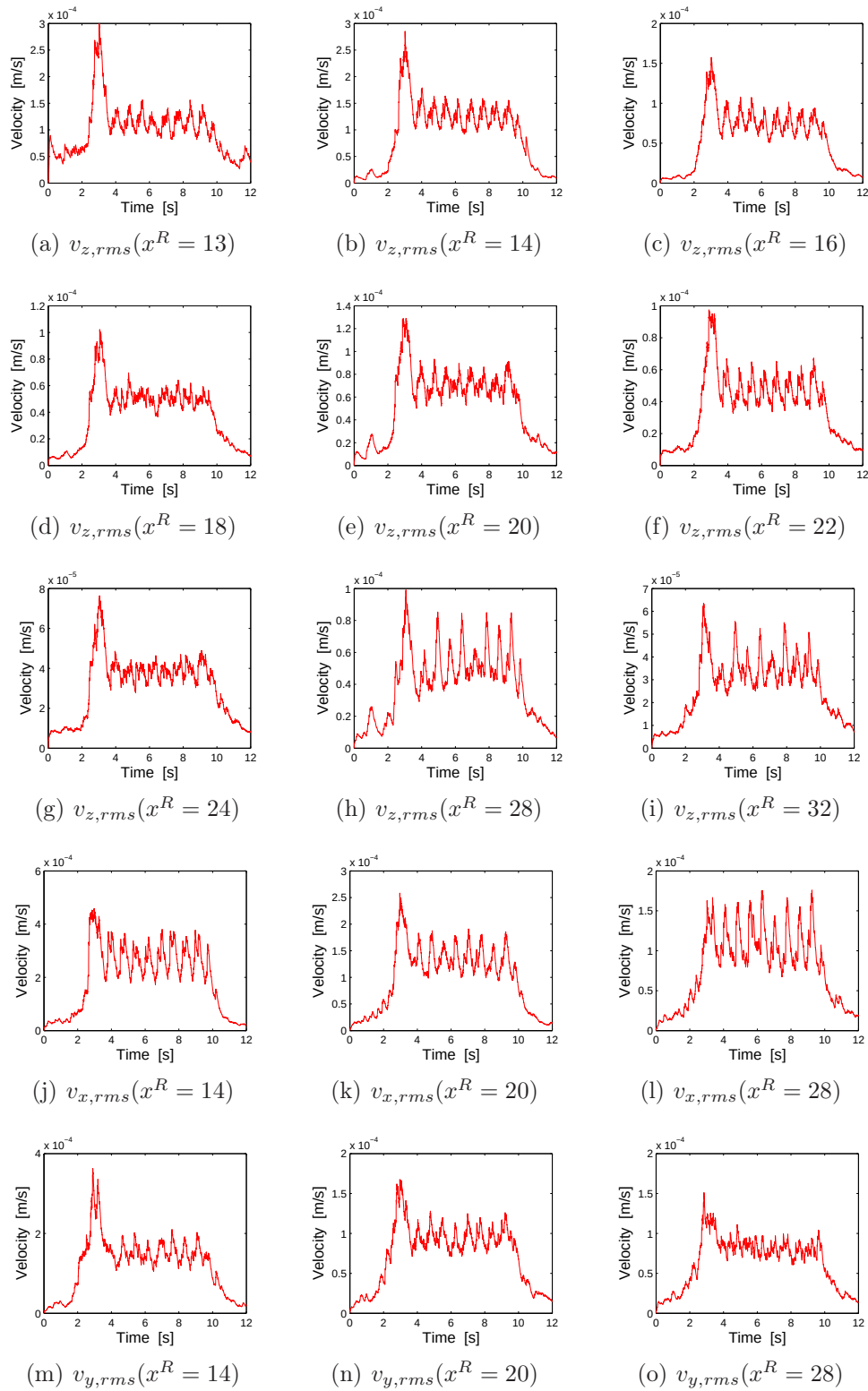


Figure 2.32: Time-average of the vertical and horizontal velocities measured in free field during the passage of a M4 railcar at 120 km/h

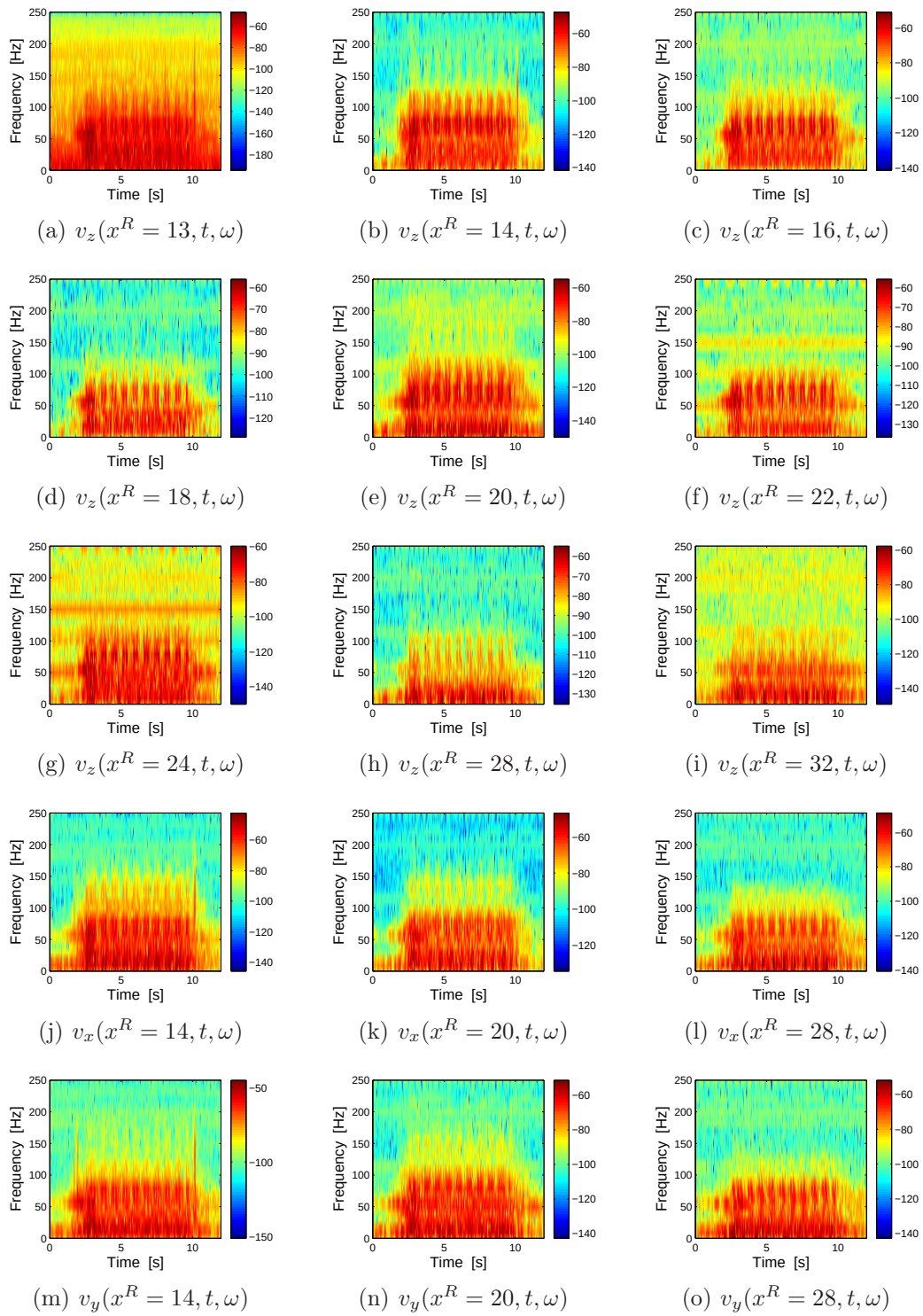


Figure 2.33: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of a M4 railcar at 120 km/h

2.9 AM75 unit at 110 km/h

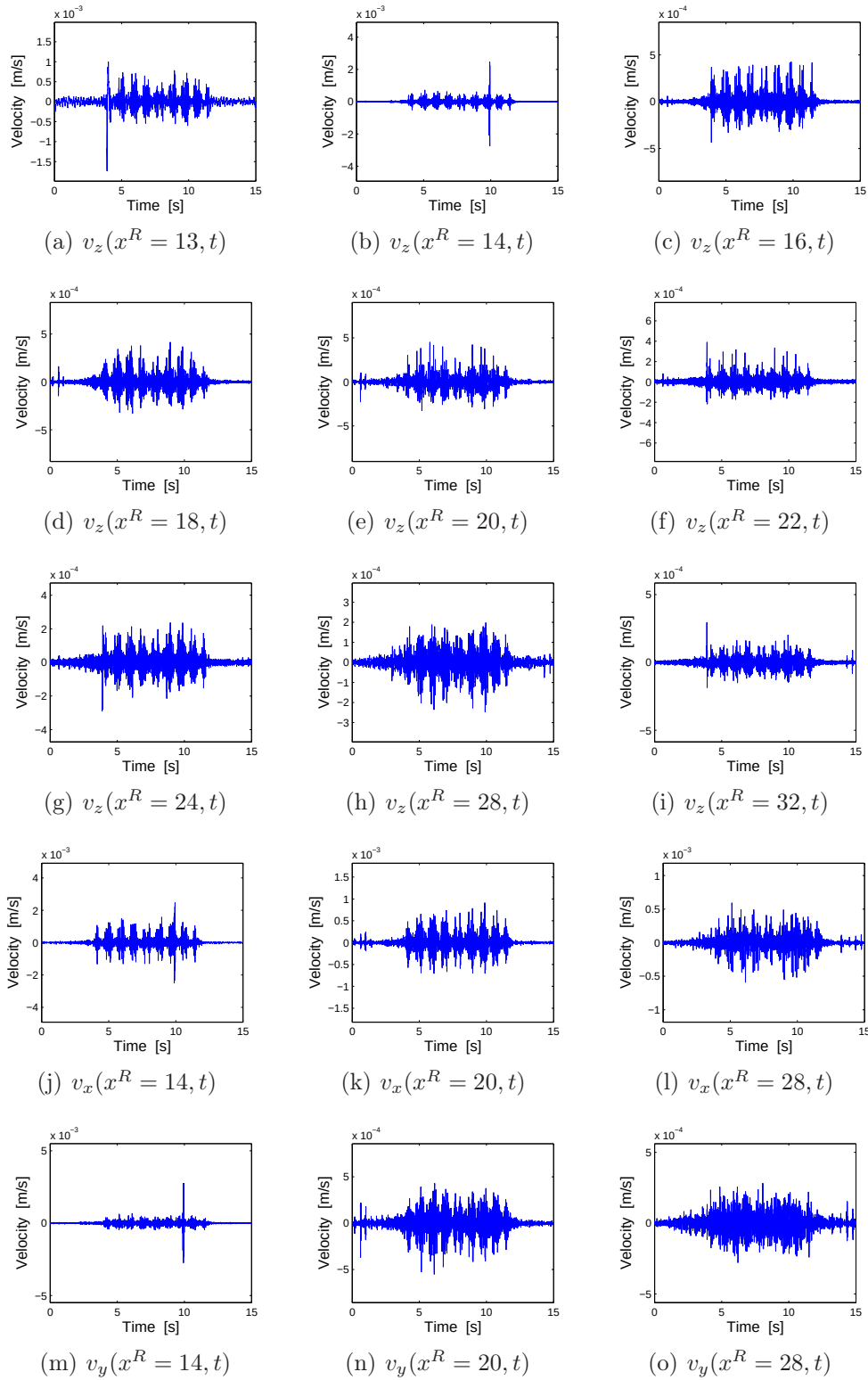


Figure 2.34: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 110 km/h

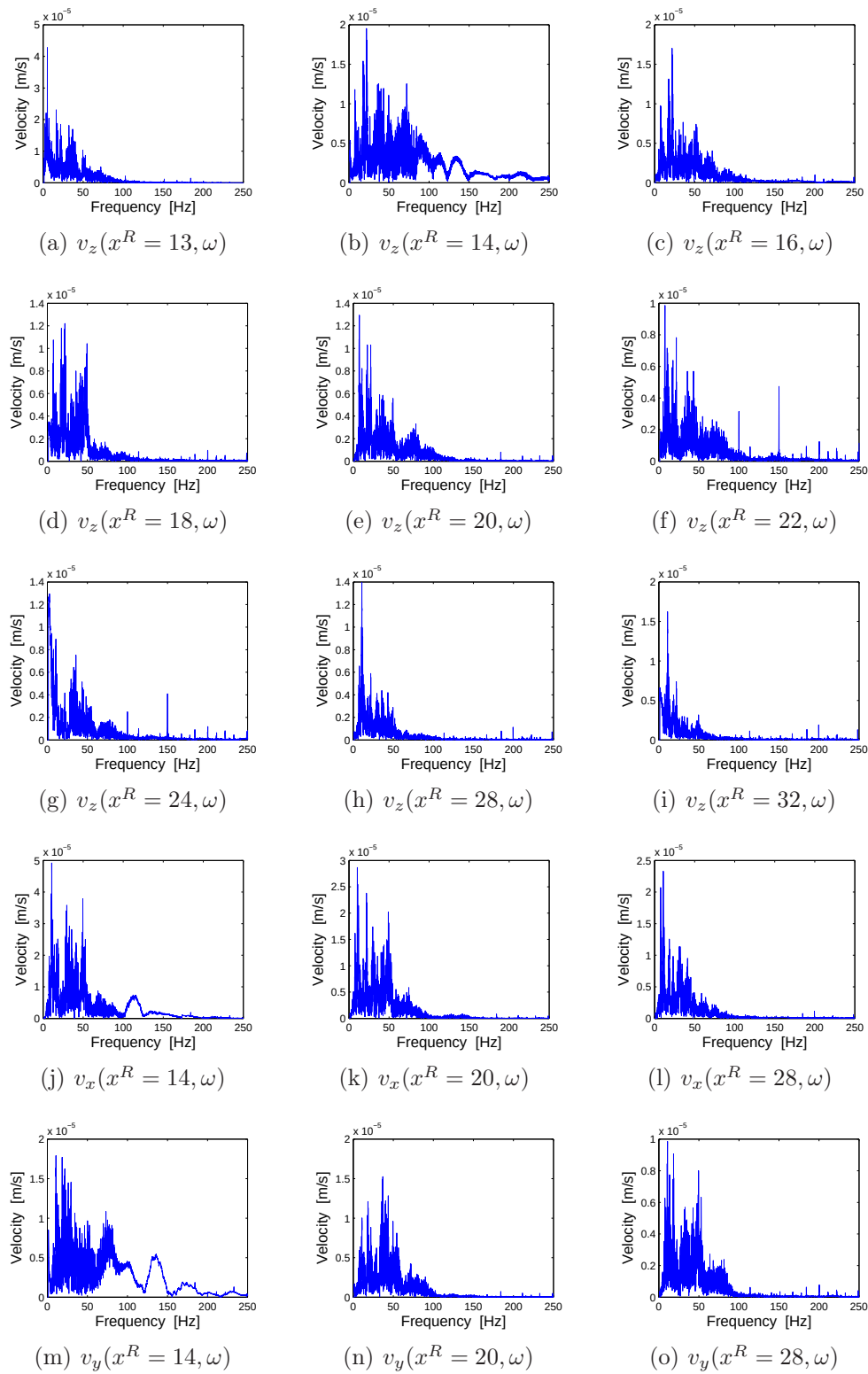


Figure 2.35: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 110 km/h

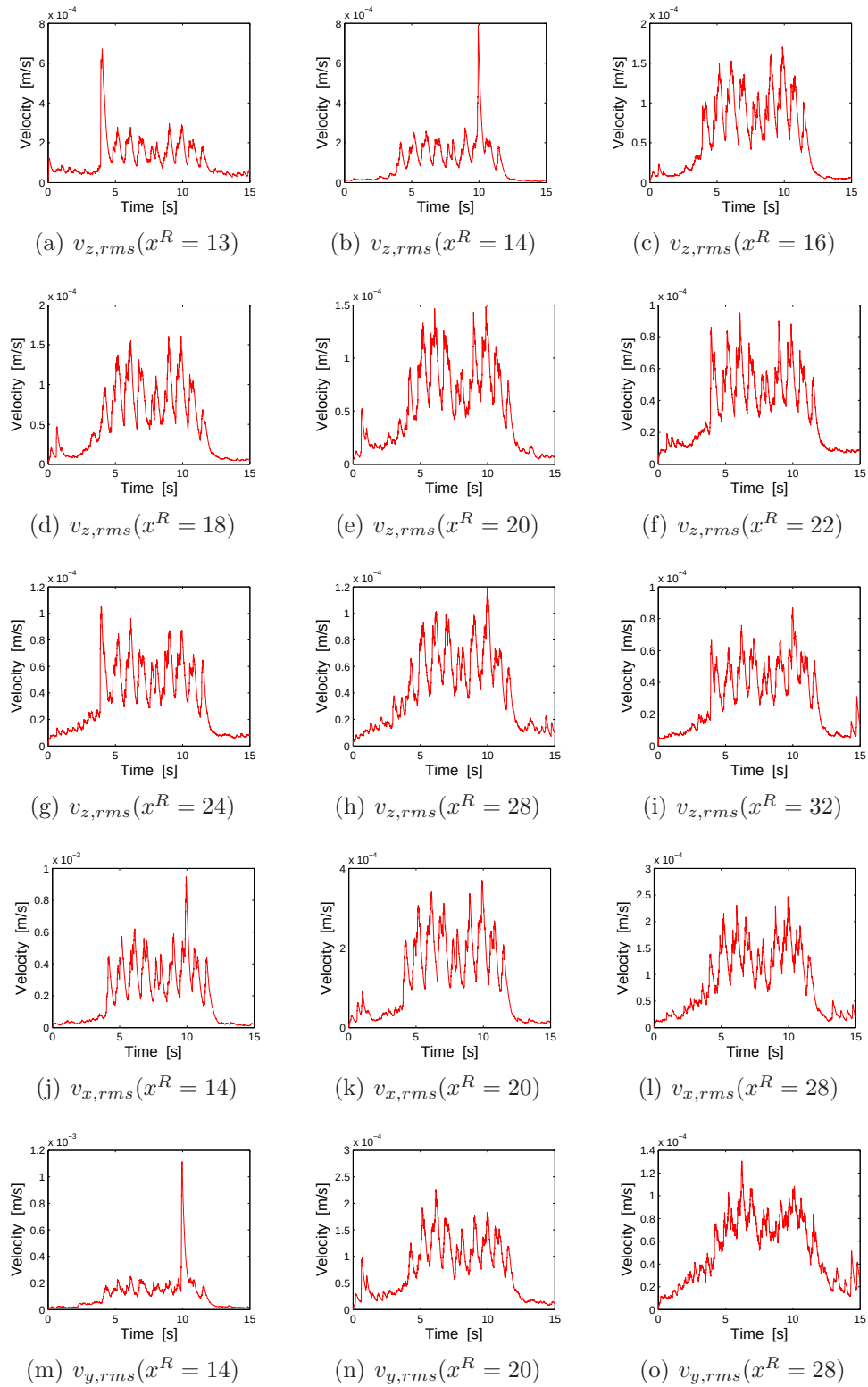


Figure 2.36: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 110 km/h

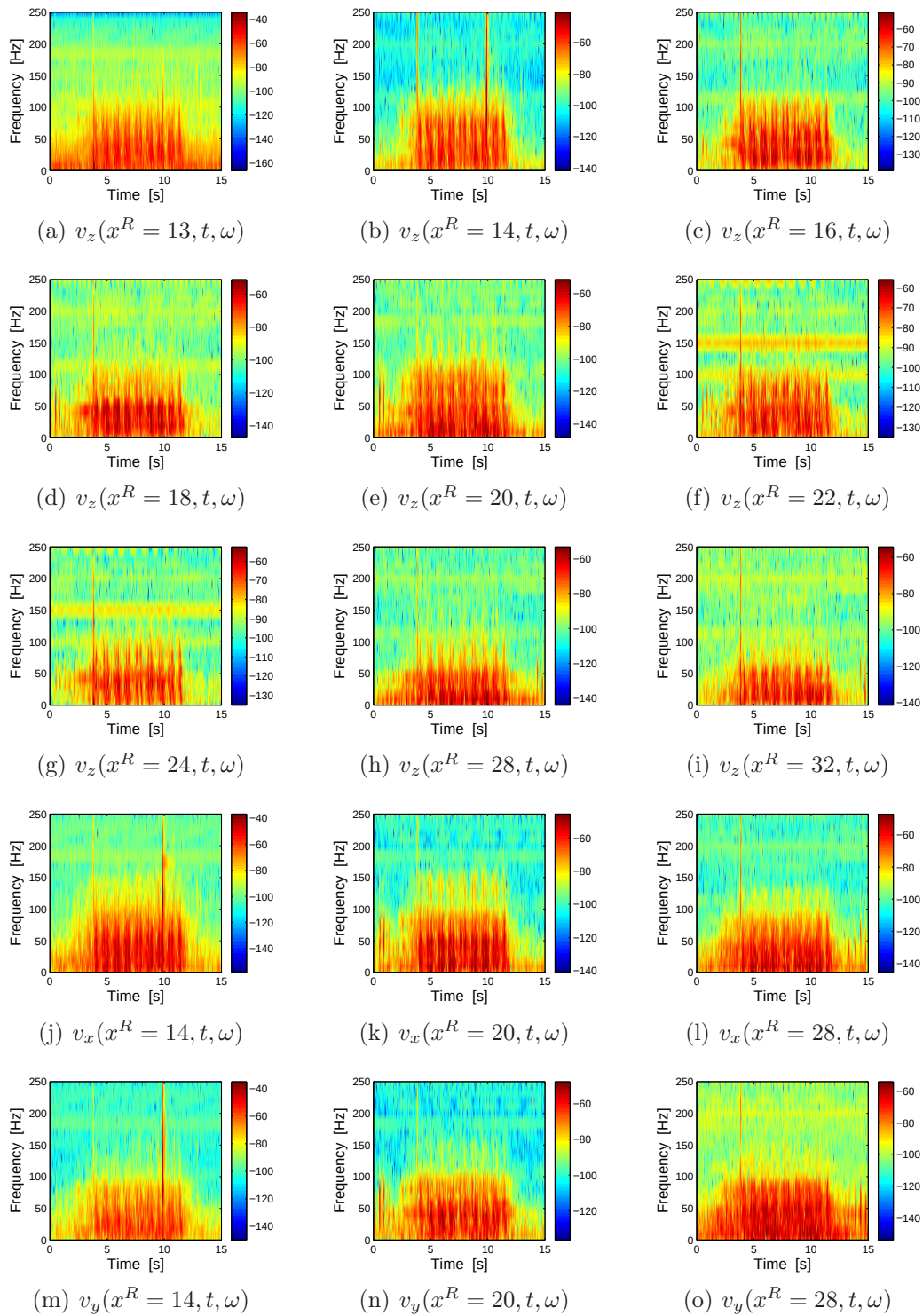


Figure 2.37: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 110 km/h

2.10 AM80 unit at 80 km/h

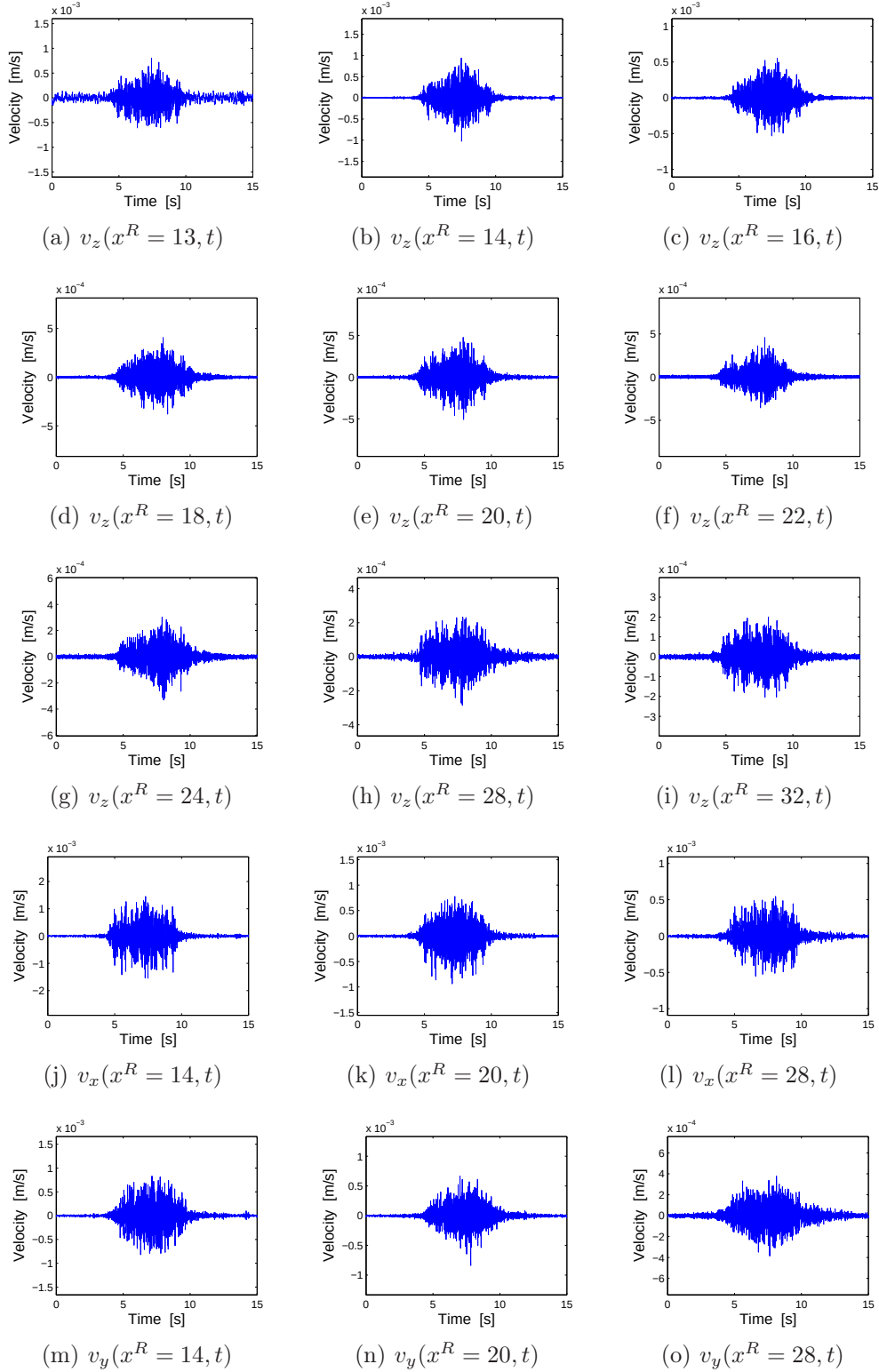


Figure 2.38: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 80 km/h

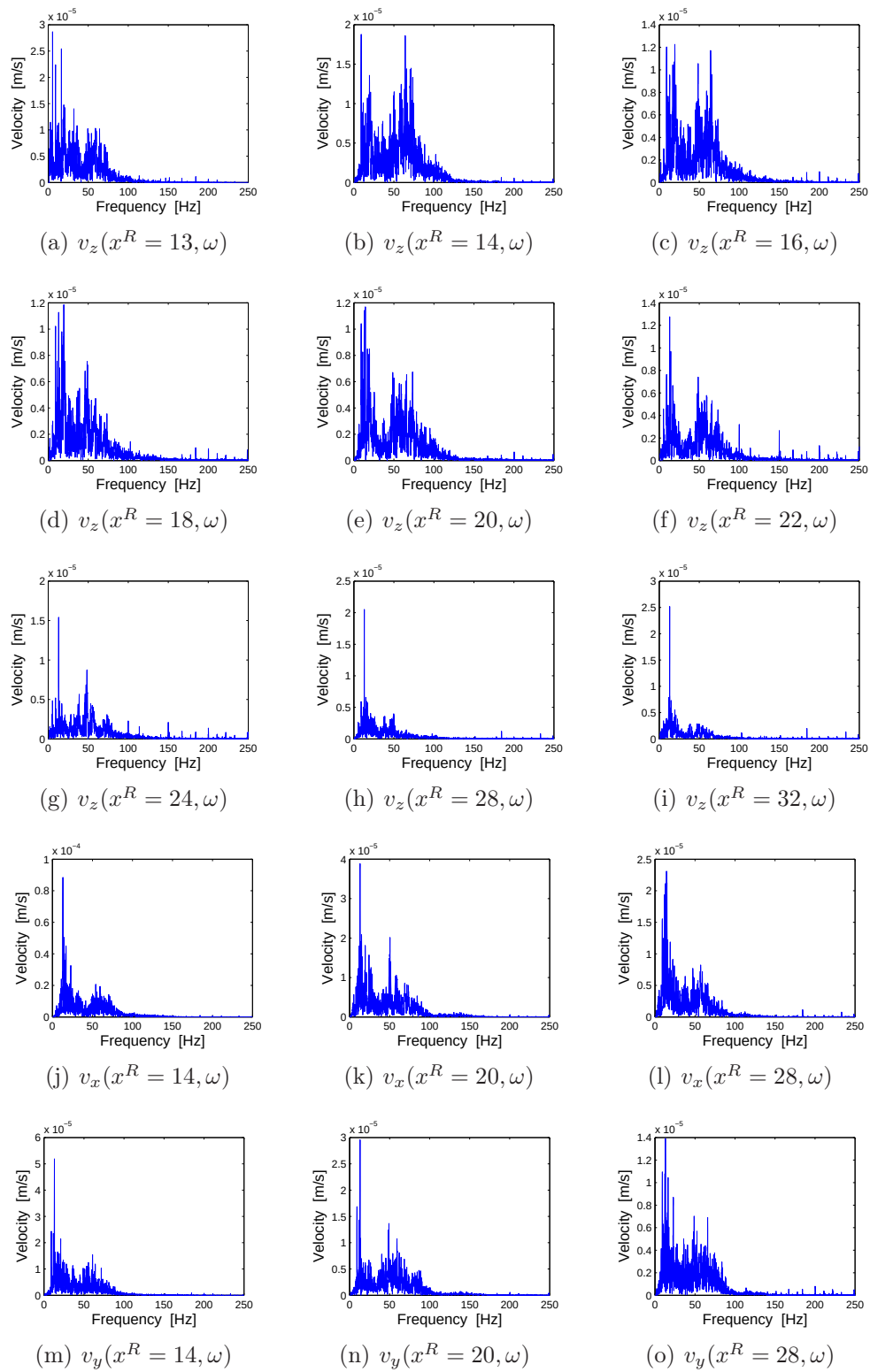


Figure 2.39: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 80 km/h

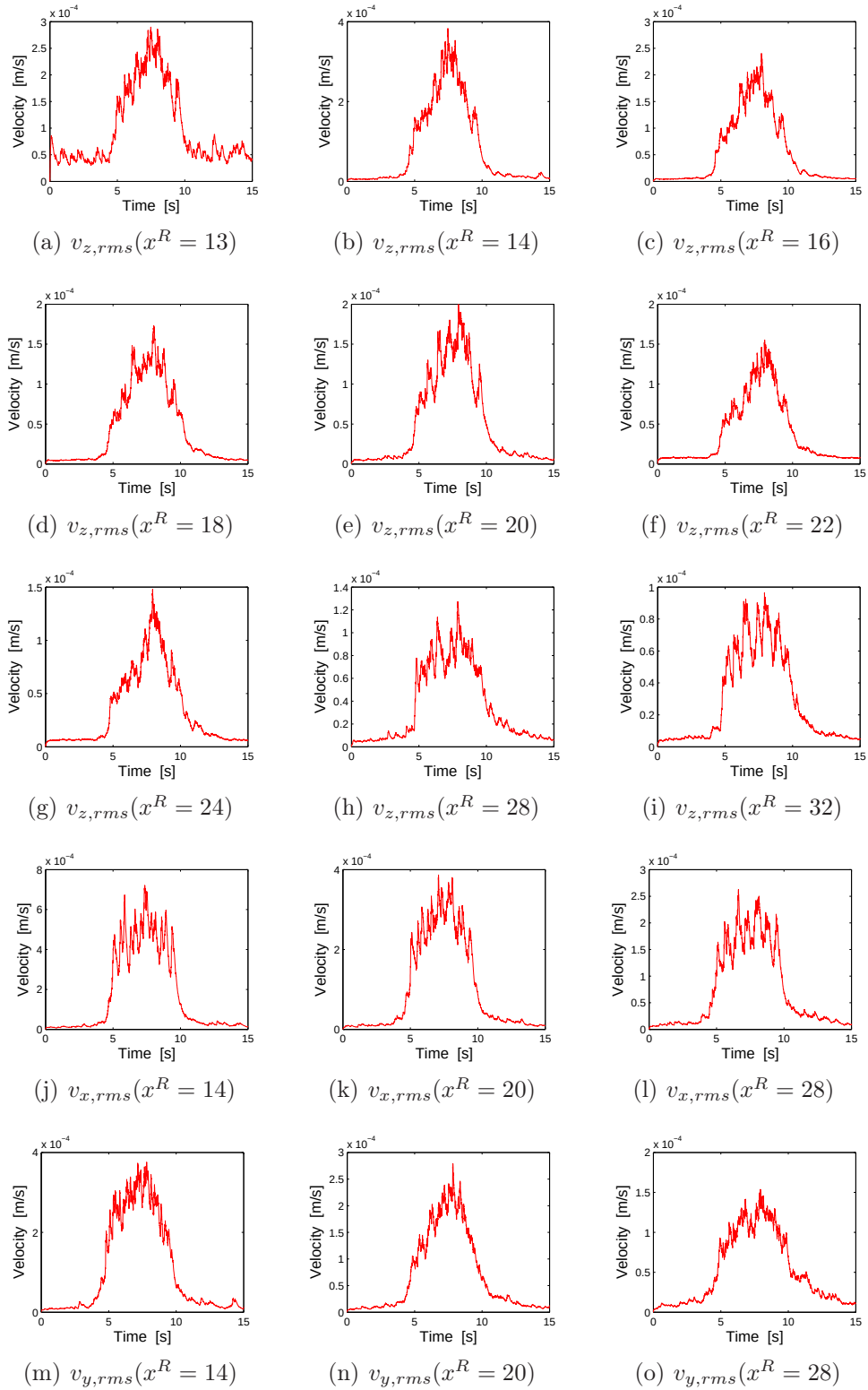


Figure 2.40: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 80 km/h

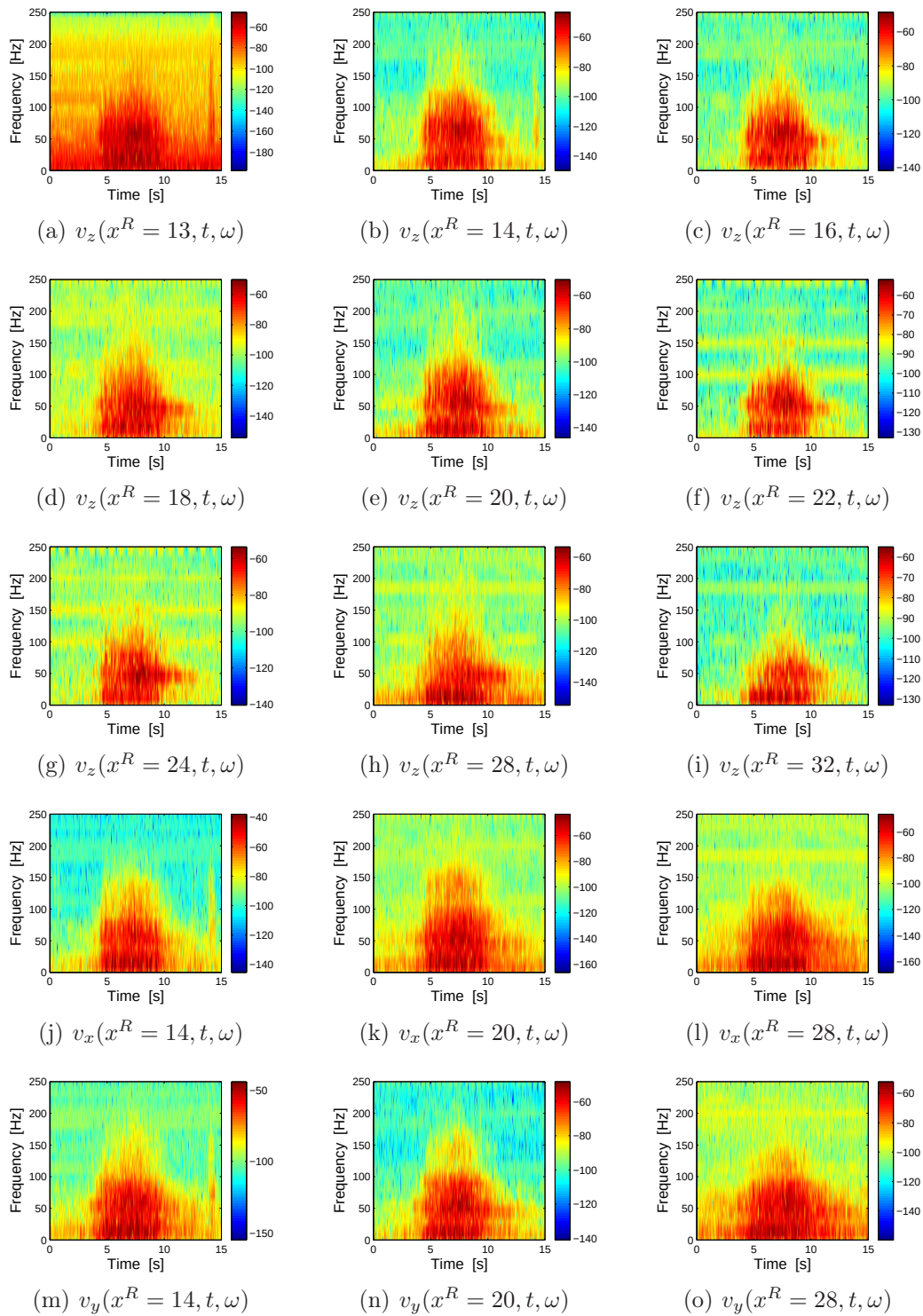


Figure 2.41: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 80 km/h

2.11 AM80 unit at 90 km/h

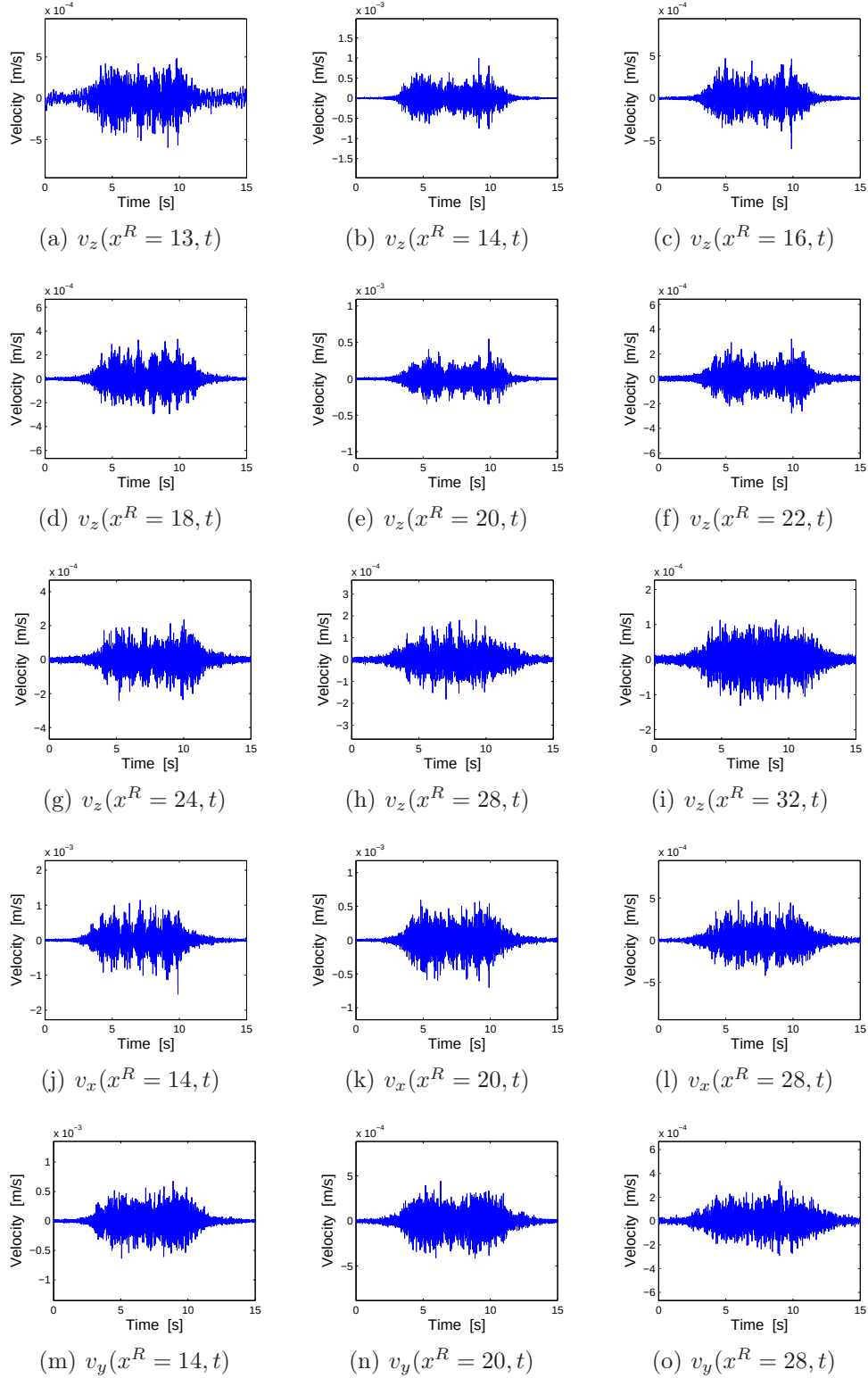


Figure 2.42: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 90 km/h

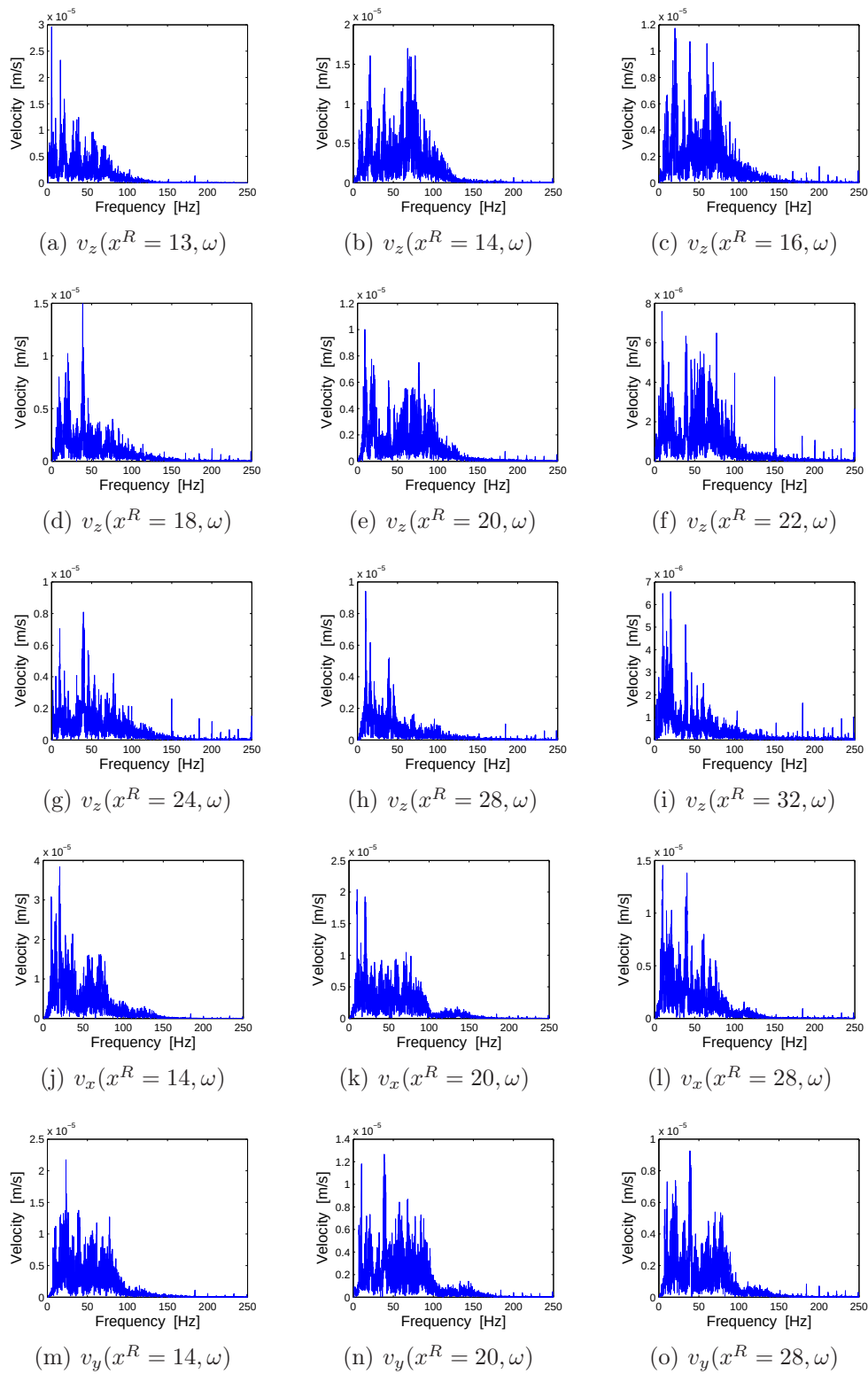


Figure 2.43: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 90 km/h

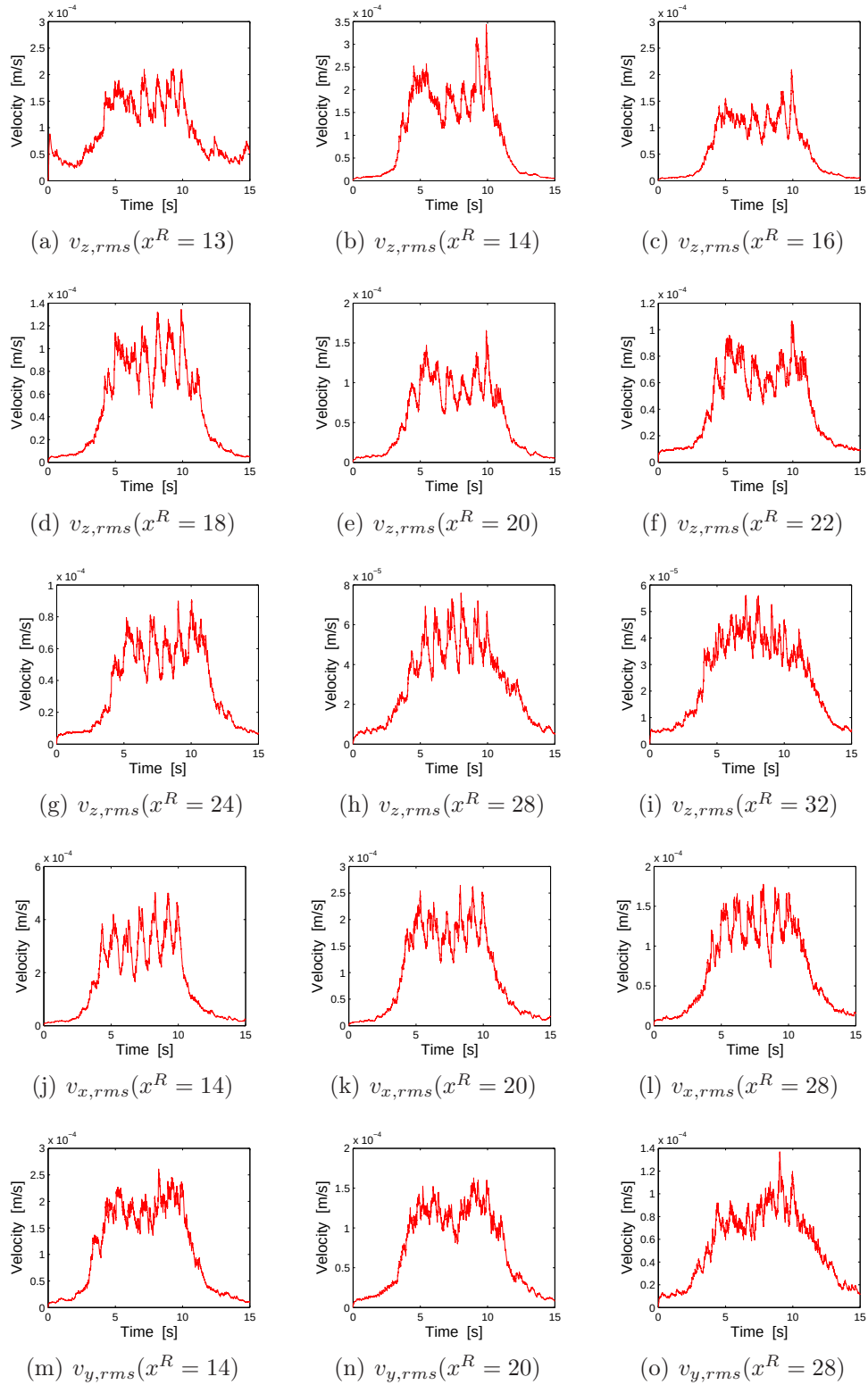


Figure 2.44: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 90 km/h

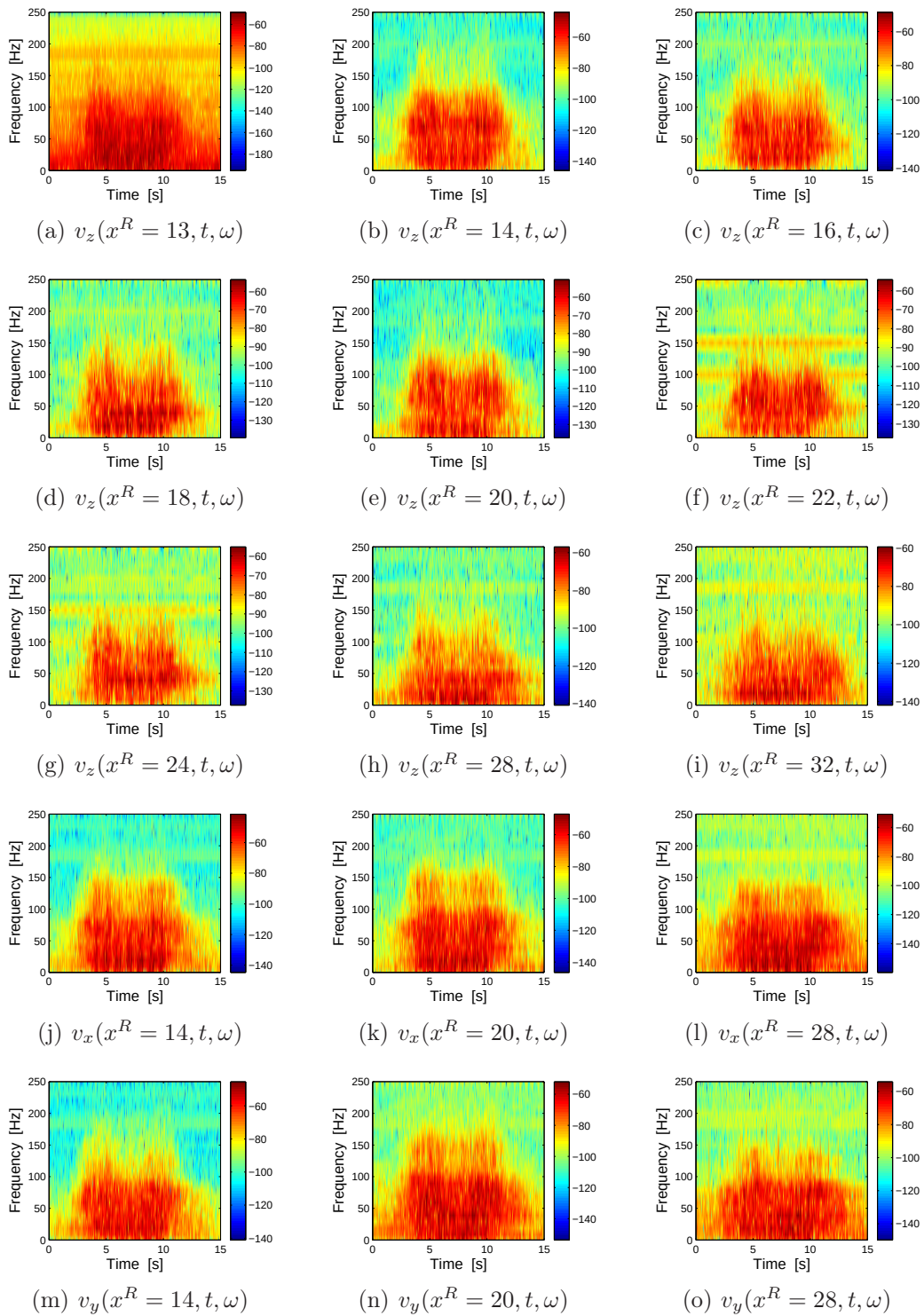


Figure 2.45: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 90 km/h

2.12 M4 railcar at 120 km/h

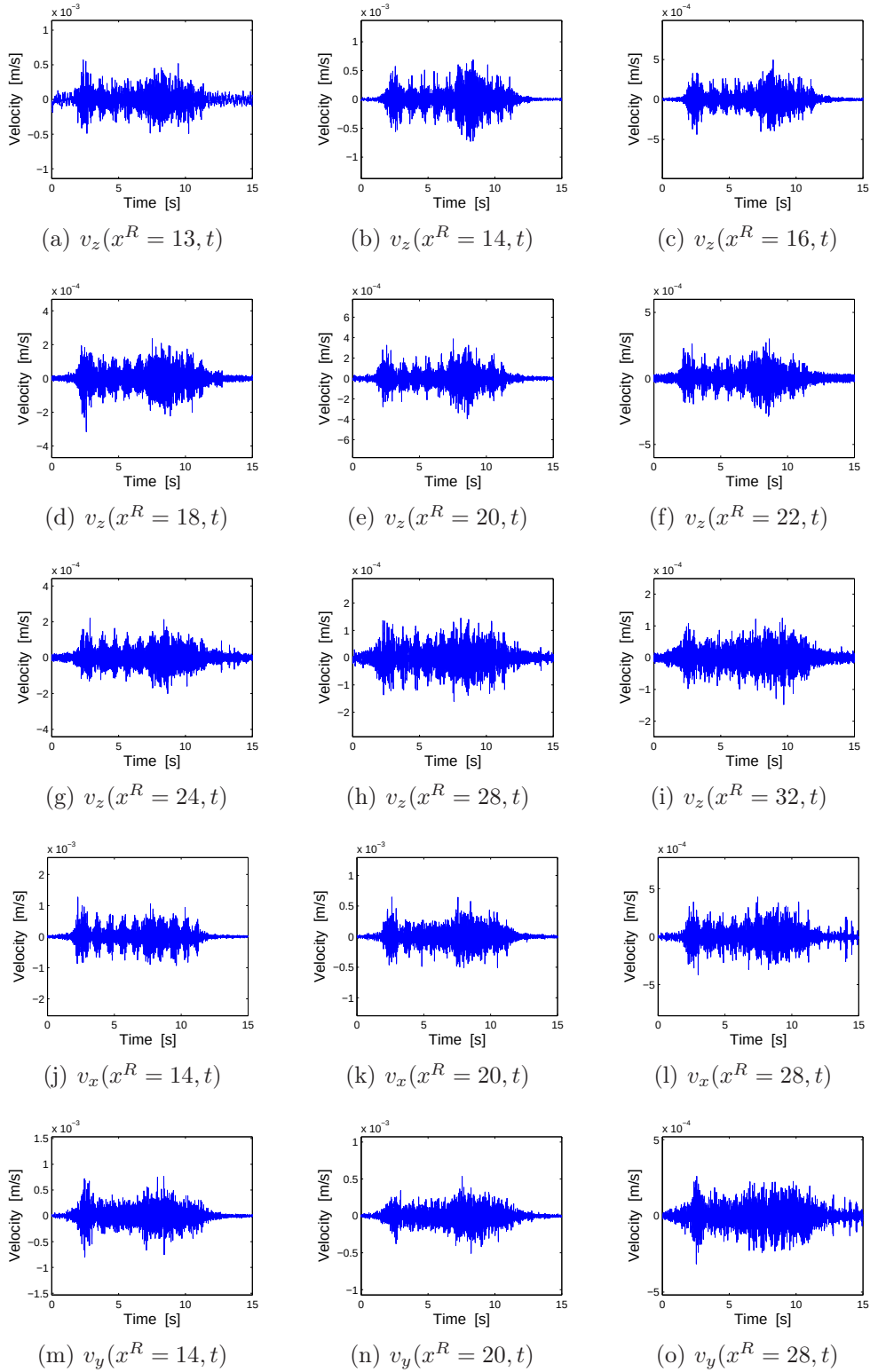


Figure 2.46: Time history of the vertical and horizontal velocities measured in free field during the passage of a M4 railcar at 120 km/h

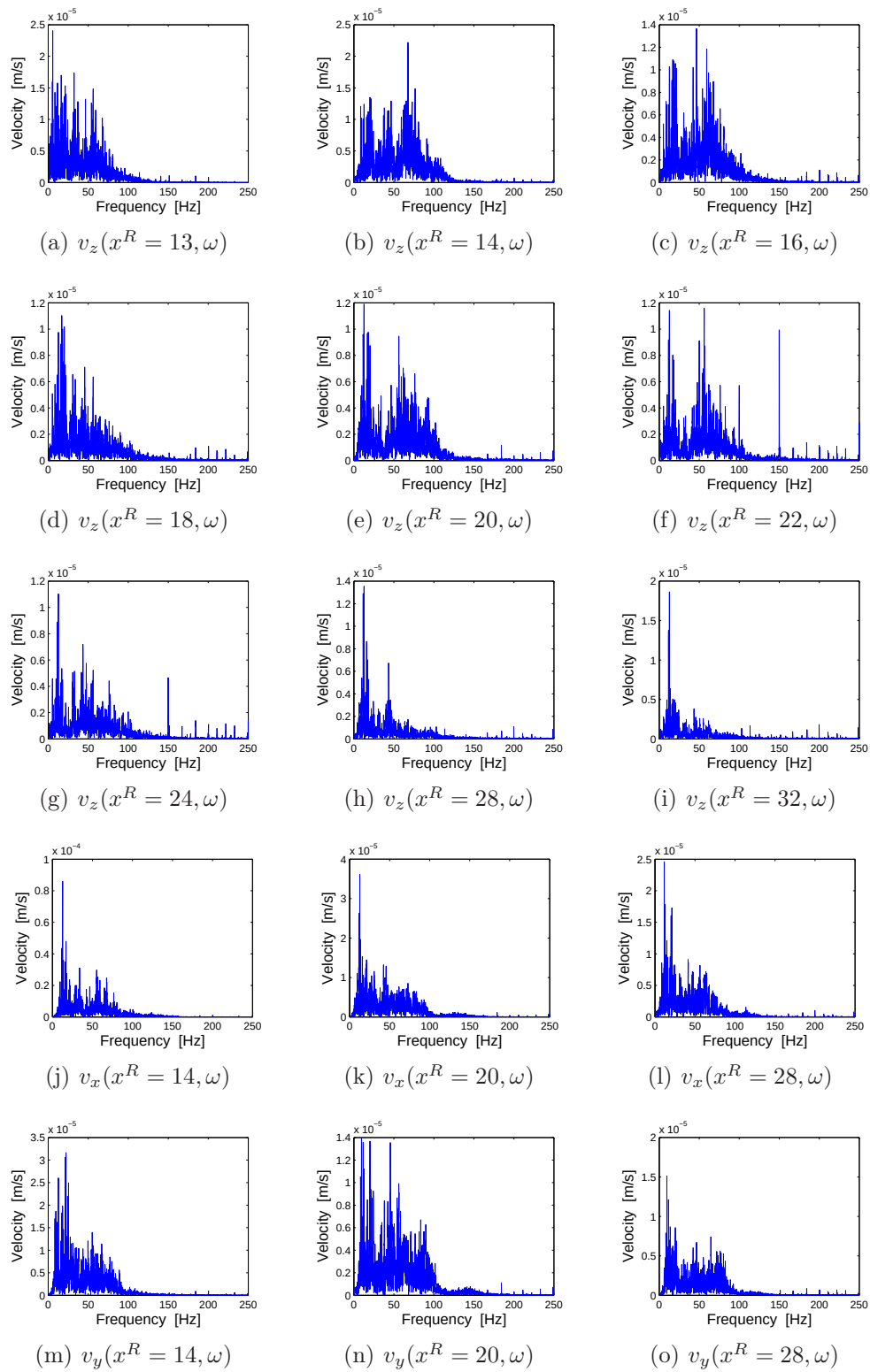


Figure 2.47: Spectral content of the vertical and horizontal velocities measured in free field during the passage of a M4 railcar at 120 km/h

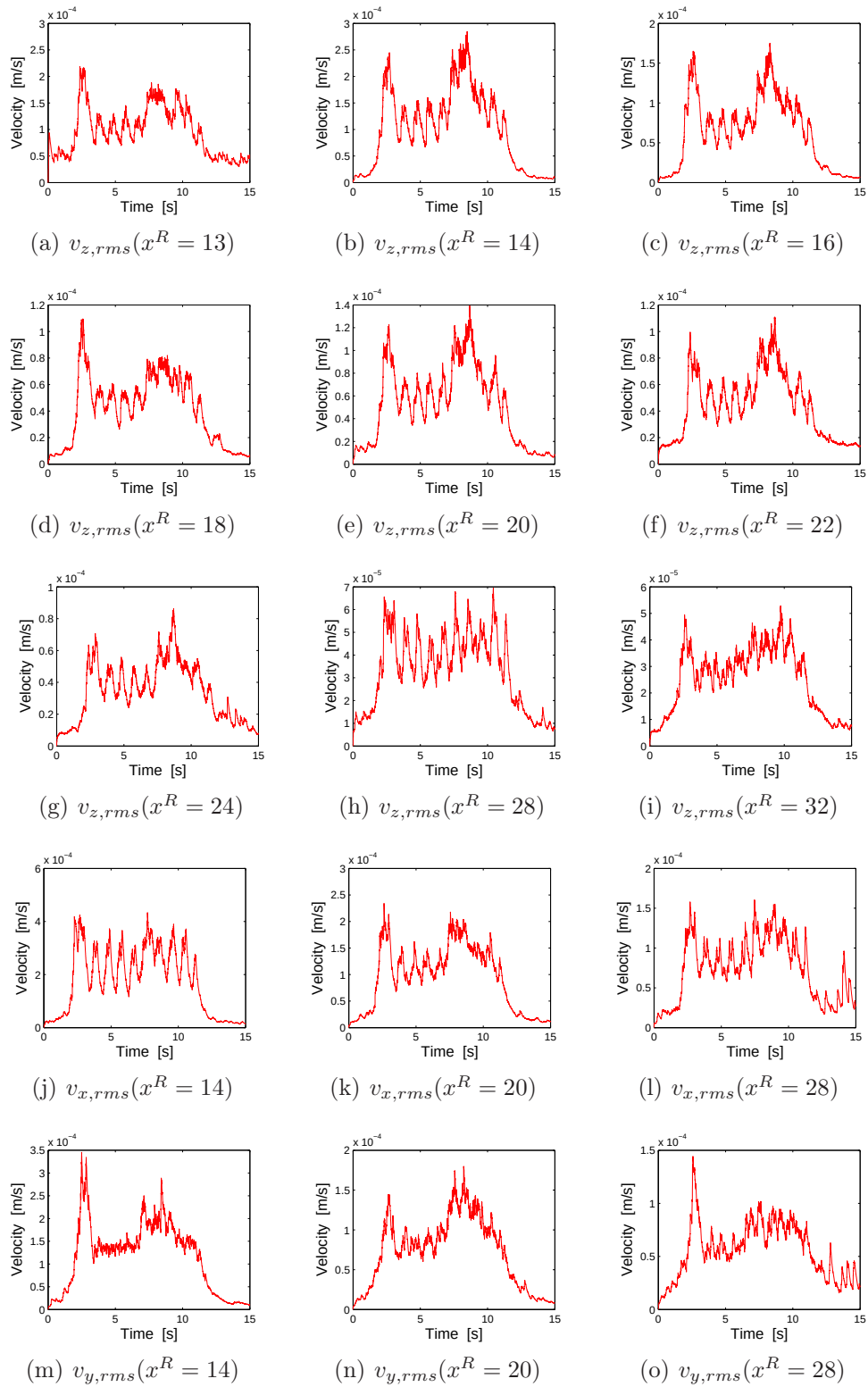


Figure 2.48: Time-average of the vertical and horizontal velocities measured in free field during the passage of a M4 railcar at 120 km/h

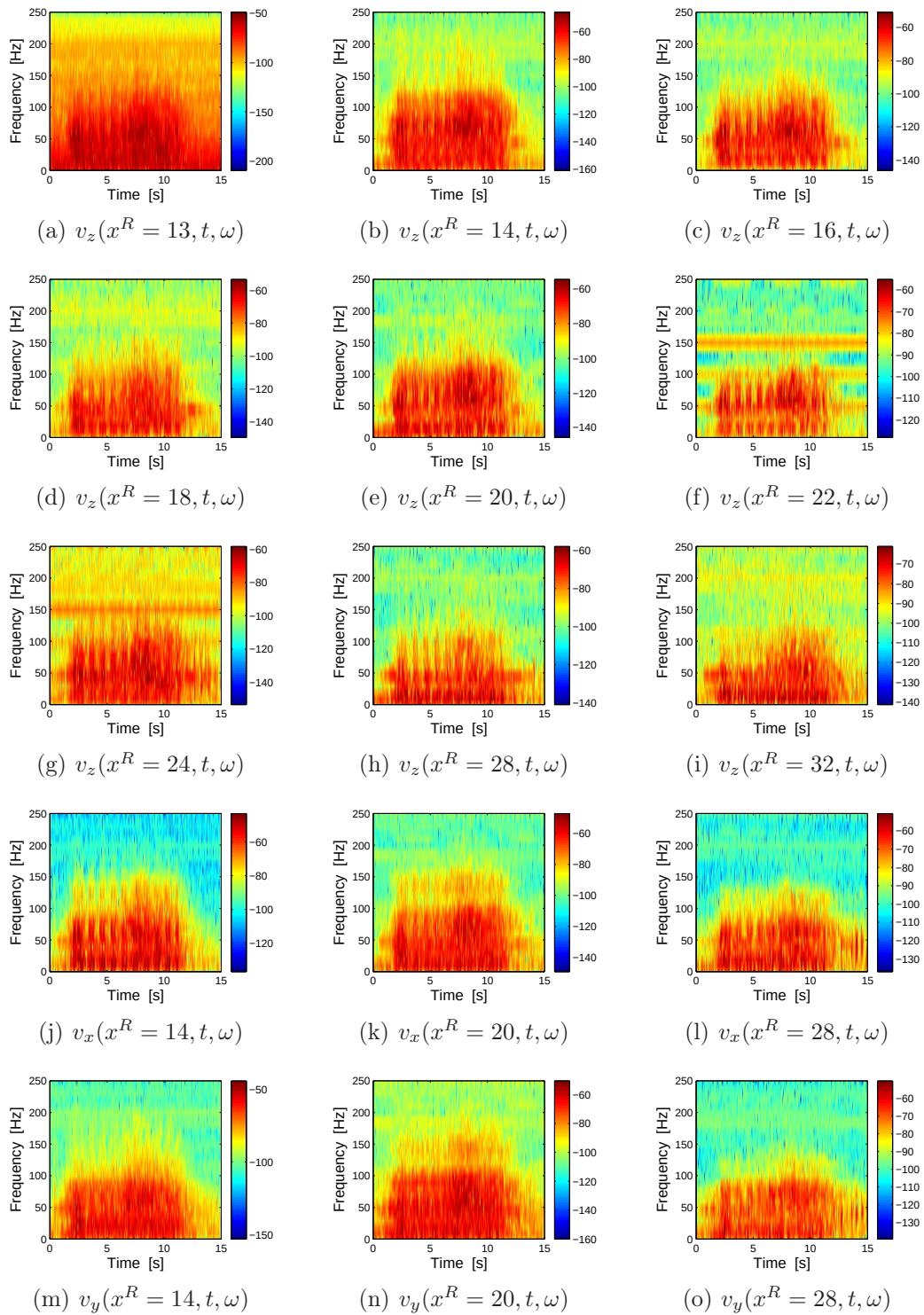


Figure 2.49: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of a M4 railcar at 120 km/h

2.13 AM96 unit at 110 km/h

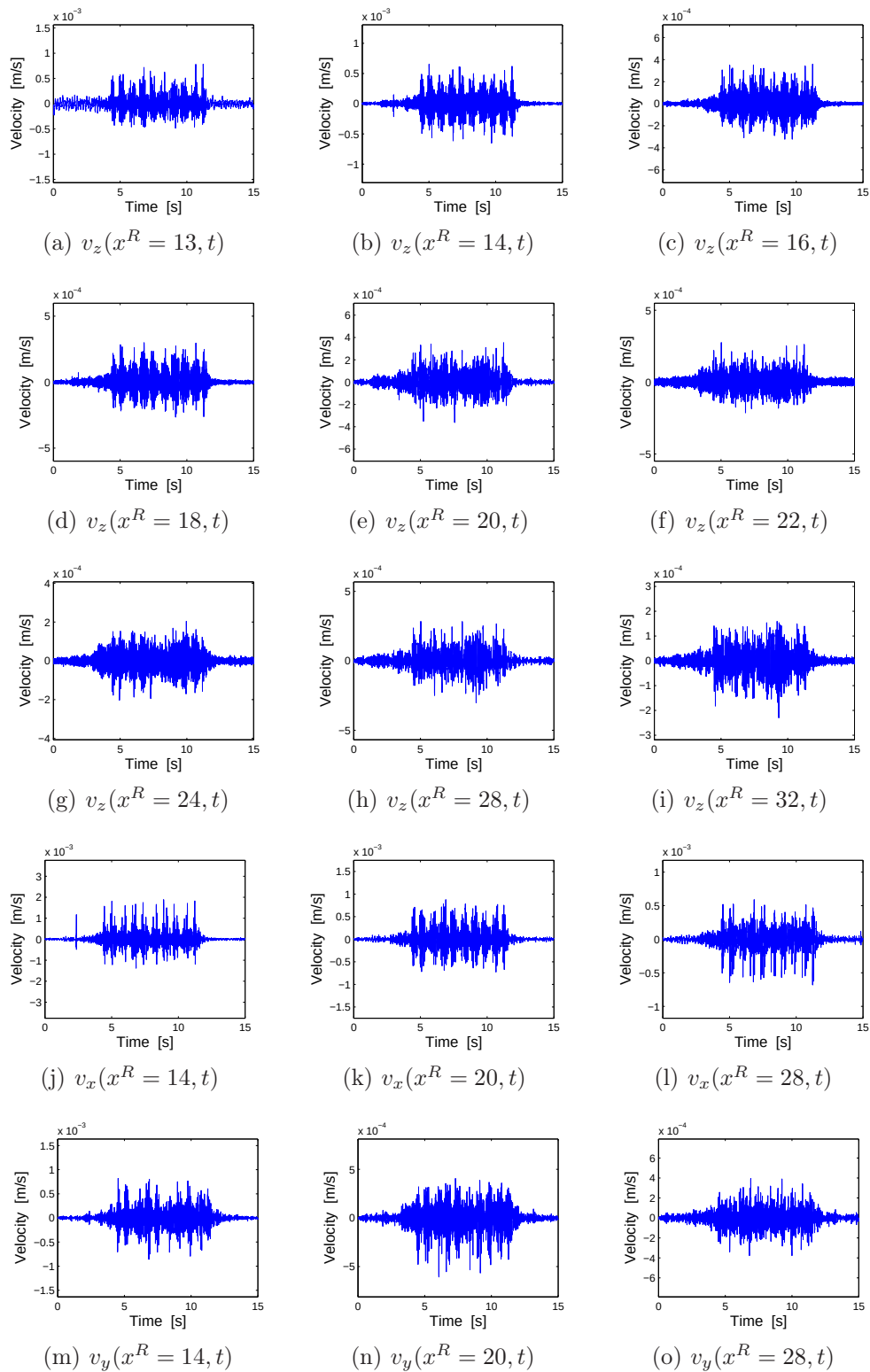


Figure 2.50: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 110 km/h

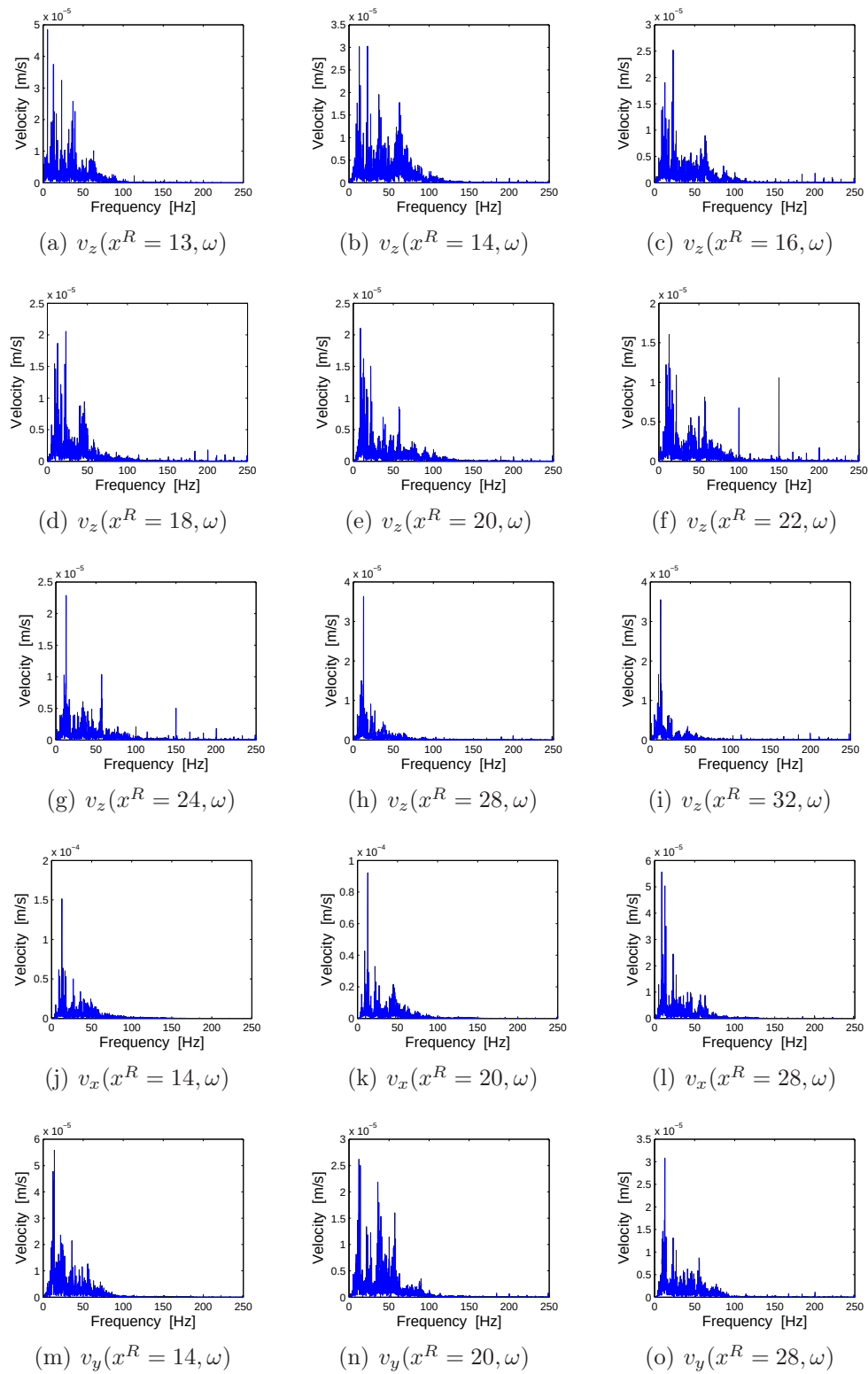


Figure 2.51: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 110 km/h

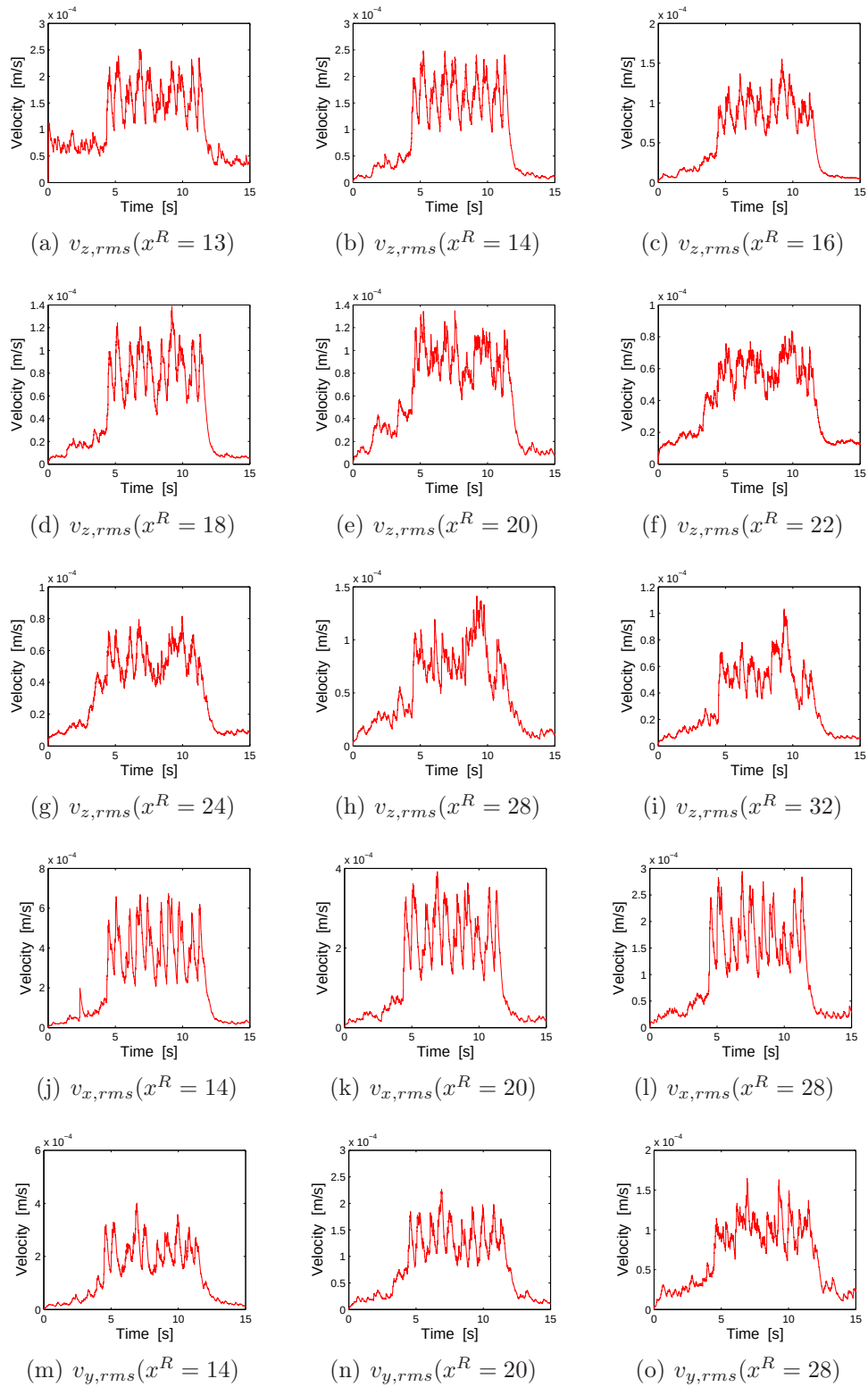


Figure 2.52: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 110 km/h

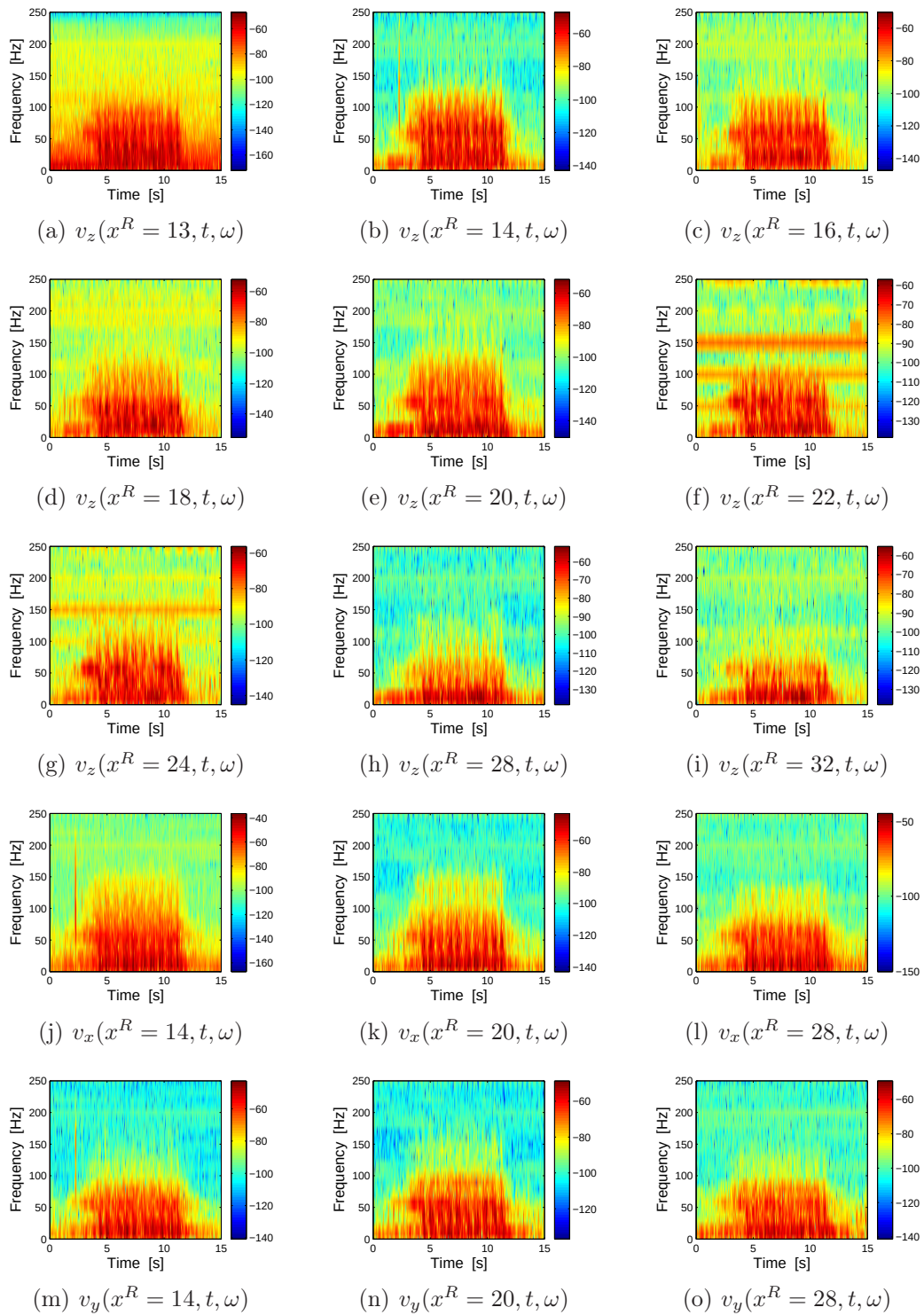


Figure 2.53: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 110 km/h

2.14 AM96 unit at 90 km/h

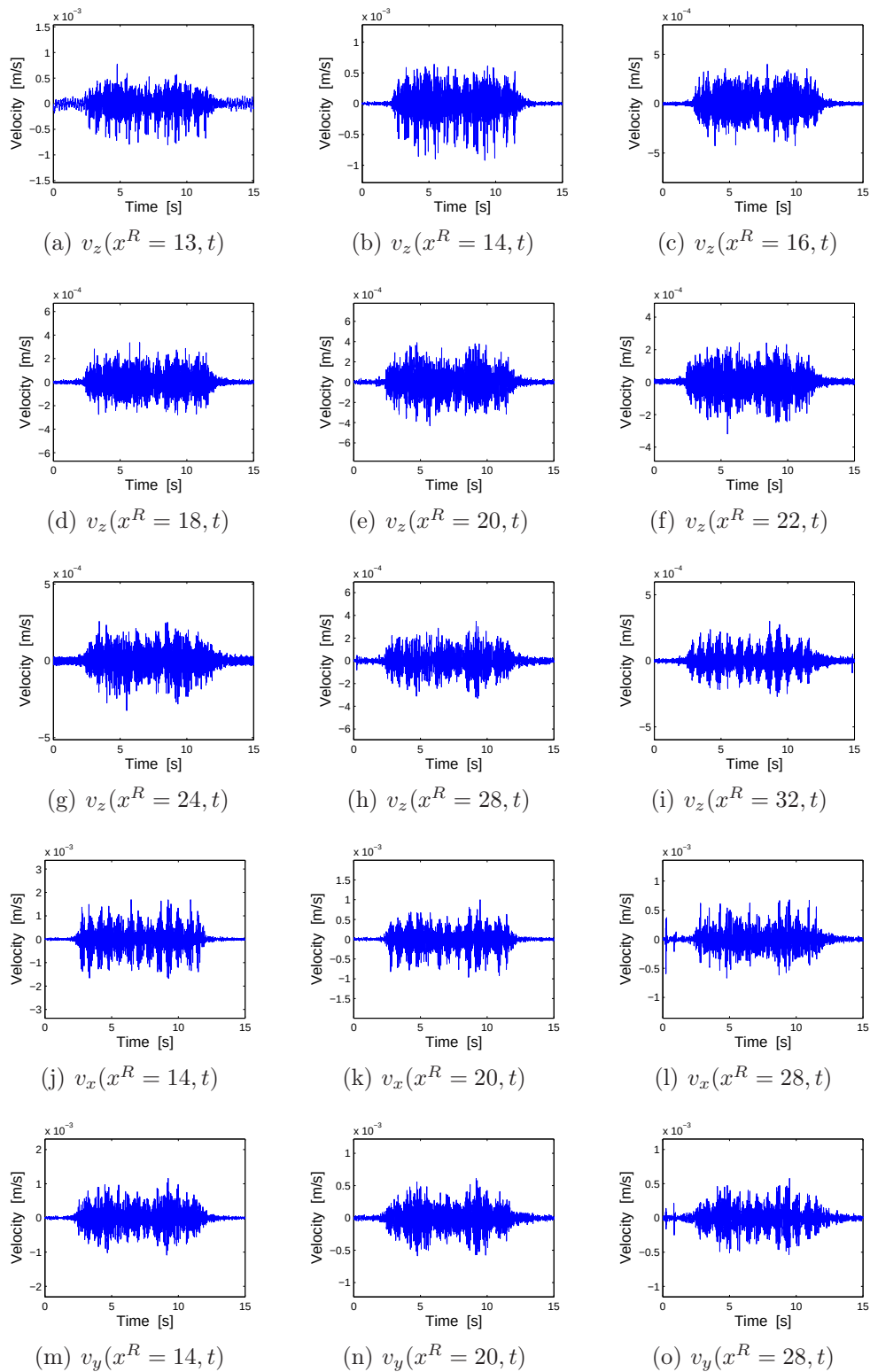


Figure 2.54: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 90 km/h

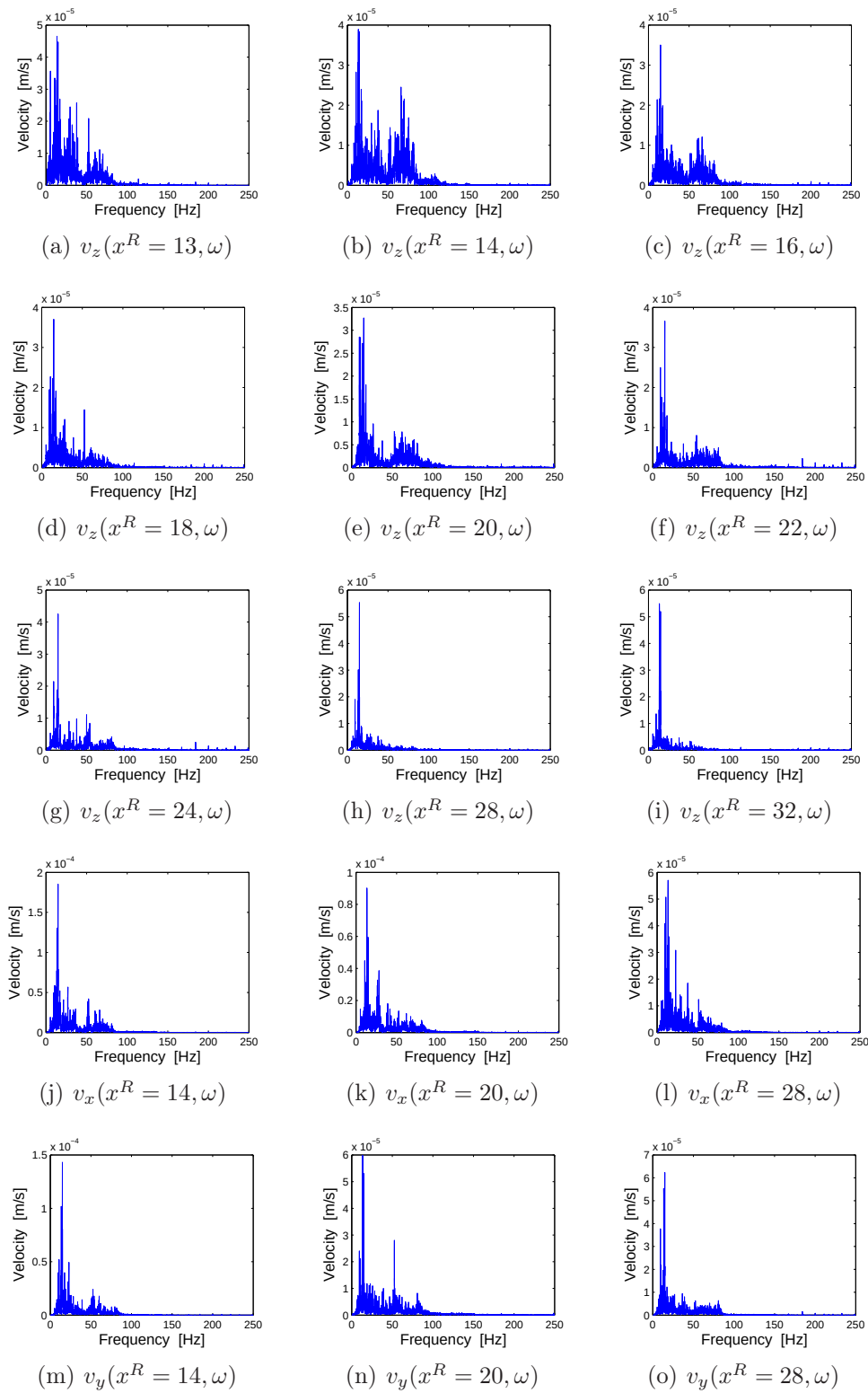


Figure 2.55: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 90 km/h

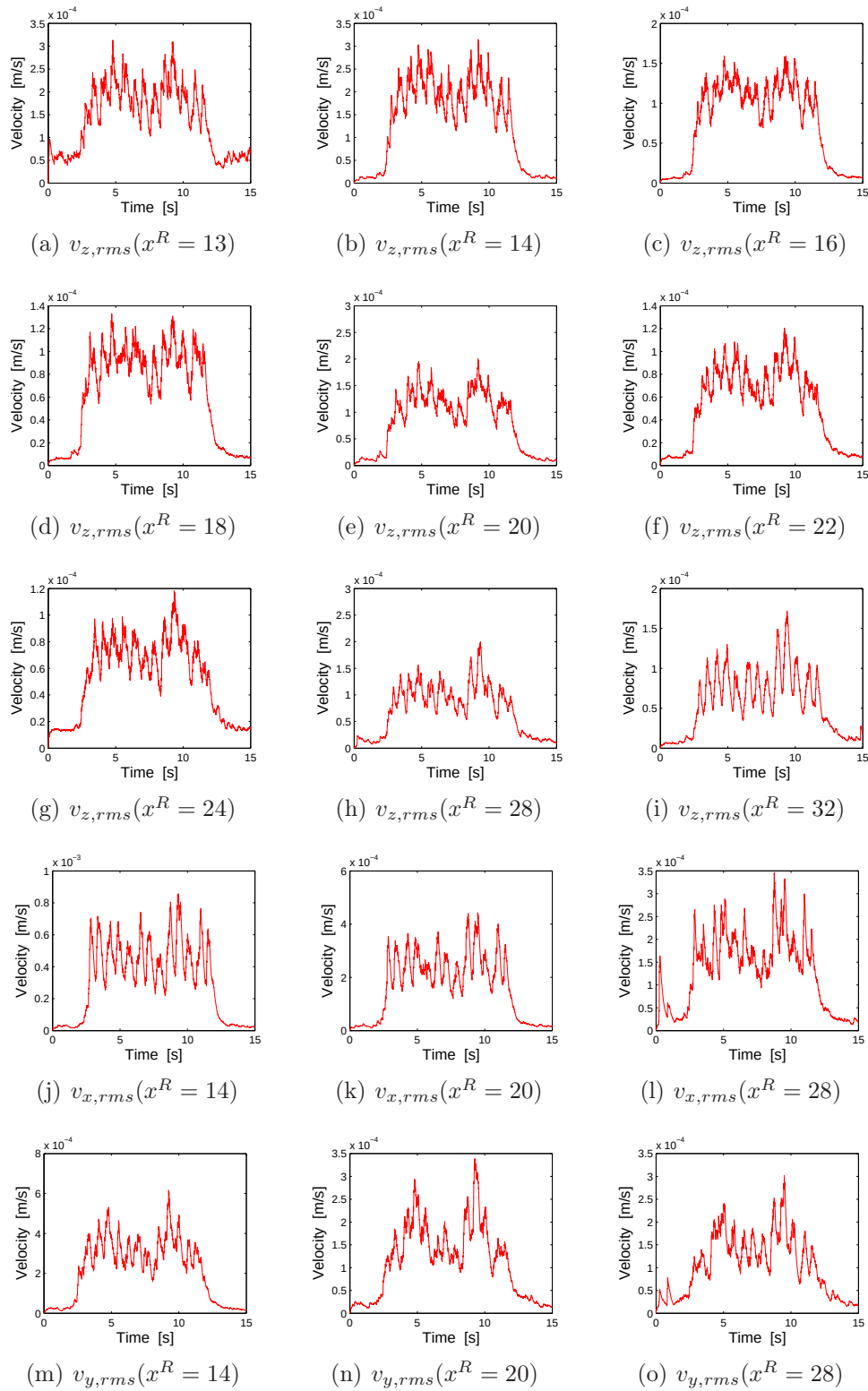


Figure 2.56: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 90 km/h

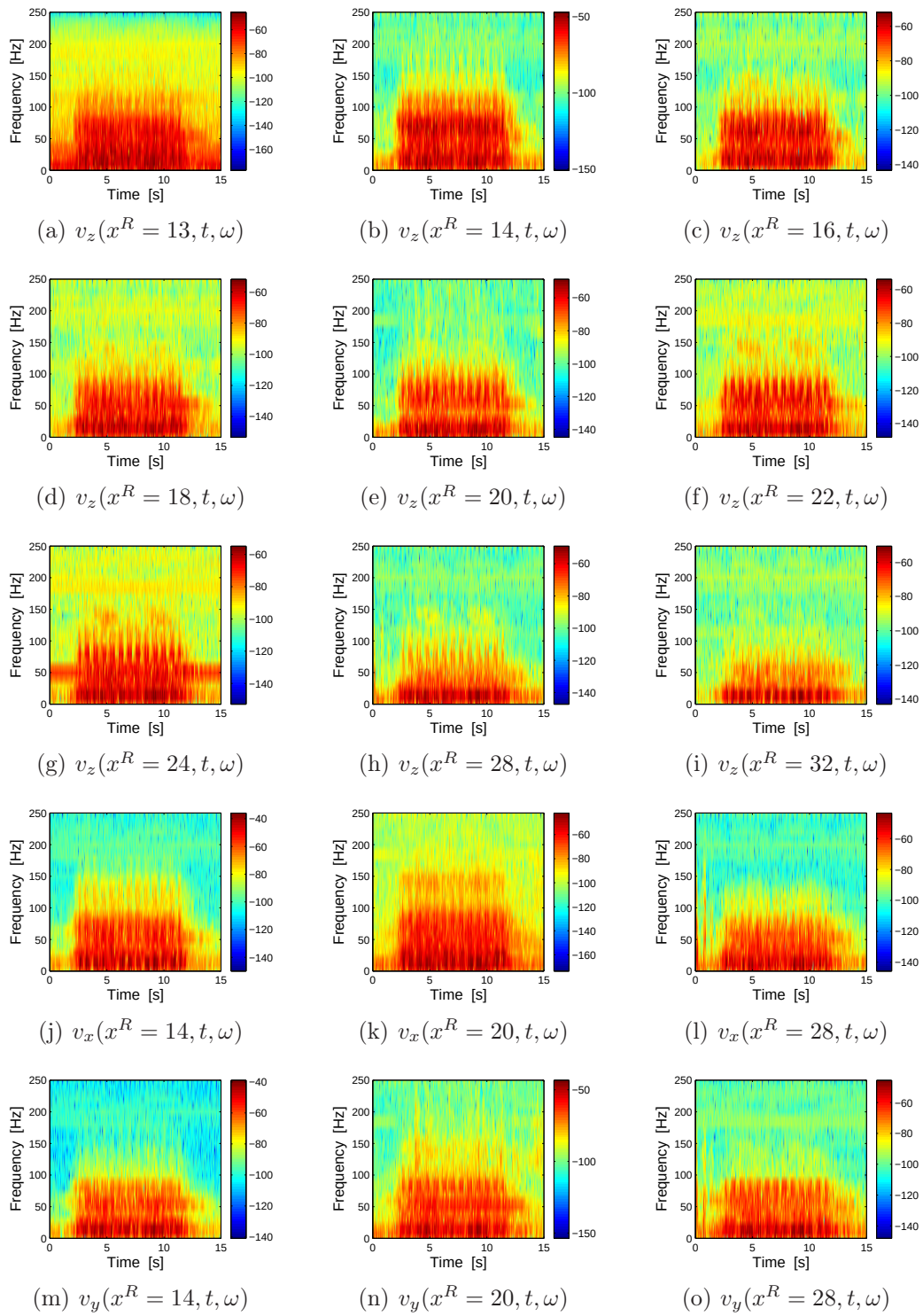


Figure 2.57: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 90 km/h

2.15 AM75 unit at 115 km/h

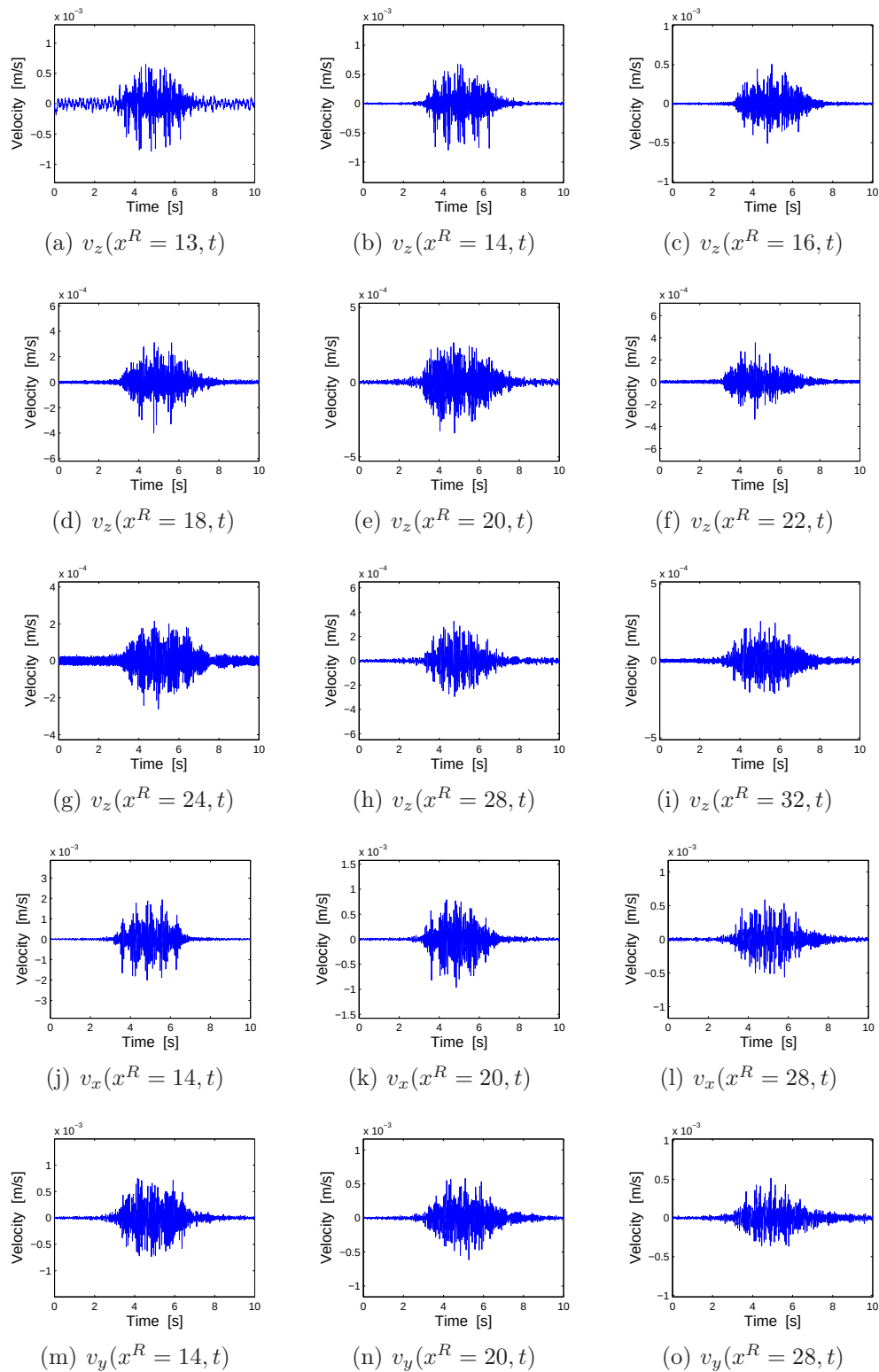


Figure 2.58: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 115 km/h

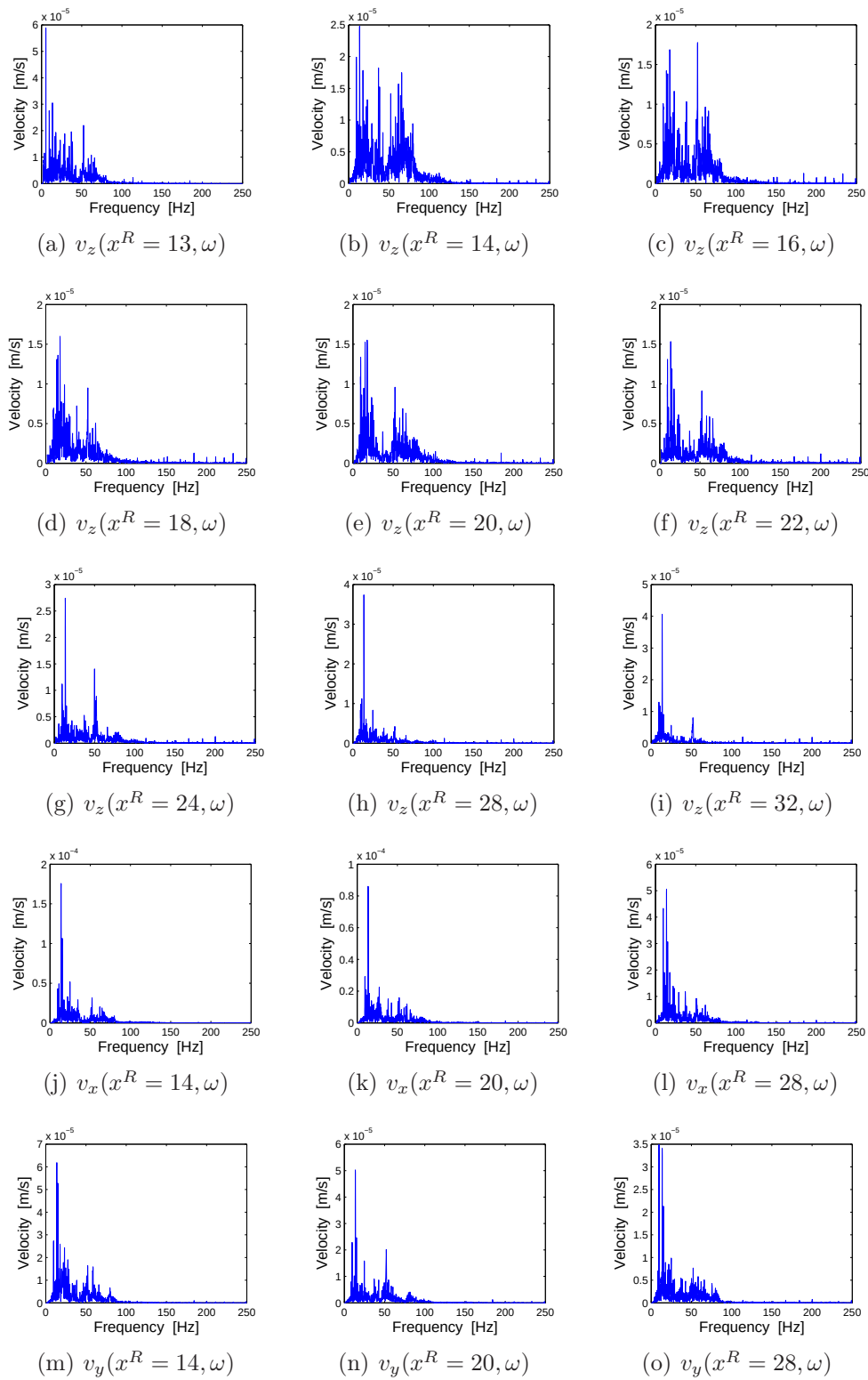


Figure 2.59: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 115 km/h

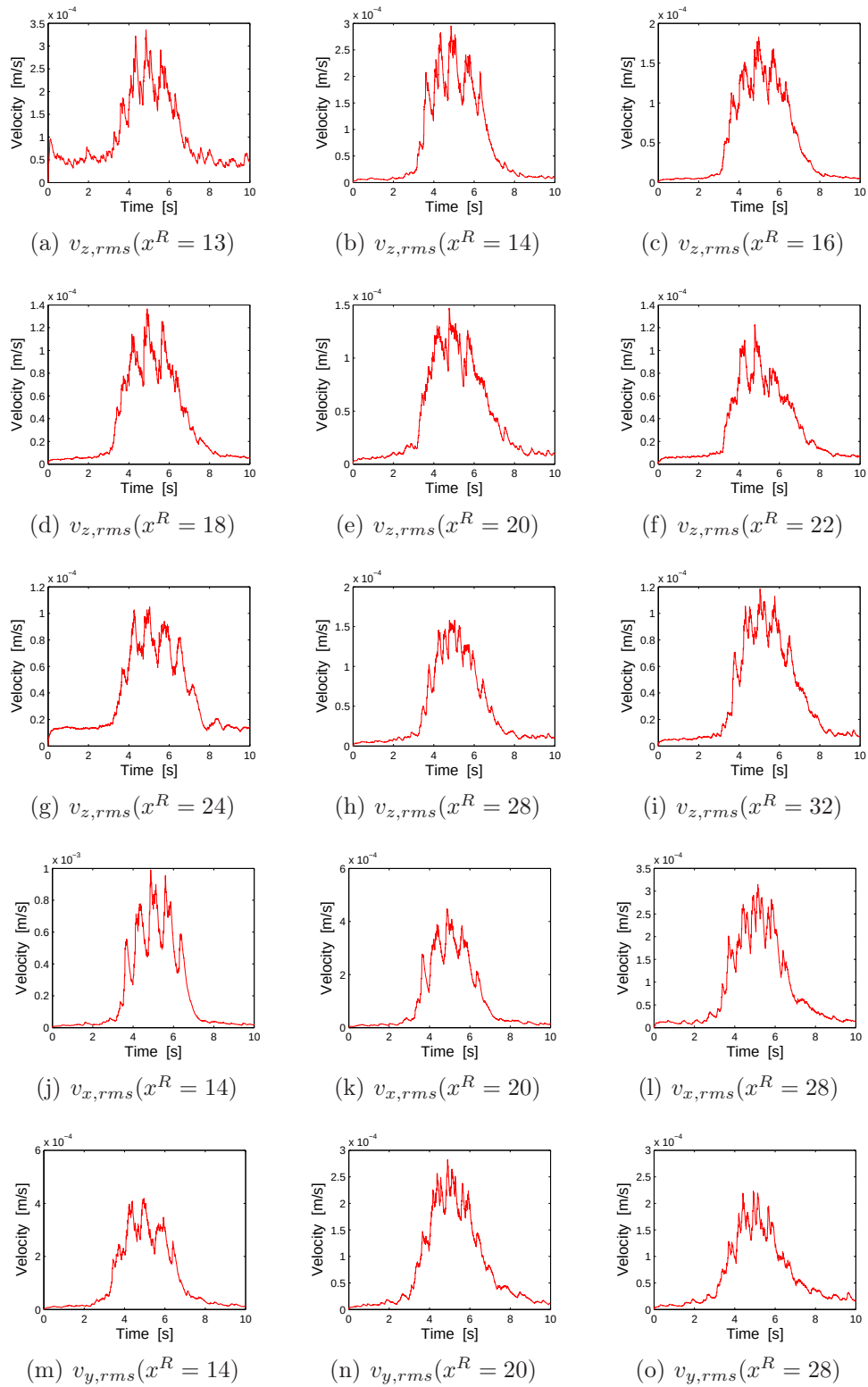


Figure 2.60: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 115 km/h

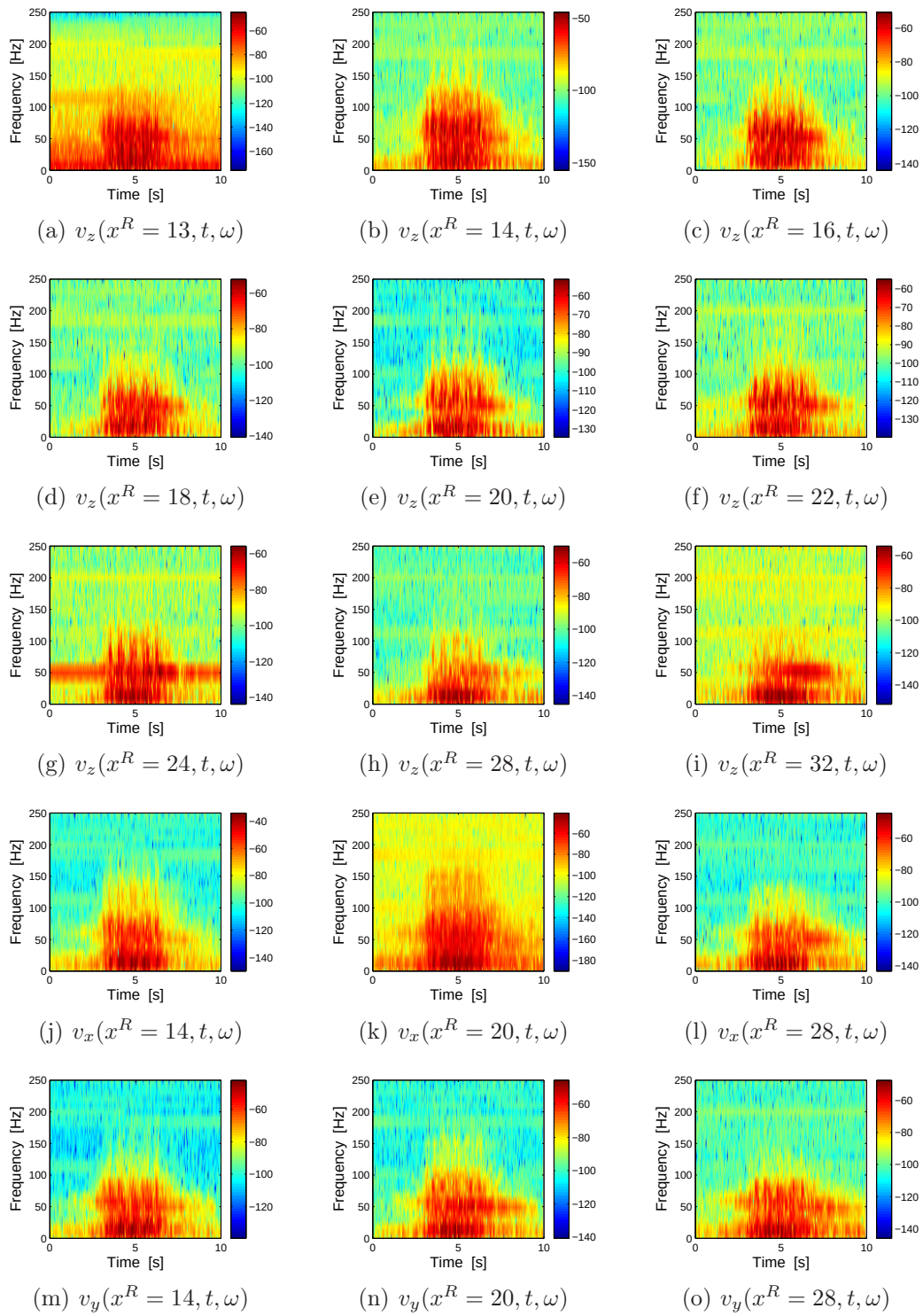


Figure 2.61: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 115 km/h

2.16 M4 railcar at 120 km/h

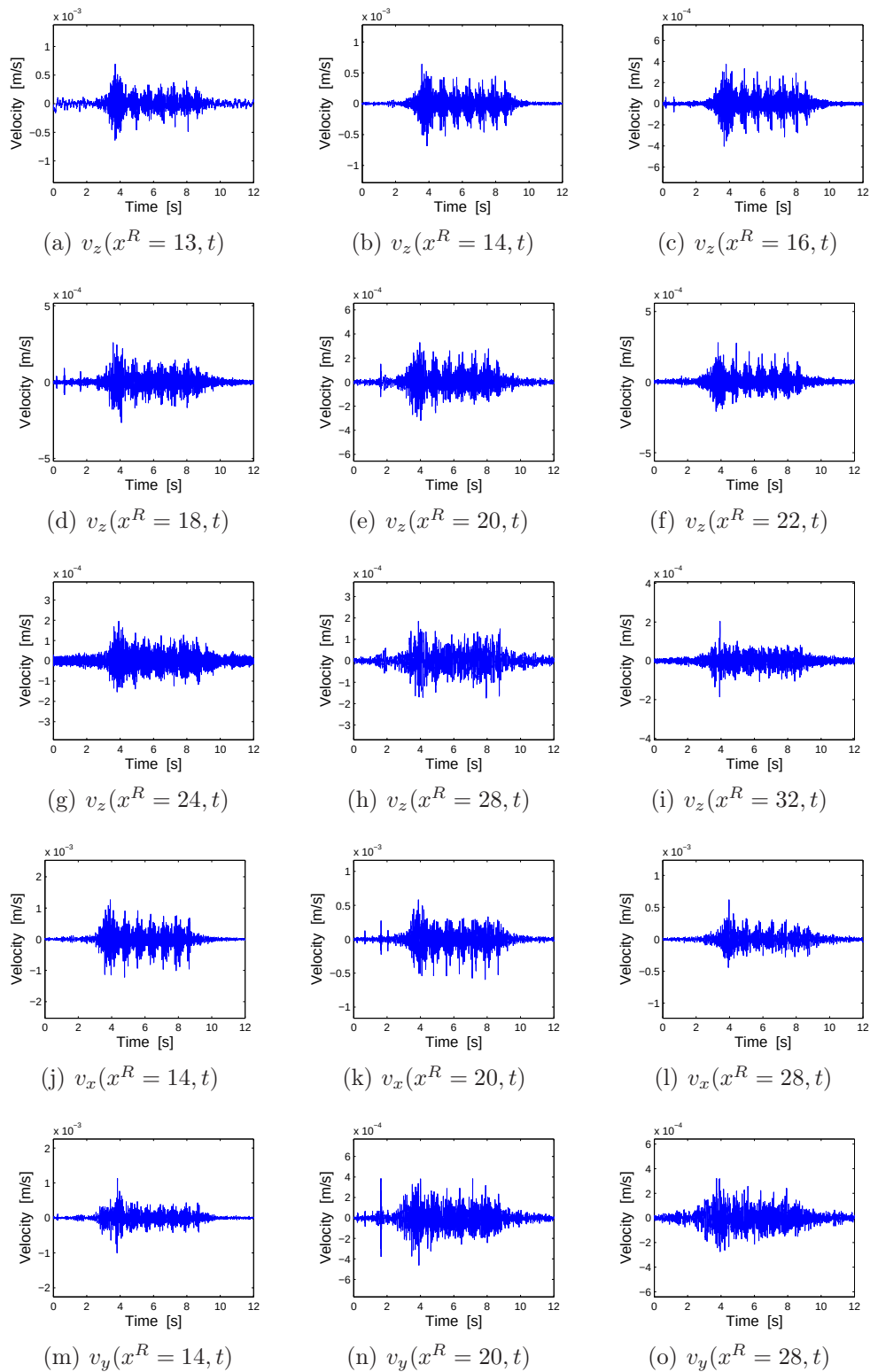


Figure 2.62: Time history of the vertical and horizontal velocities measured in free field during the passage of a M4 railcar at 120 km/h

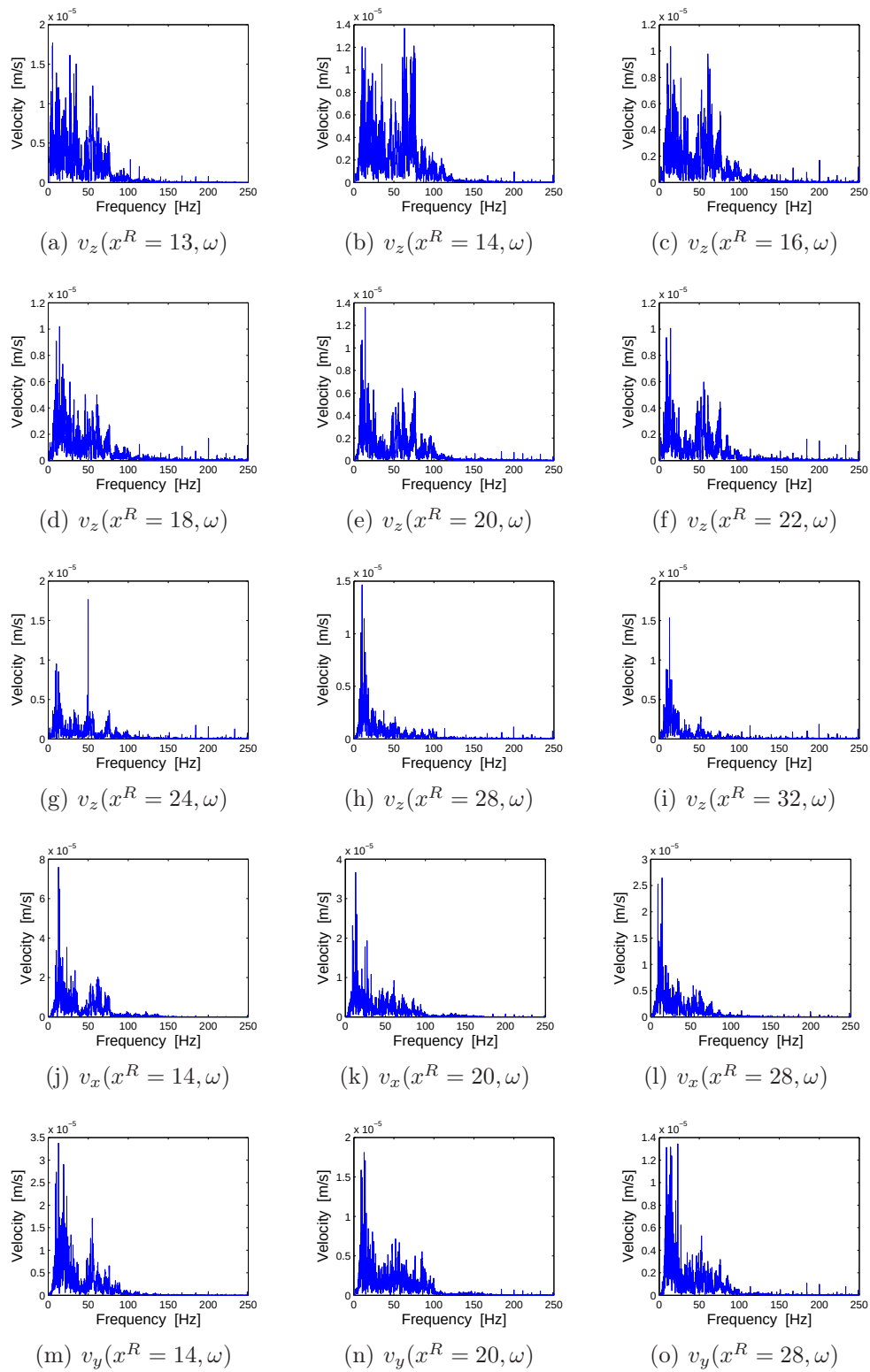


Figure 2.63: Spectral content of the vertical and horizontal velocities measured in free field during the passage of a M4 railcar at 120 km/h

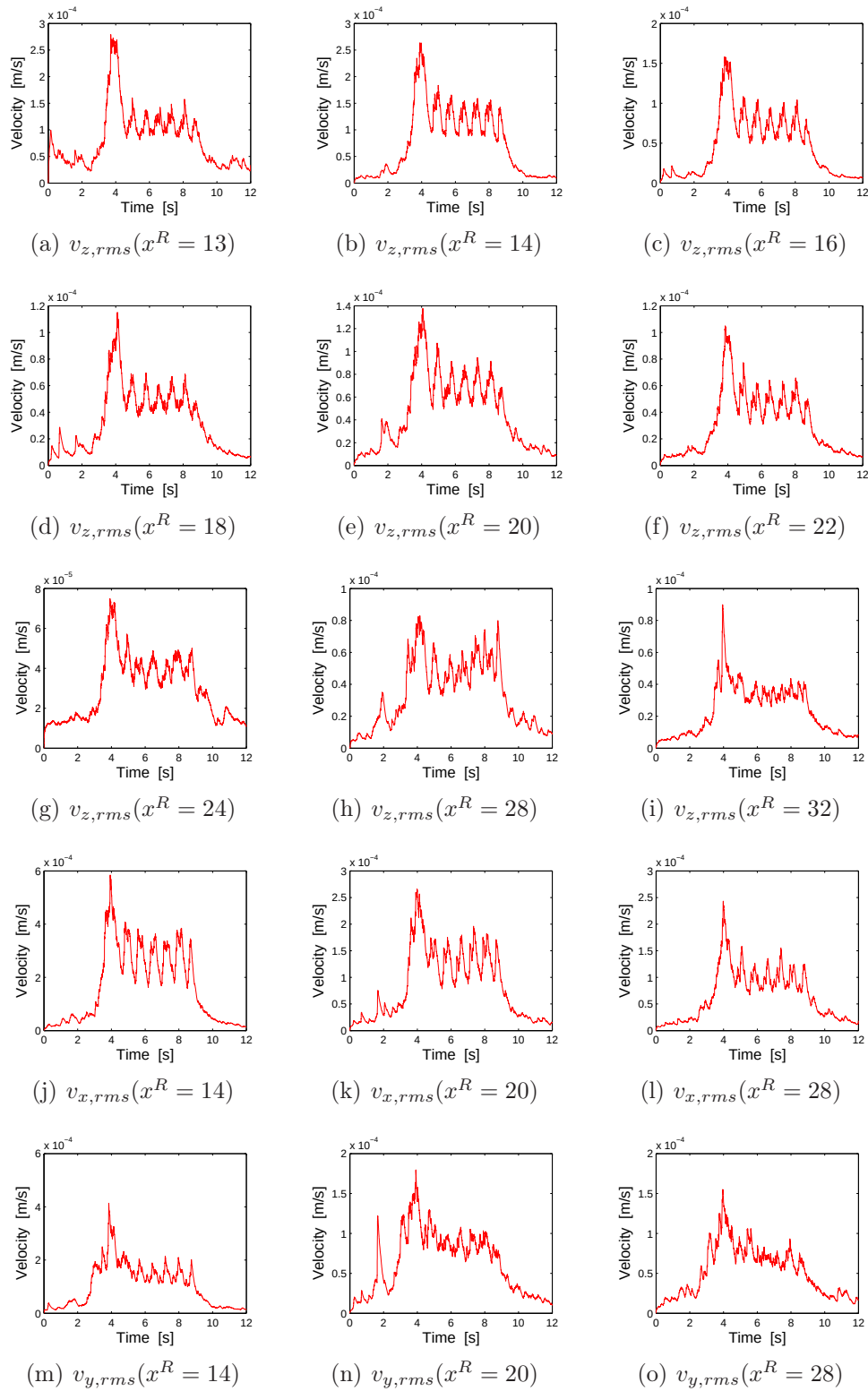


Figure 2.64: Time-average of the vertical and horizontal velocities measured in free field during the passage of a M4 railcar at 120 km/h

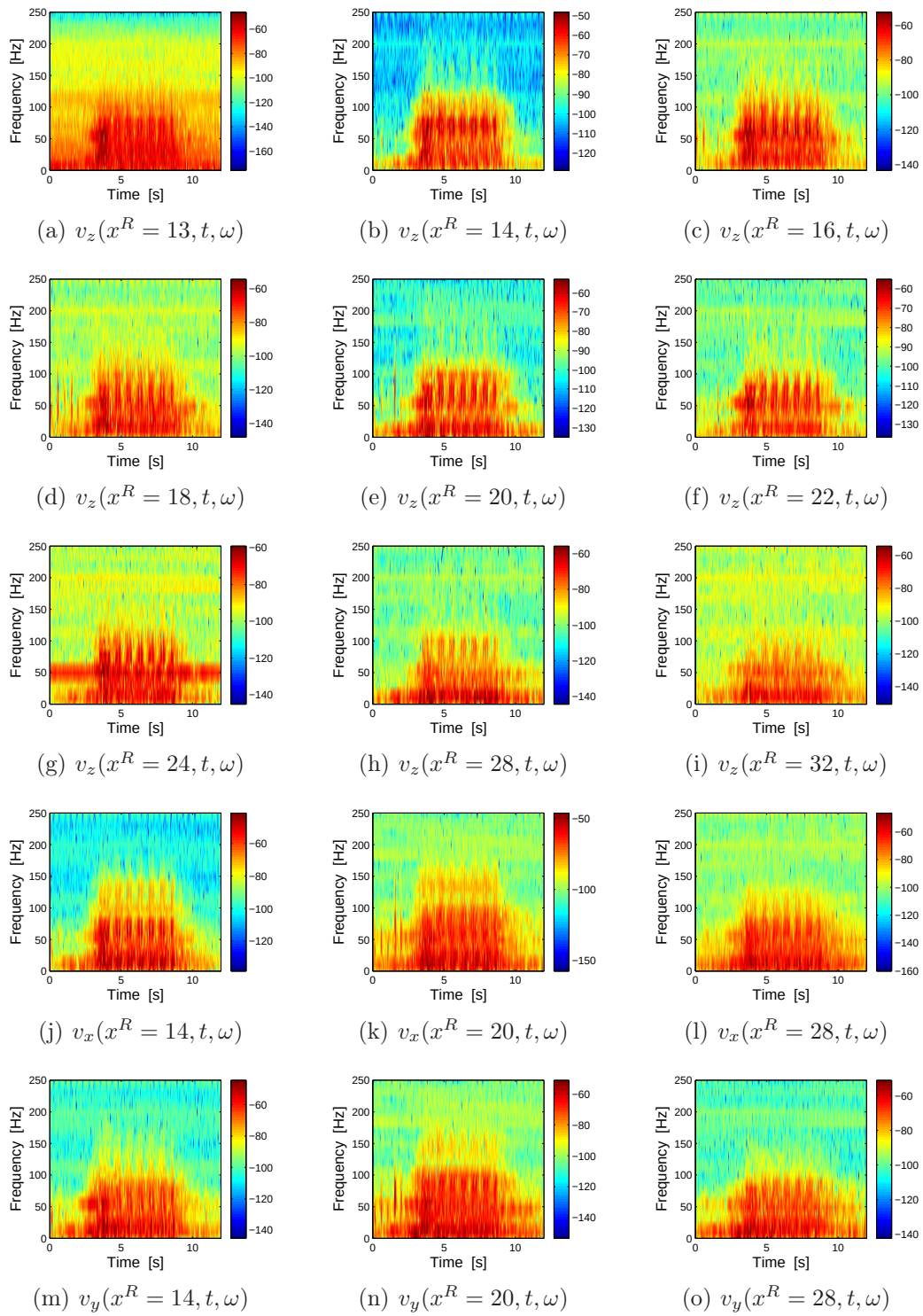


Figure 2.65: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of a M4 railcar at 120 km/h

2.17 AM75 unit at 85 km/h

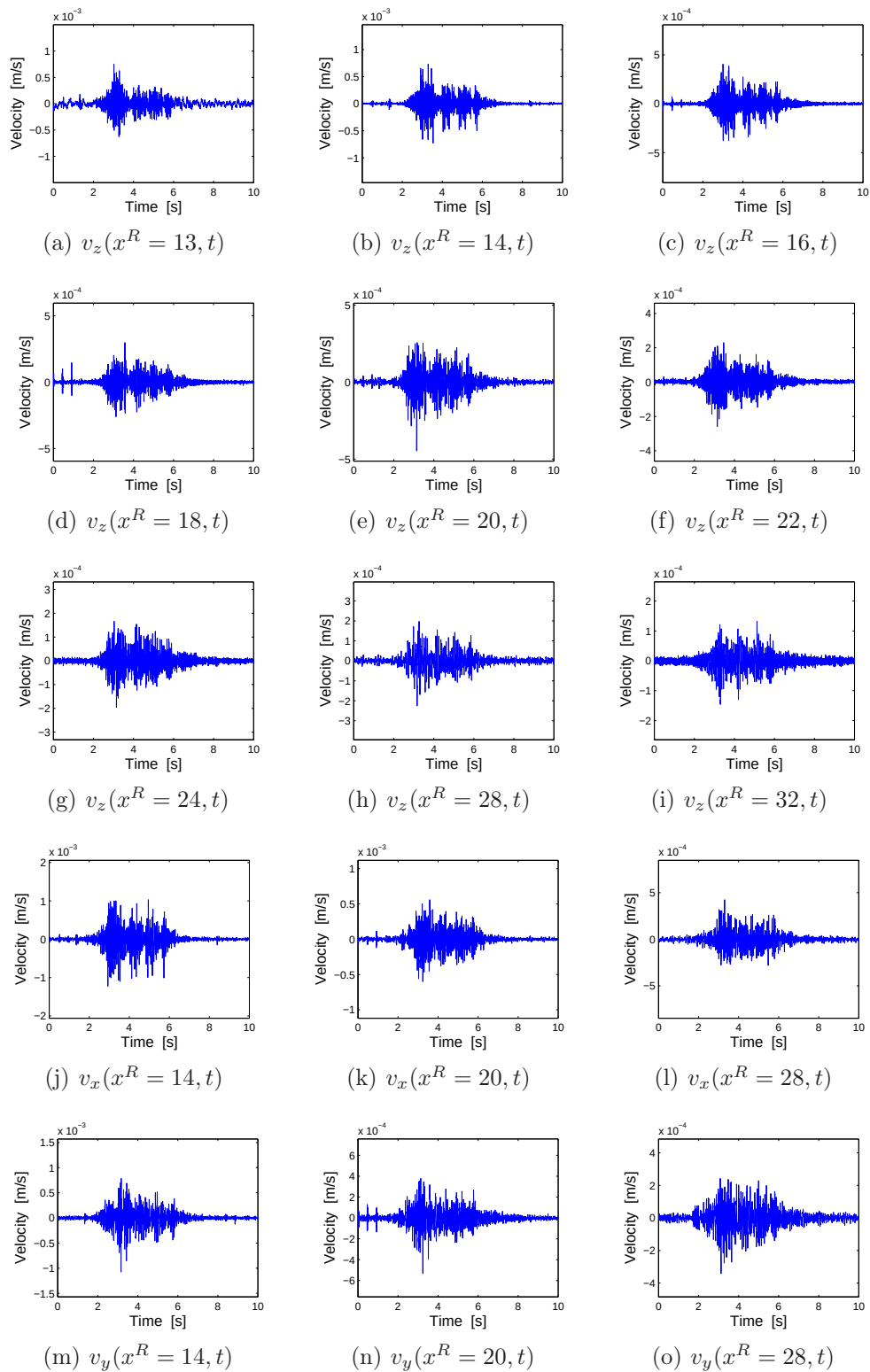


Figure 2.66: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 85 km/h

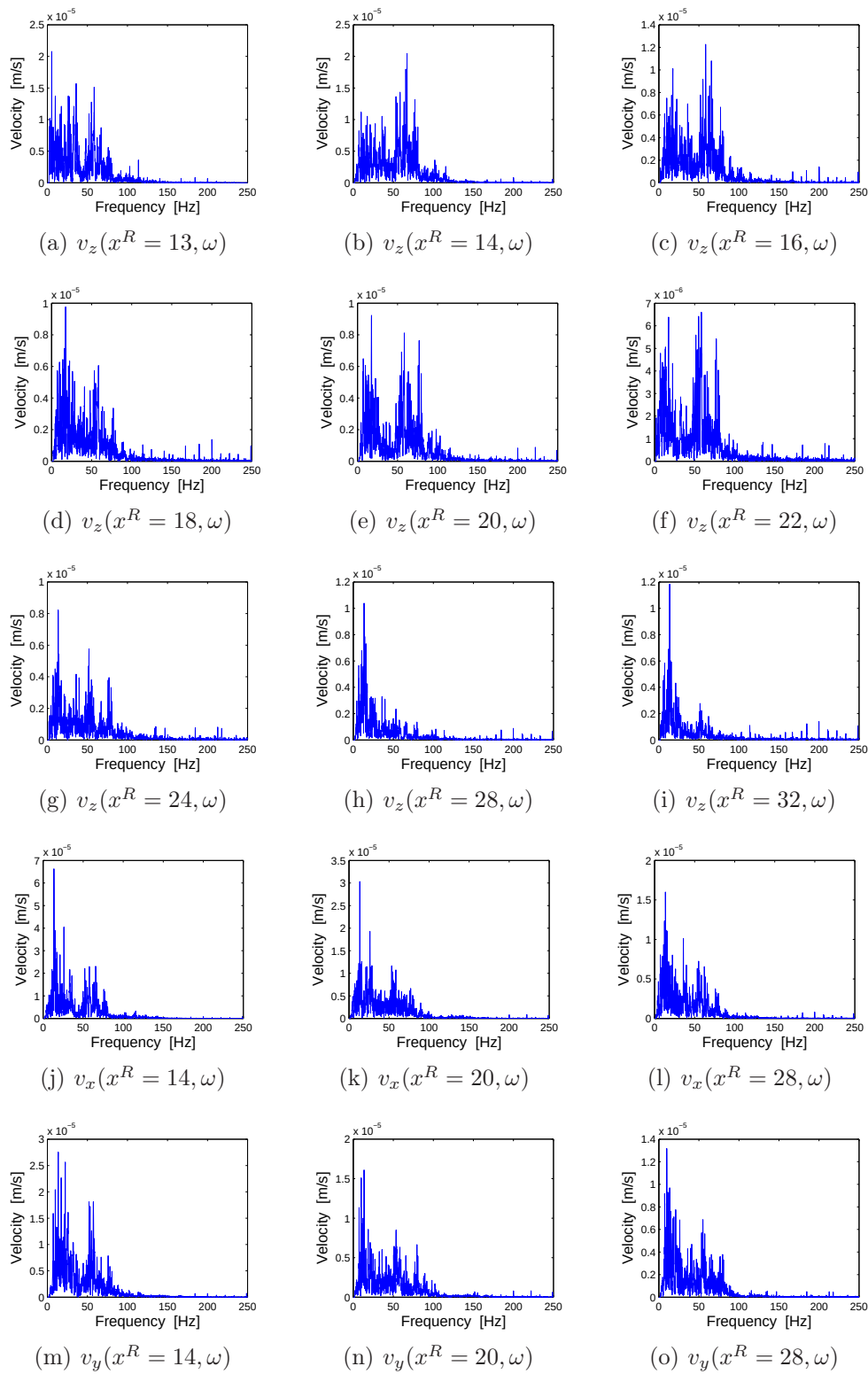


Figure 2.67: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 85 km/h

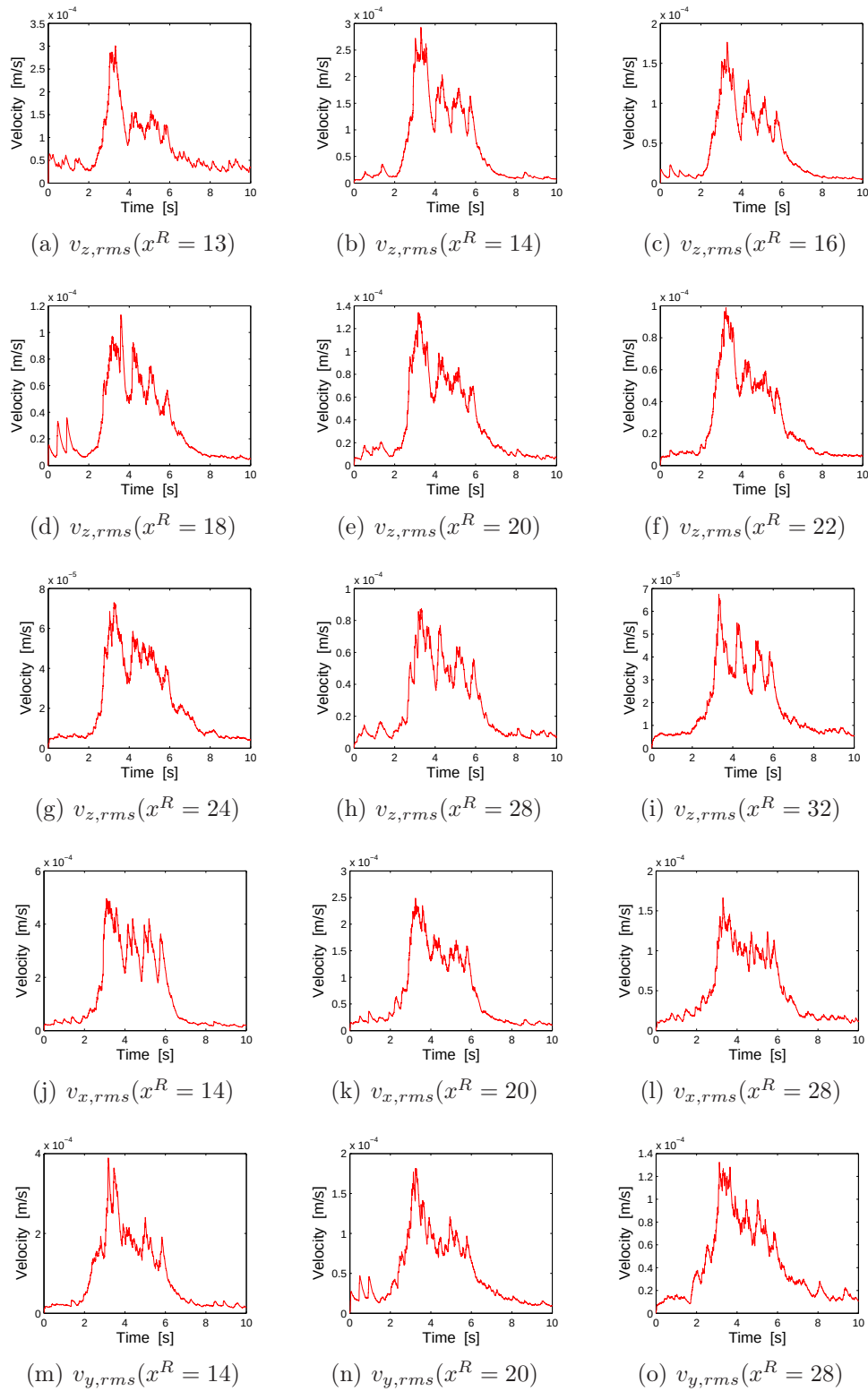


Figure 2.68: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 85 km/h

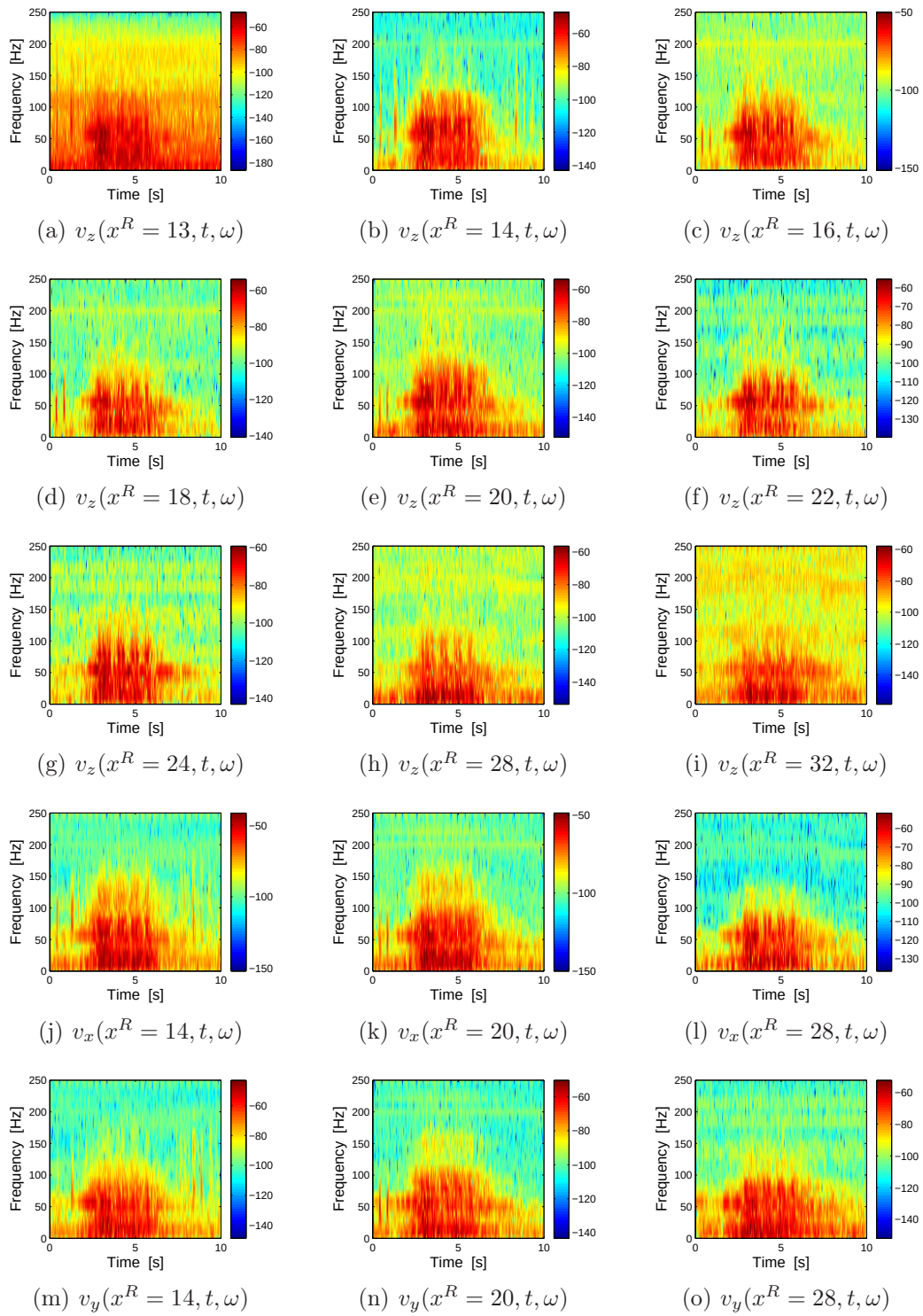


Figure 2.69: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 85 km/h

Measurement in Watermael (site 2)

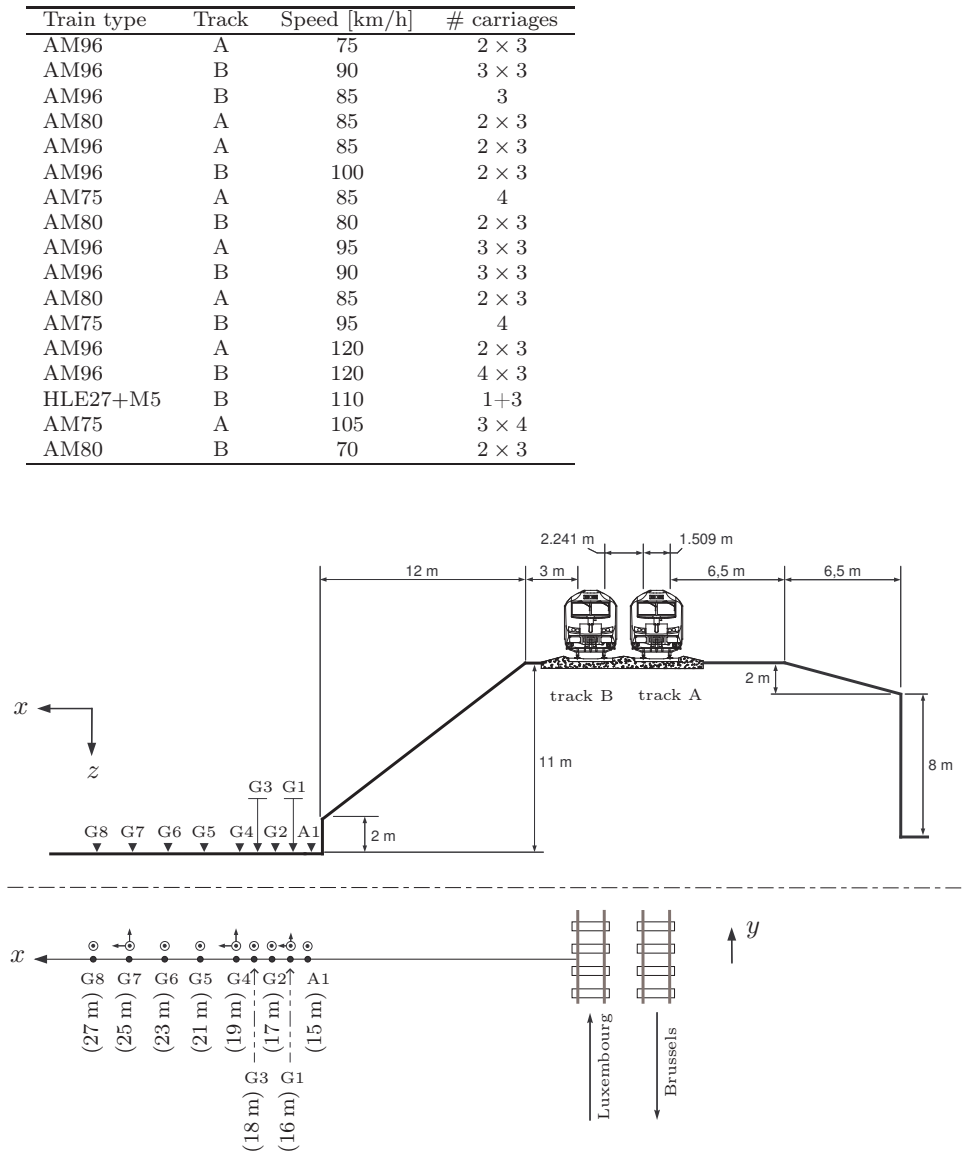


Figure 3.1: Located measurement points and review of all the train passing

3.1 AM96 unit at 75 km/h

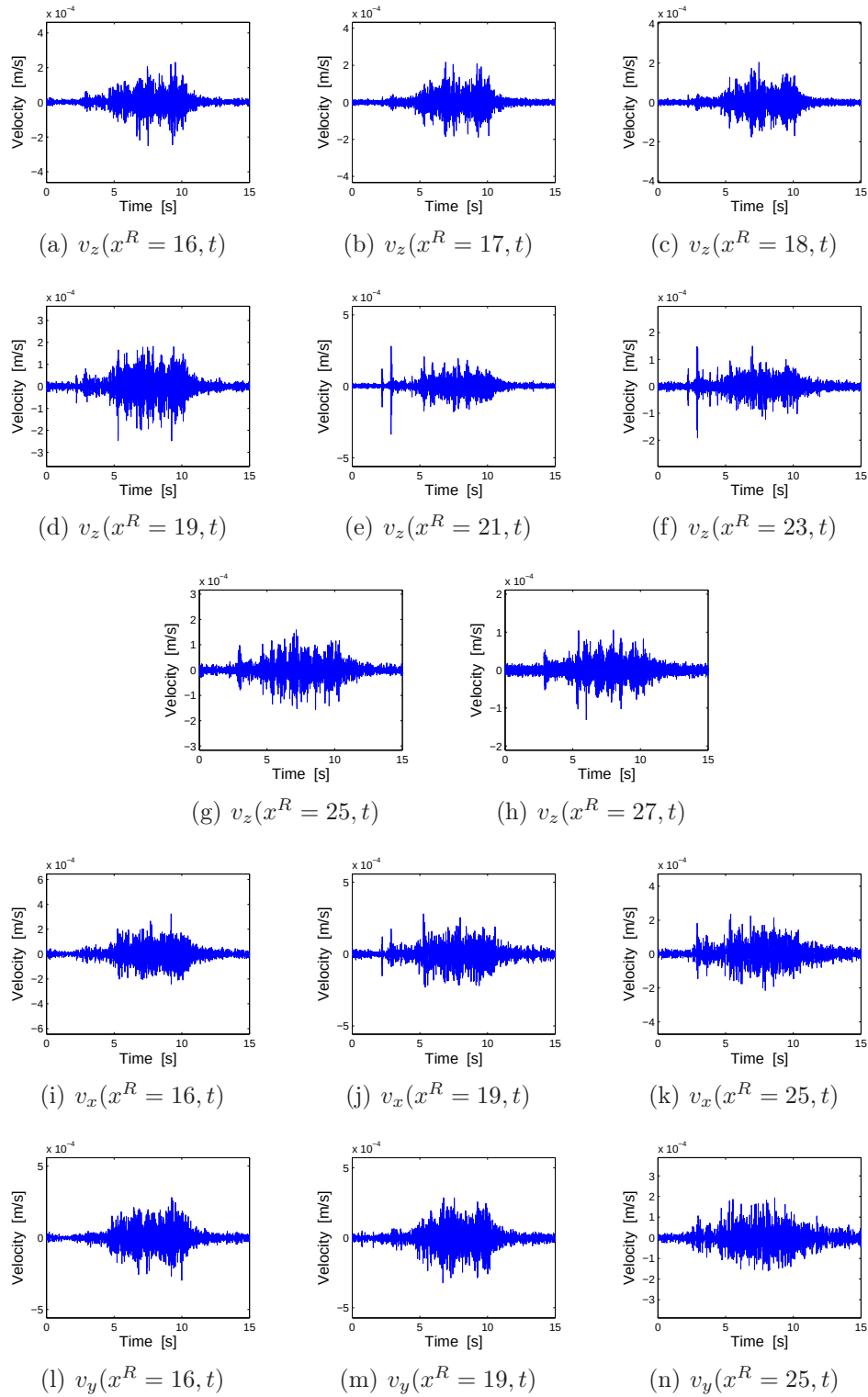


Figure 3.2: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 75 km/h

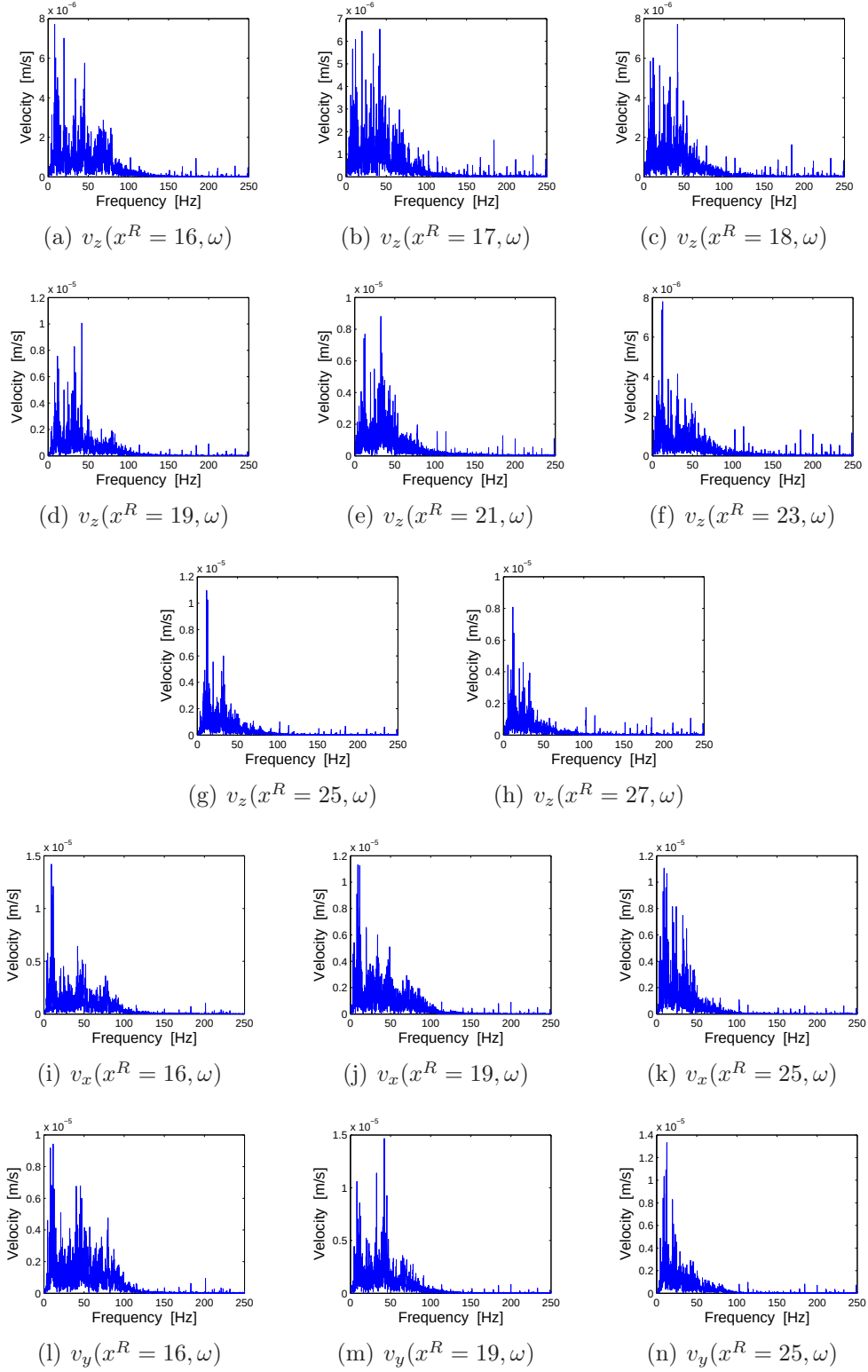


Figure 3.3: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 75 km/h

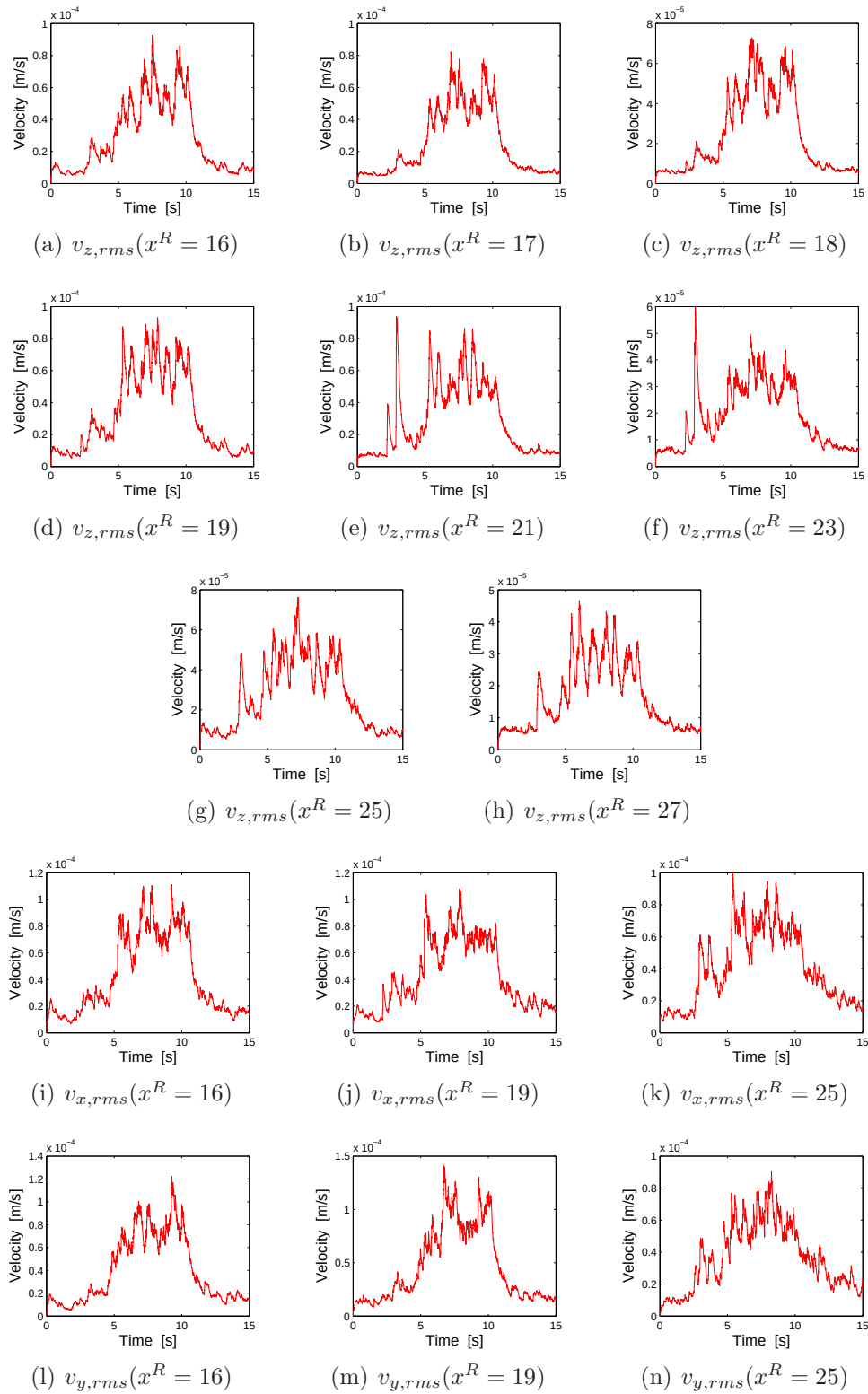


Figure 3.4: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 75 km/h

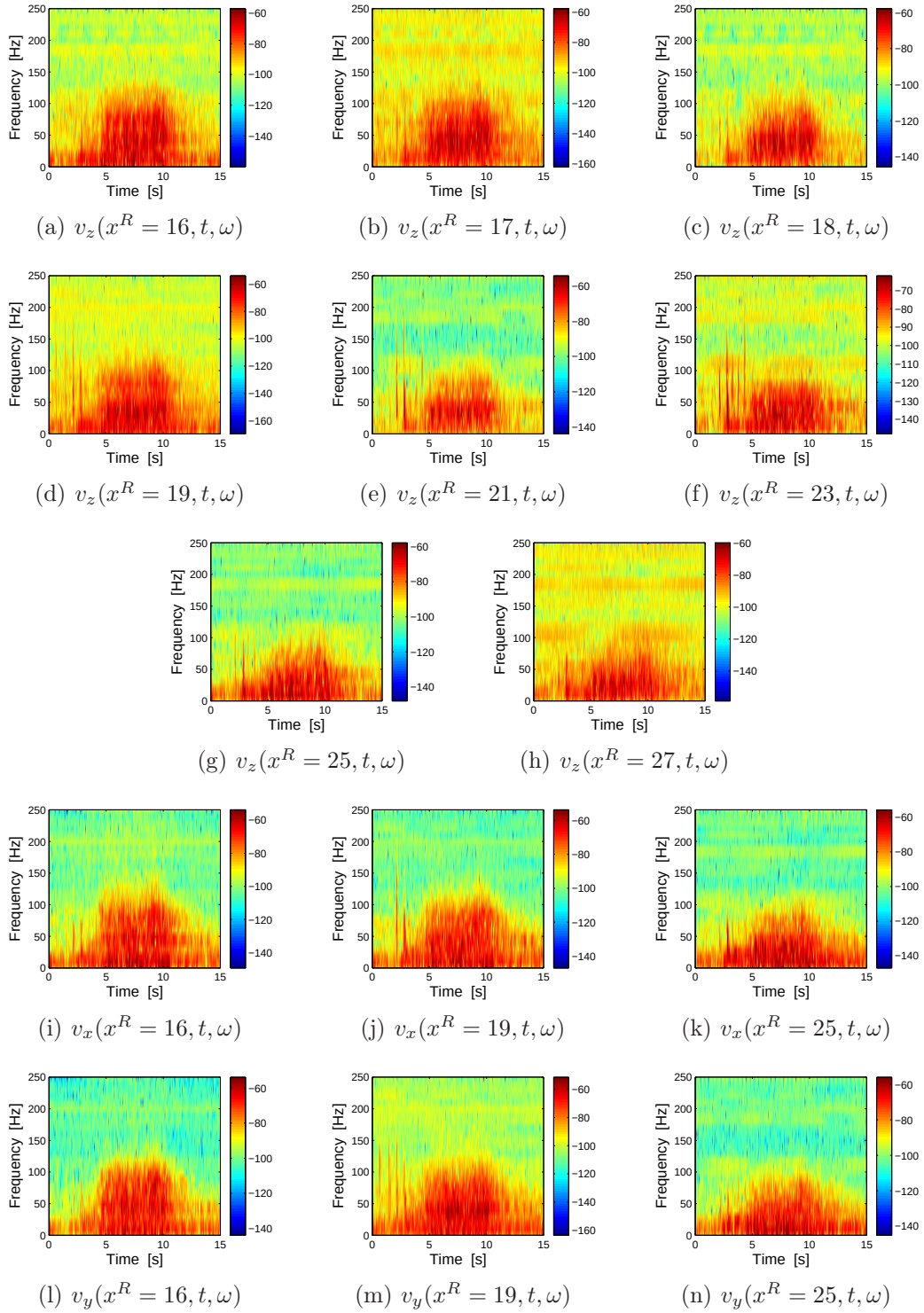


Figure 3.5: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 75 km/h

3.2 AM96 unit at 90 km/h

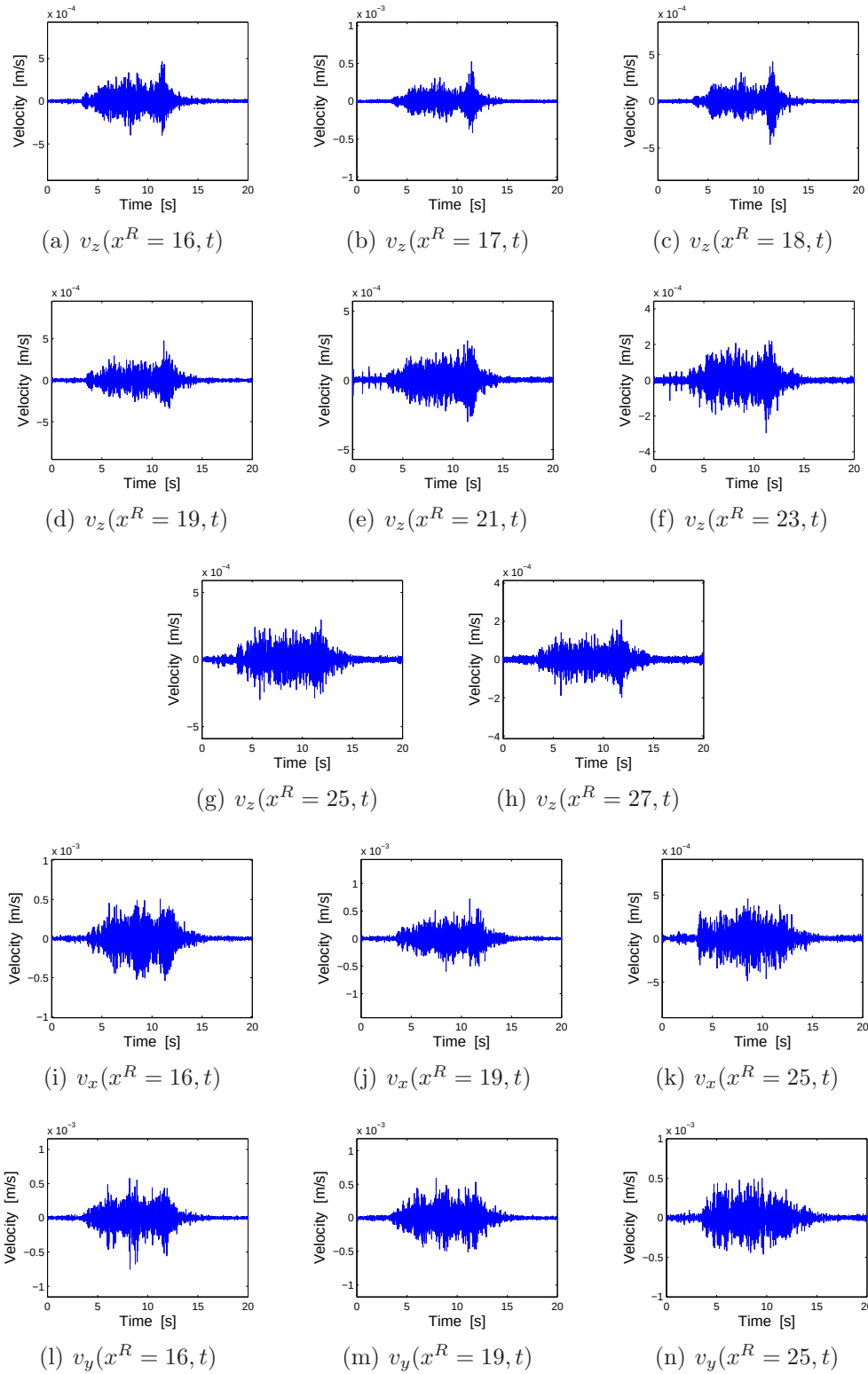


Figure 3.6: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 90 km/h

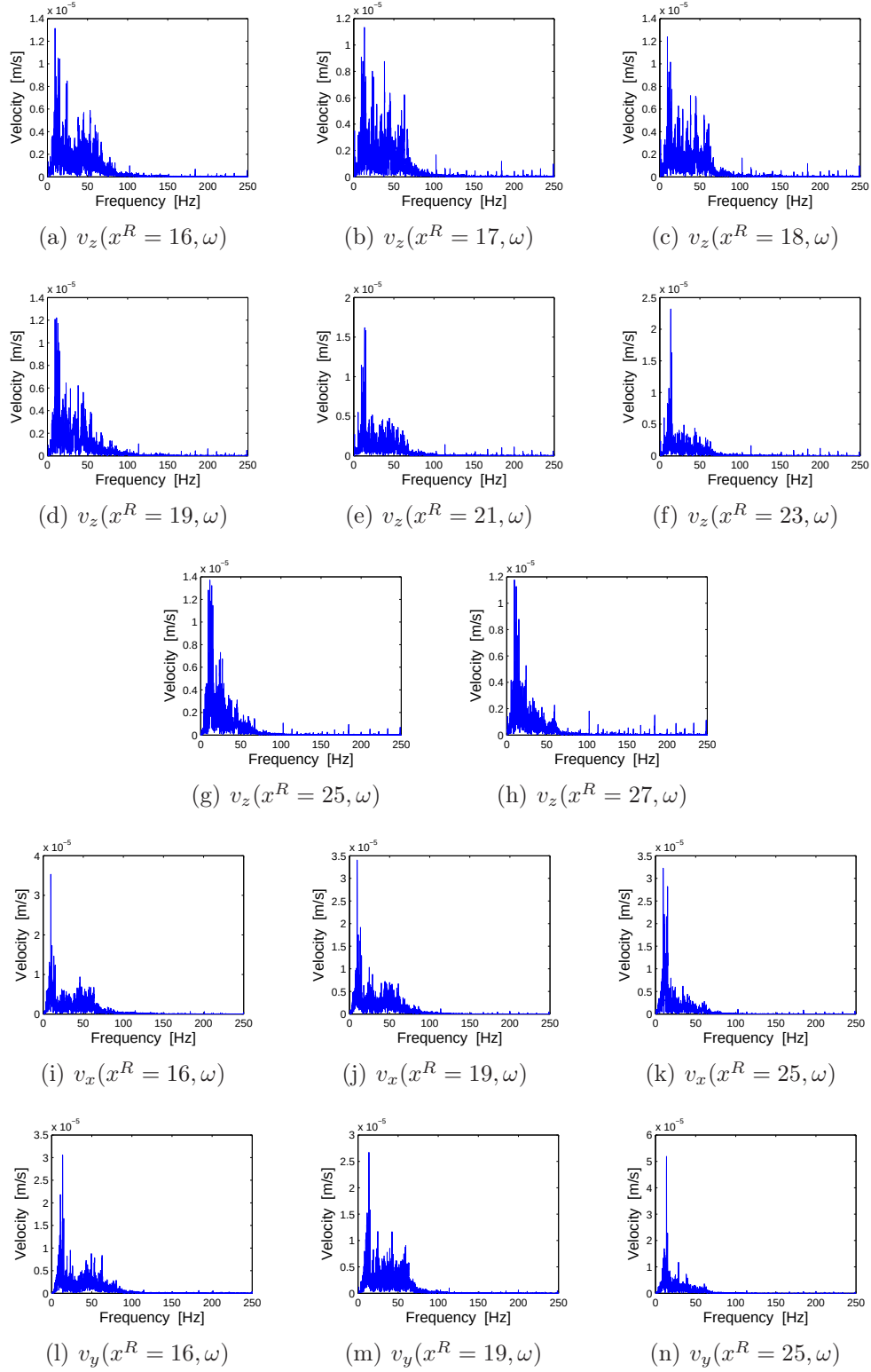


Figure 3.7: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 90 km/h

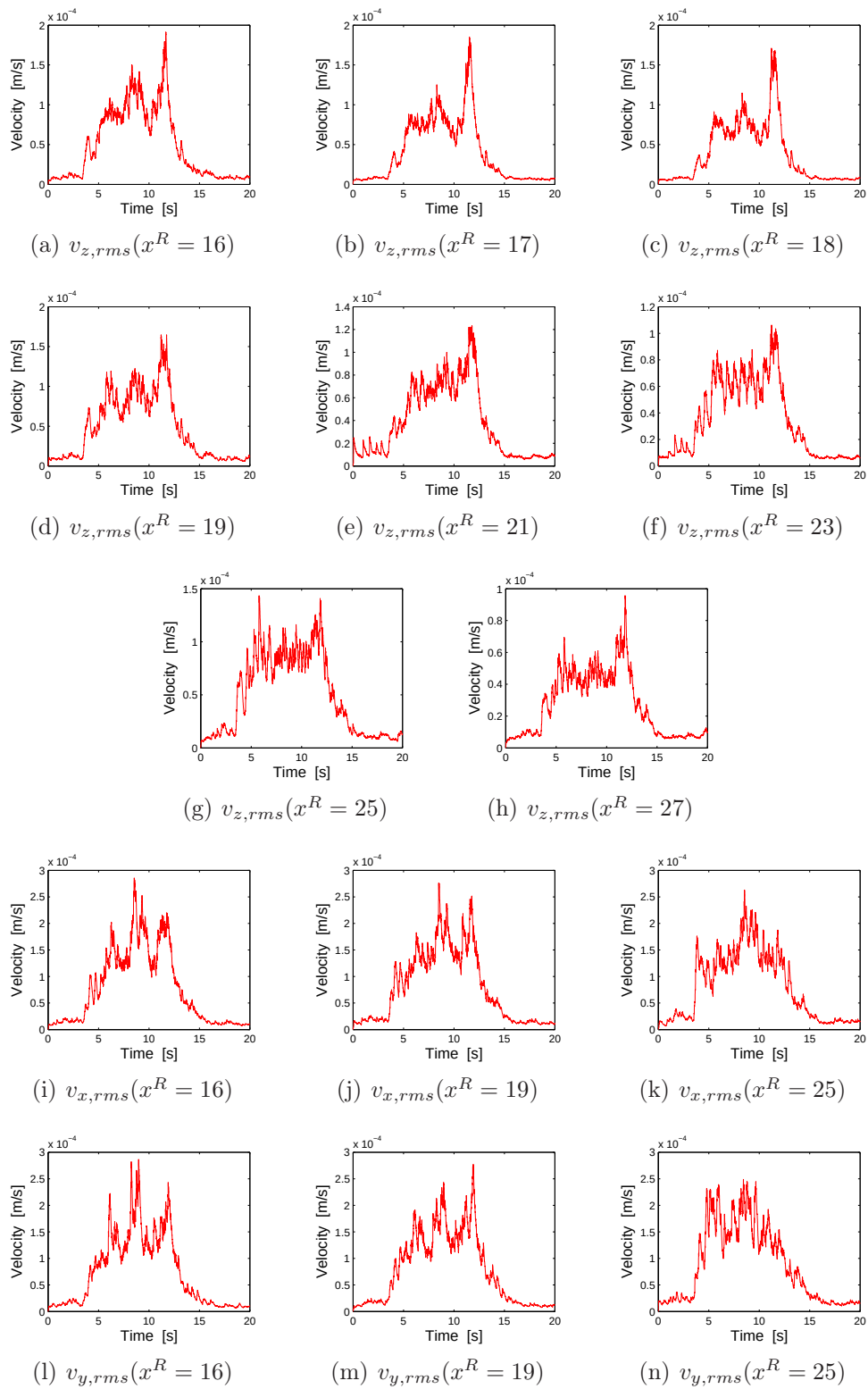


Figure 3.8: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 90 km/h

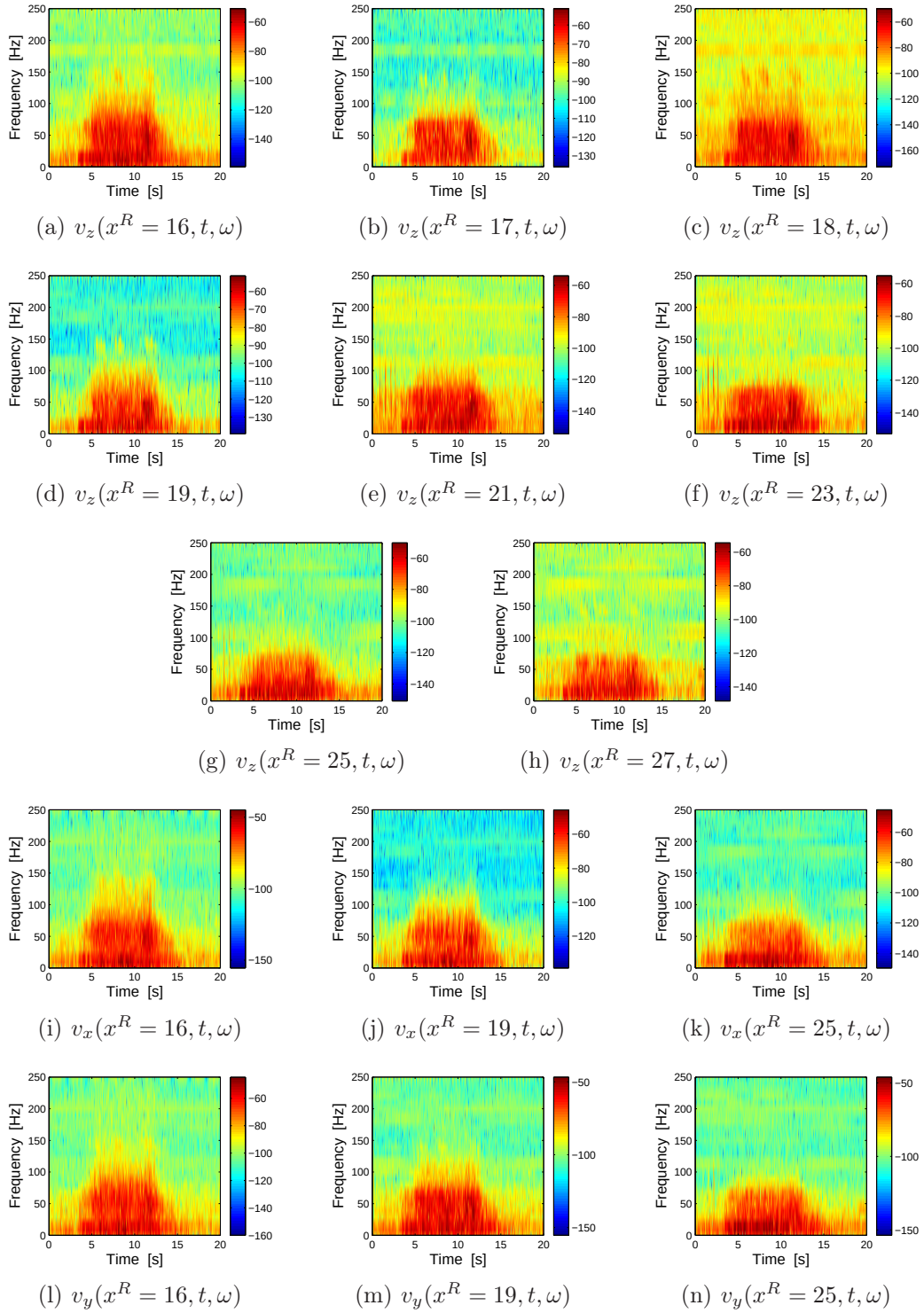


Figure 3.9: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 90 km/h

3.3 AM96 unit at 85 km/h

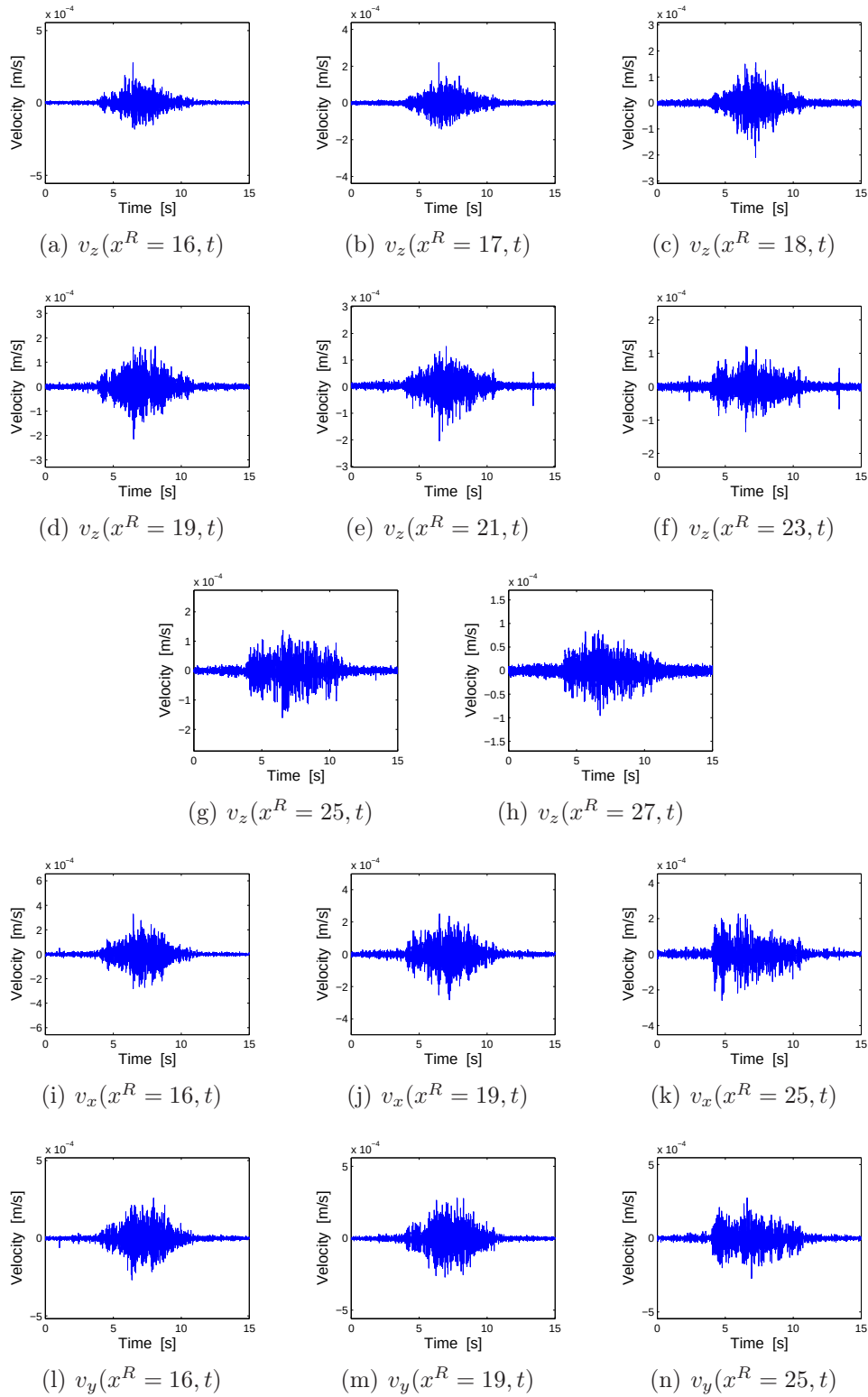


Figure 3.10: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 85 km/h

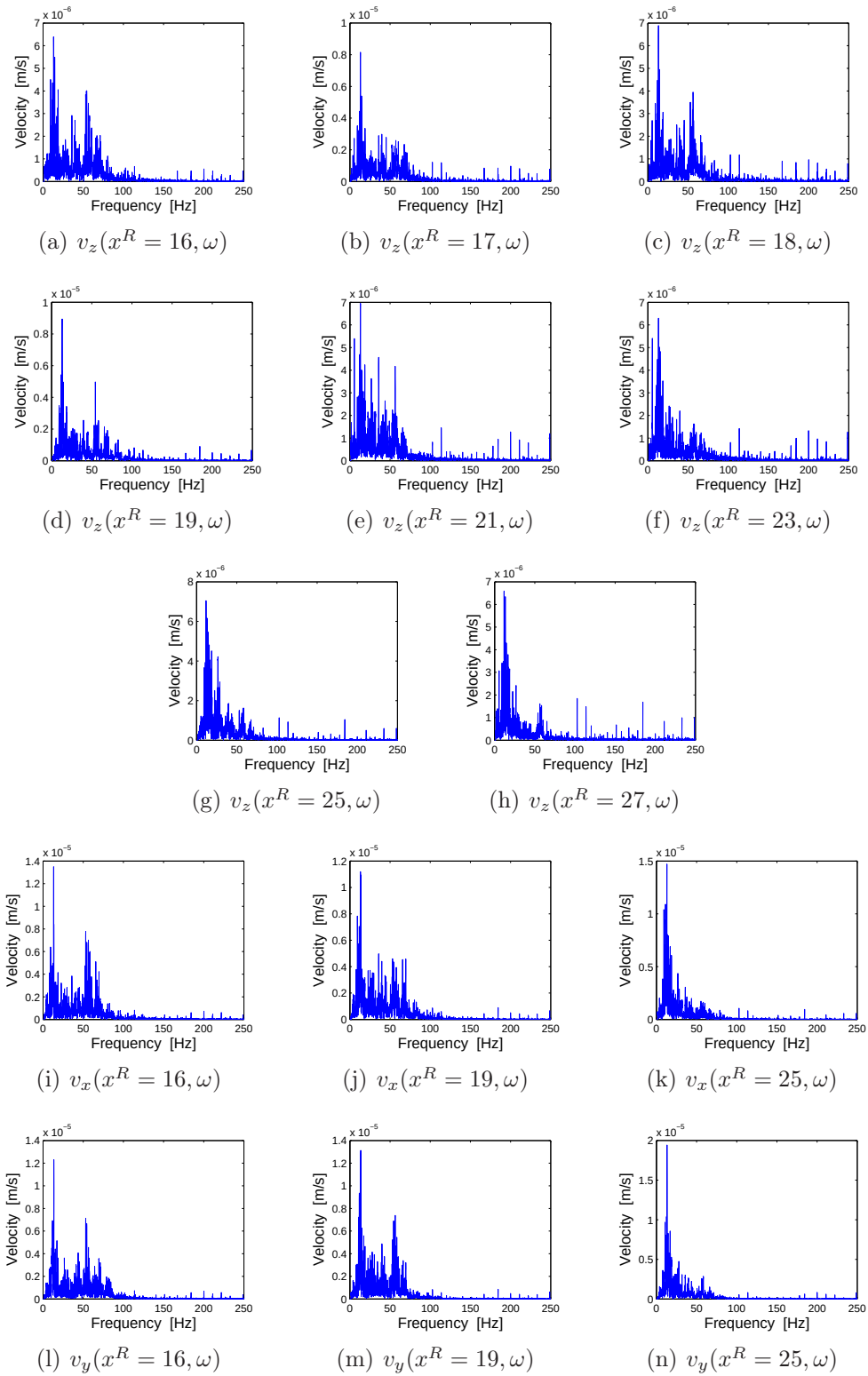


Figure 3.11: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 85 km/h

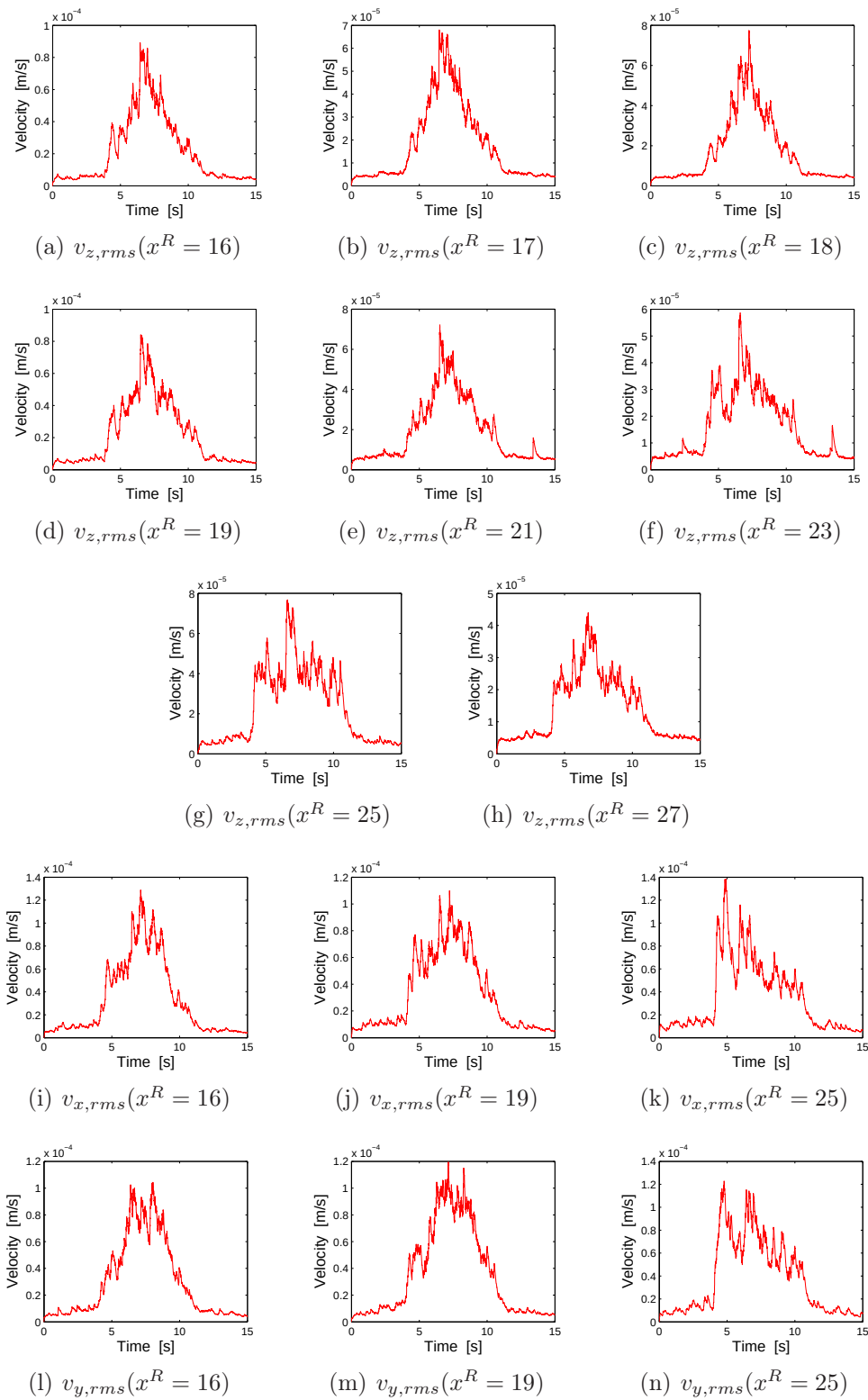


Figure 3.12: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 85 km/h

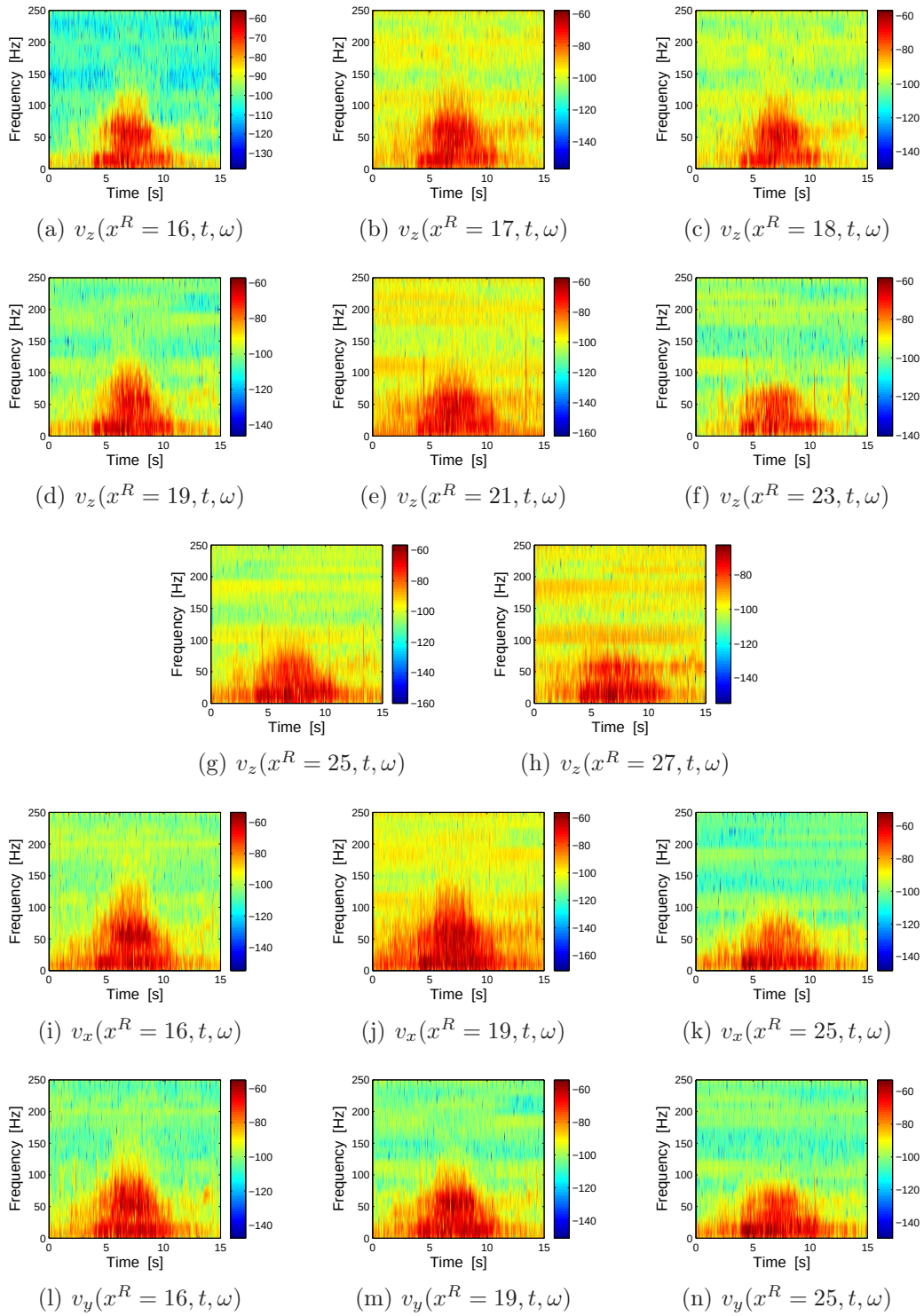


Figure 3.13: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 85 km/h

3.4 AM80 unit at 85 km/h

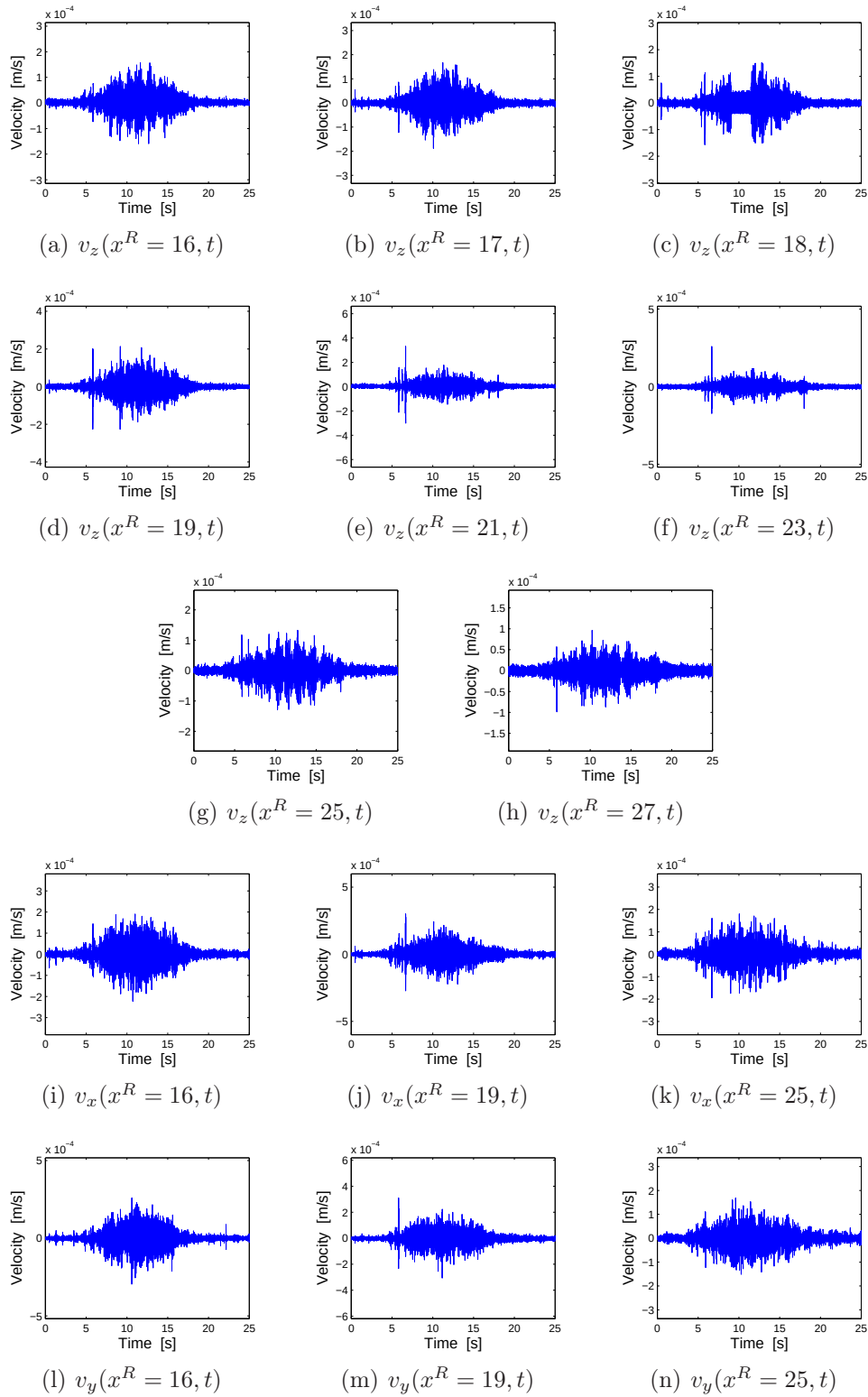


Figure 3.14: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 85 km/h

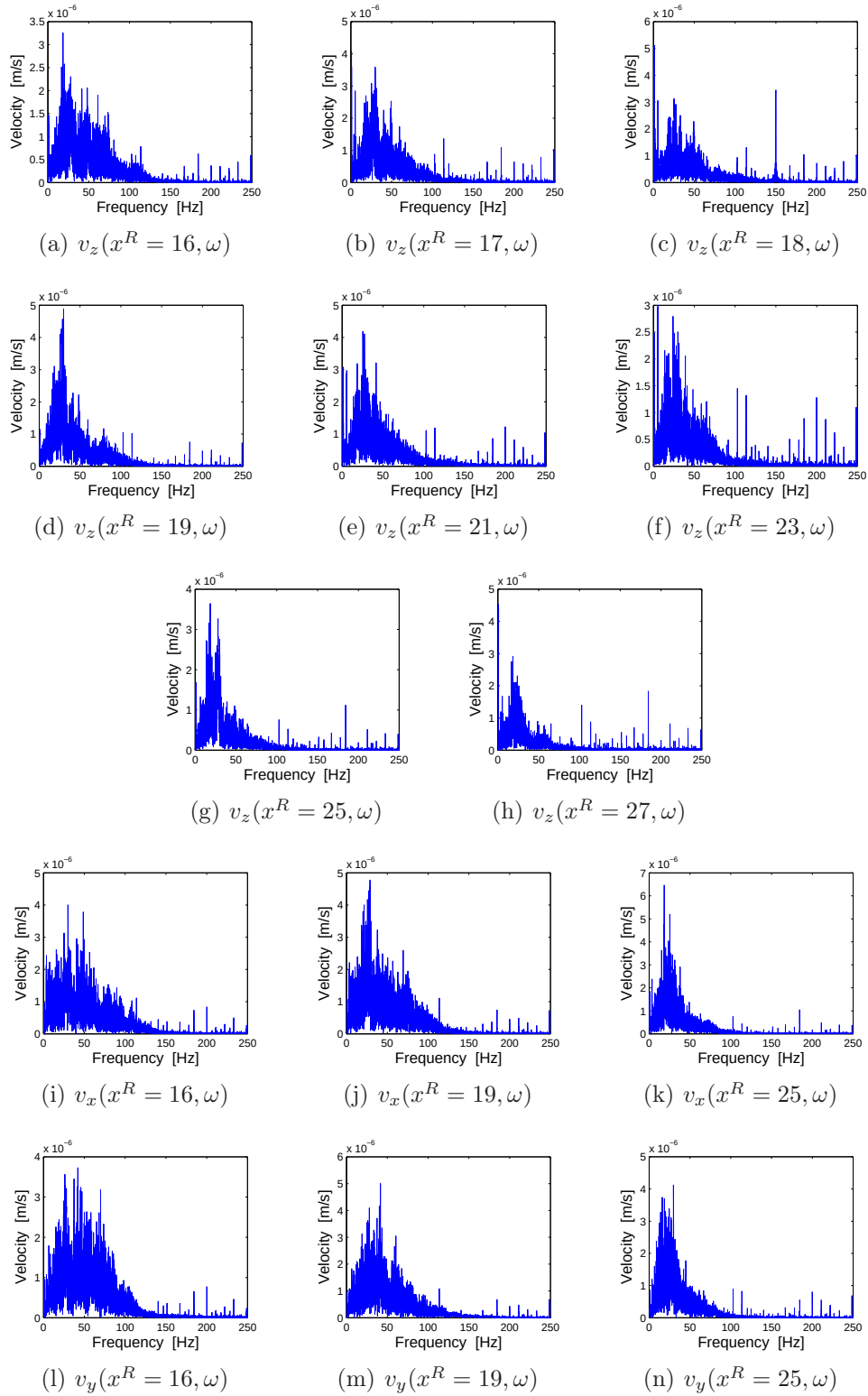


Figure 3.15: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 85 km/h

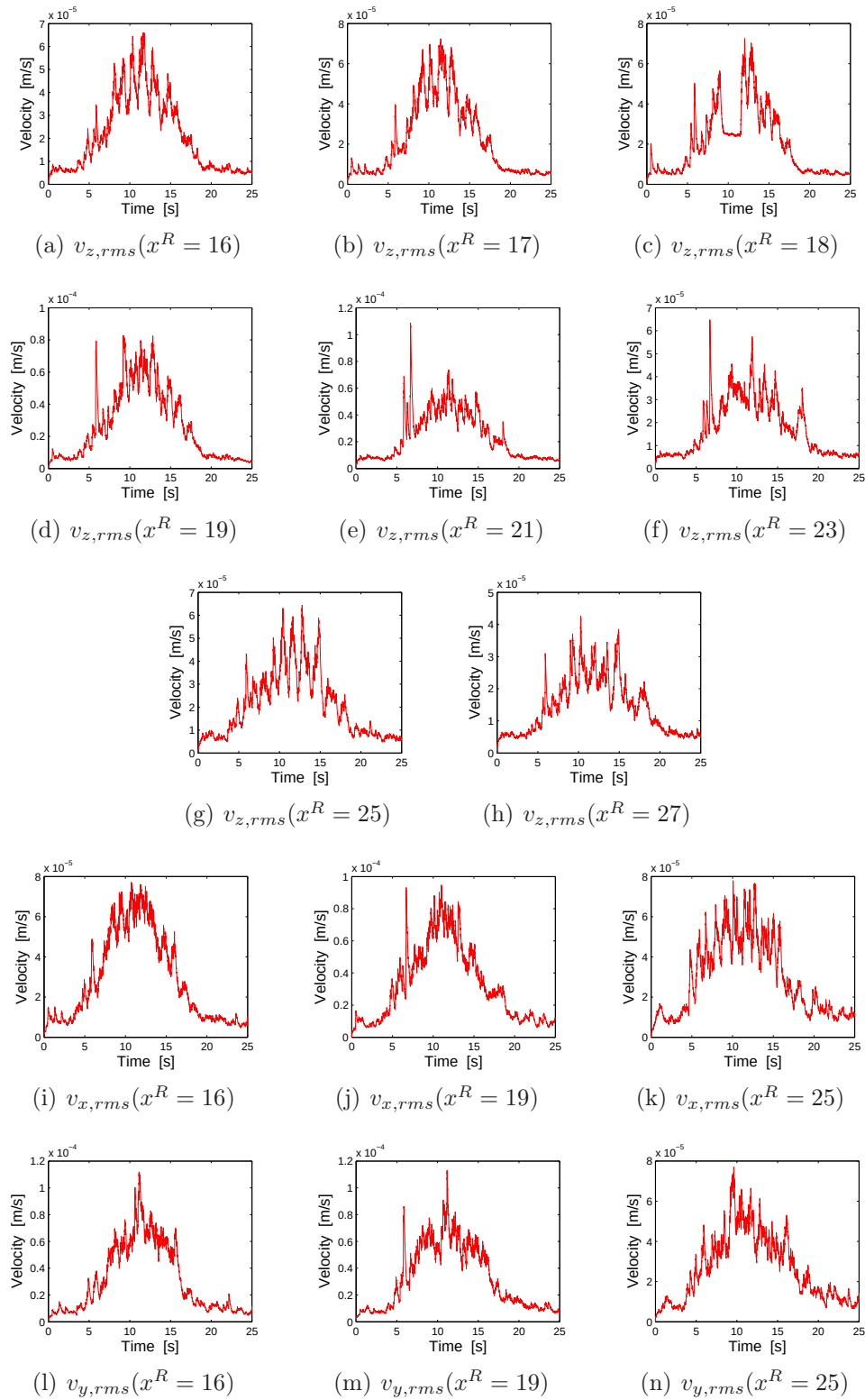


Figure 3.16: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 85 km/h

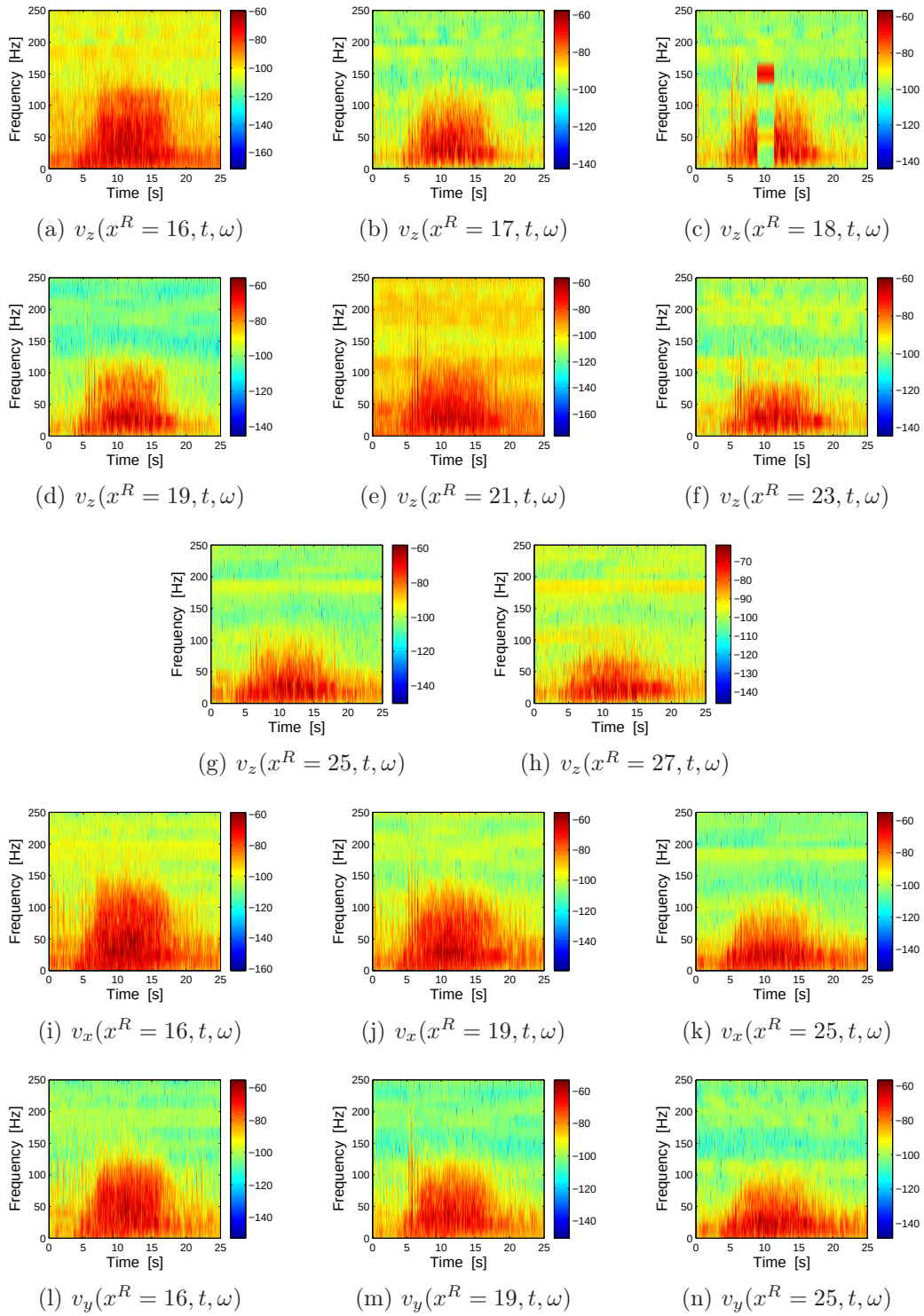


Figure 3.17: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 85 km/h

3.5 AM96 unit at 85 km/h

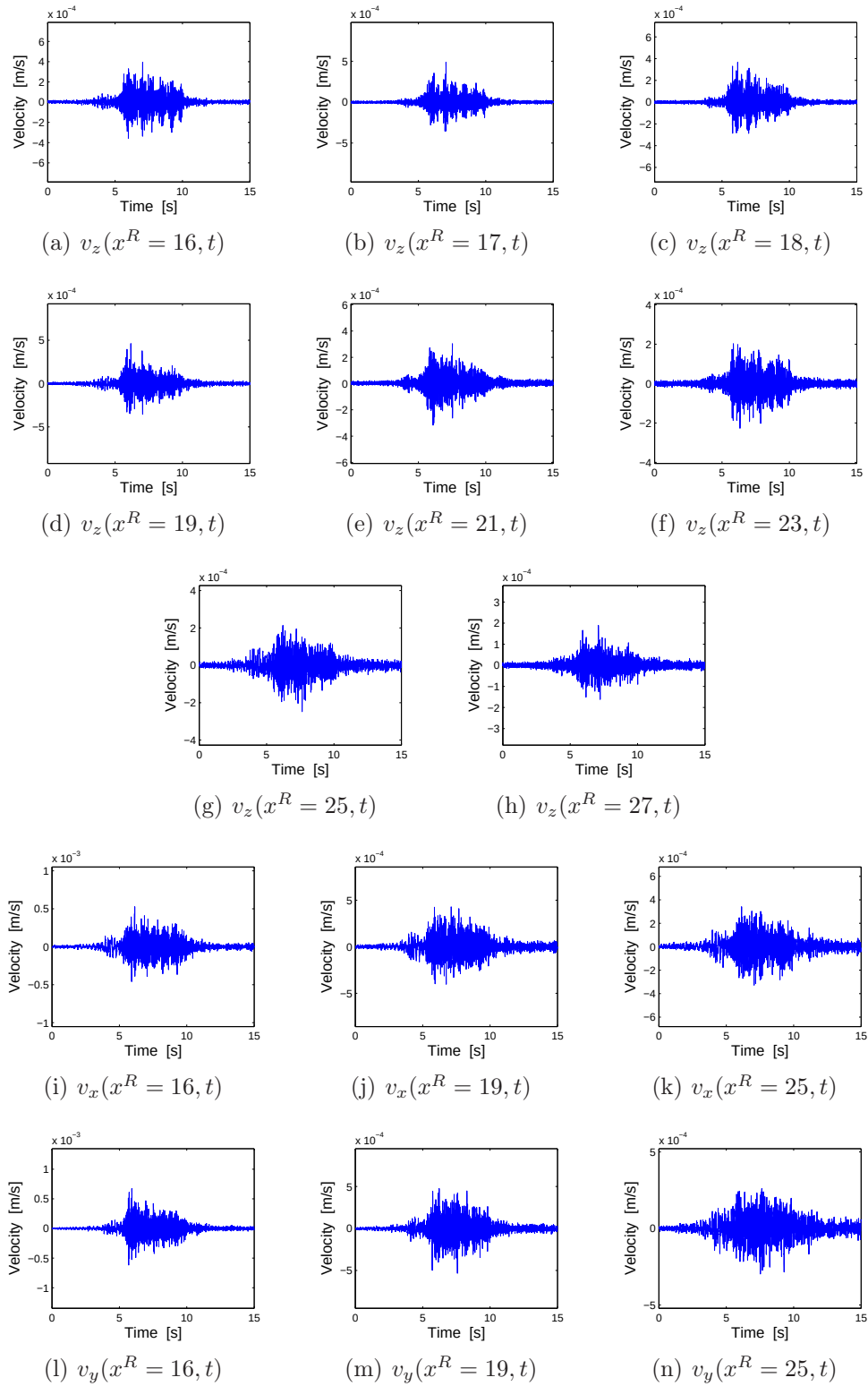


Figure 3.18: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 85 km/h

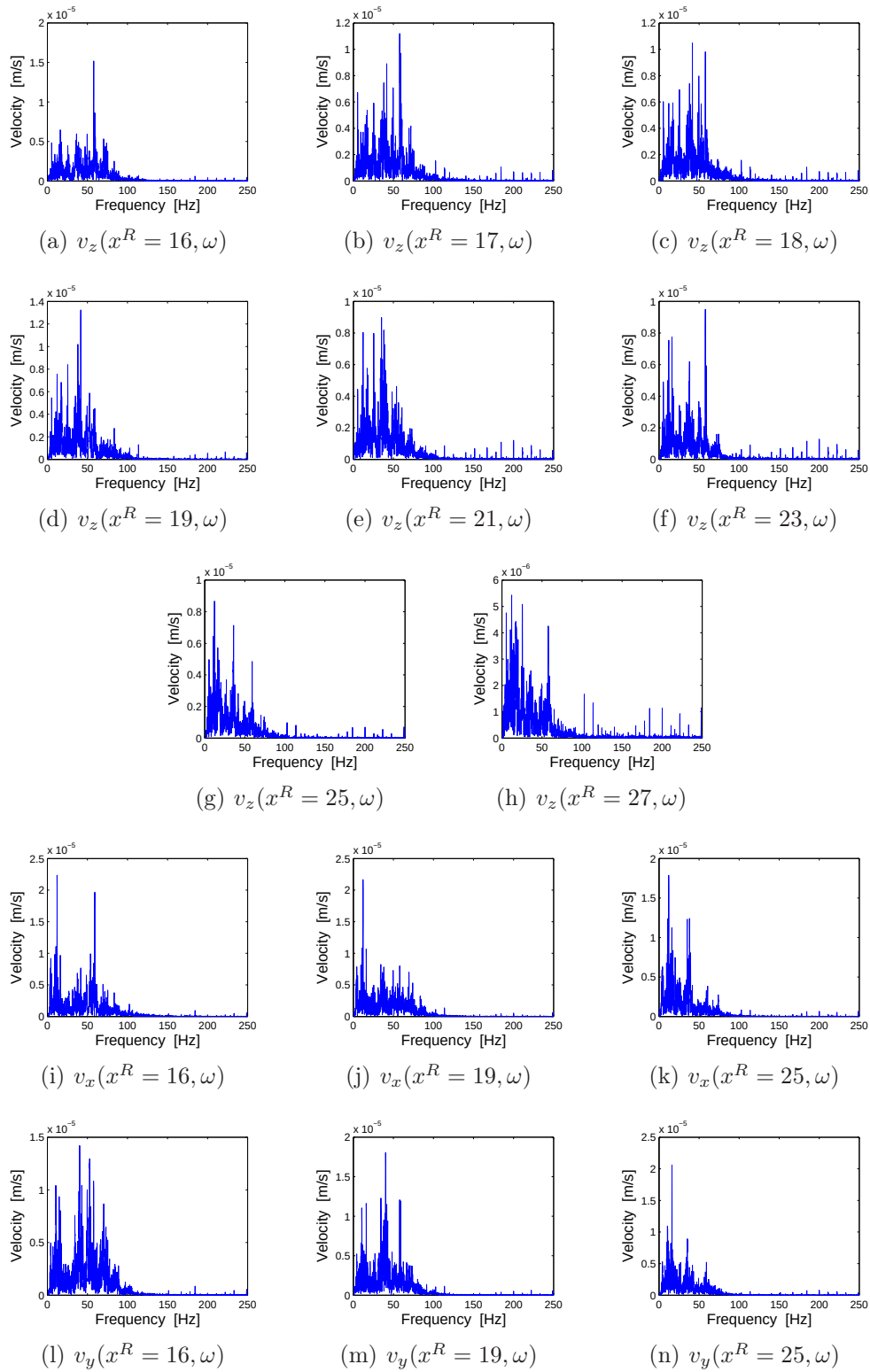


Figure 3.19: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 85 km/h

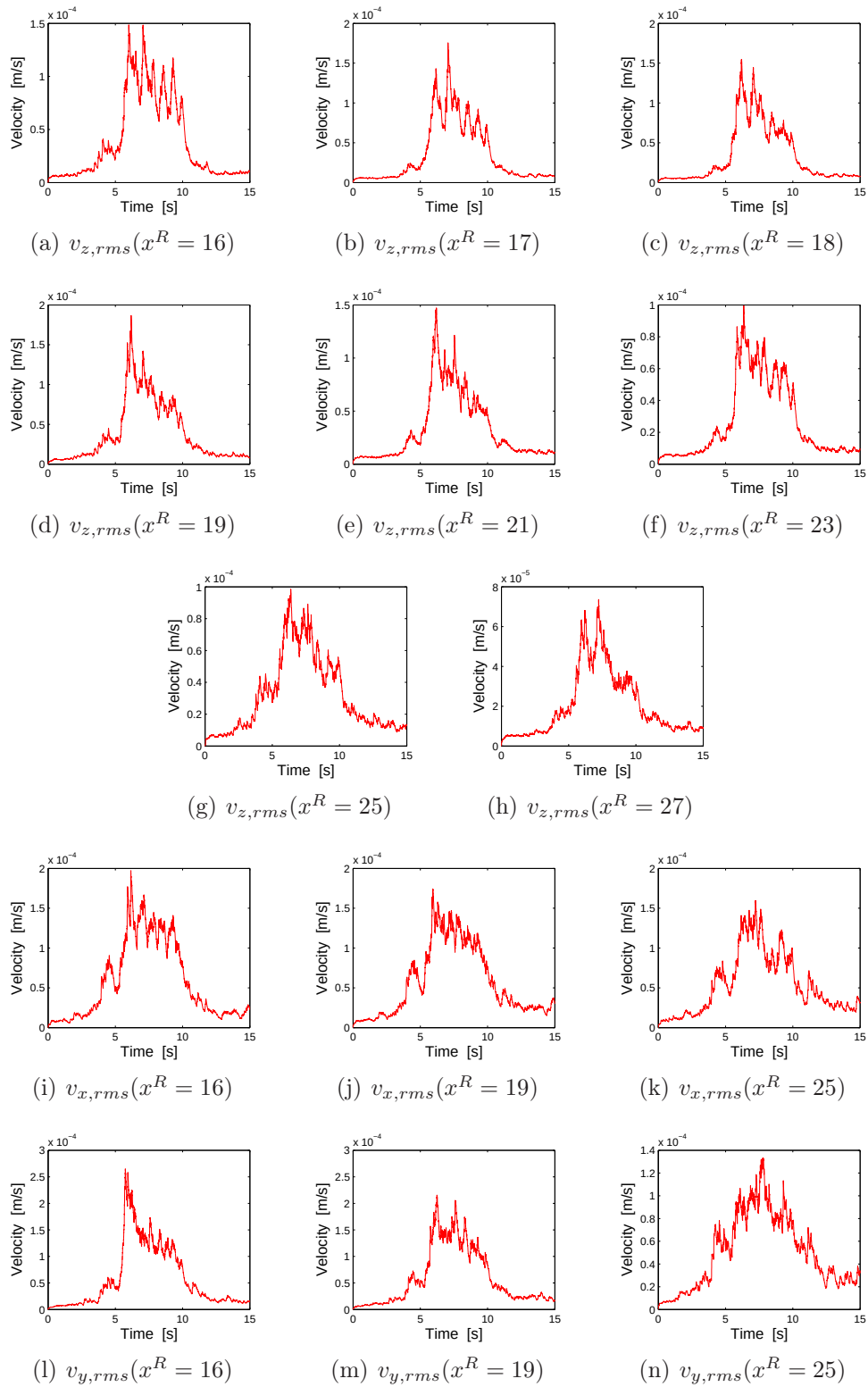


Figure 3.20: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 85 km/h

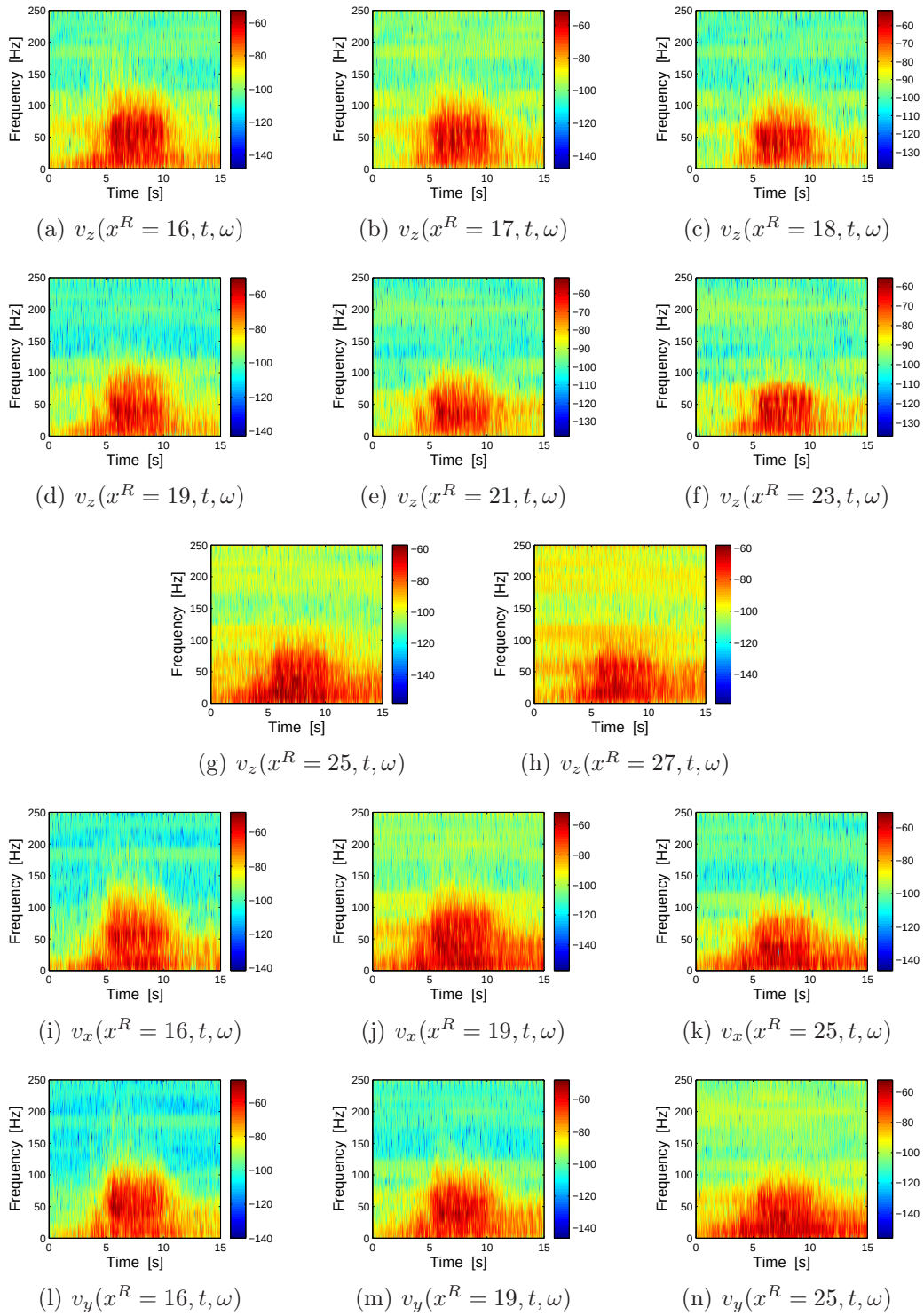


Figure 3.21: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 85 km/h

3.6 AM96 unit at 100 km/h

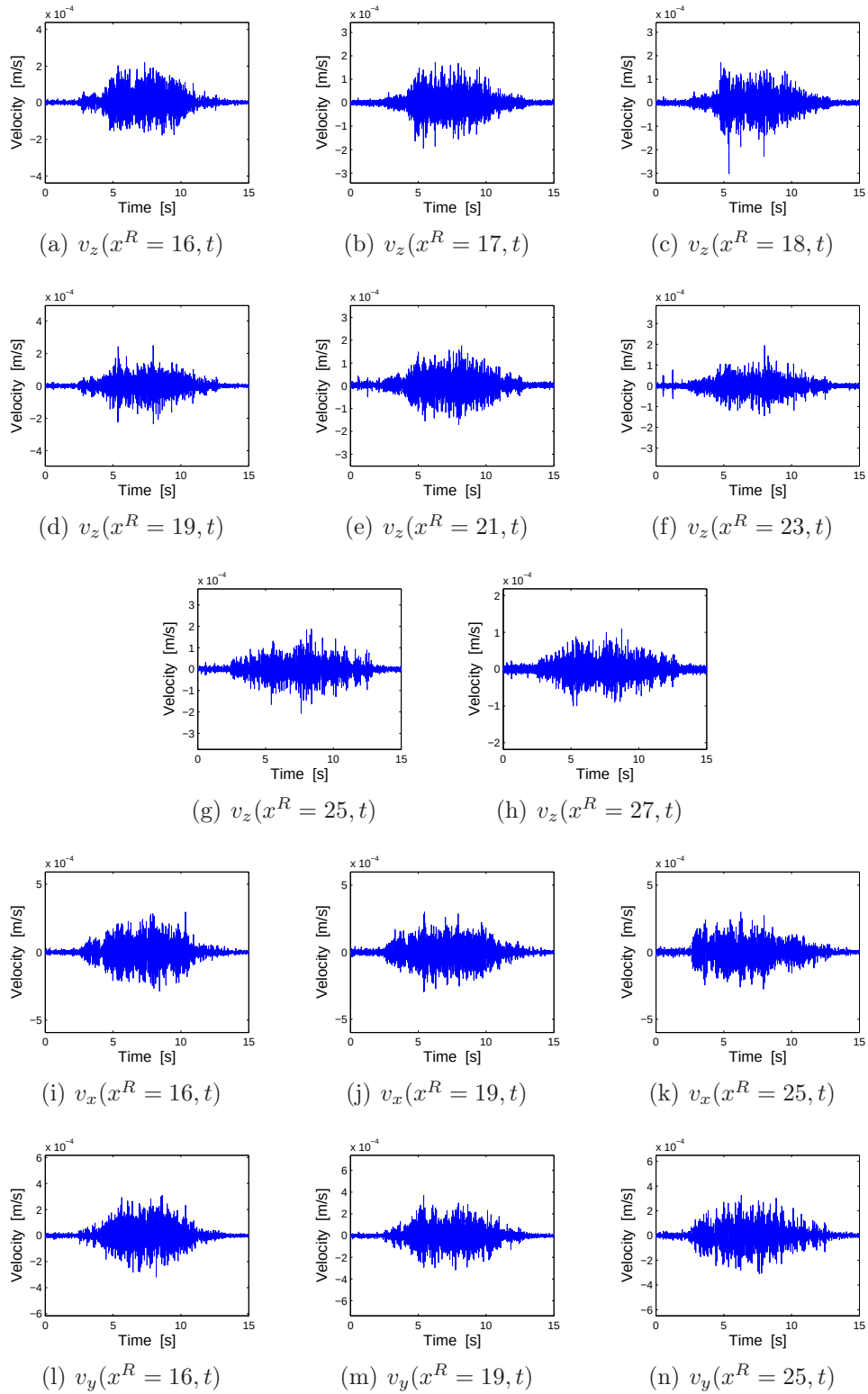


Figure 3.22: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 100 km/h

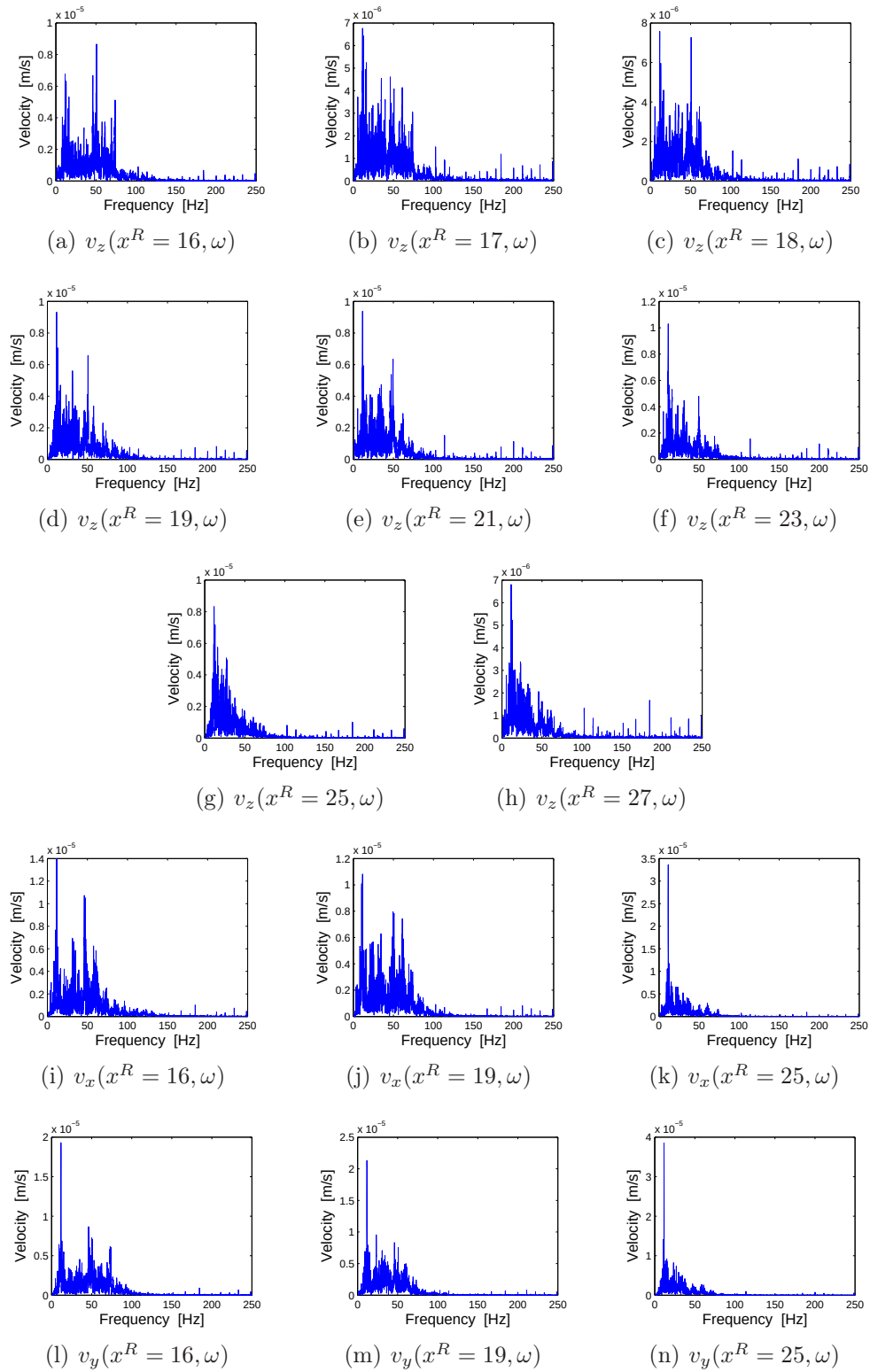


Figure 3.23: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 100 km/h

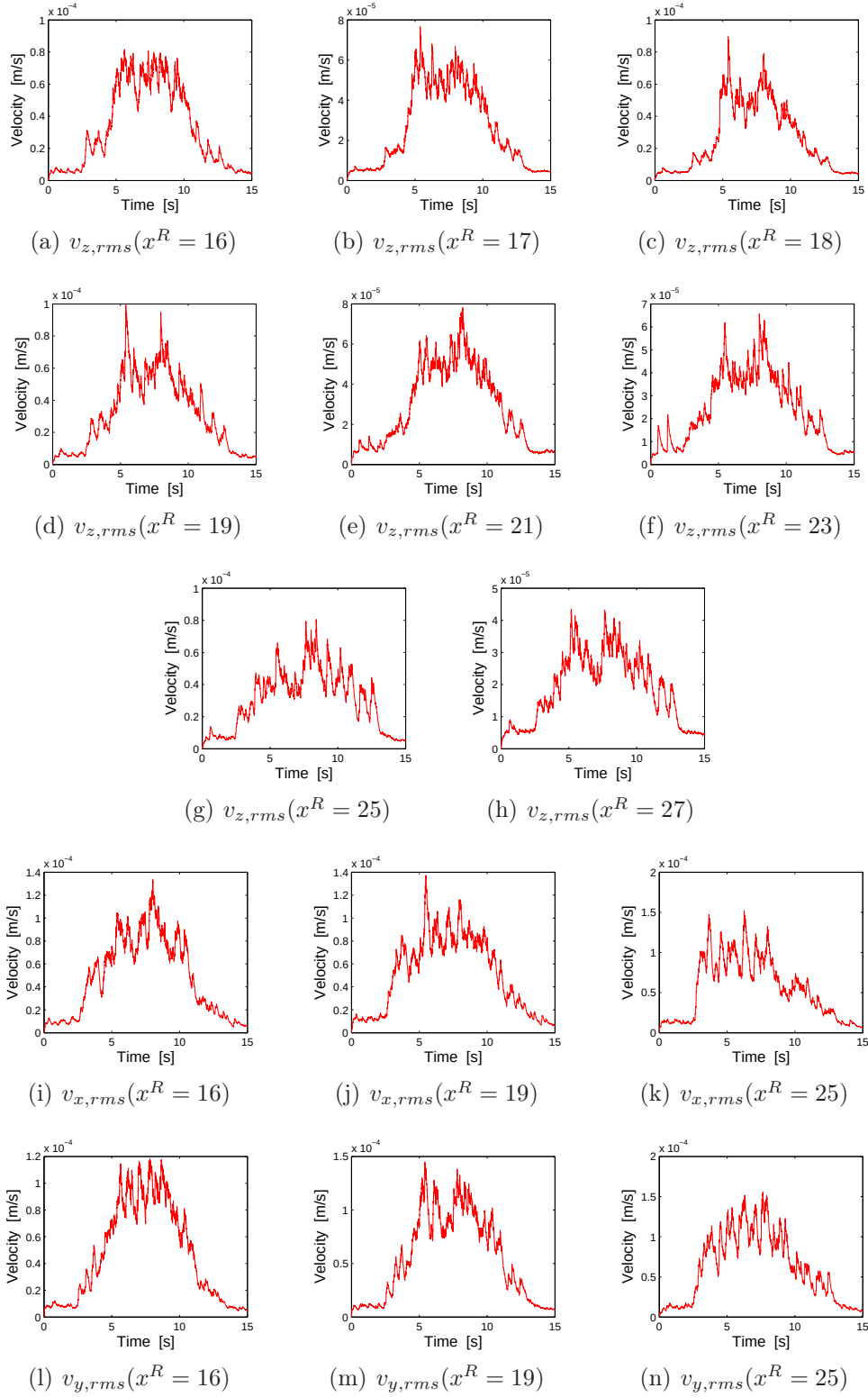


Figure 3.24: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 100 km/h

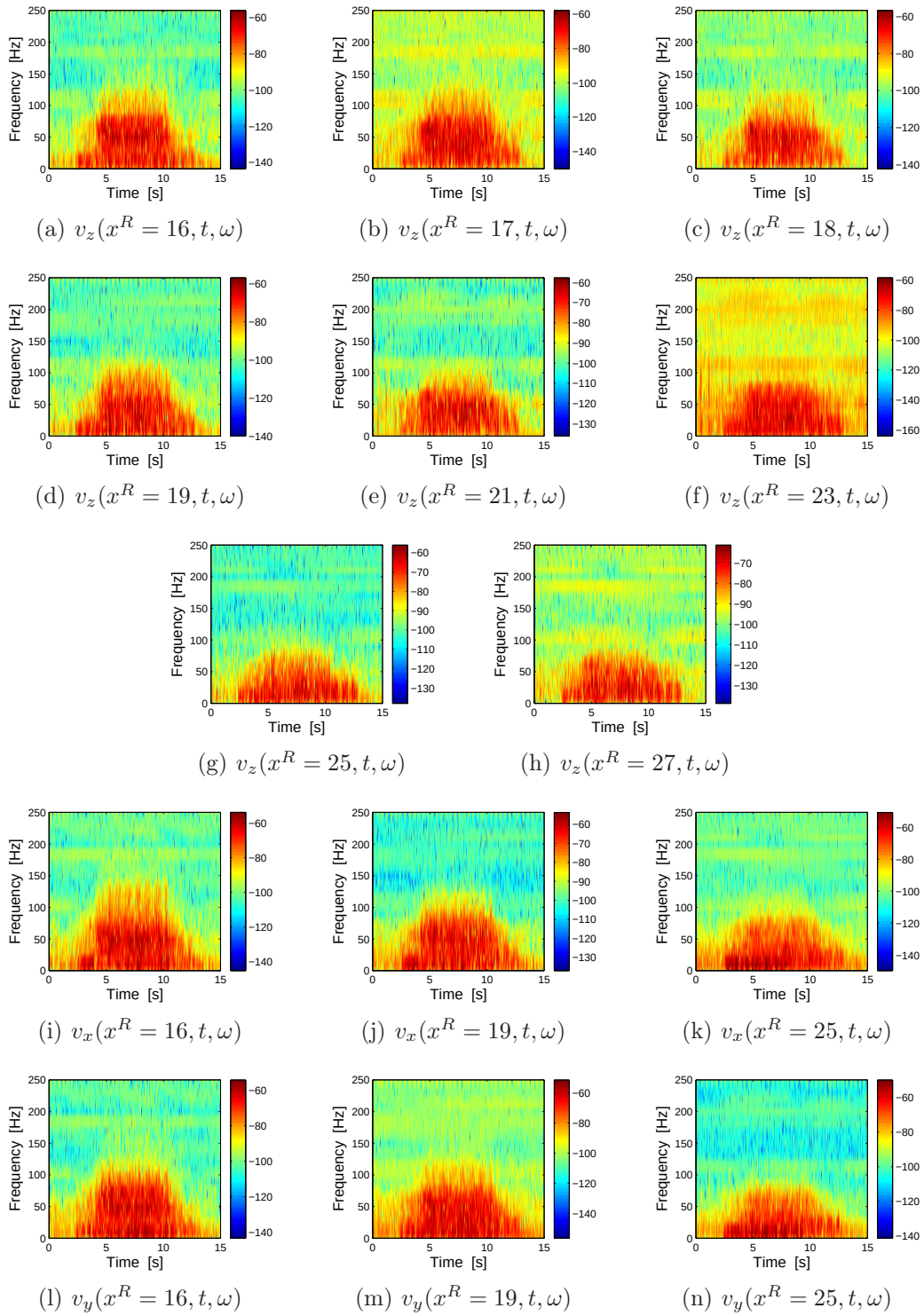


Figure 3.25: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 100 km/h

3.7 AM75 unit at 85 km/h

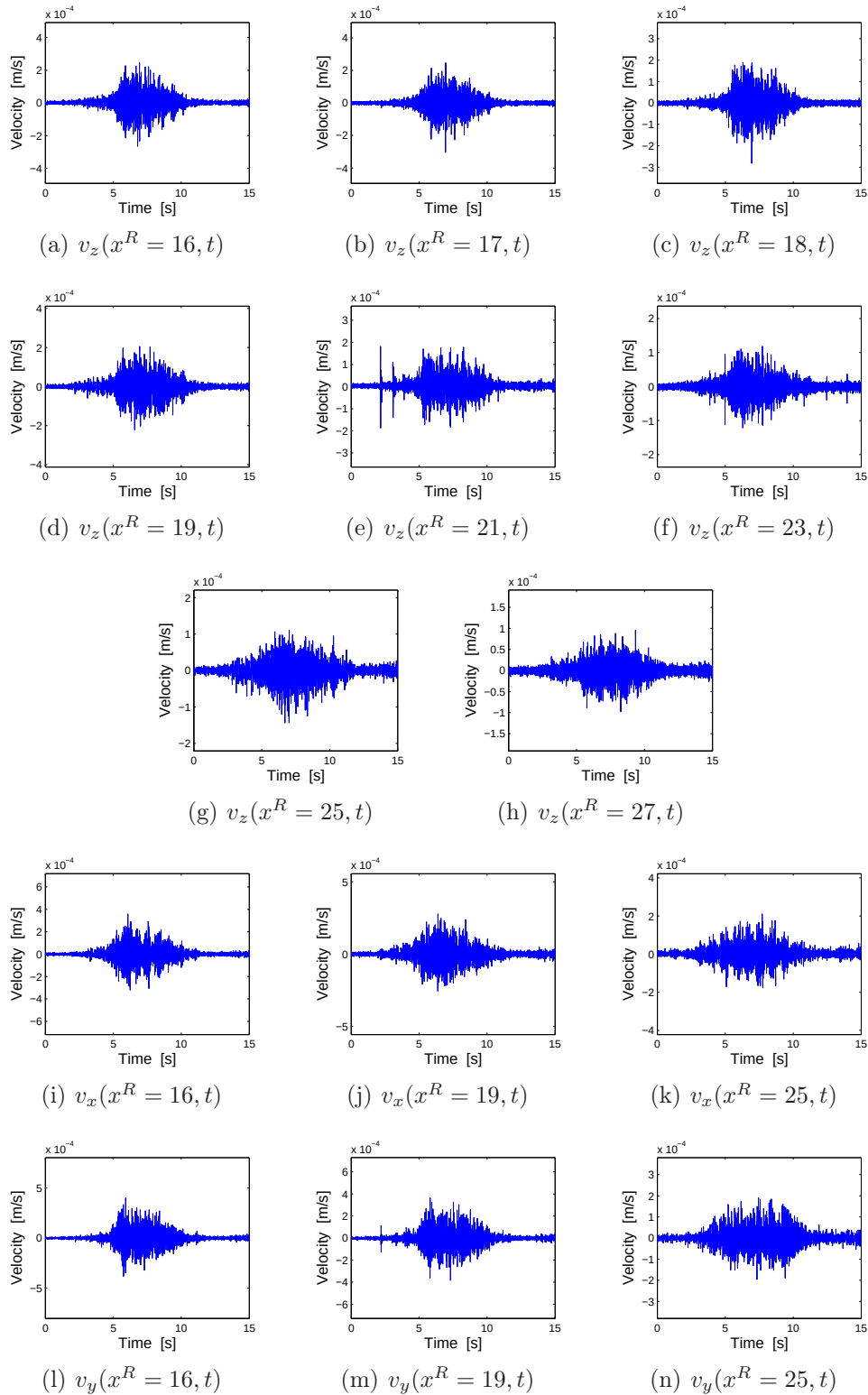


Figure 3.26: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 85 km/h

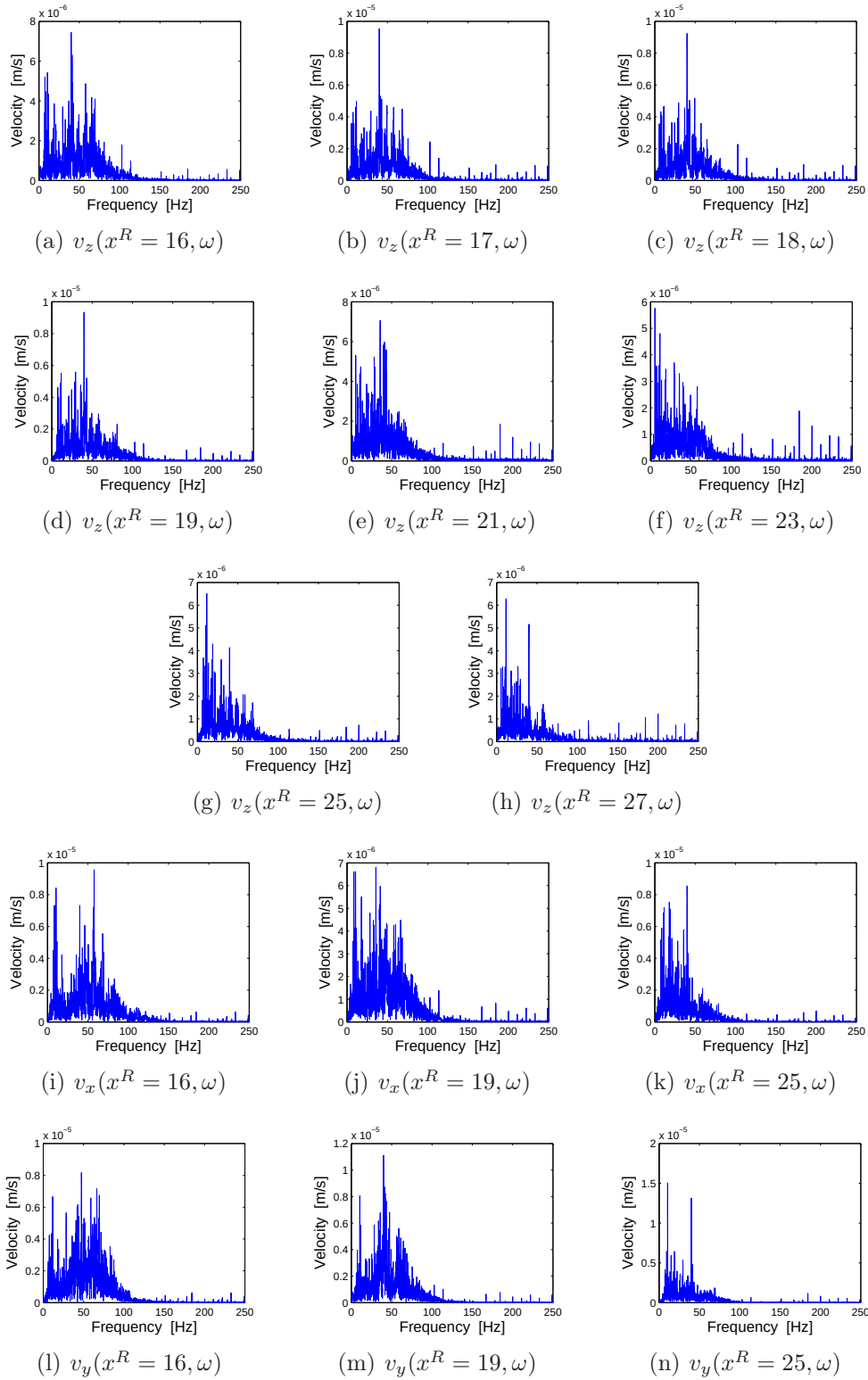


Figure 3.27: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 85 km/h

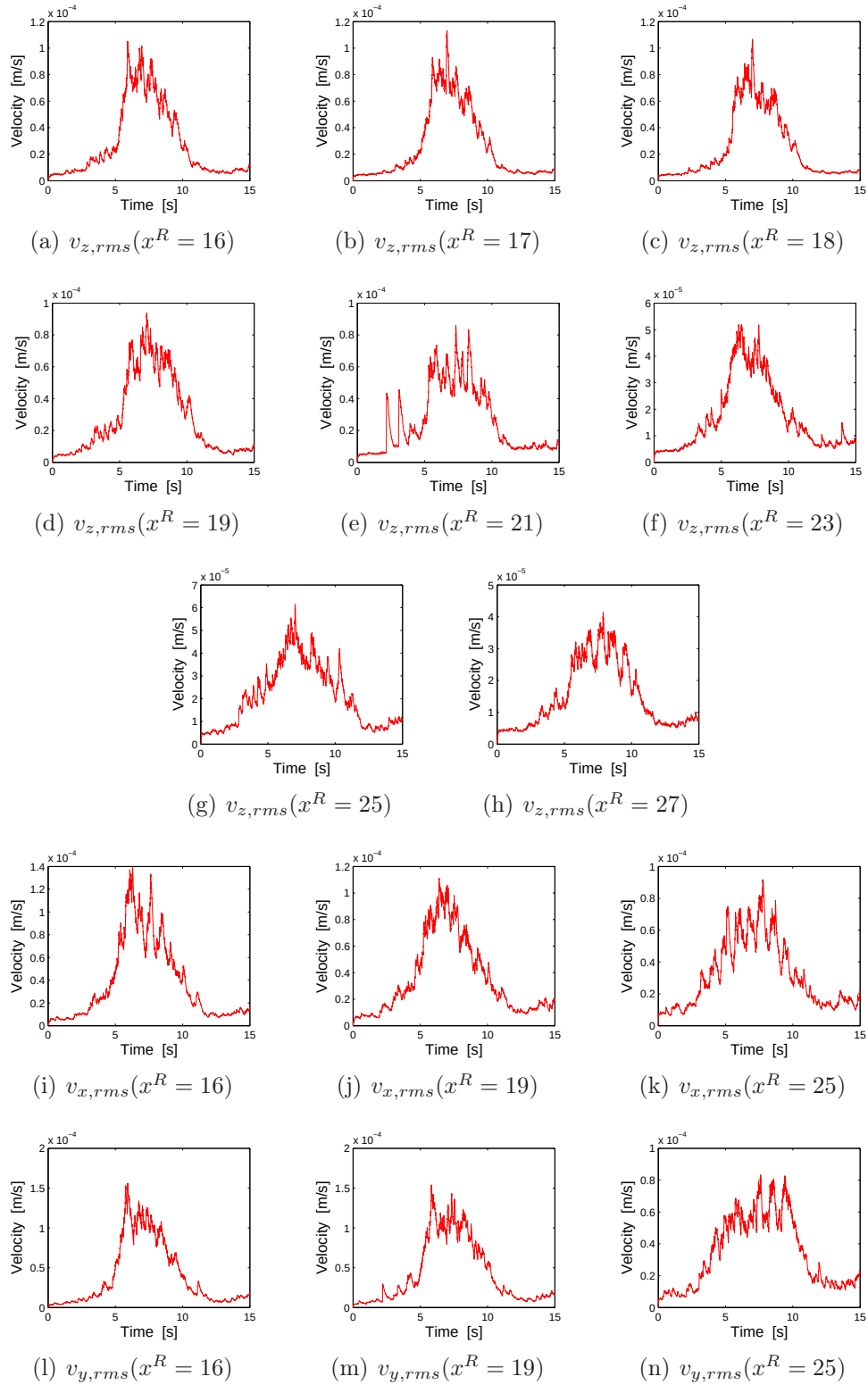


Figure 3.28: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 85 km/h

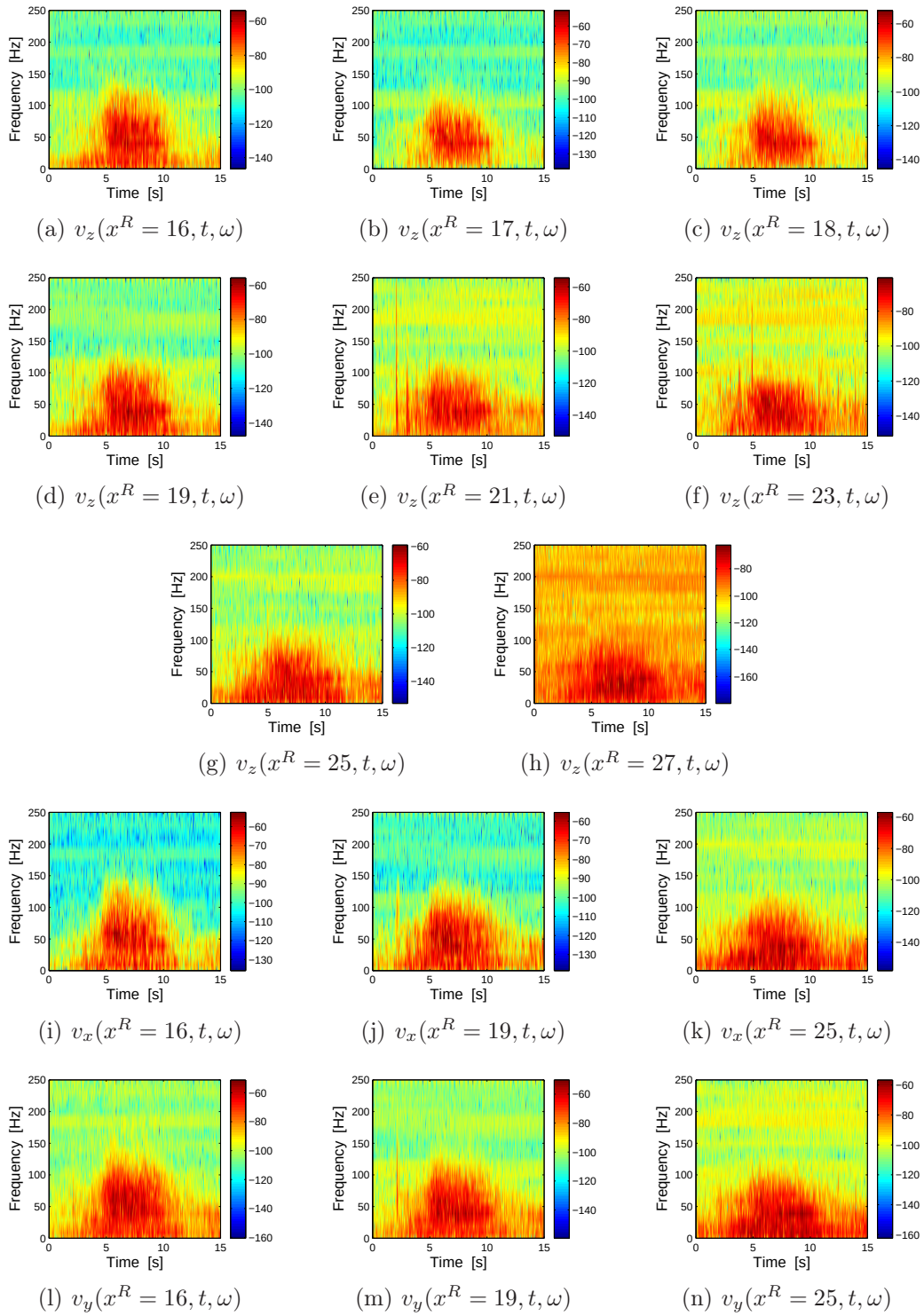


Figure 3.29: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 85 km/h

3.8 AM80 unit at 80 km/h

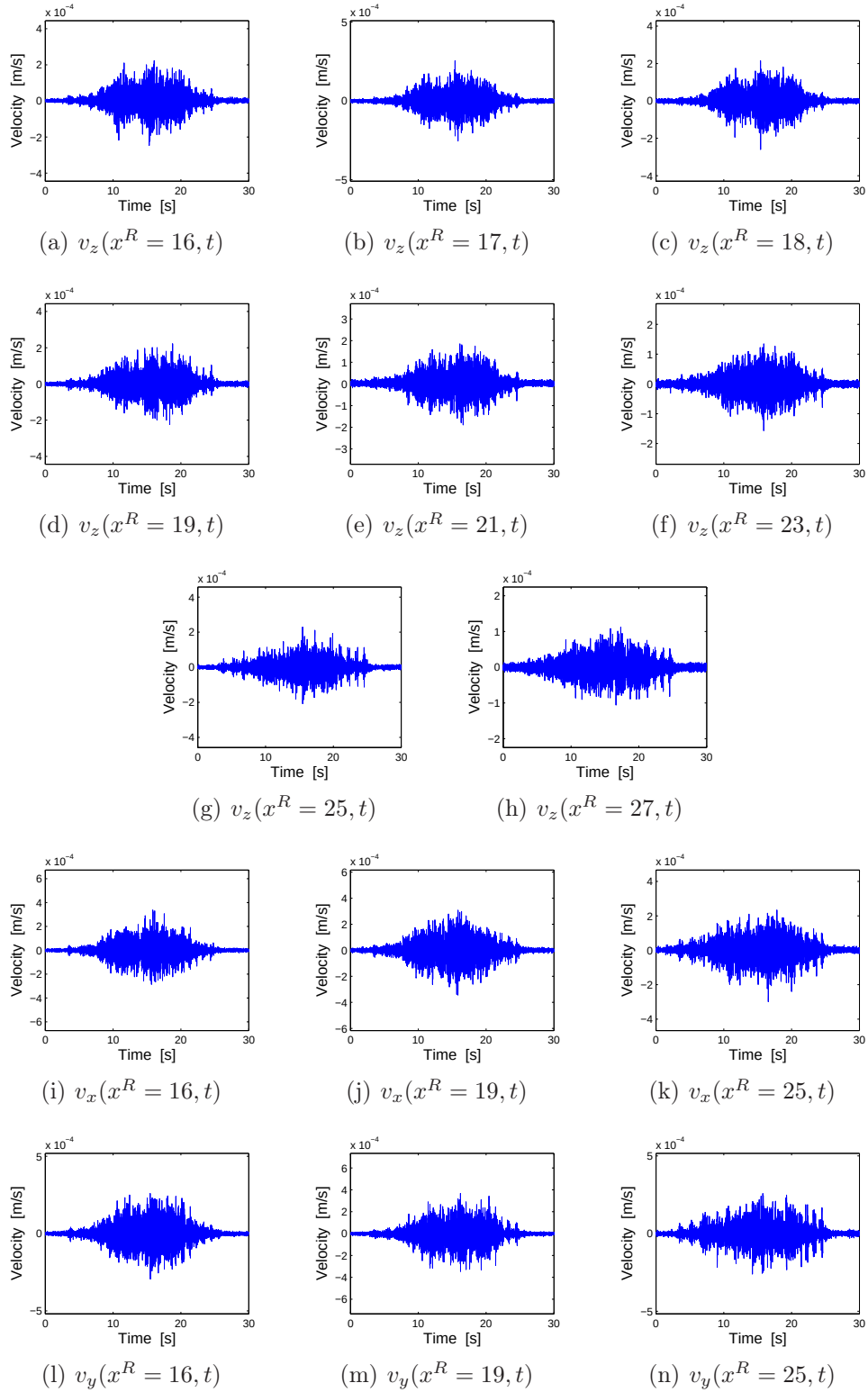


Figure 3.30: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 80 km/h

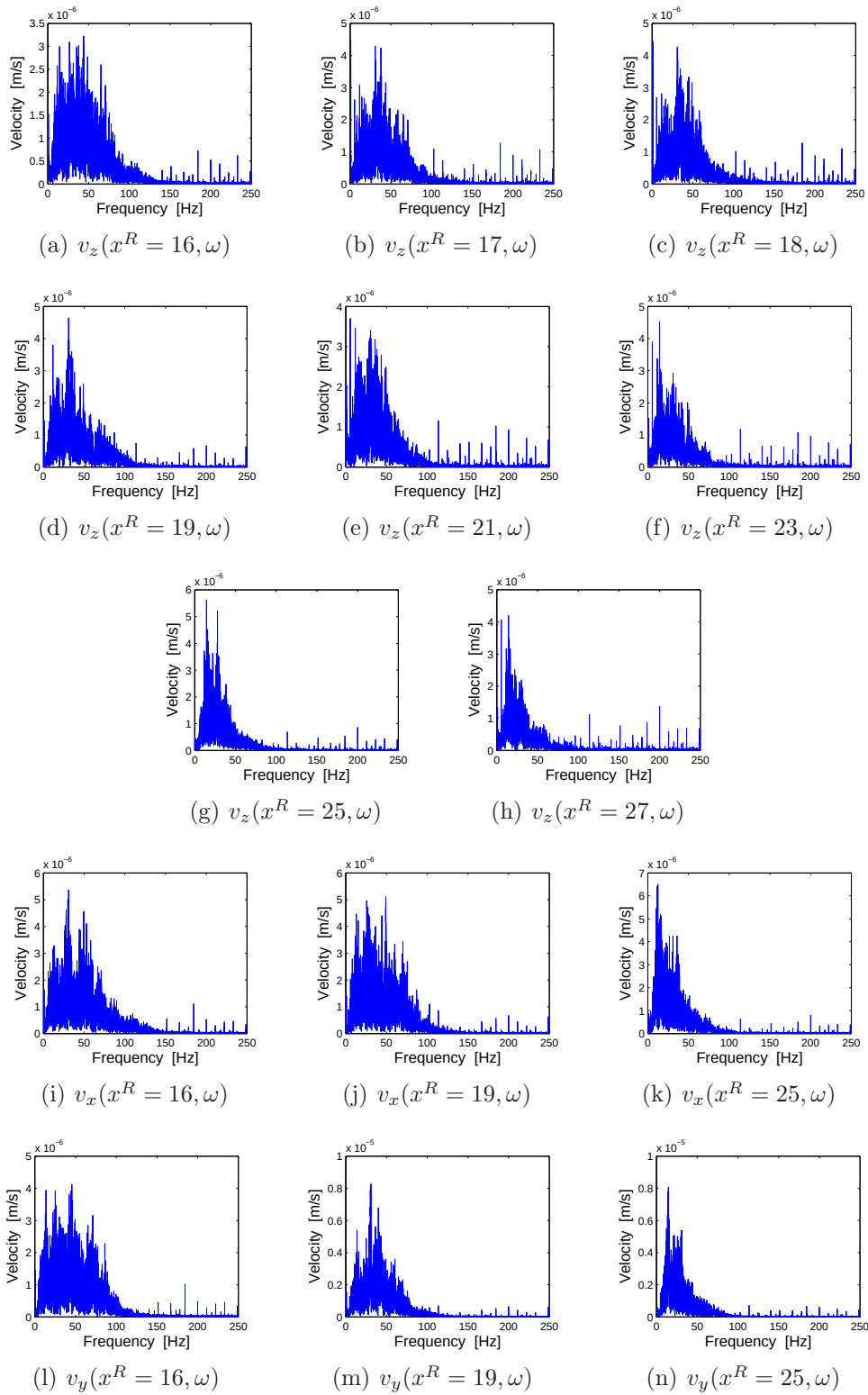


Figure 3.31: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 80 km/h

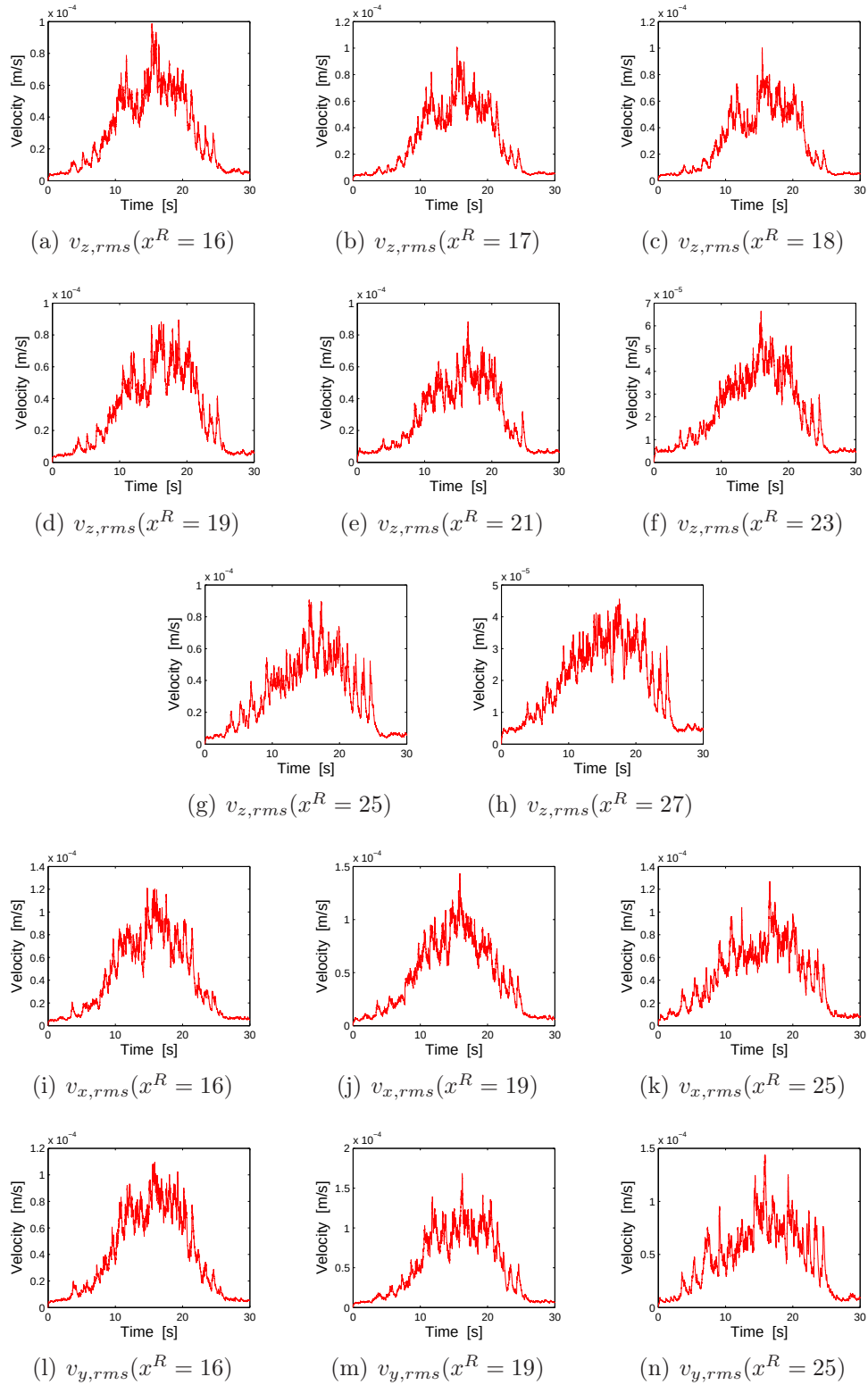


Figure 3.32: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 80 km/h

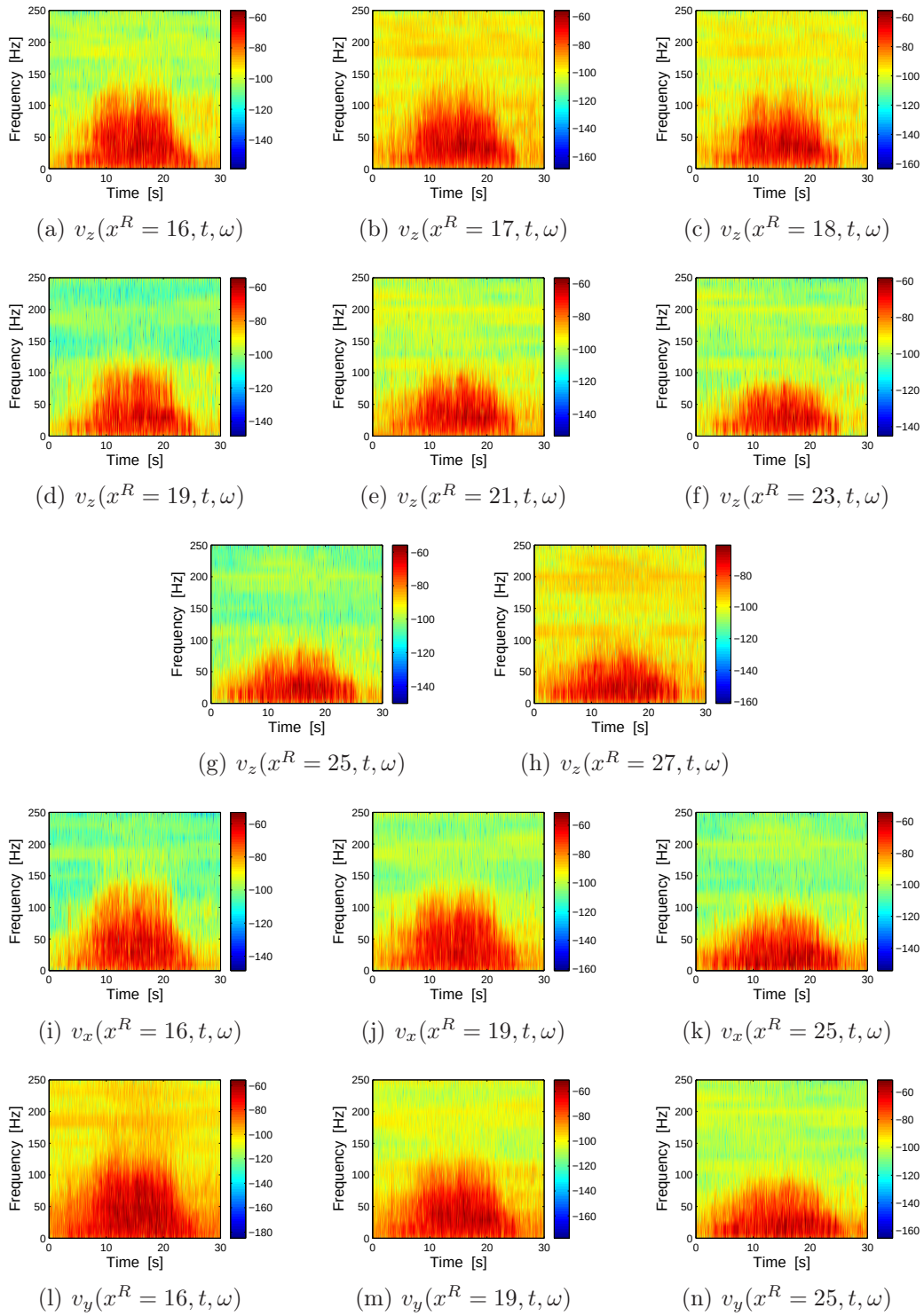


Figure 3.33: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 80 km/h

3.9 AM96 unit at 95 km/h

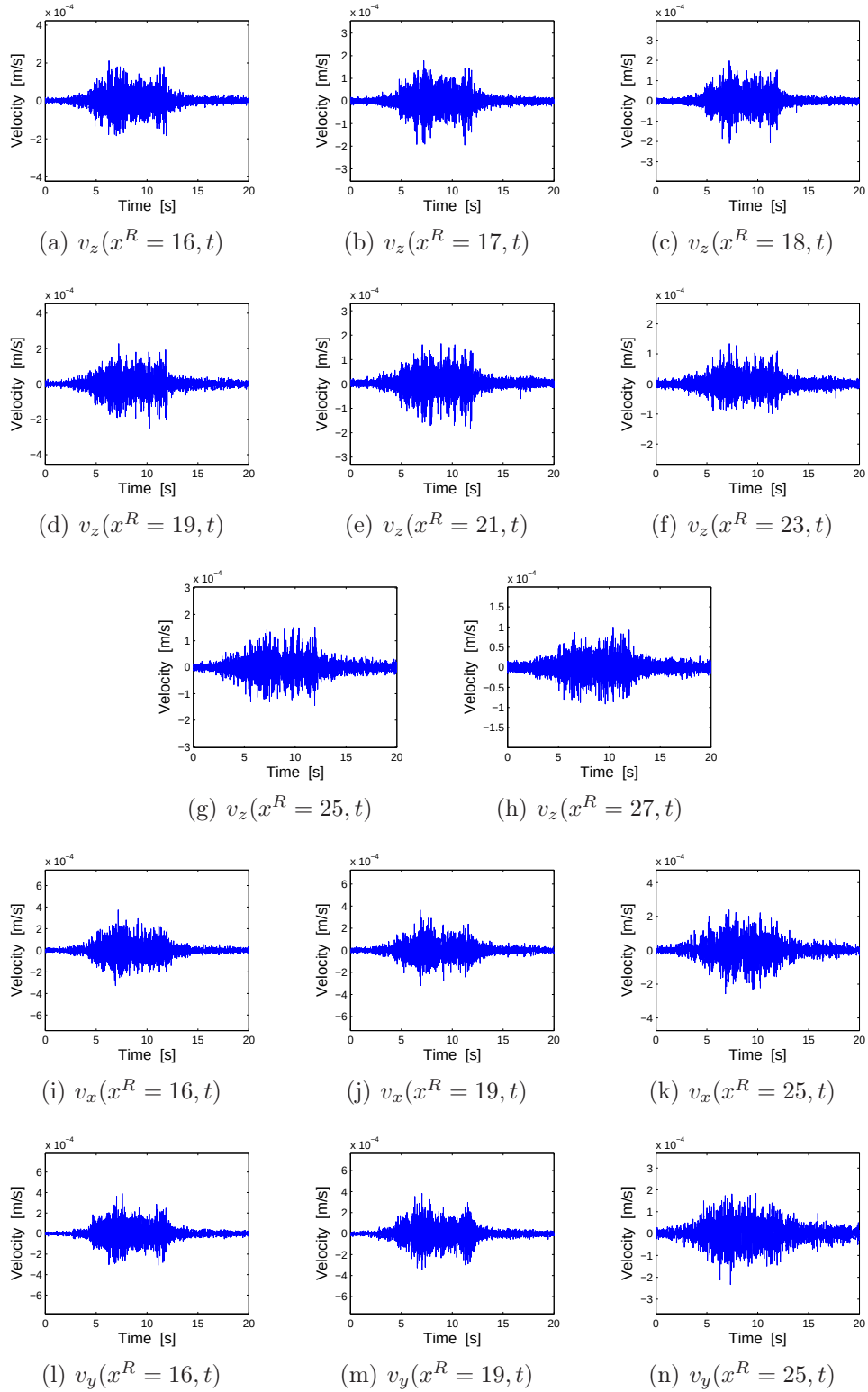


Figure 3.34: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 95 km/h

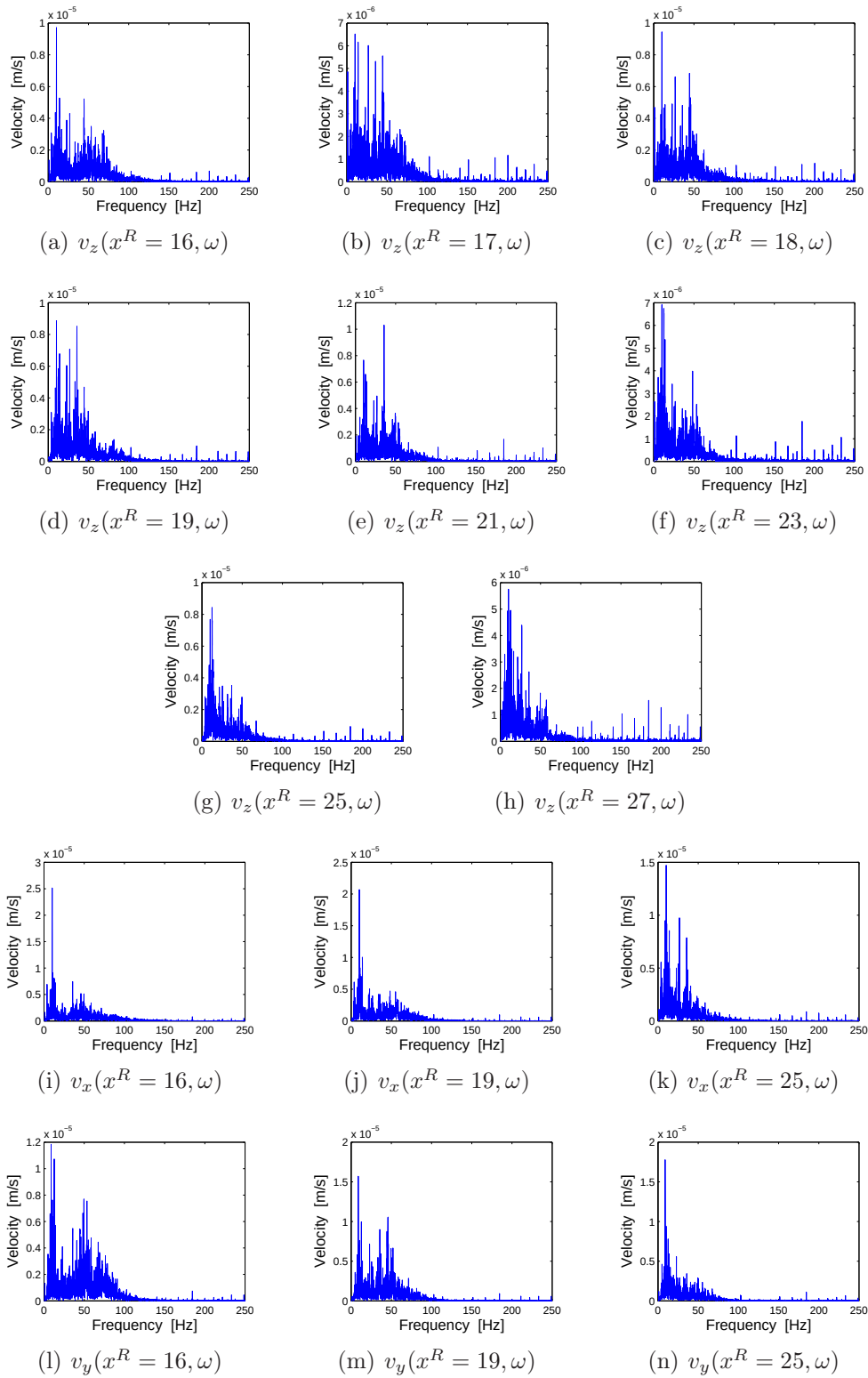


Figure 3.35: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 95 km/h

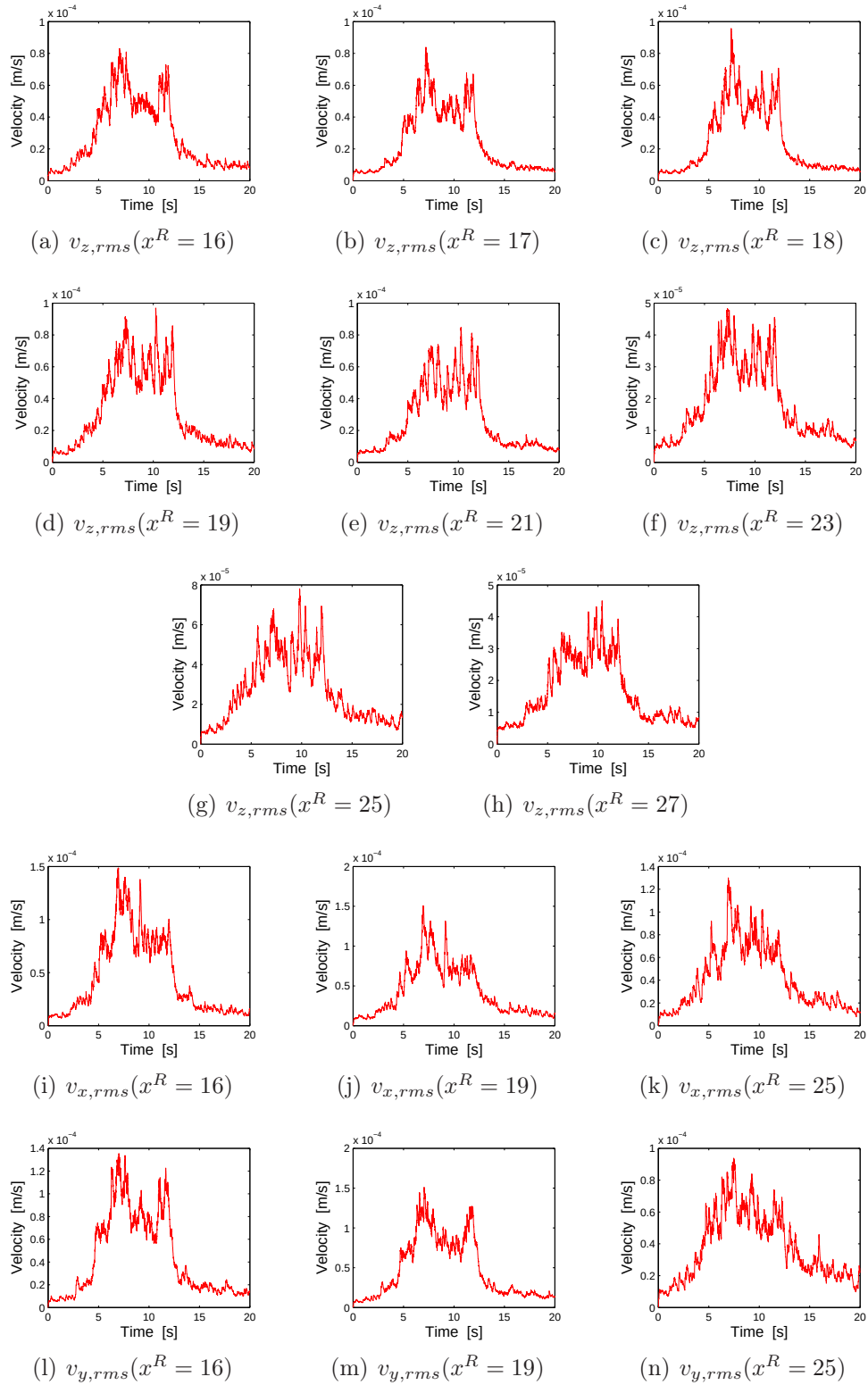


Figure 3.36: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 95 km/h

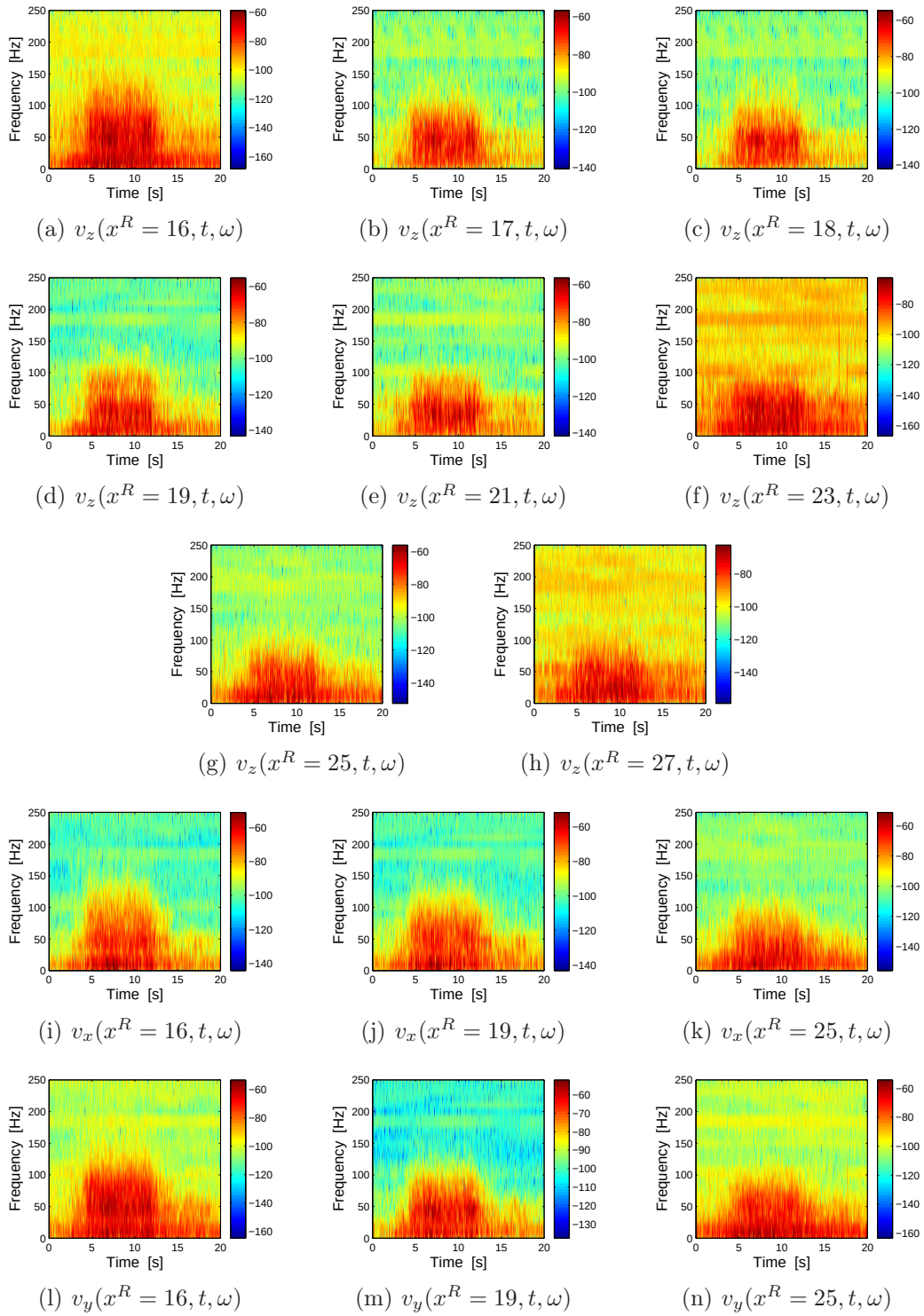


Figure 3.37: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 95 km/h

3.10 AM96 unit at 90 km/h

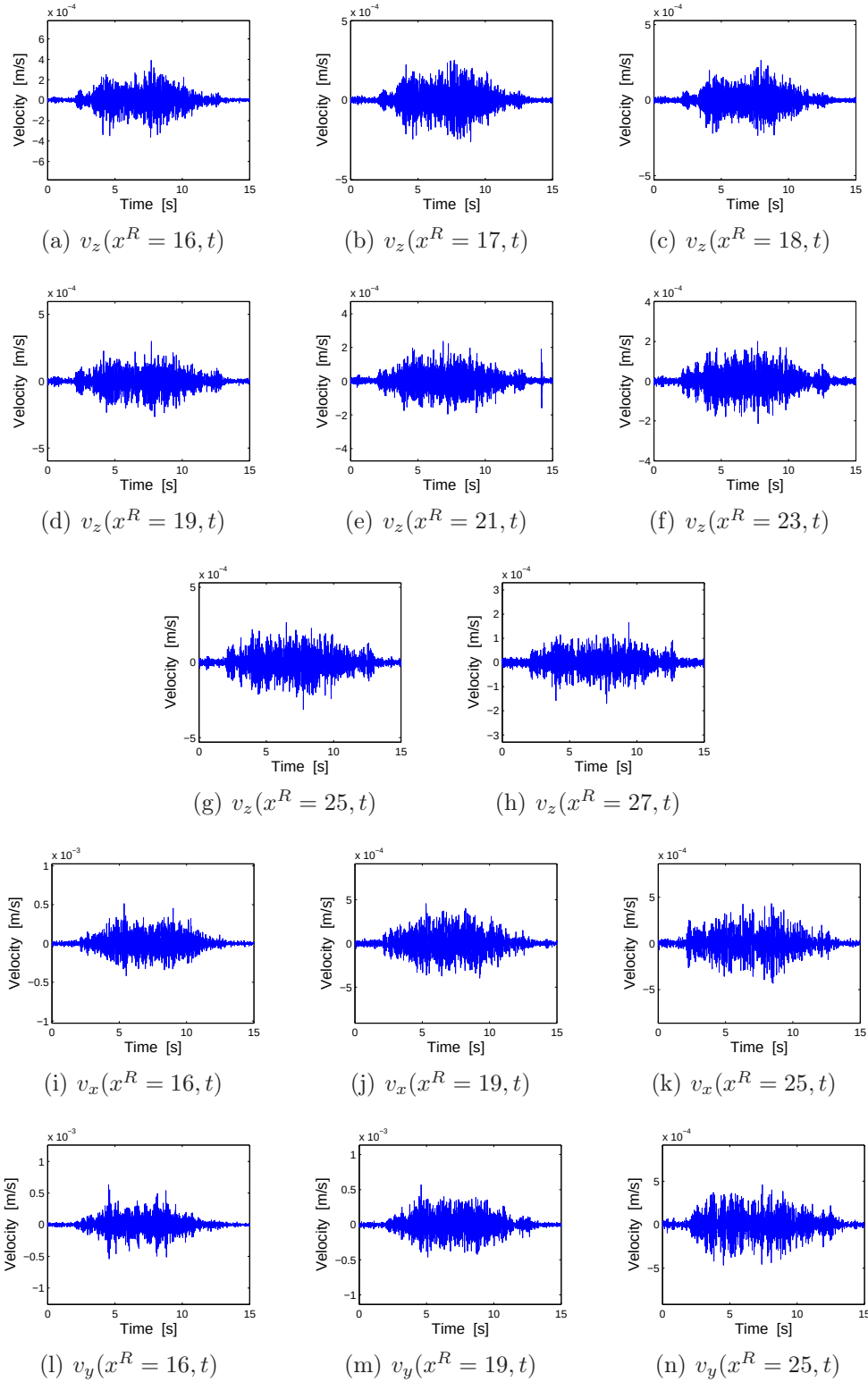


Figure 3.38: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 90 km/h

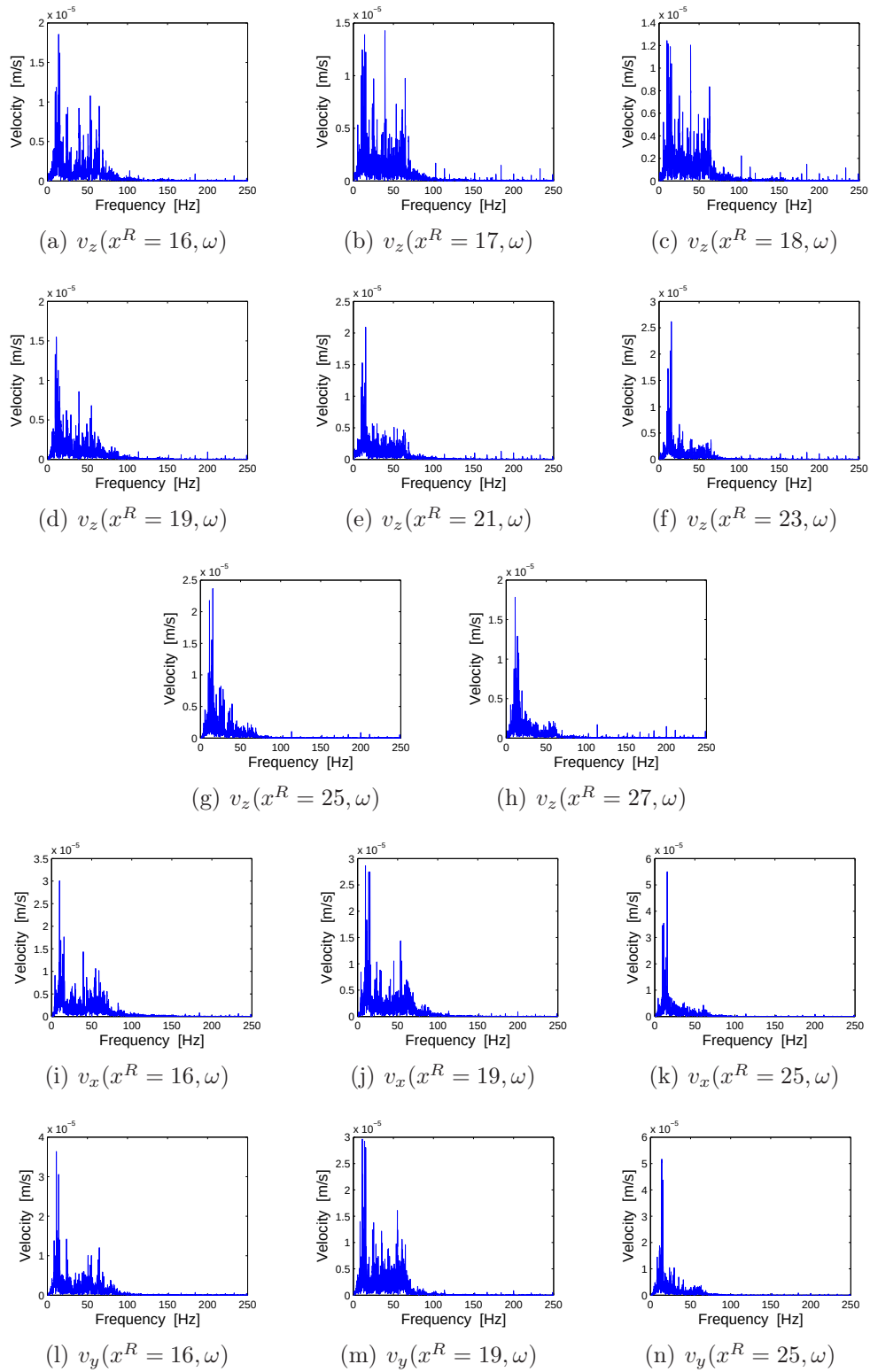


Figure 3.39: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 90 km/h

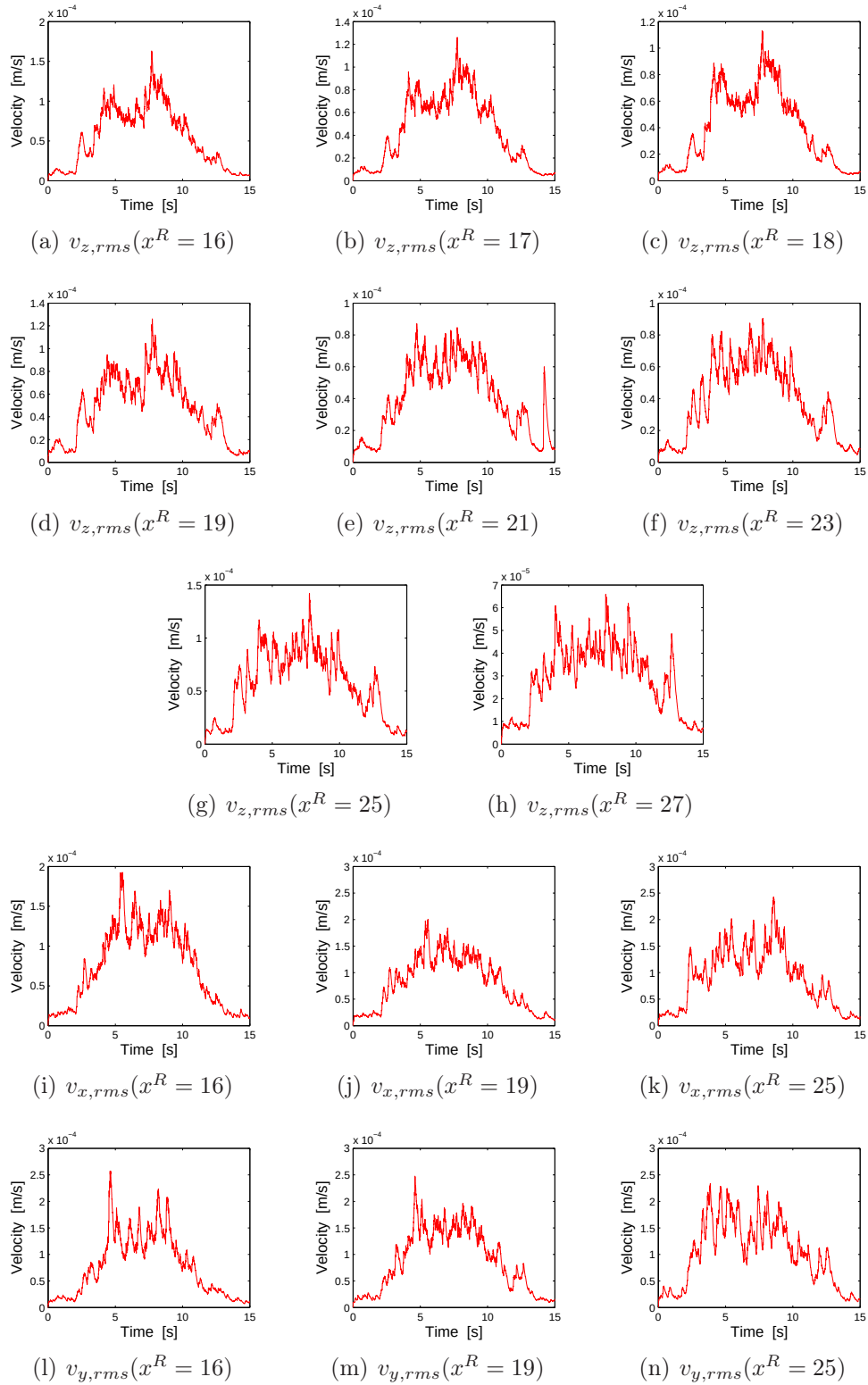


Figure 3.40: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 90 km/h

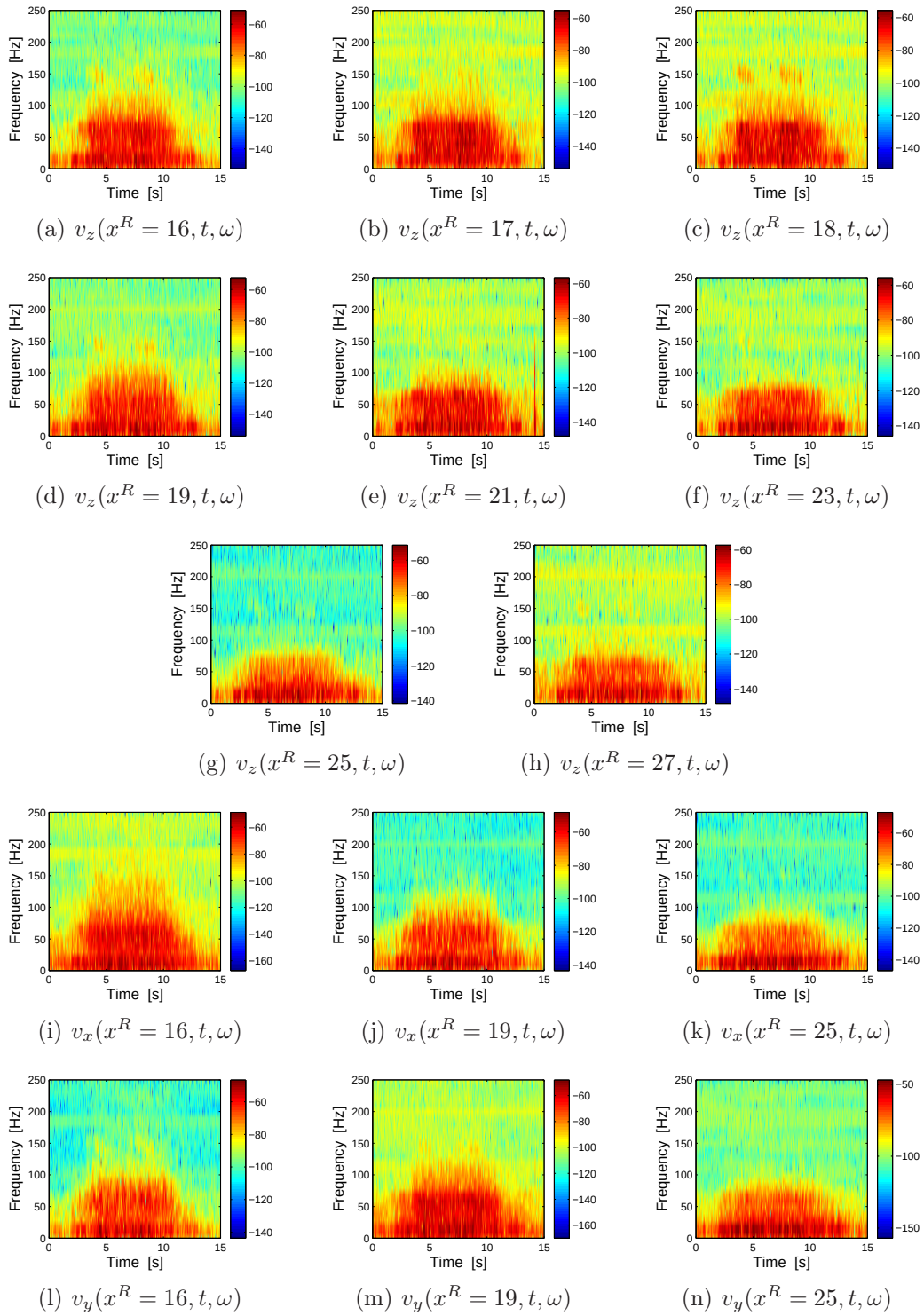


Figure 3.41: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 90 km/h

3.11 AM80 unit at 85 km/h

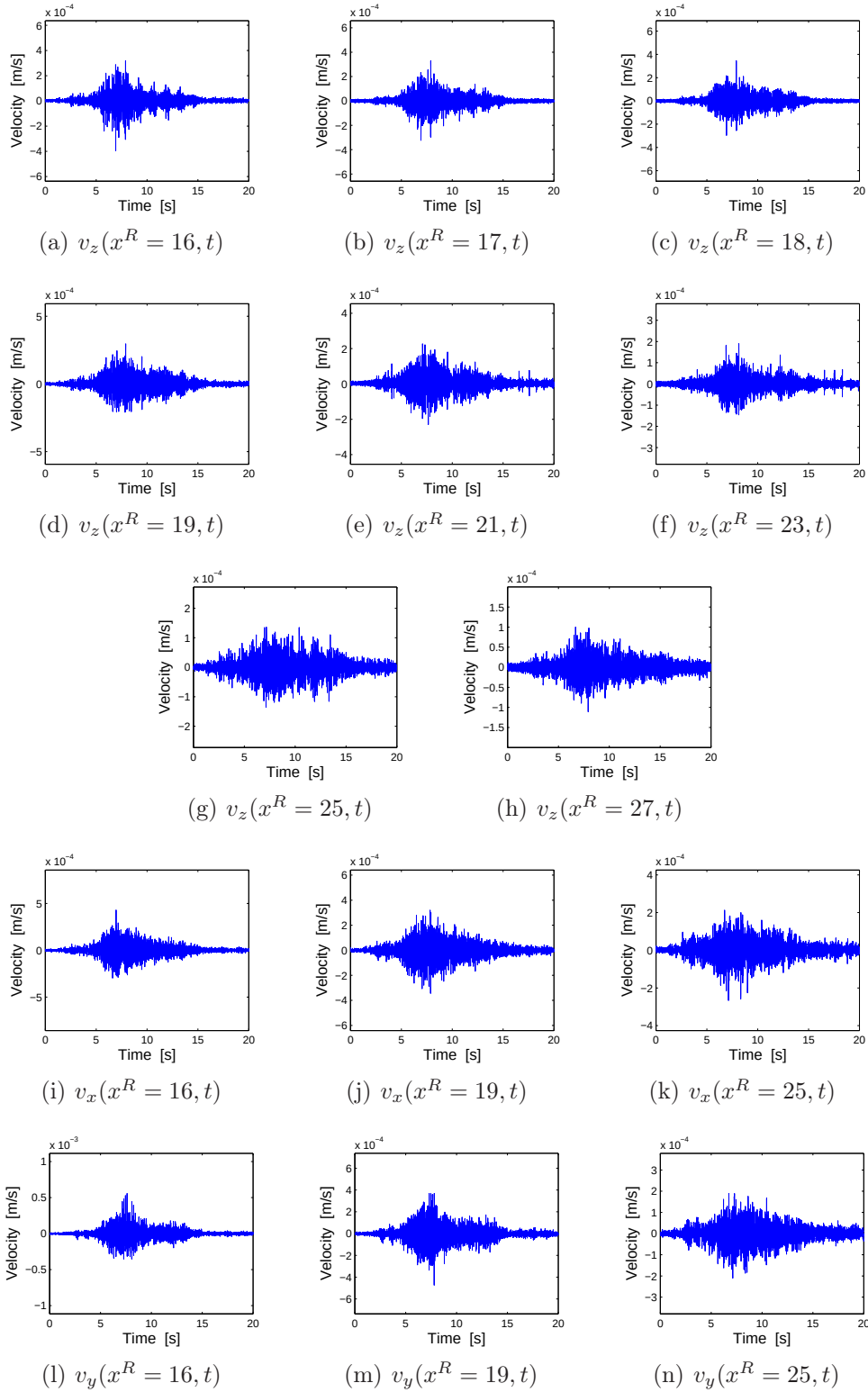


Figure 3.42: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 85 km/h

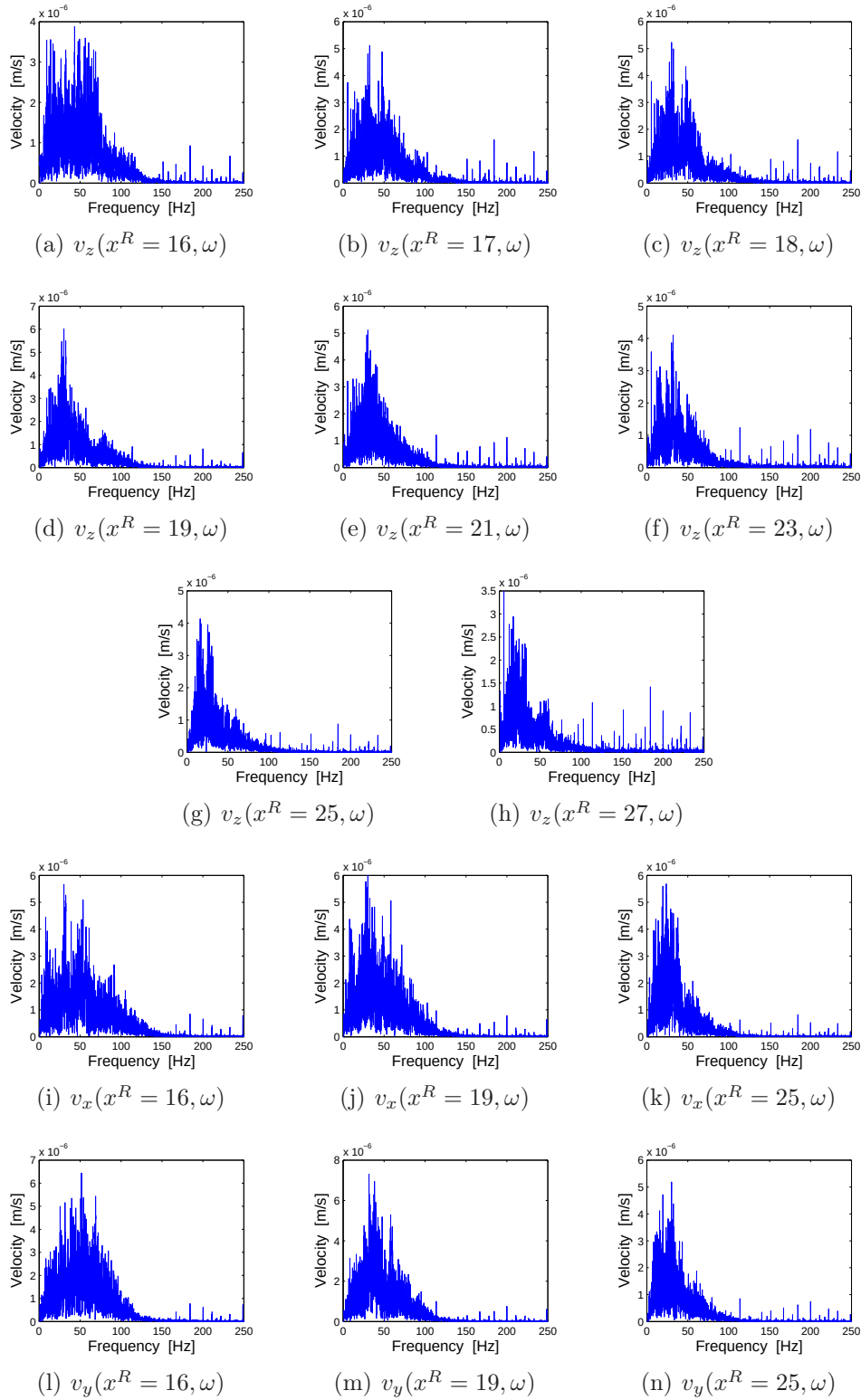


Figure 3.43: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 85 km/h

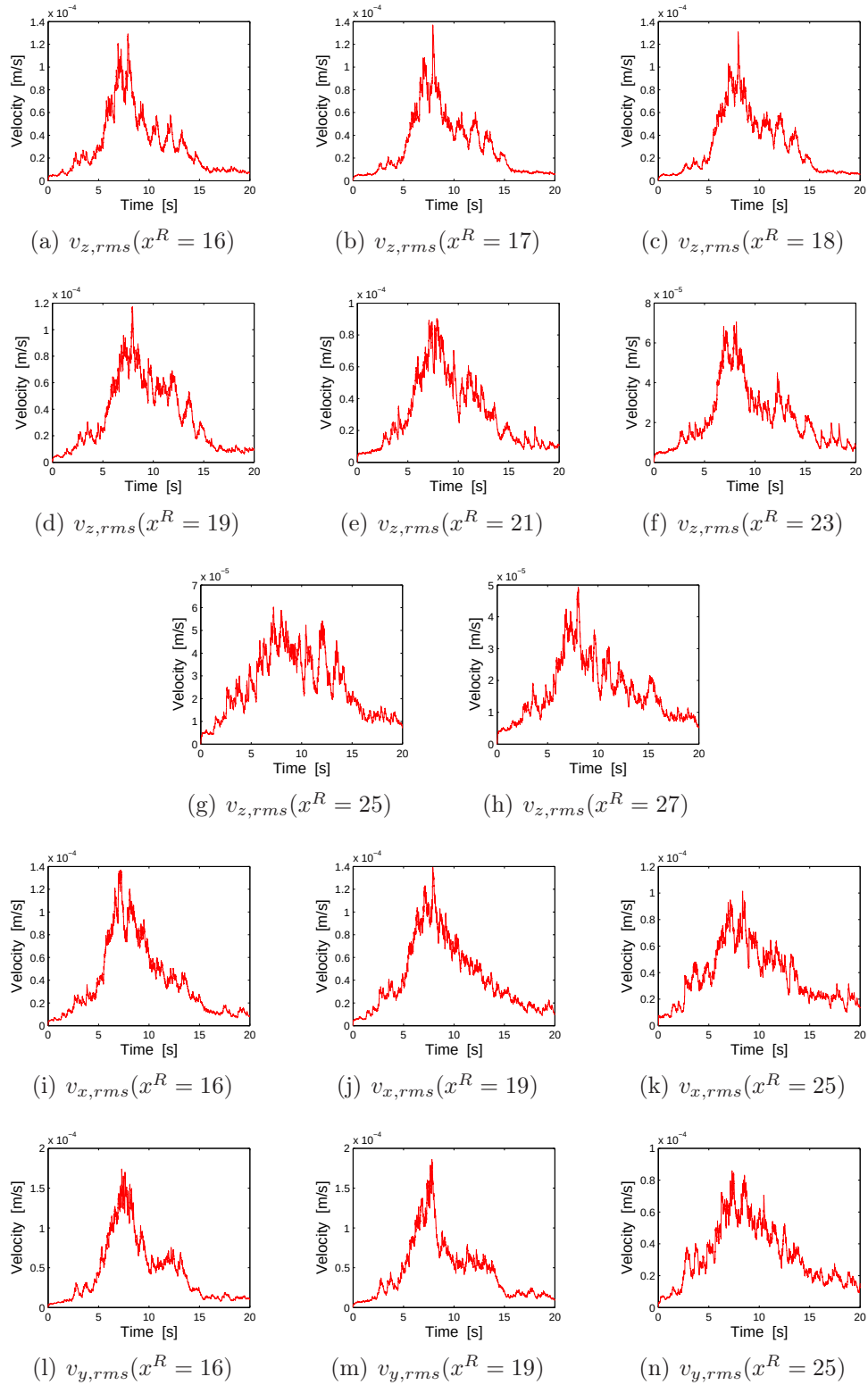


Figure 3.44: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 85 km/h

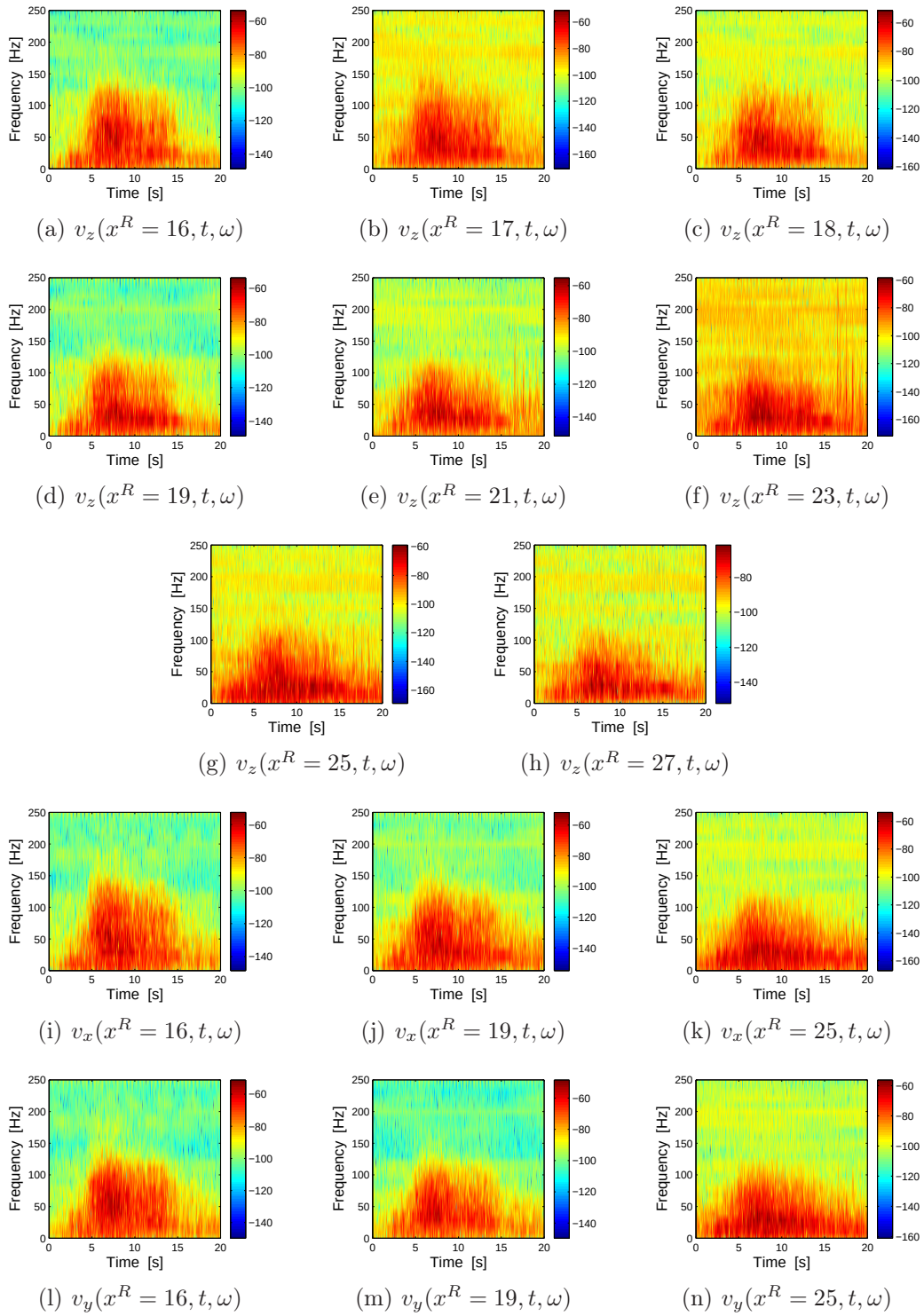


Figure 3.45: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 85 km/h

3.12 AM75 unit at 95 km/h

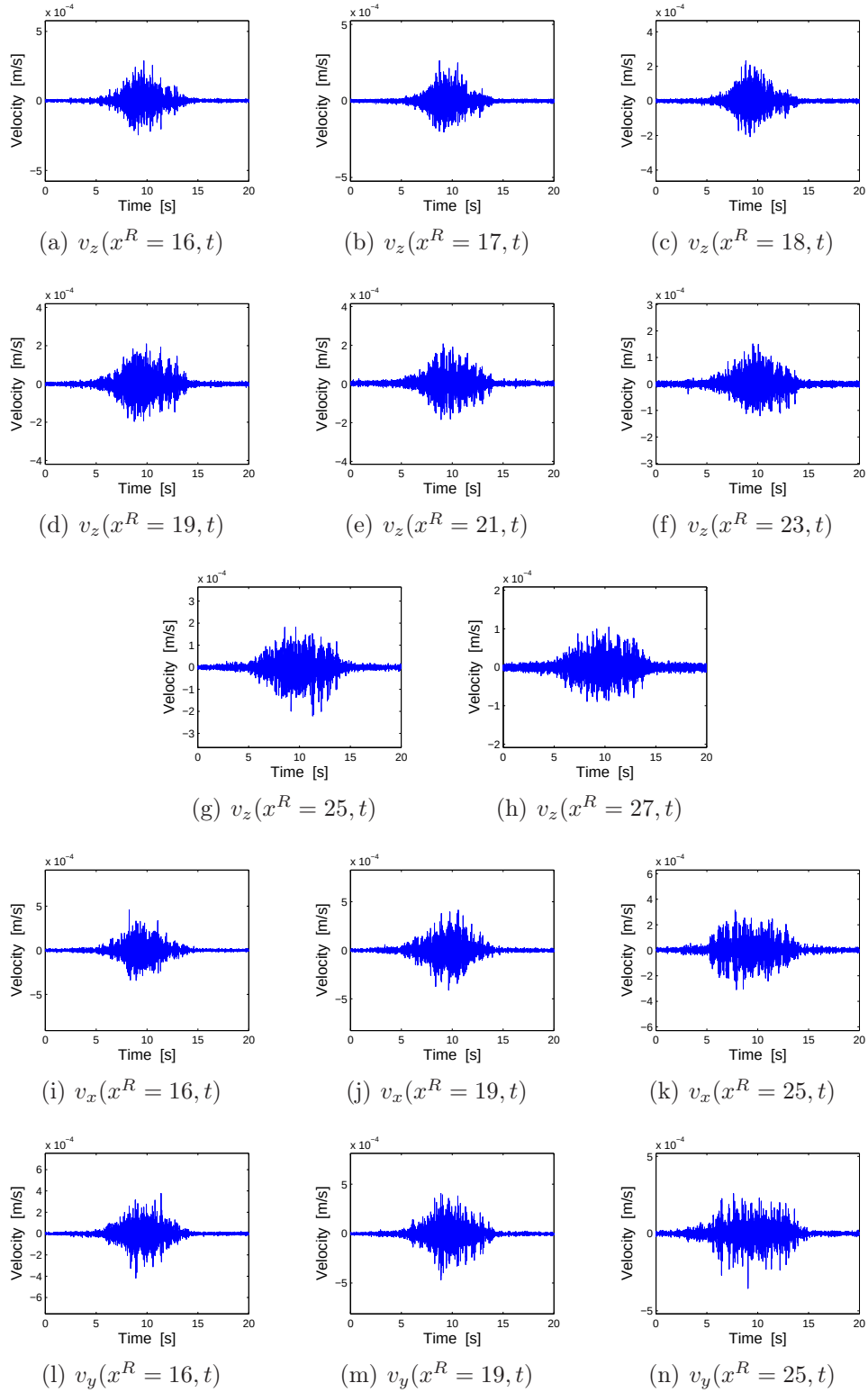


Figure 3.46: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 95 km/h

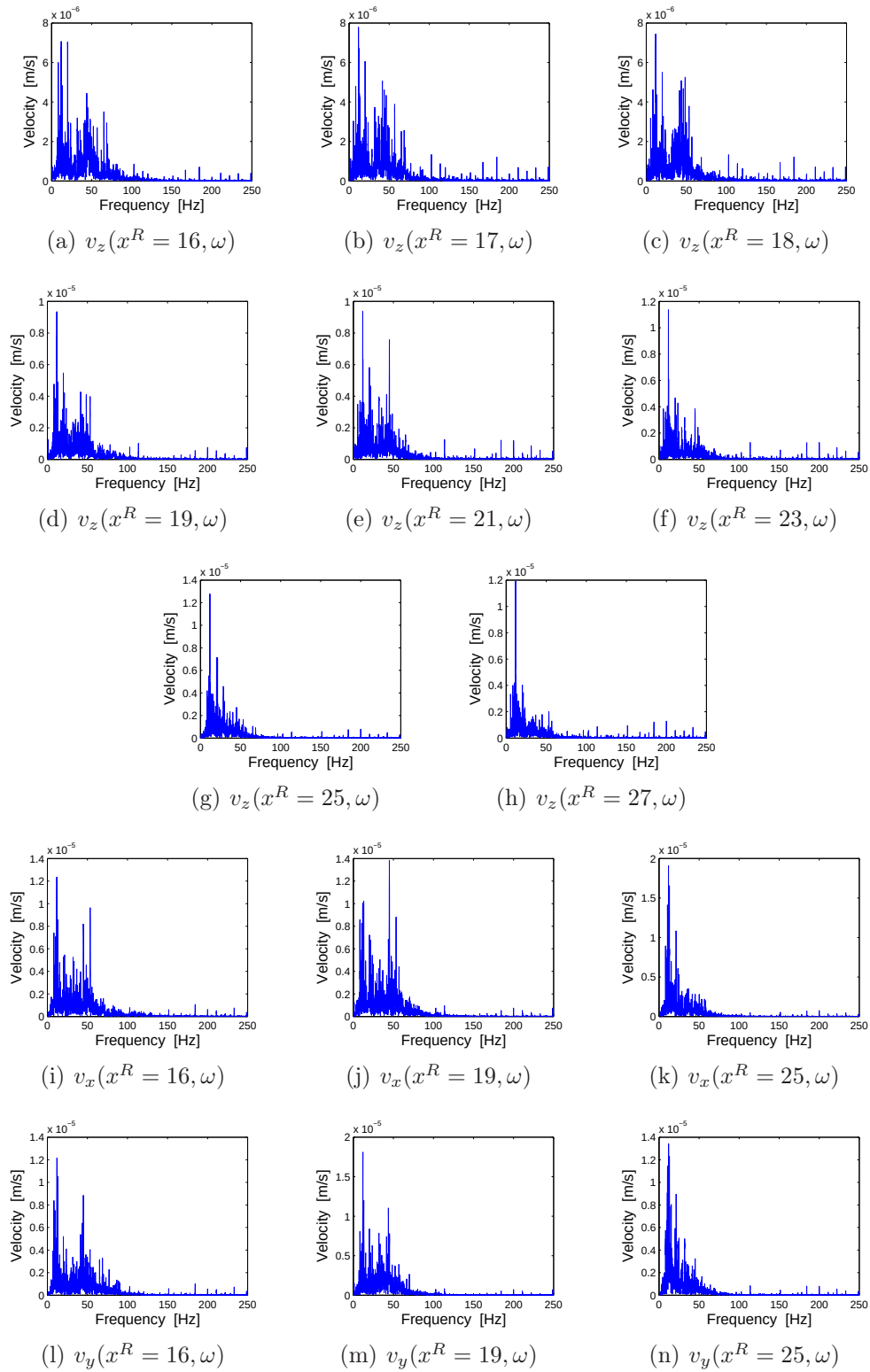


Figure 3.47: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 95 km/h

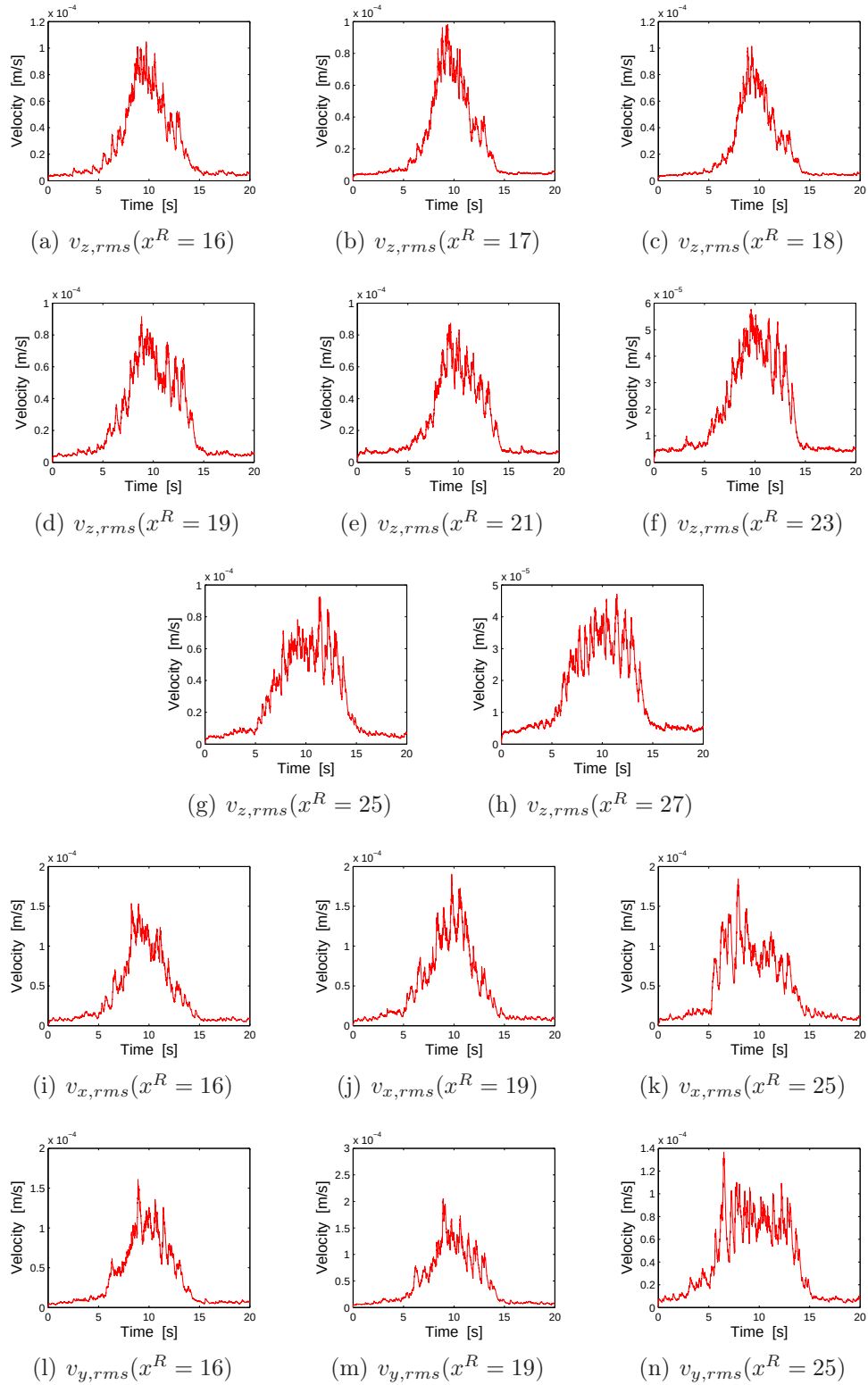


Figure 3.48: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 95 km/h

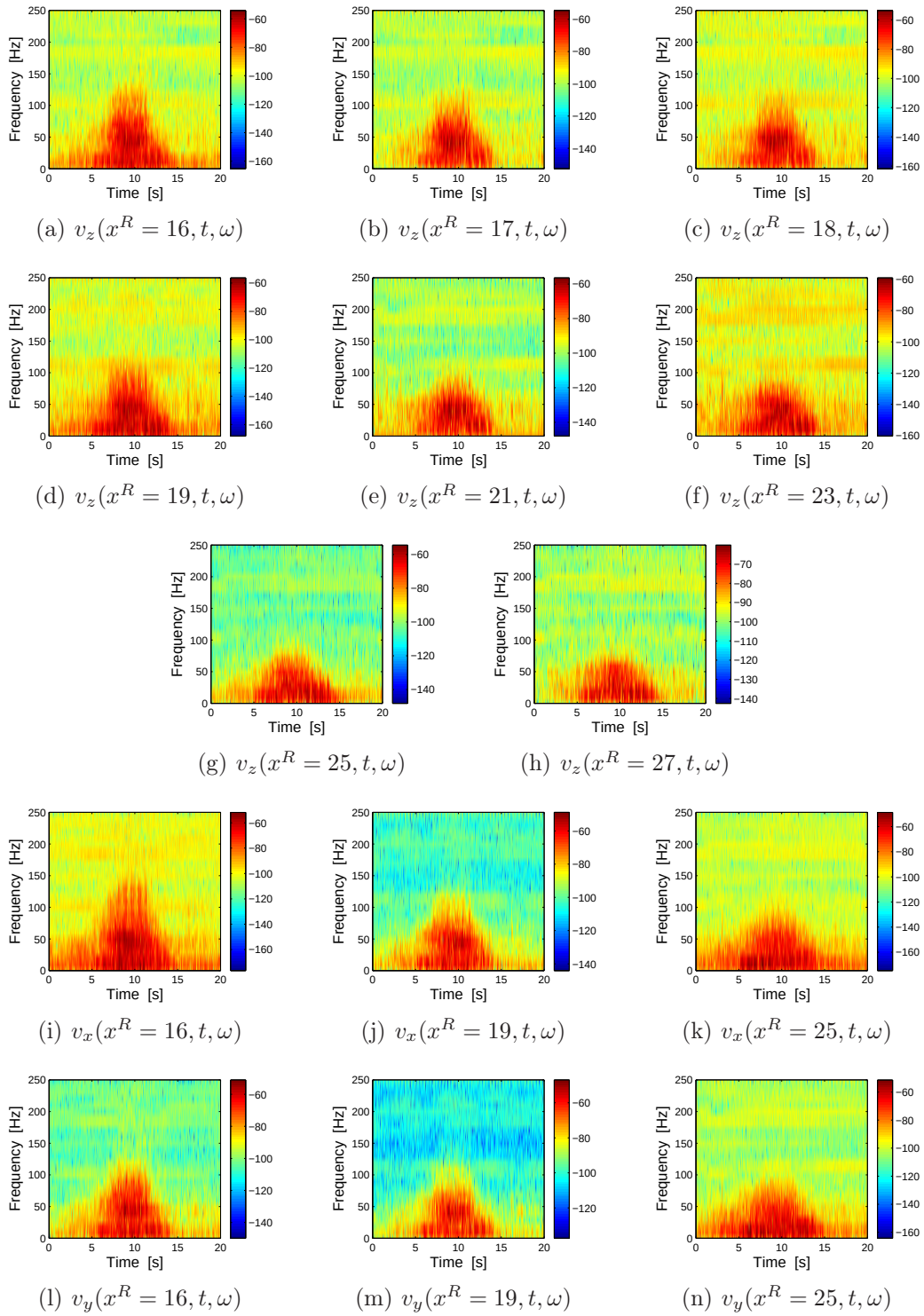


Figure 3.49: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 95 km/h

3.13 AM96 unit at 120 km/h

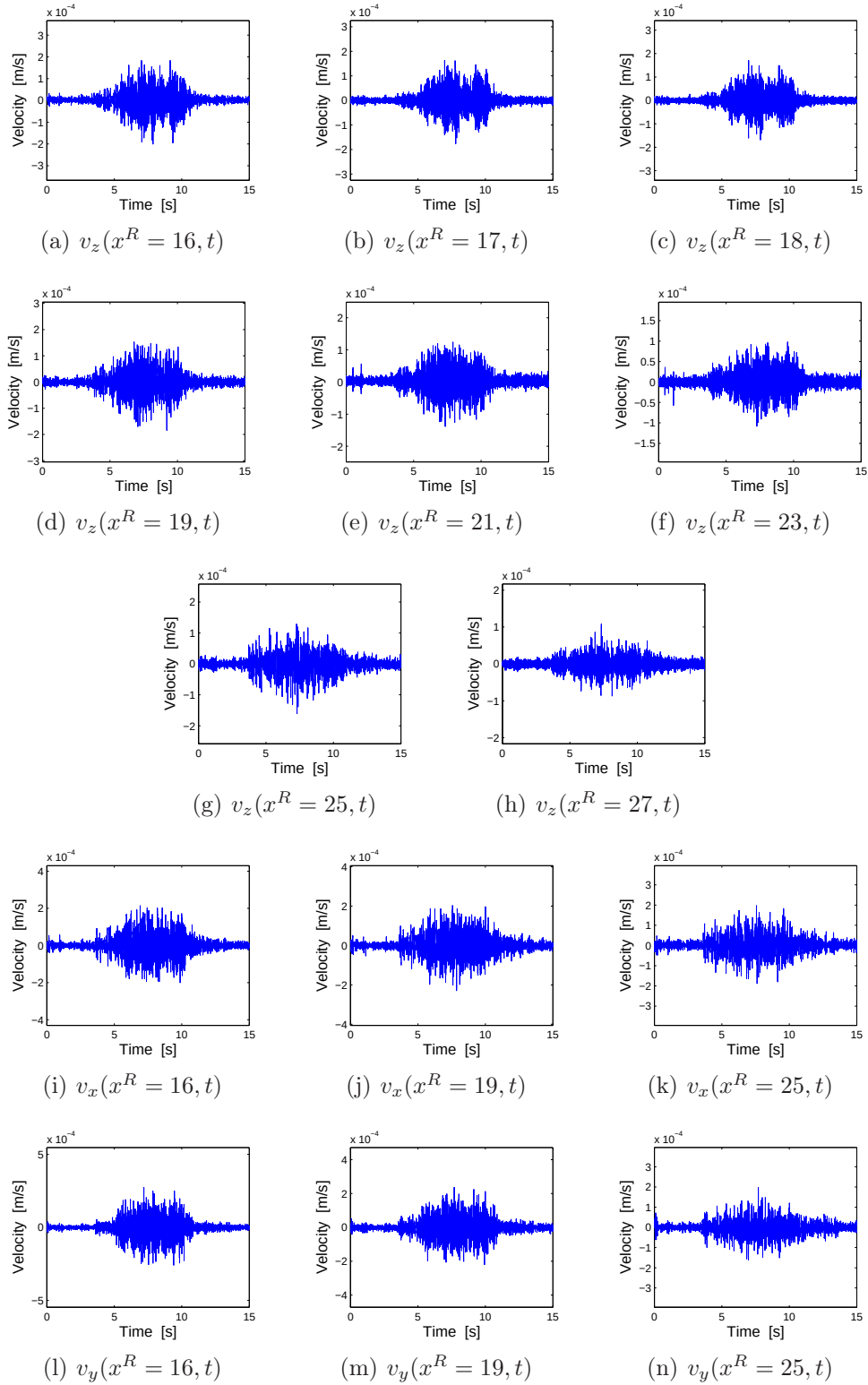


Figure 3.50: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 120 km/h

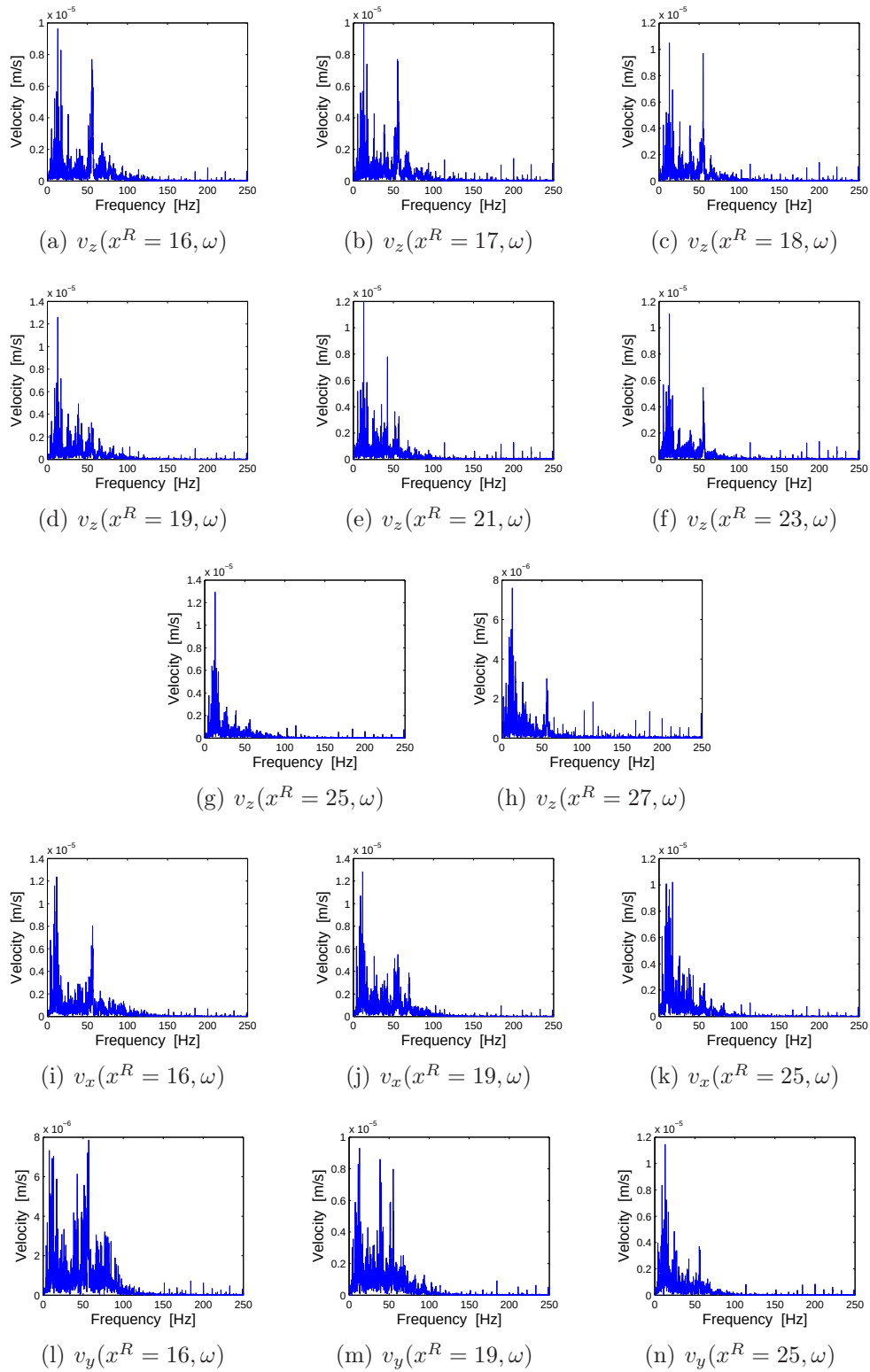


Figure 3.51: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 120 km/h

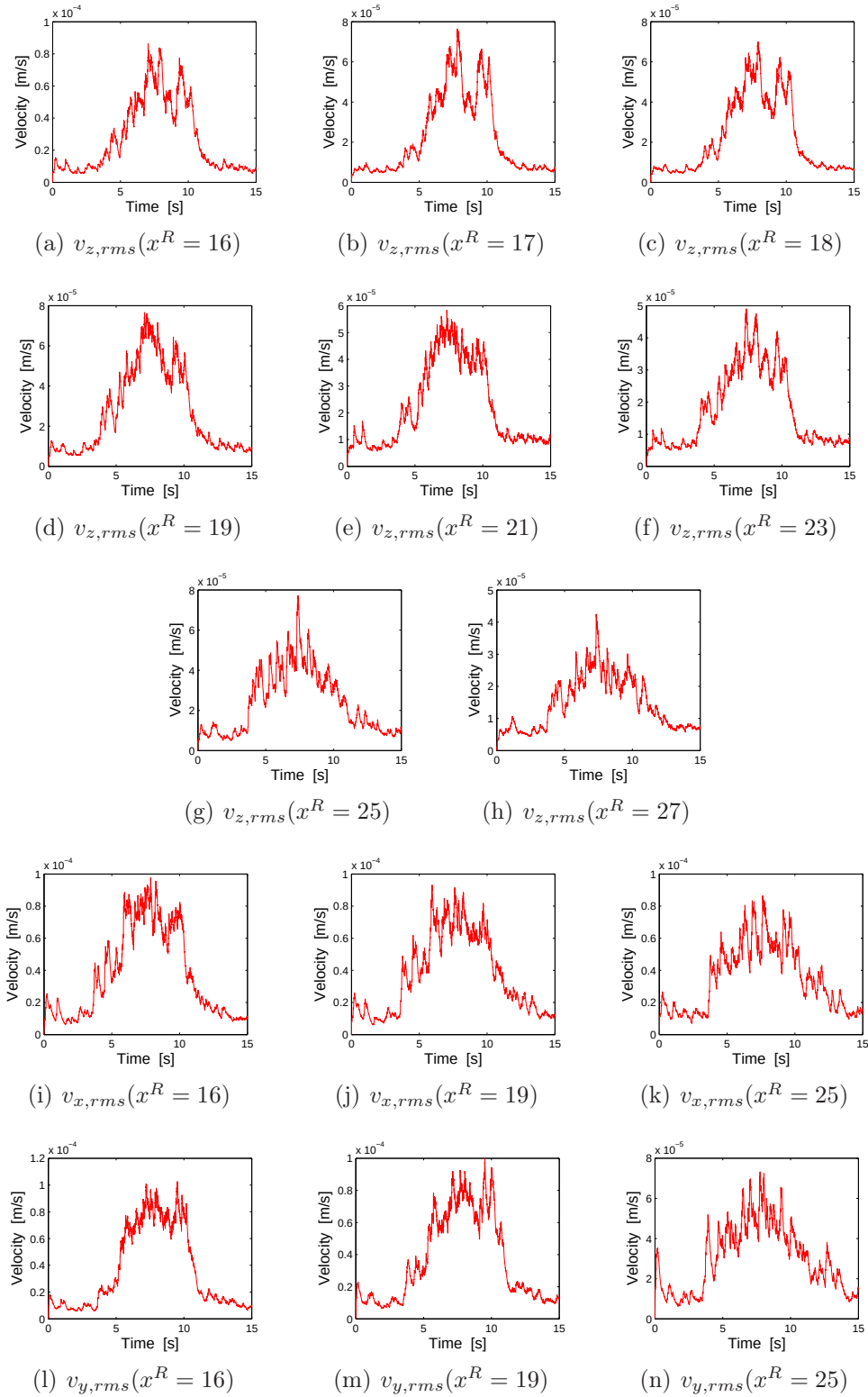


Figure 3.52: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 120 km/h

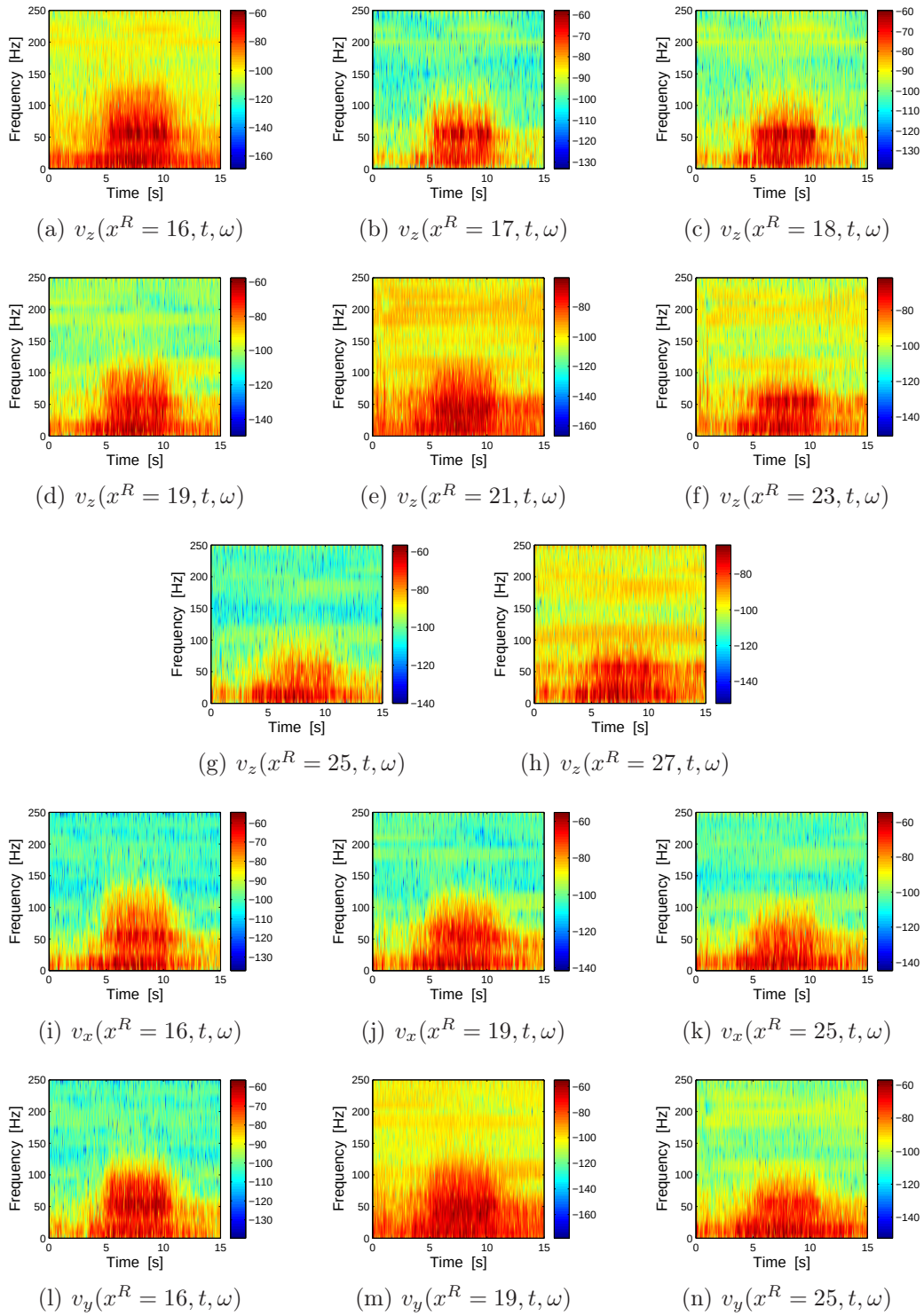


Figure 3.53: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 120 km/h

3.14 AM96 unit at 120 km/h

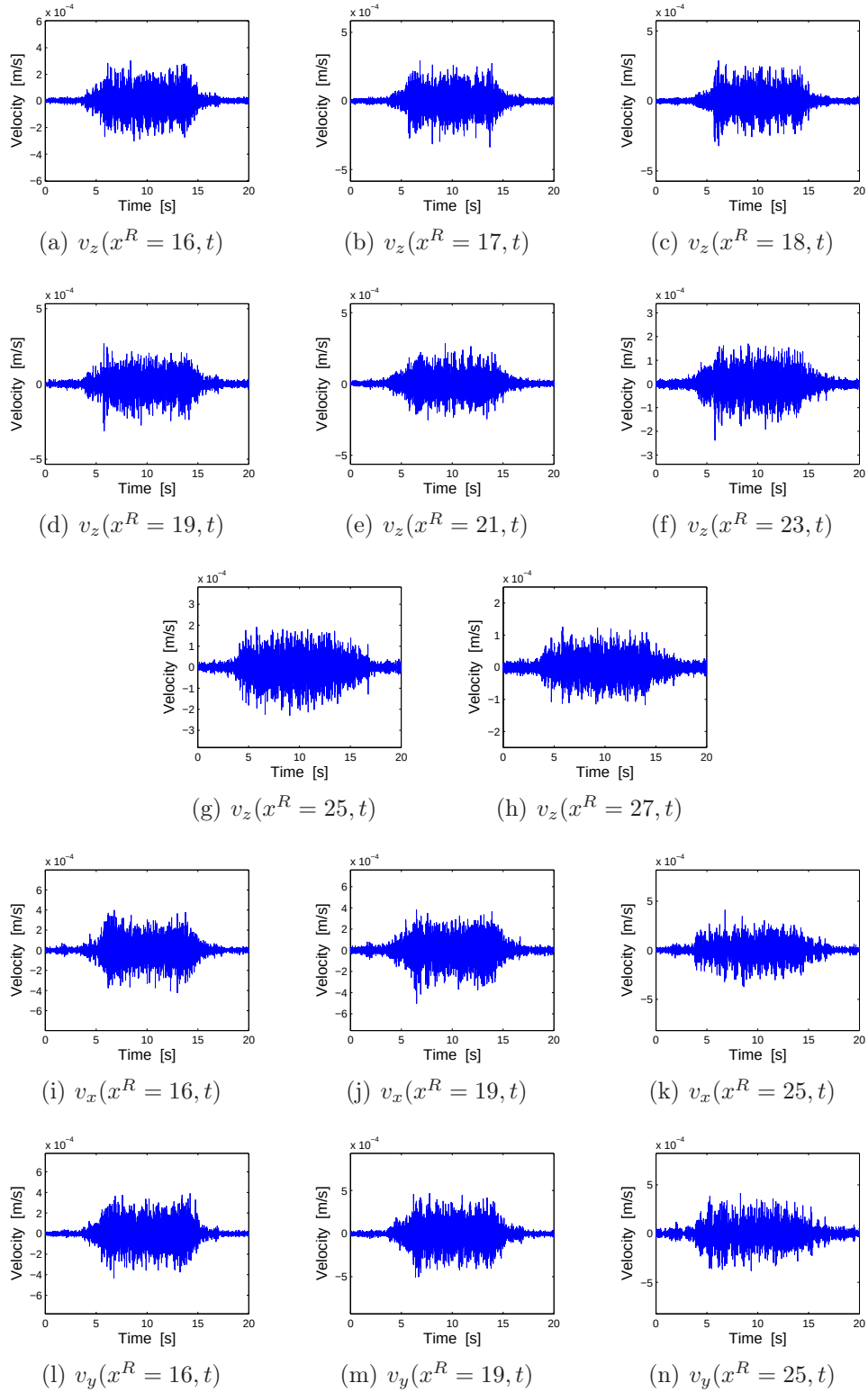


Figure 3.54: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 120 km/h

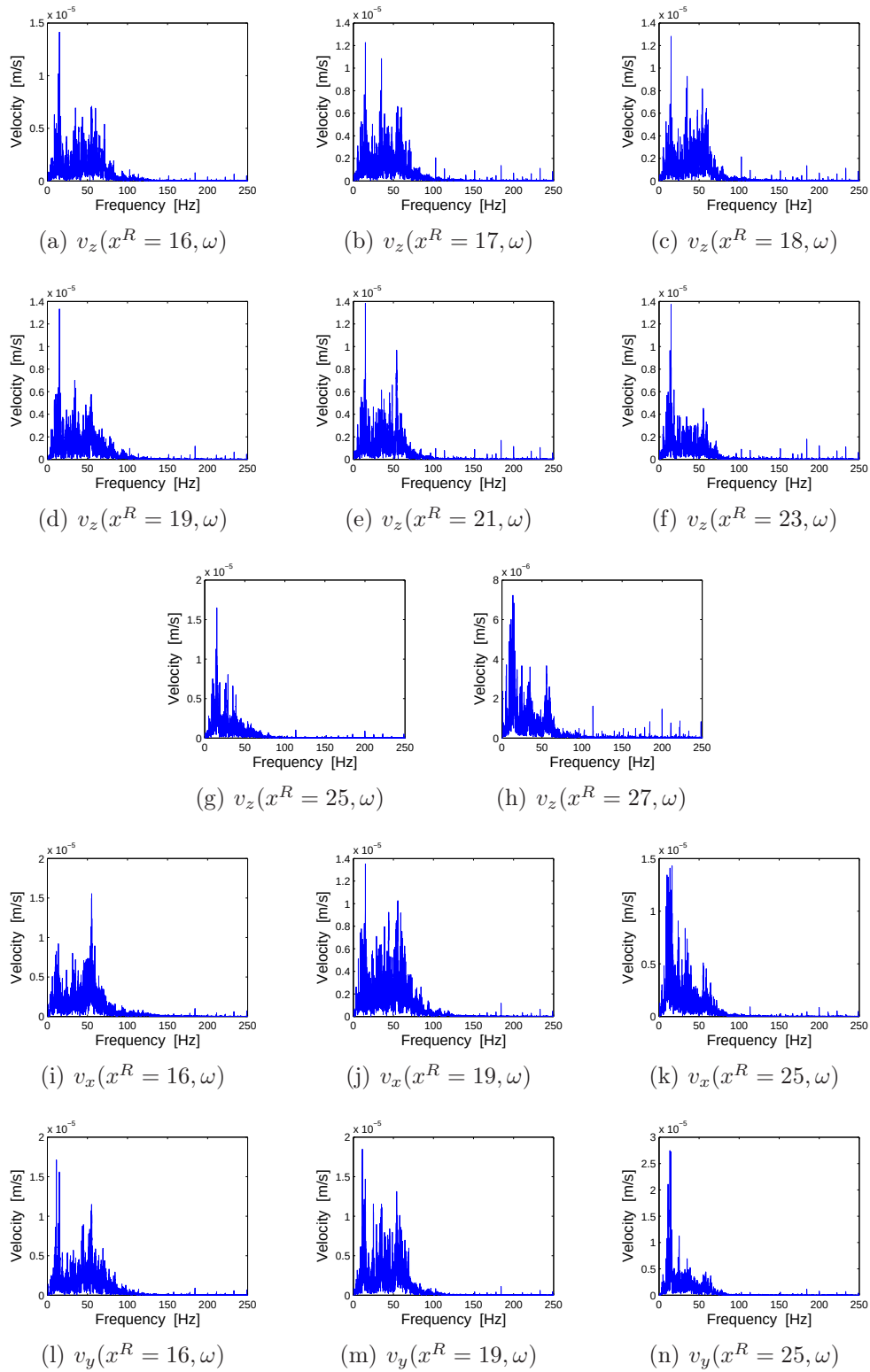


Figure 3.55: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 120 km/h

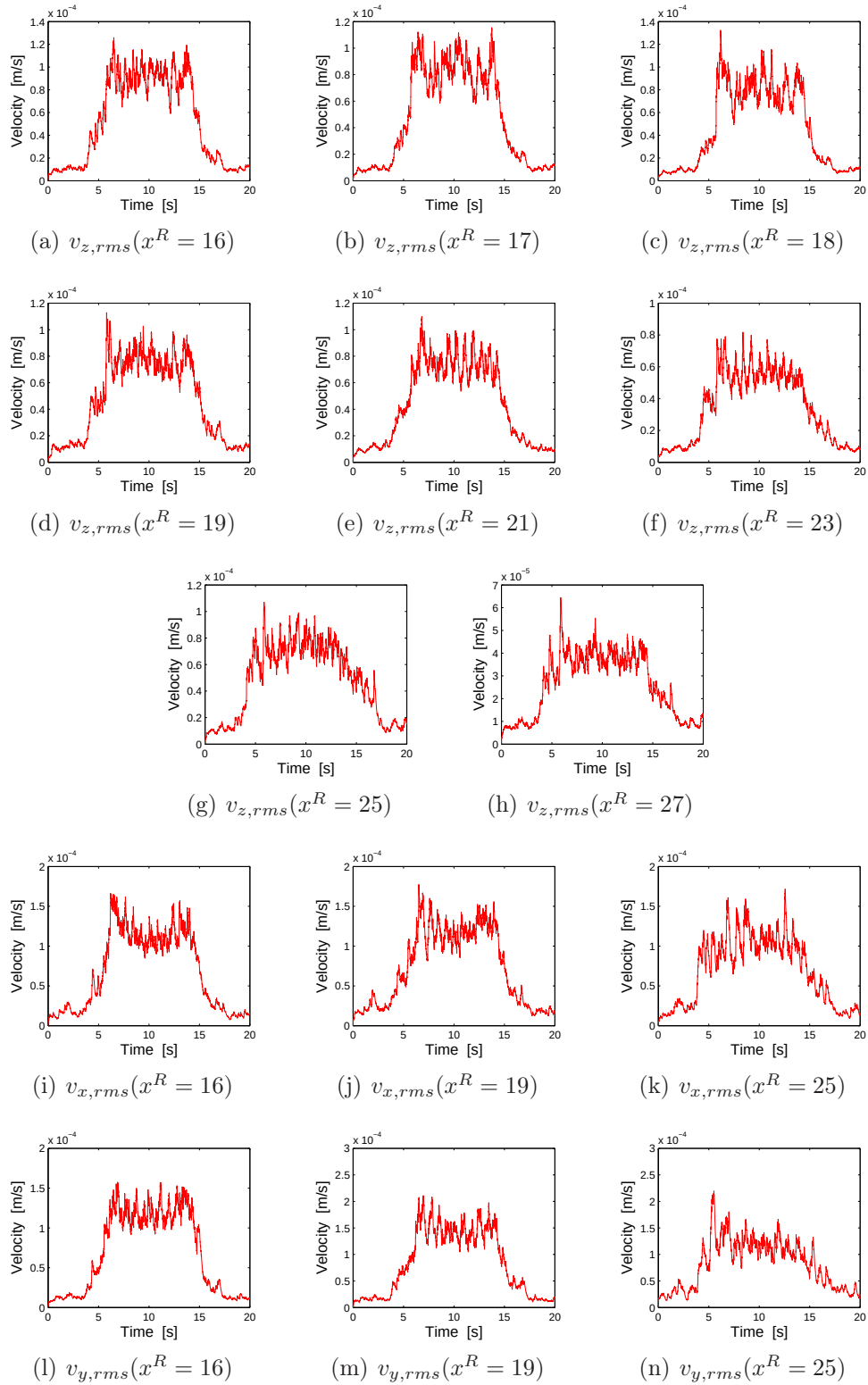


Figure 3.56: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 120 km/h

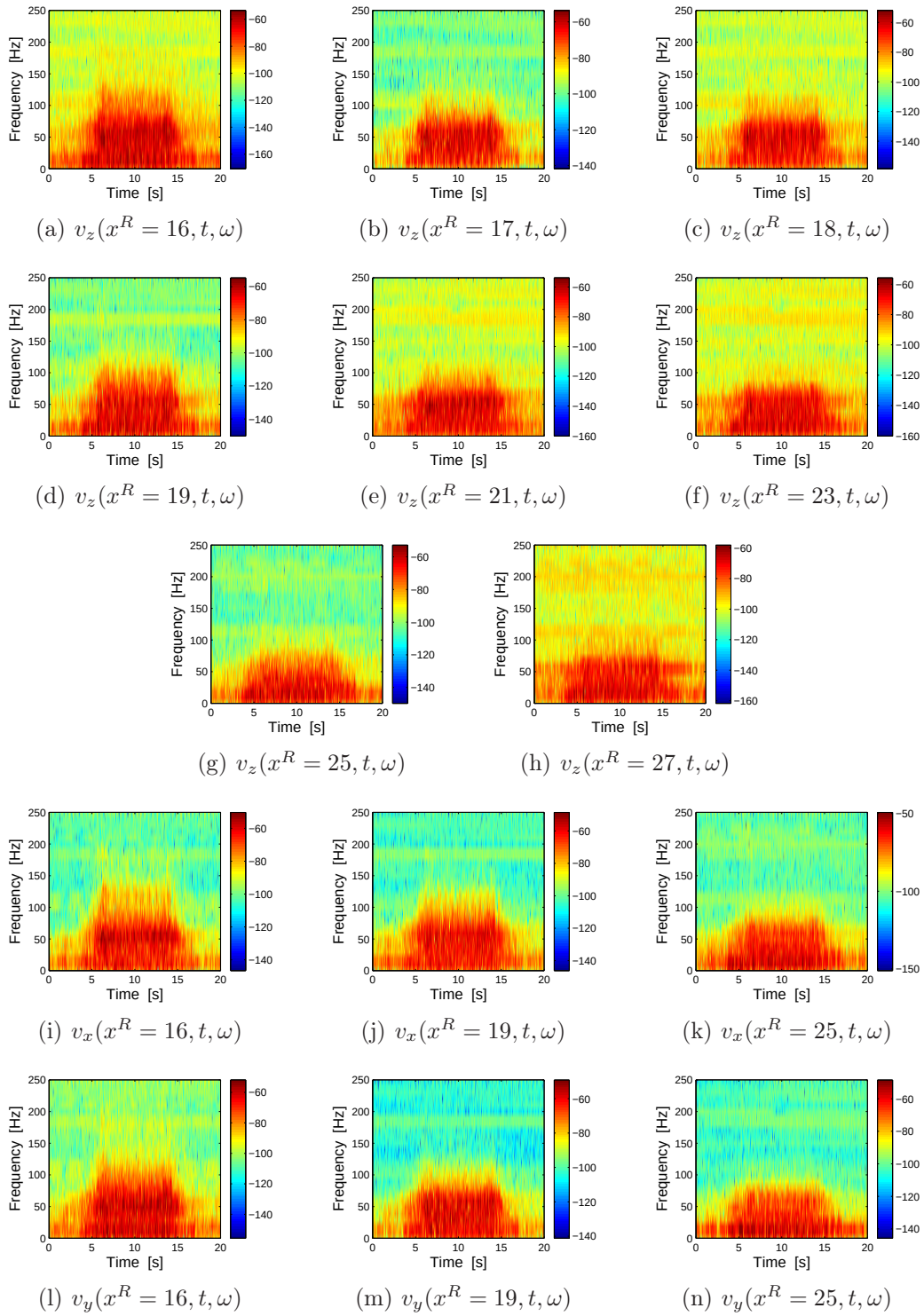


Figure 3.57: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 120 km/h

3.15 M5 railcar at 110 km/h

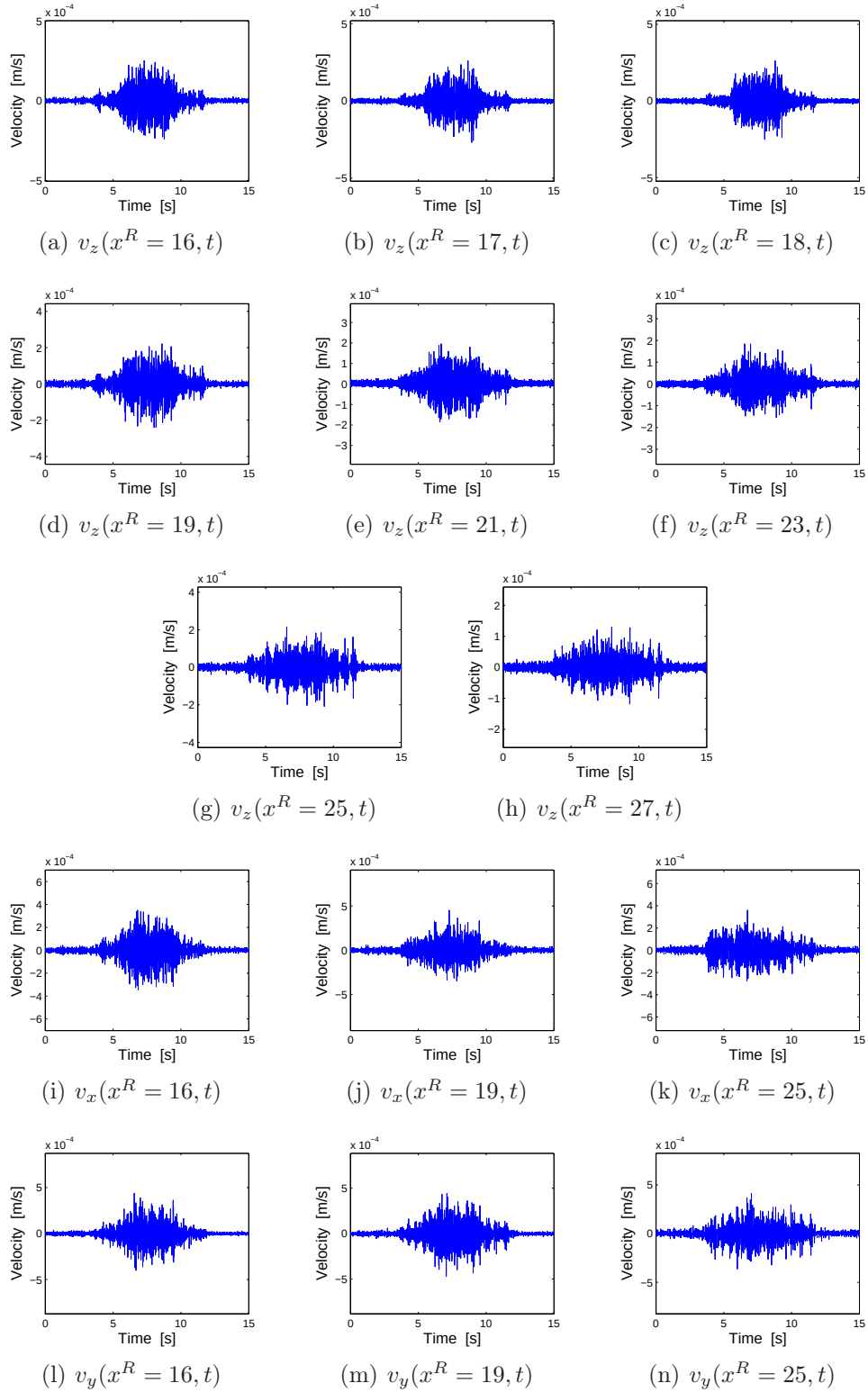


Figure 3.58: Time history of the vertical and horizontal velocities measured in free field during the passage of a M5 railcar at 110 km/h

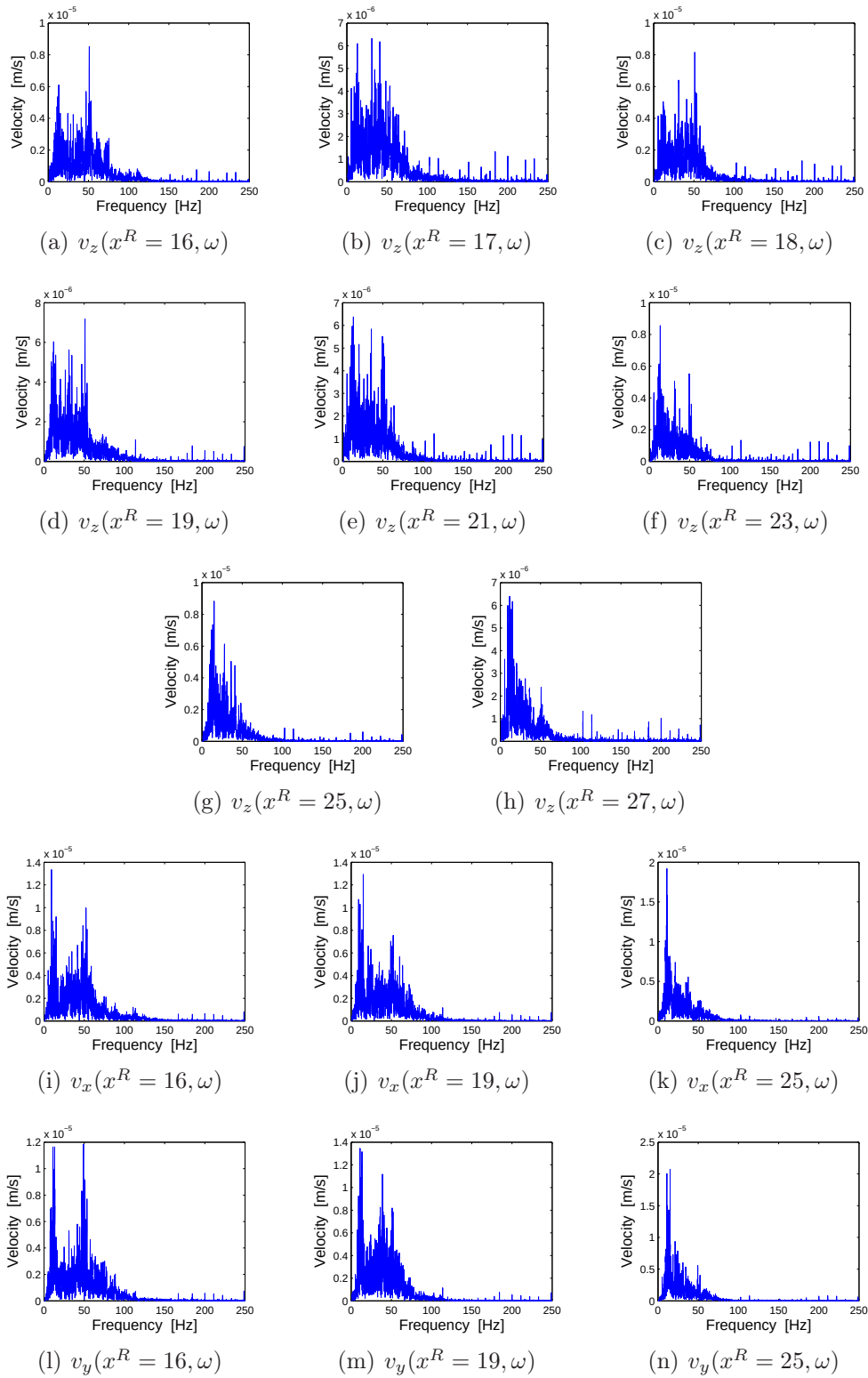


Figure 3.59: Spectral content of the vertical and horizontal velocities measured in free field during the passage of a M5 railcar at 110 km/h

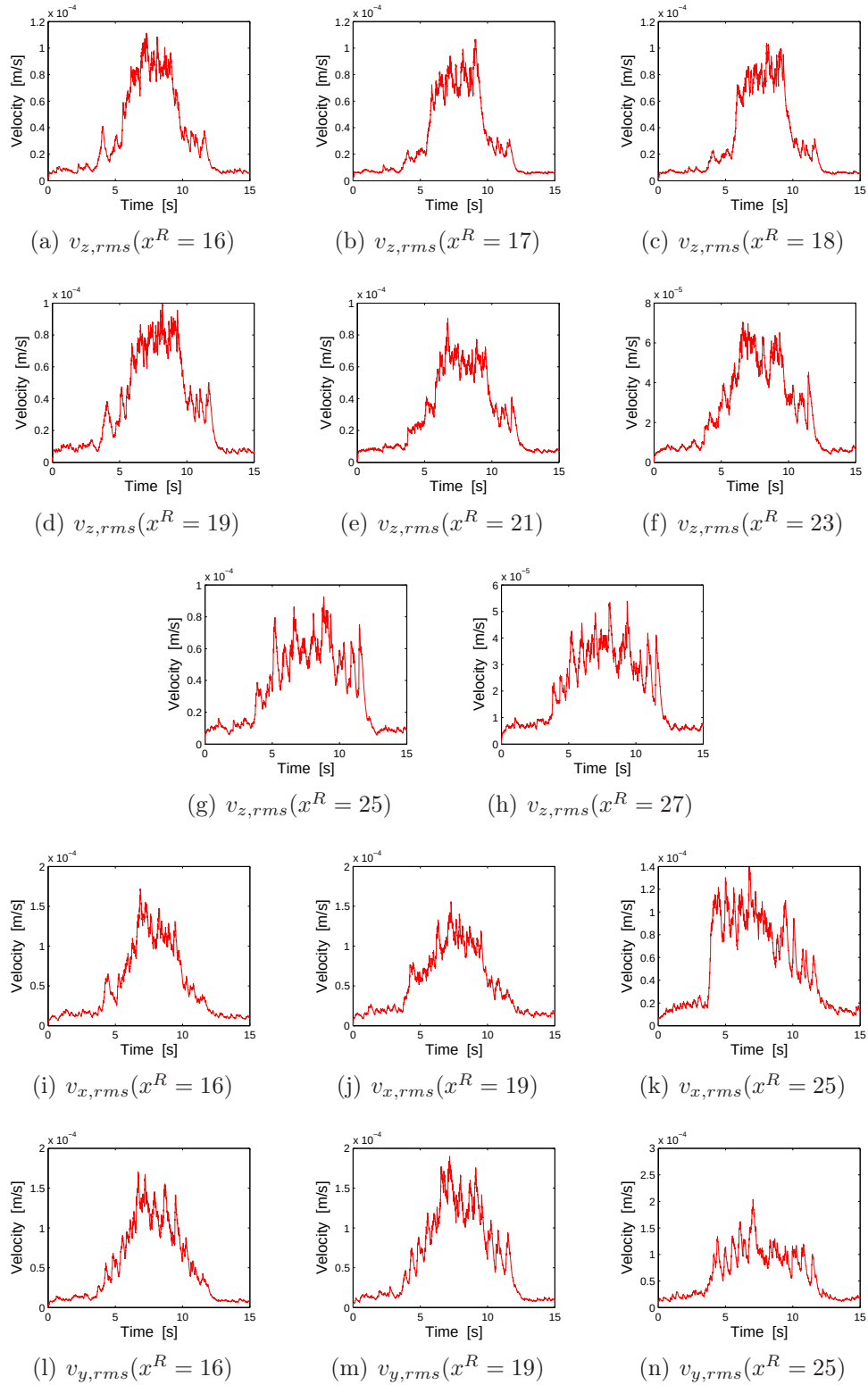


Figure 3.60: Time-average of the vertical and horizontal velocities measured in free field during the passage of a M5 railcar at 110km/h

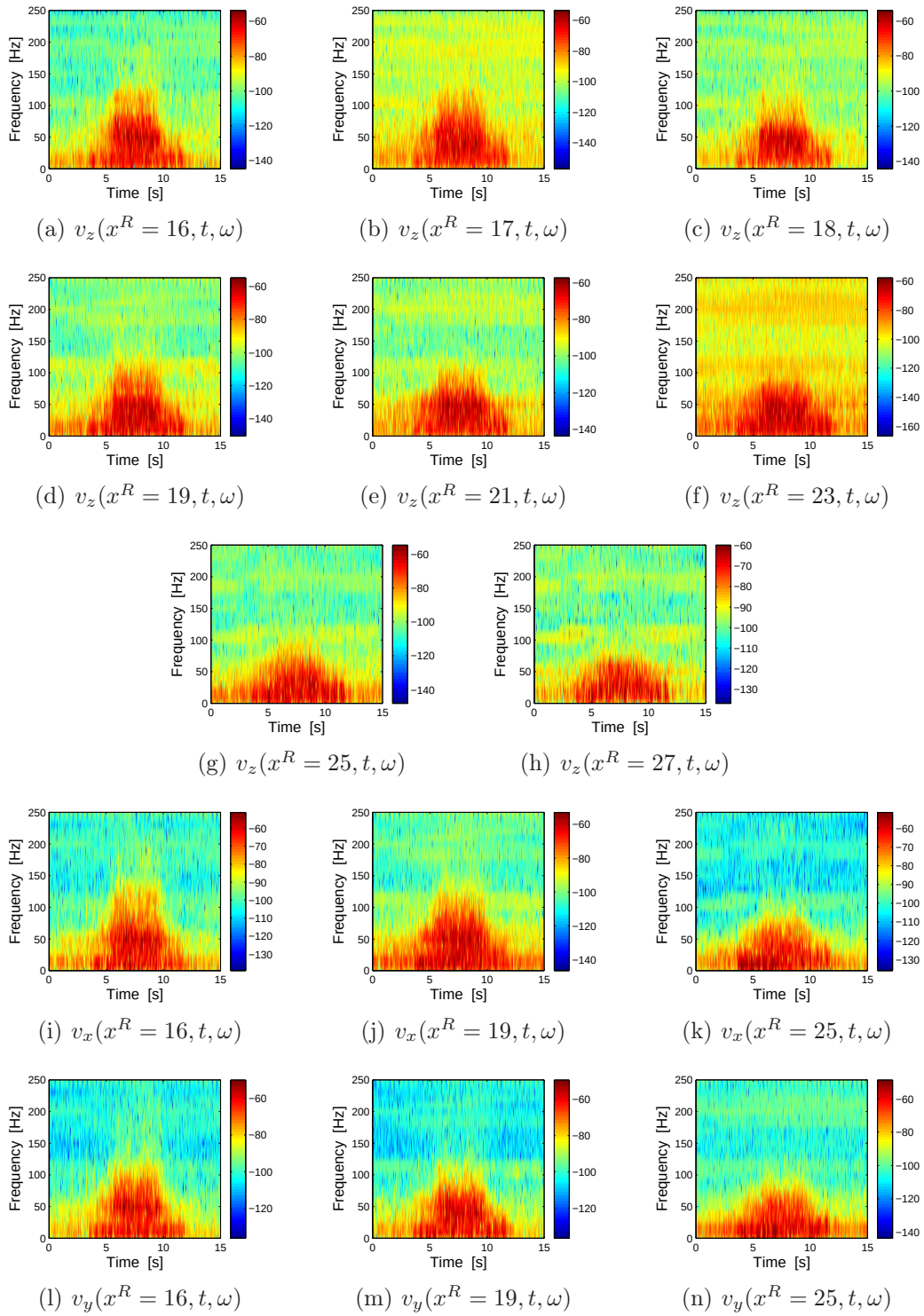


Figure 3.61: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of a M5 railcar at 110 km/h

3.16 AM75 unit at 105 km/h

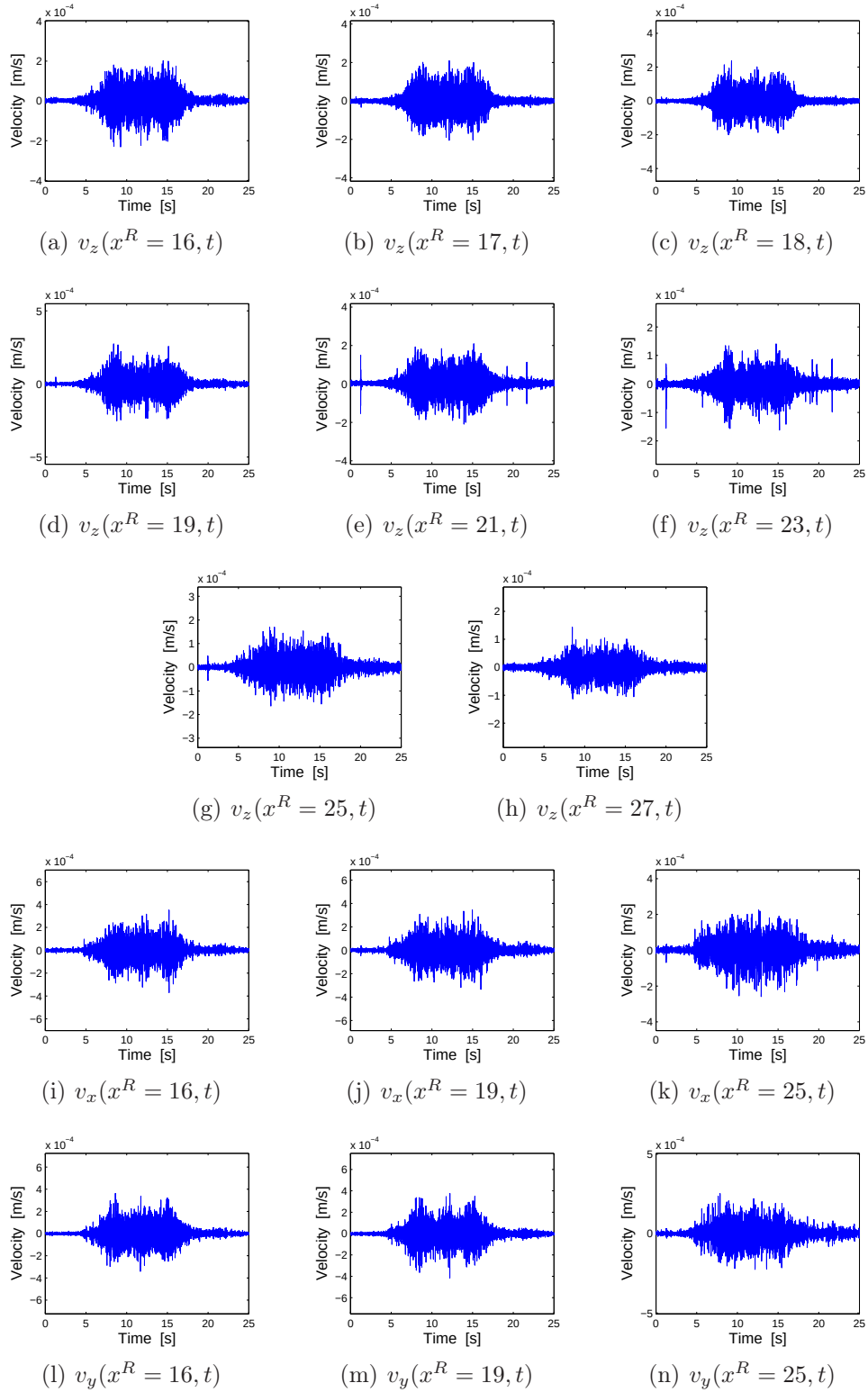


Figure 3.62: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 105 km/h

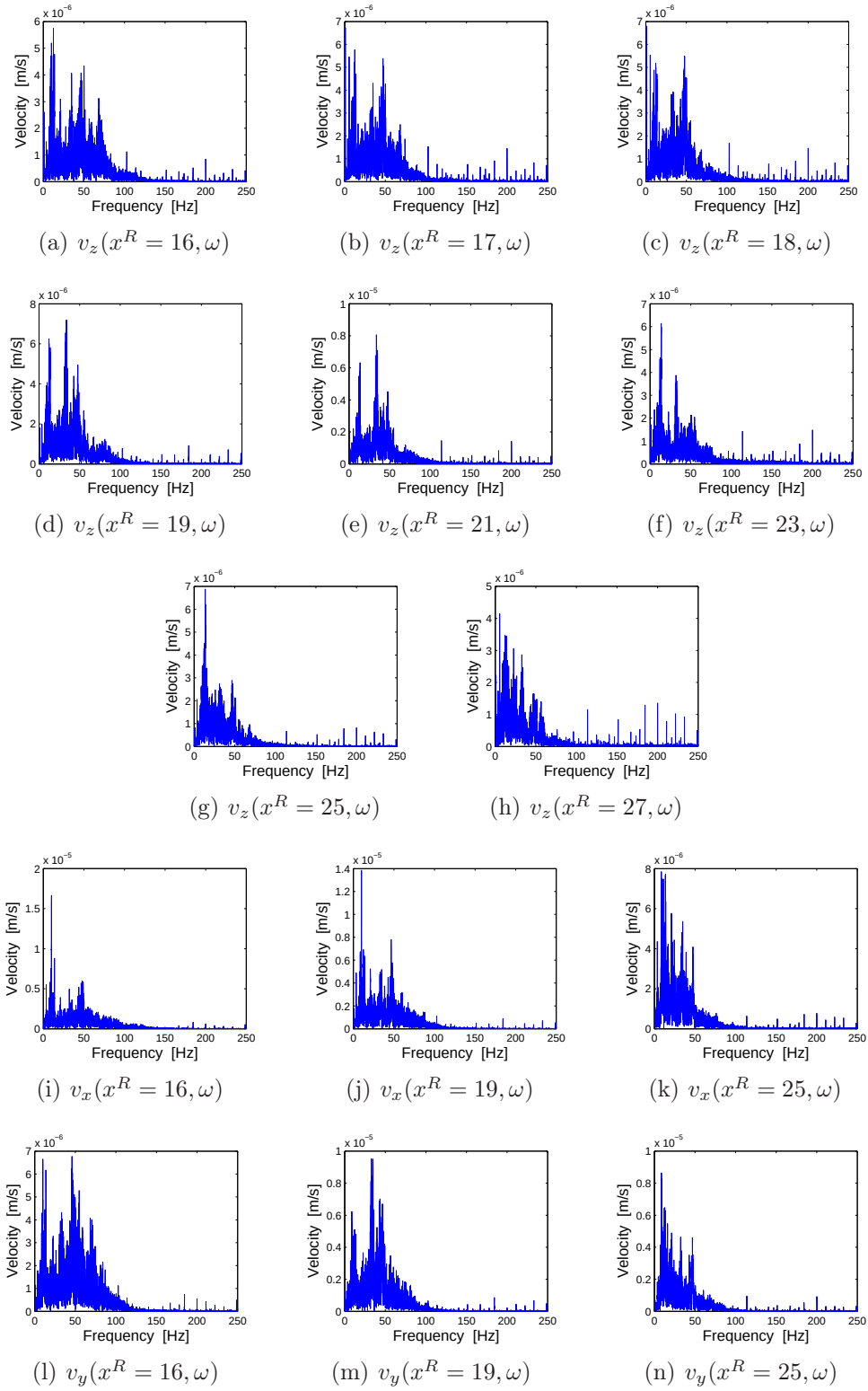


Figure 3.63: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 105 km/h

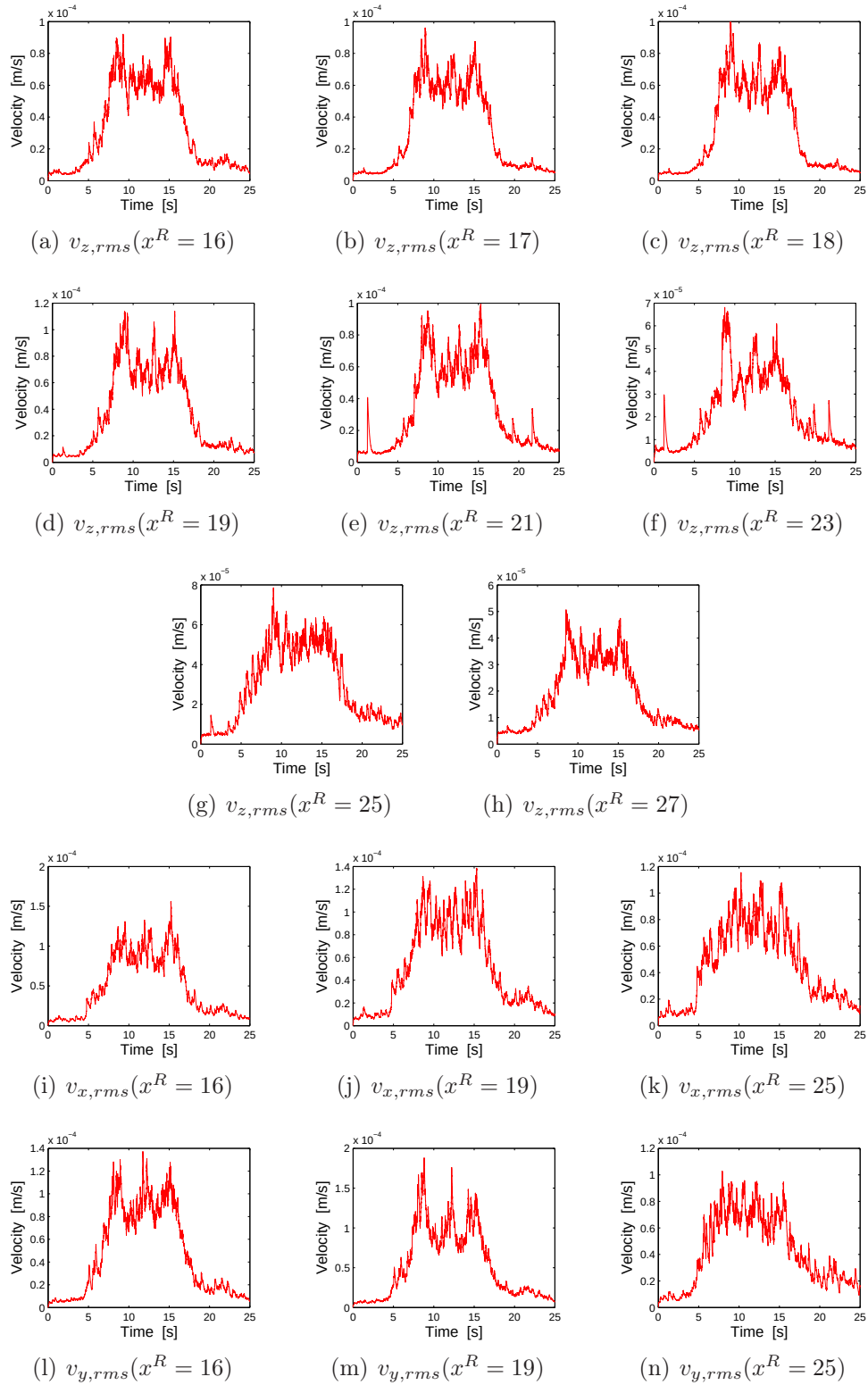


Figure 3.64: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 105 km/h

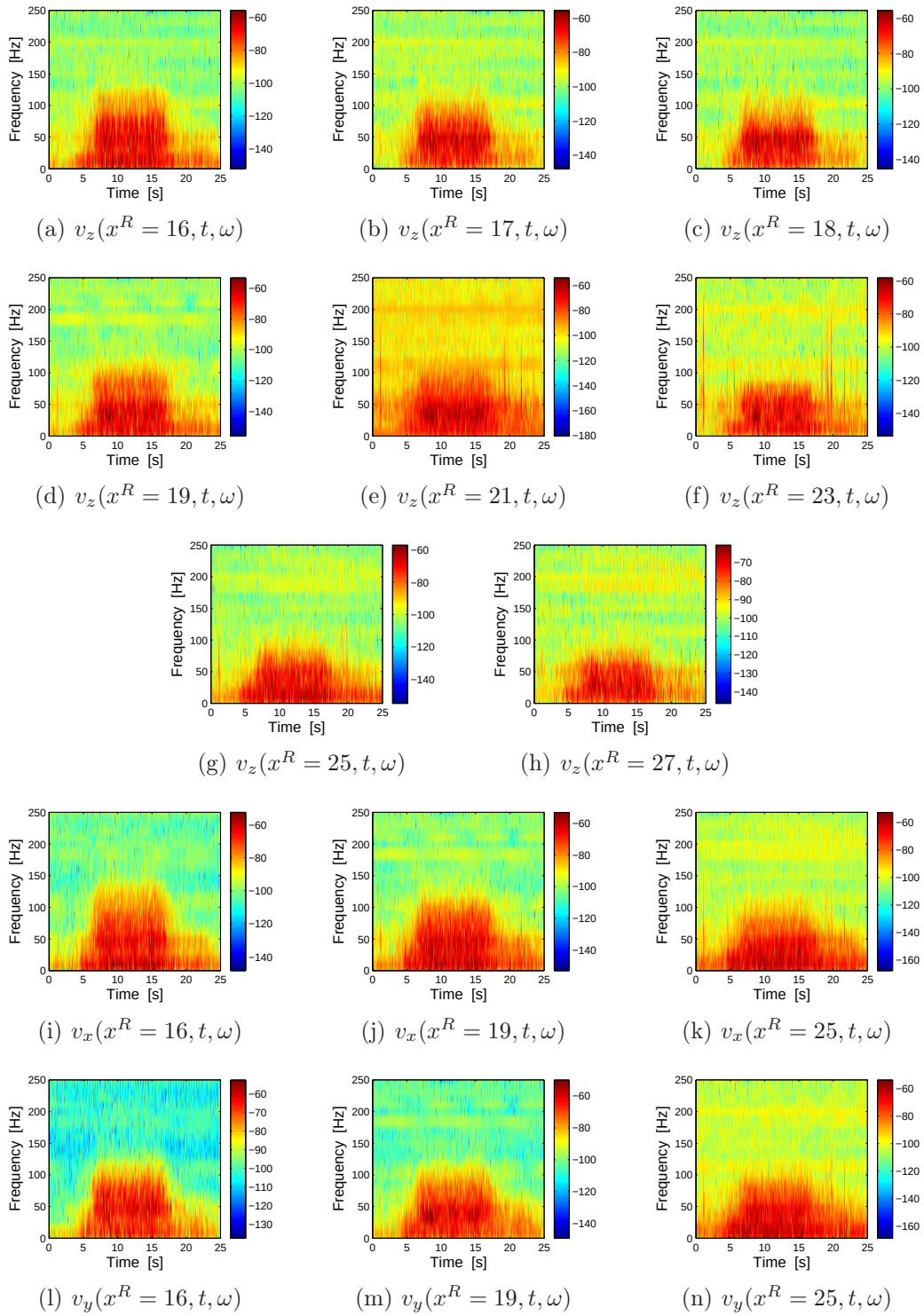


Figure 3.65: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 105 km/h

3.17 AM80 unit at 70 km/h

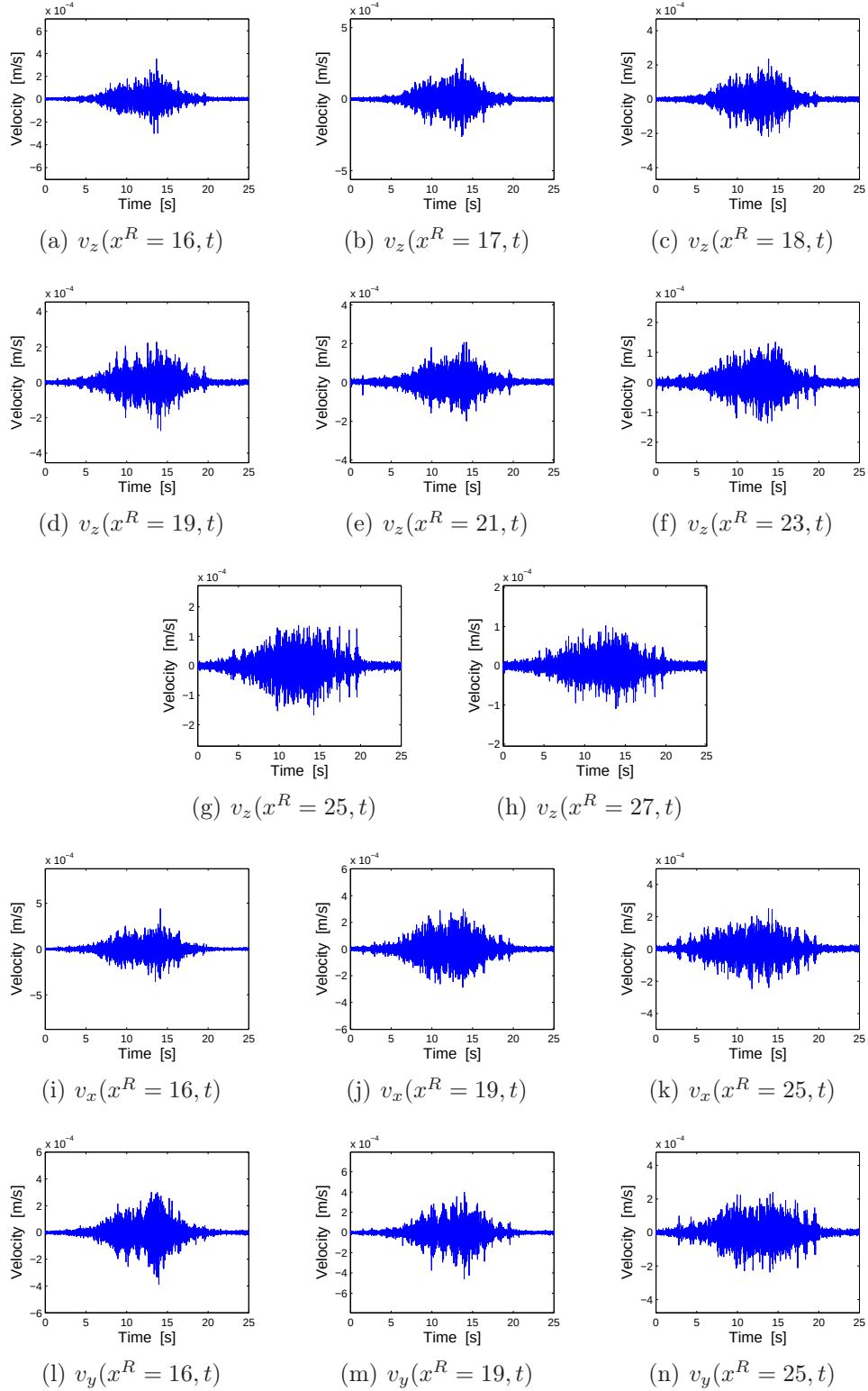


Figure 3.66: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 70 km/h

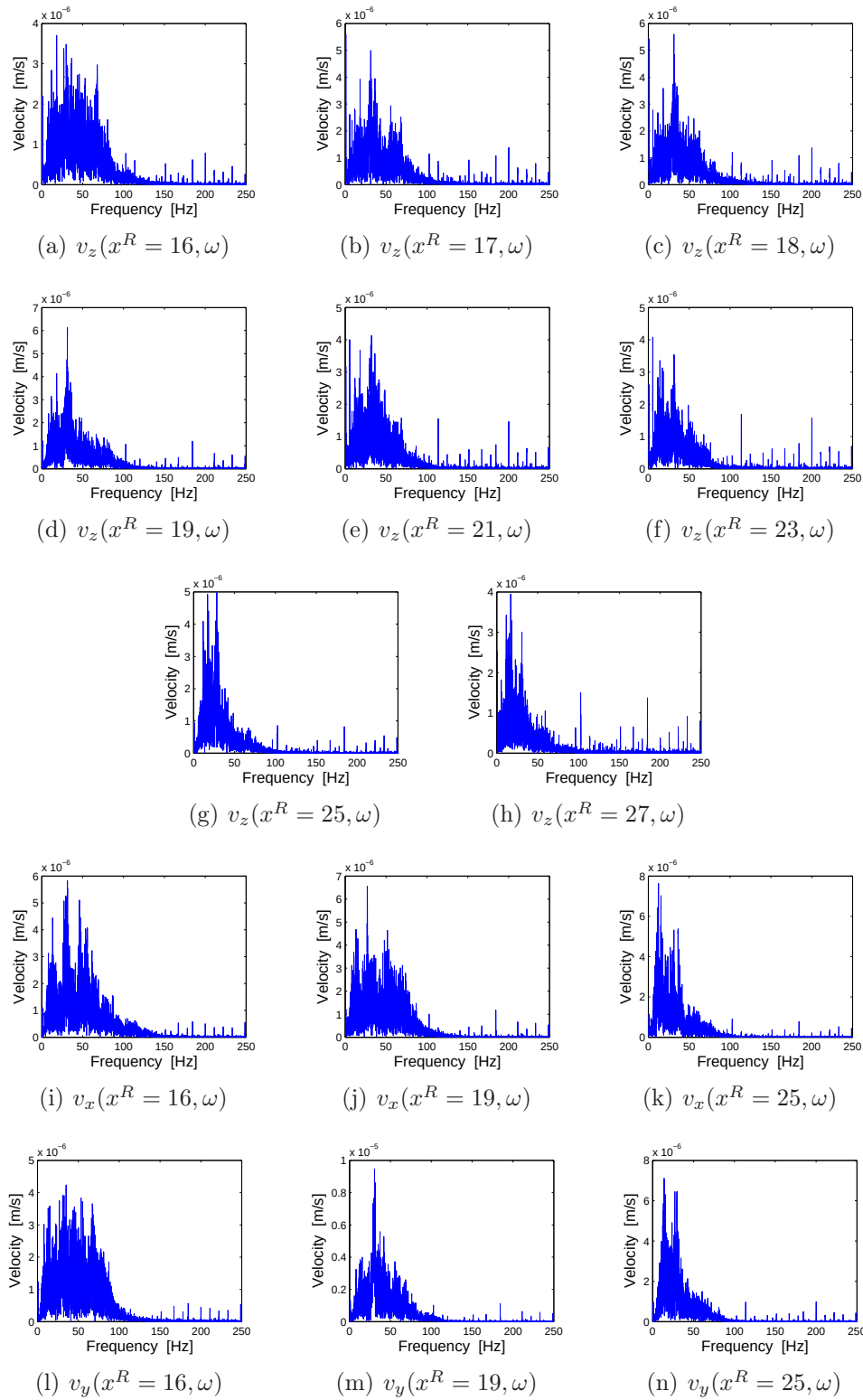


Figure 3.67: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 70 km/h

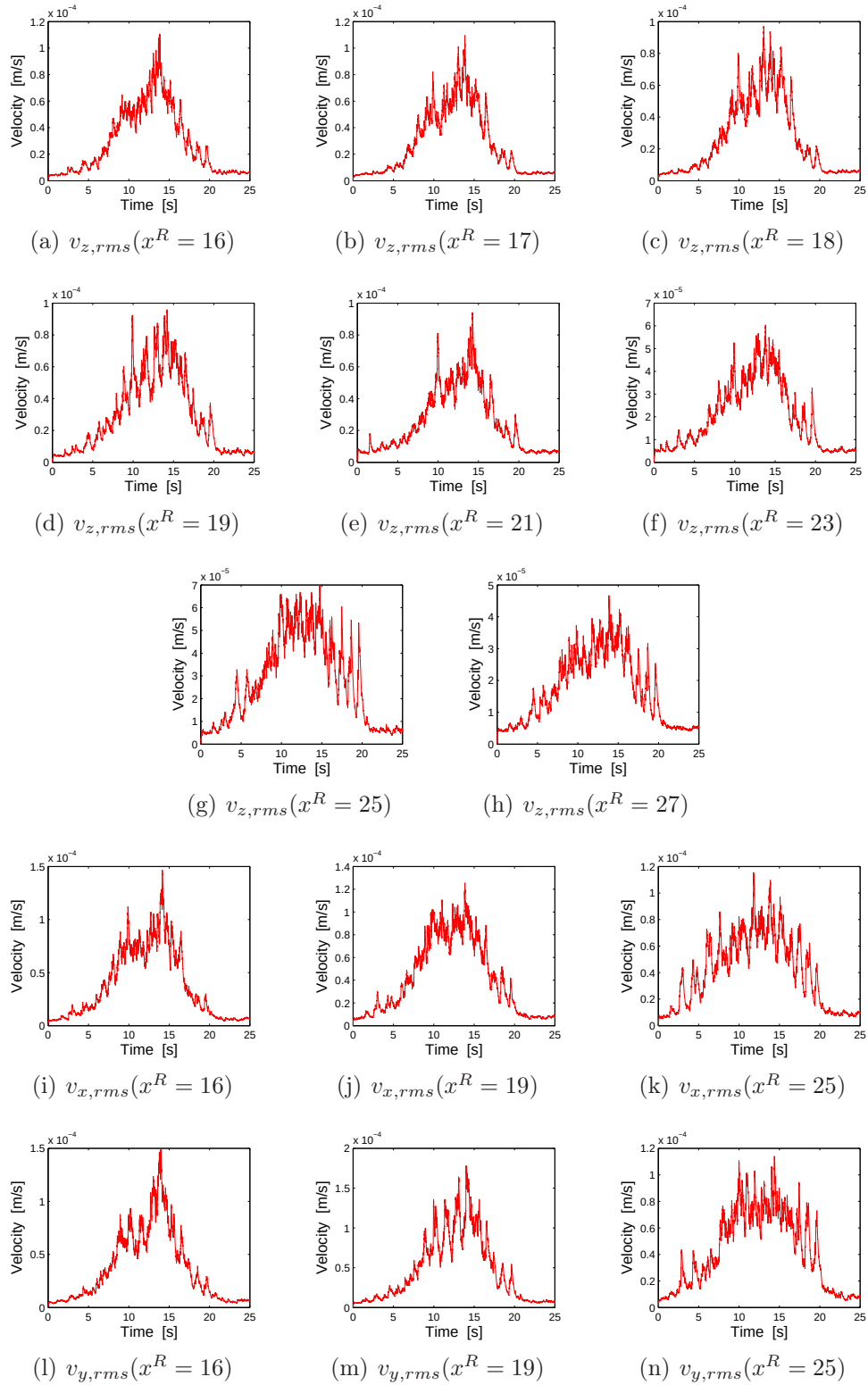


Figure 3.68: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 70 km/h

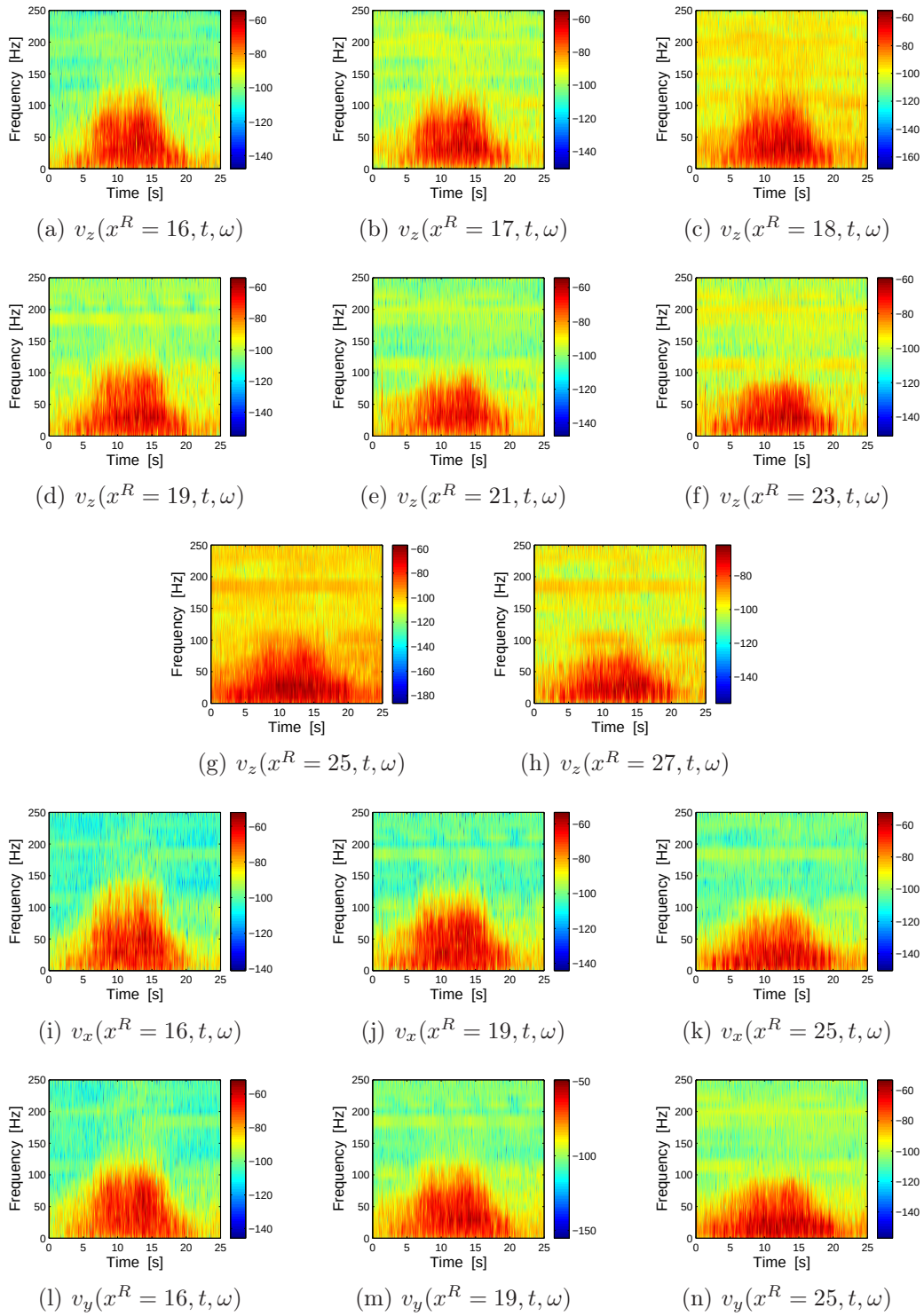


Figure 3.69: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 70 km/h

Train type	Track	Speed [km/h]	# carriages
AM86	A	65	2
AM80	A	70	2×2
HLE27+M4	A	110	$1 + 3$
AM80	A	80	$3 + 2 \times 2$
AM96	B	90	3×3
AM75	B	85	4
AM75	A	65	4
AM96	A	85	2×3
AM96	B	85	3
AM86	B	70	2
HLE27	A	40	1
AM80	B	75	2×2
AM80	A	55	2×2
AM75	A	65	4
AM96	A	110	2×3
AM96	B	100	2×3
AM75	A	105	4

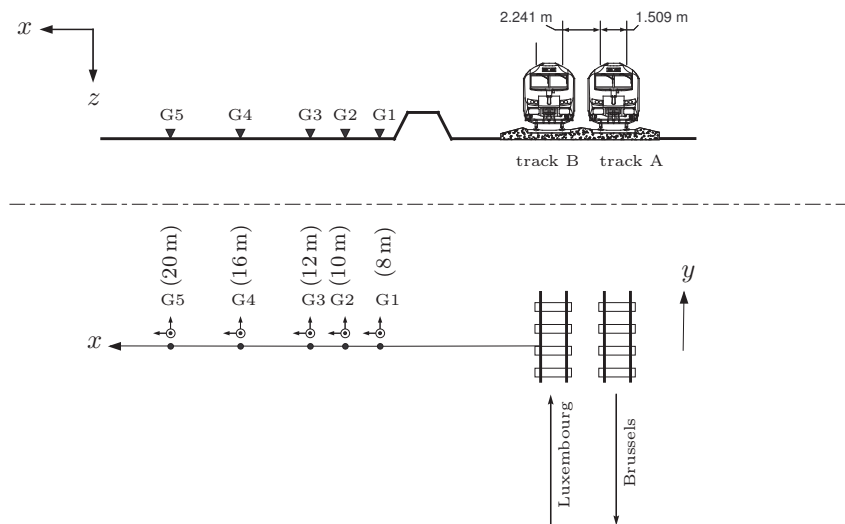


Figure 4.1: Located measurement points and review of all the train passing

4.1 AM75 unit at 65 km/h

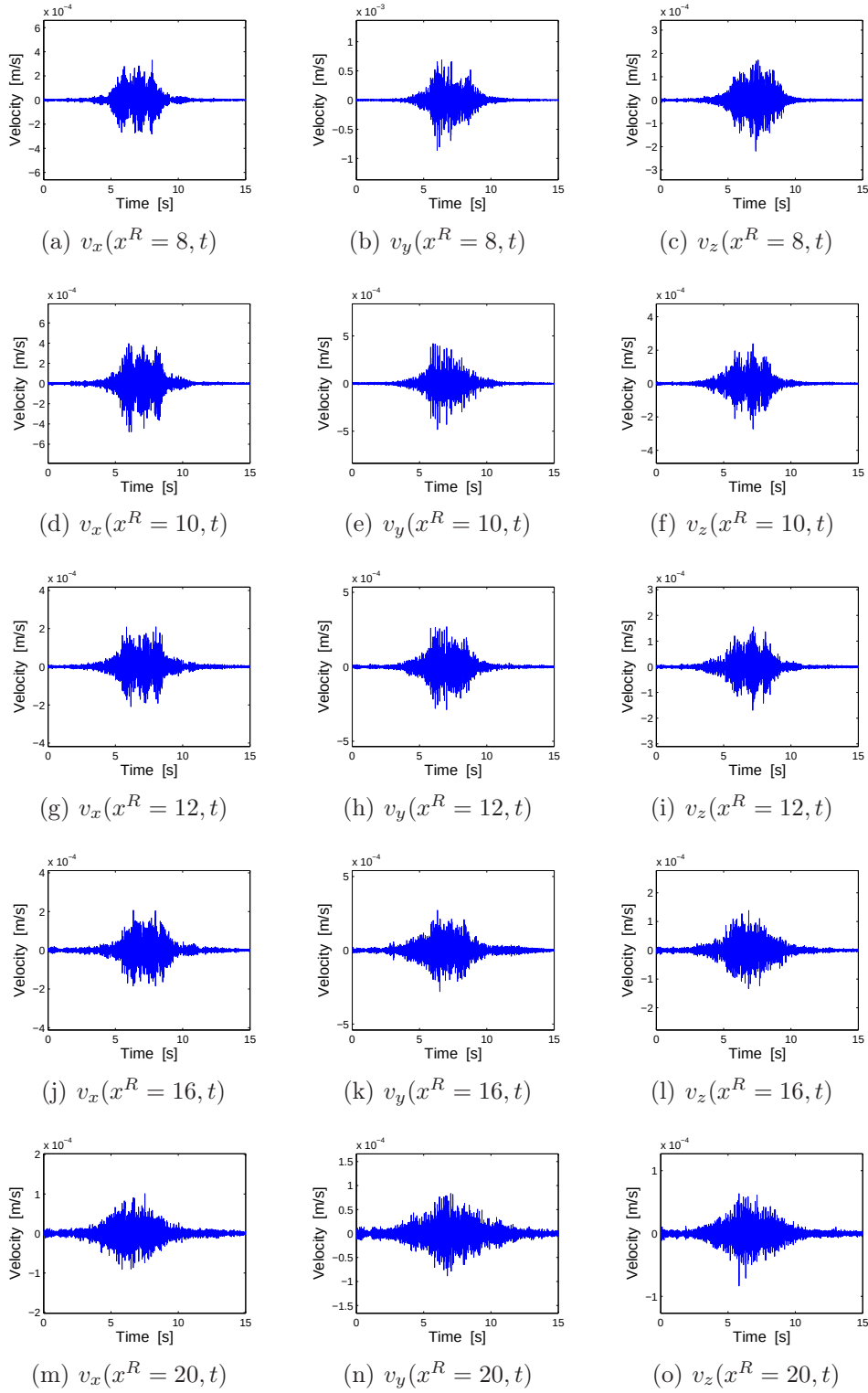


Figure 4.2: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 65 km/h

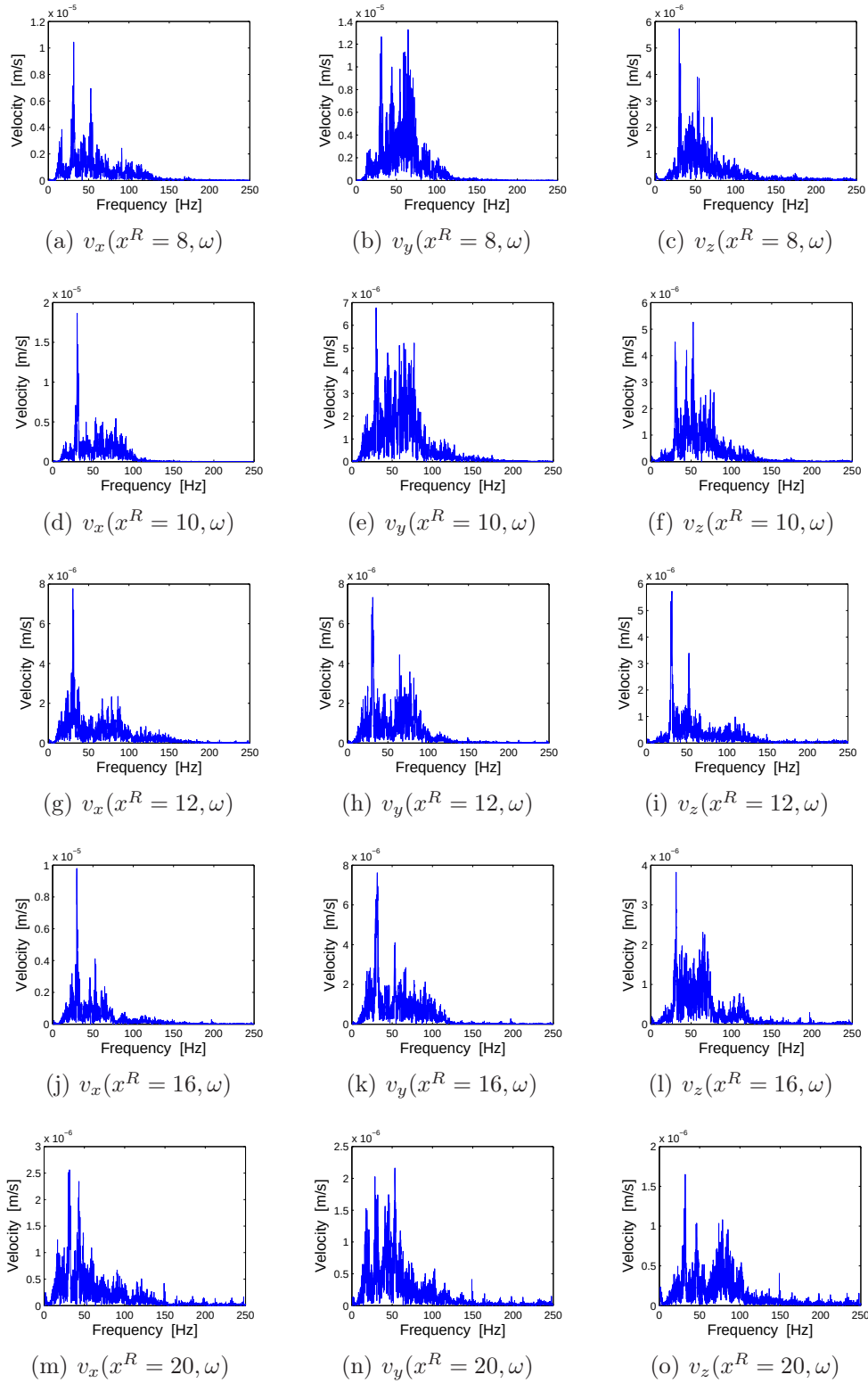


Figure 4.3: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 65 km/h

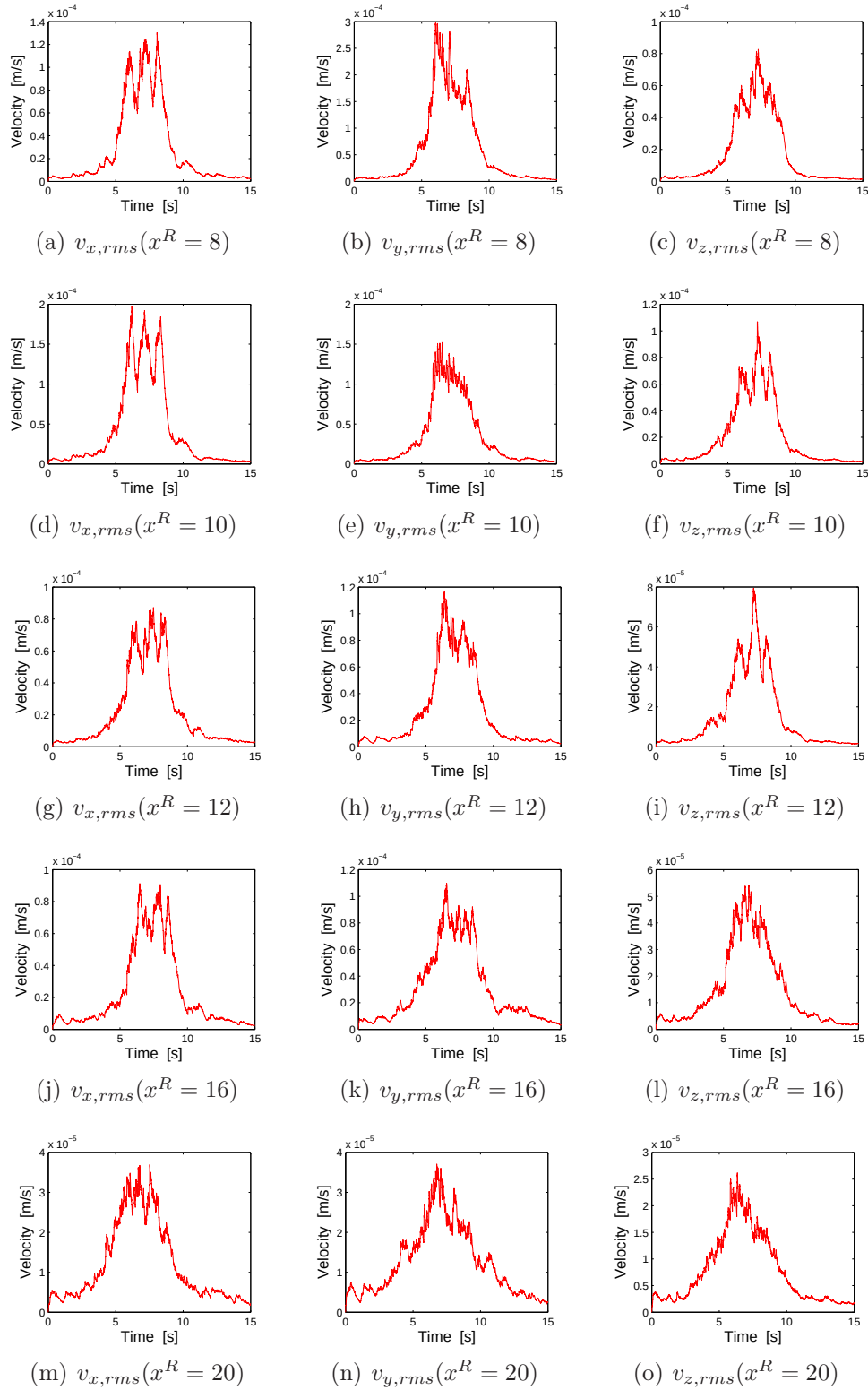


Figure 4.4: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 65 km/h

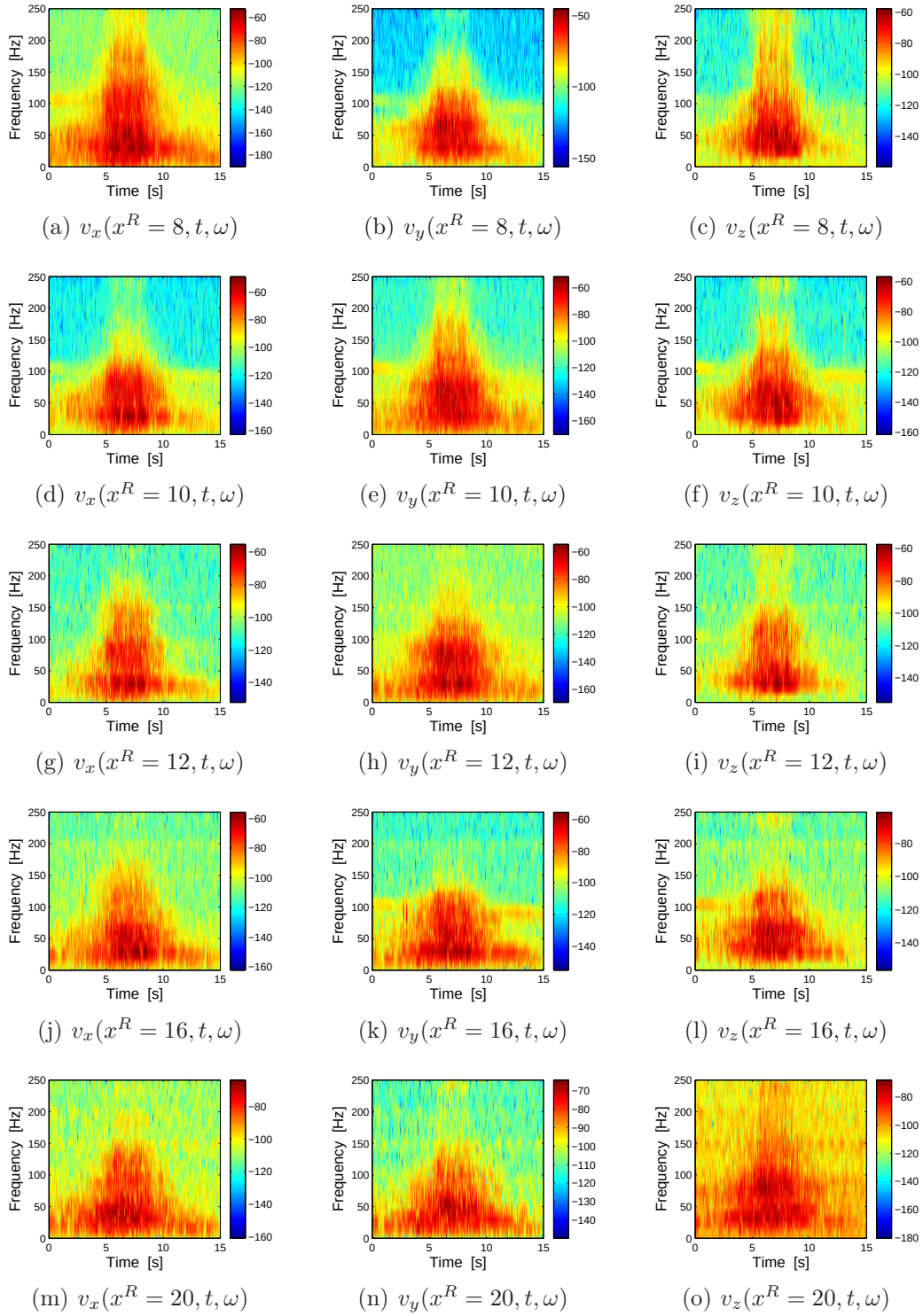


Figure 4.5: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 65 km/h

4.2 AM80 unit at 70 km/h

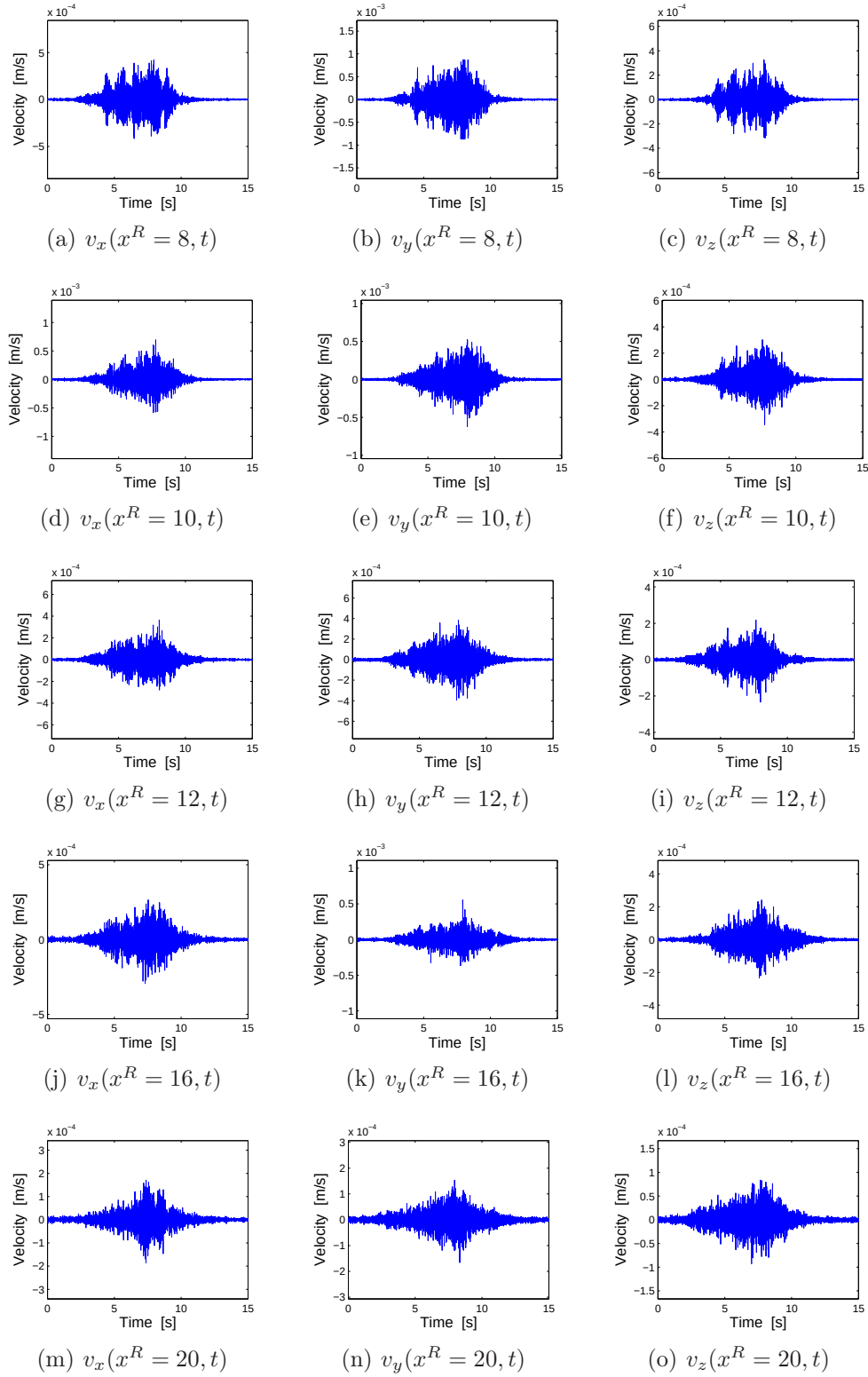


Figure 4.6: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 70 km/h

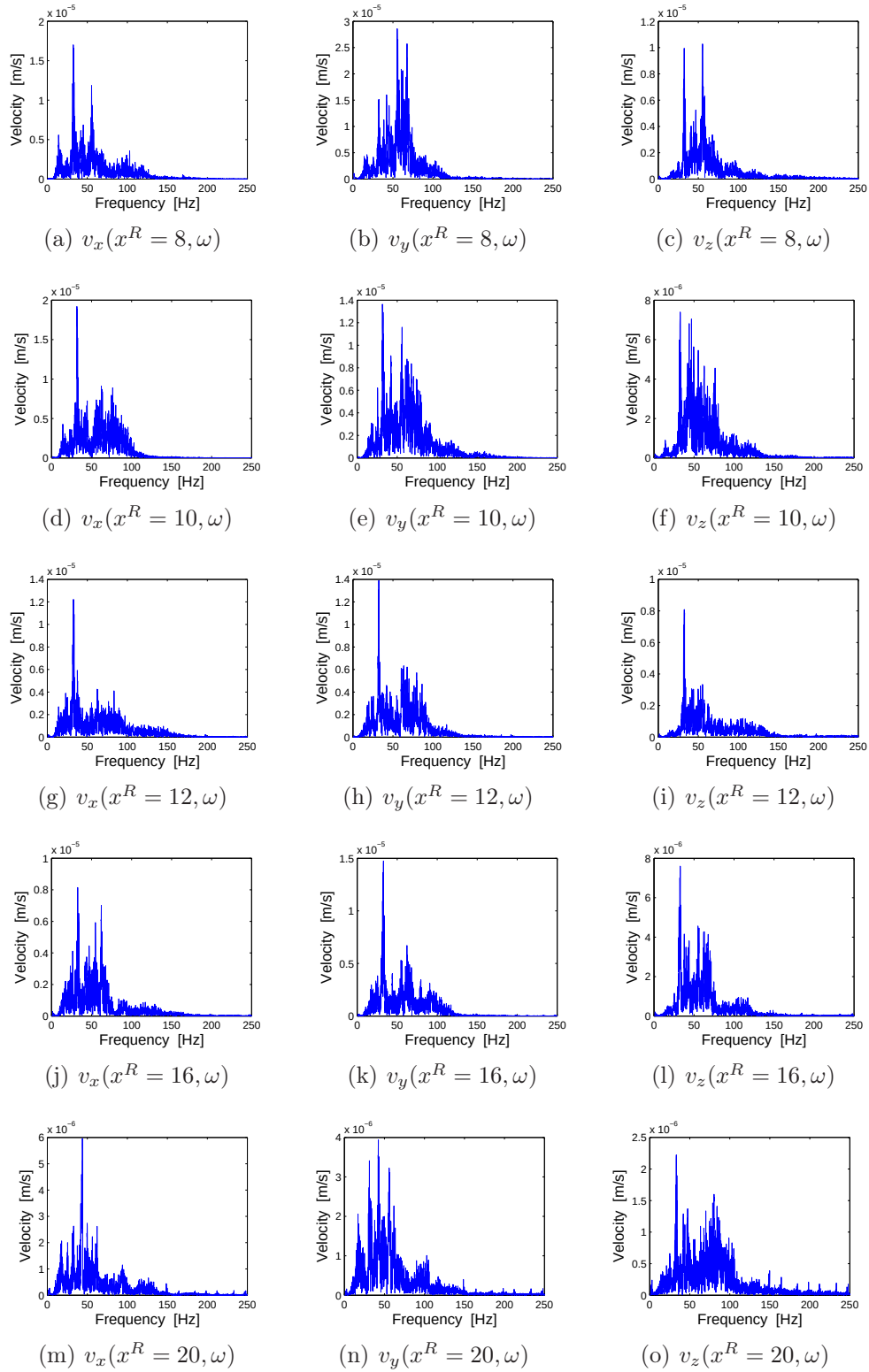


Figure 4.7: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 70 km/h

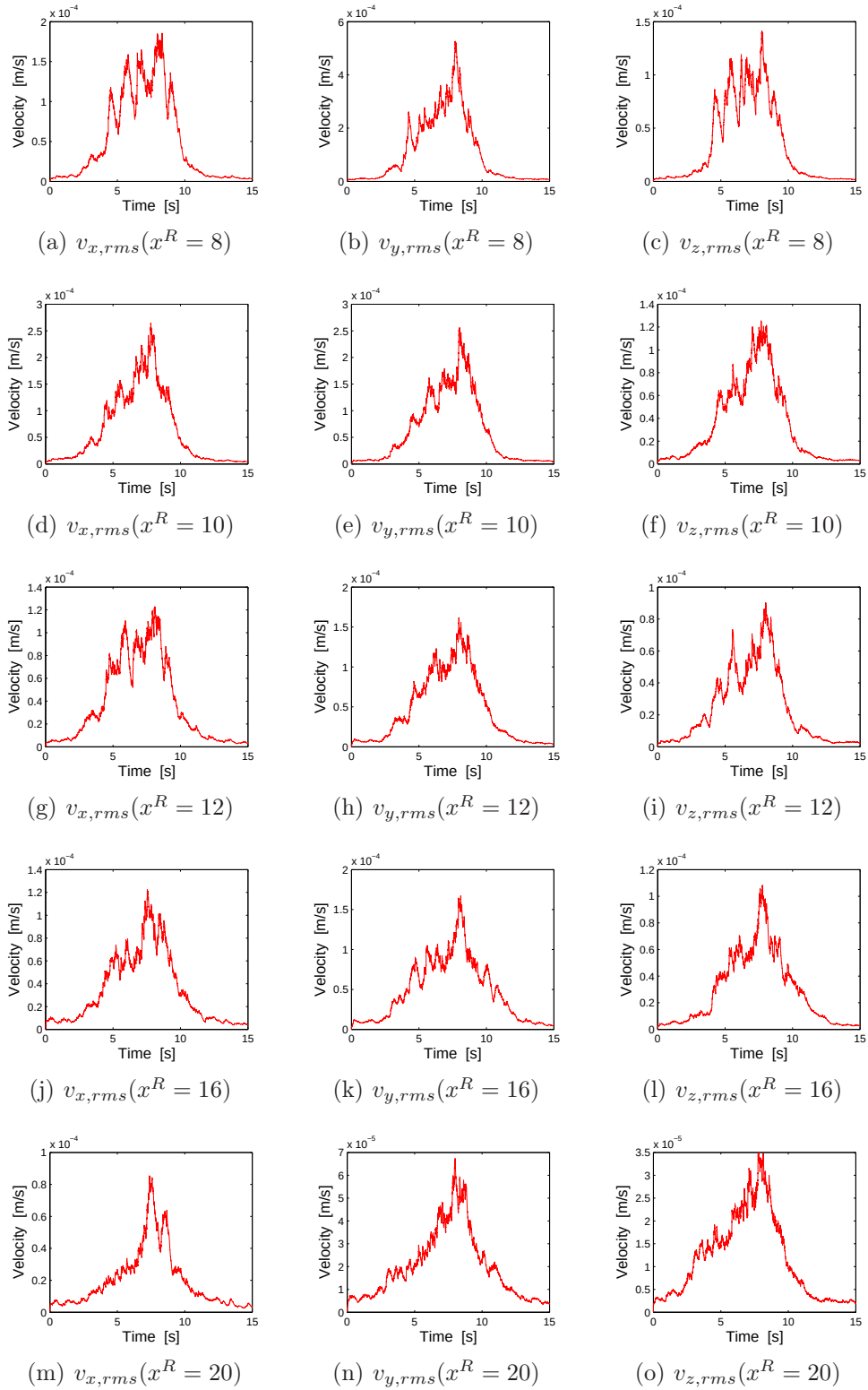


Figure 4.8: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 70 km/h

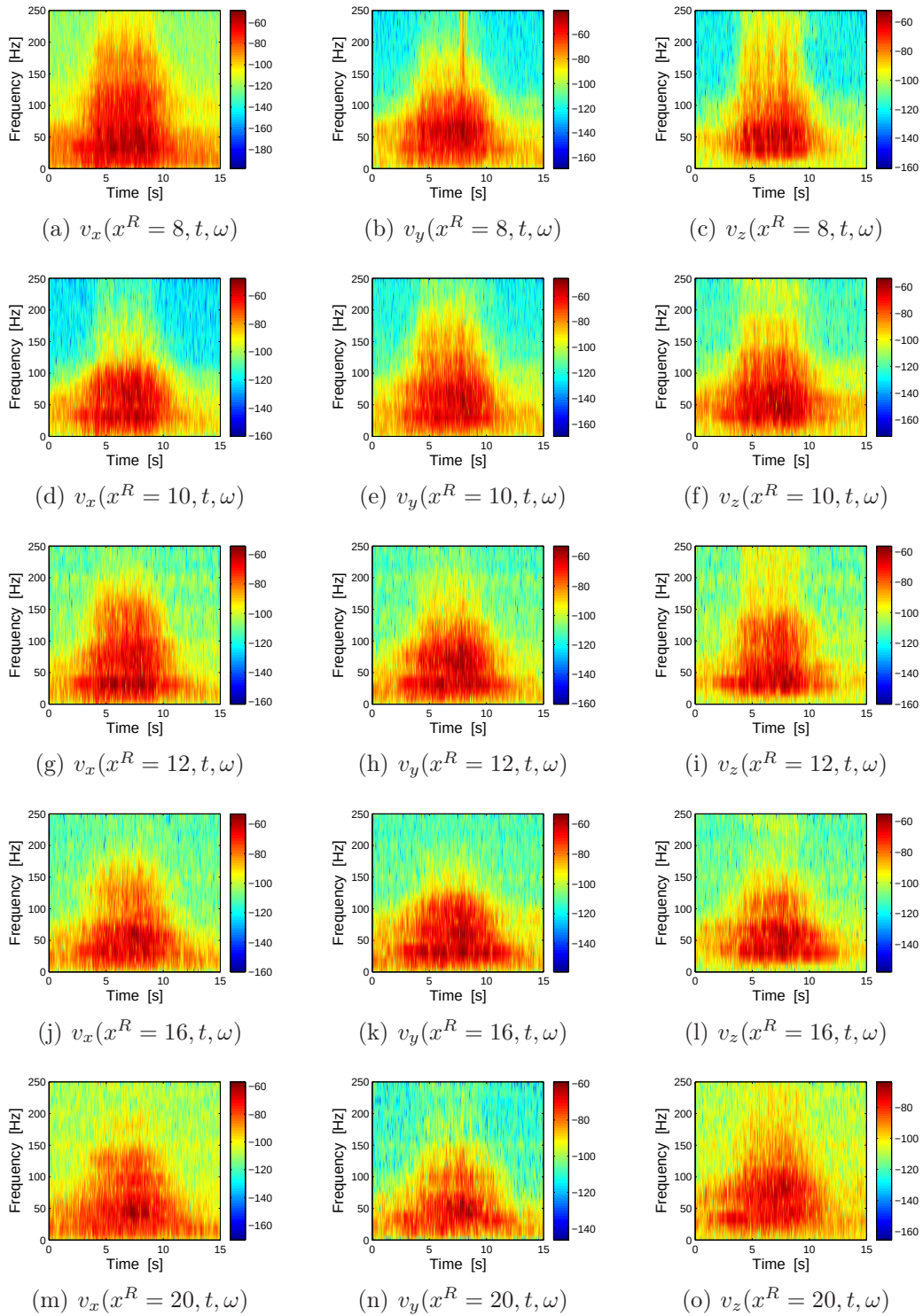


Figure 4.9: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 70 km/h

4.3 M4 railcar at 110 km/h

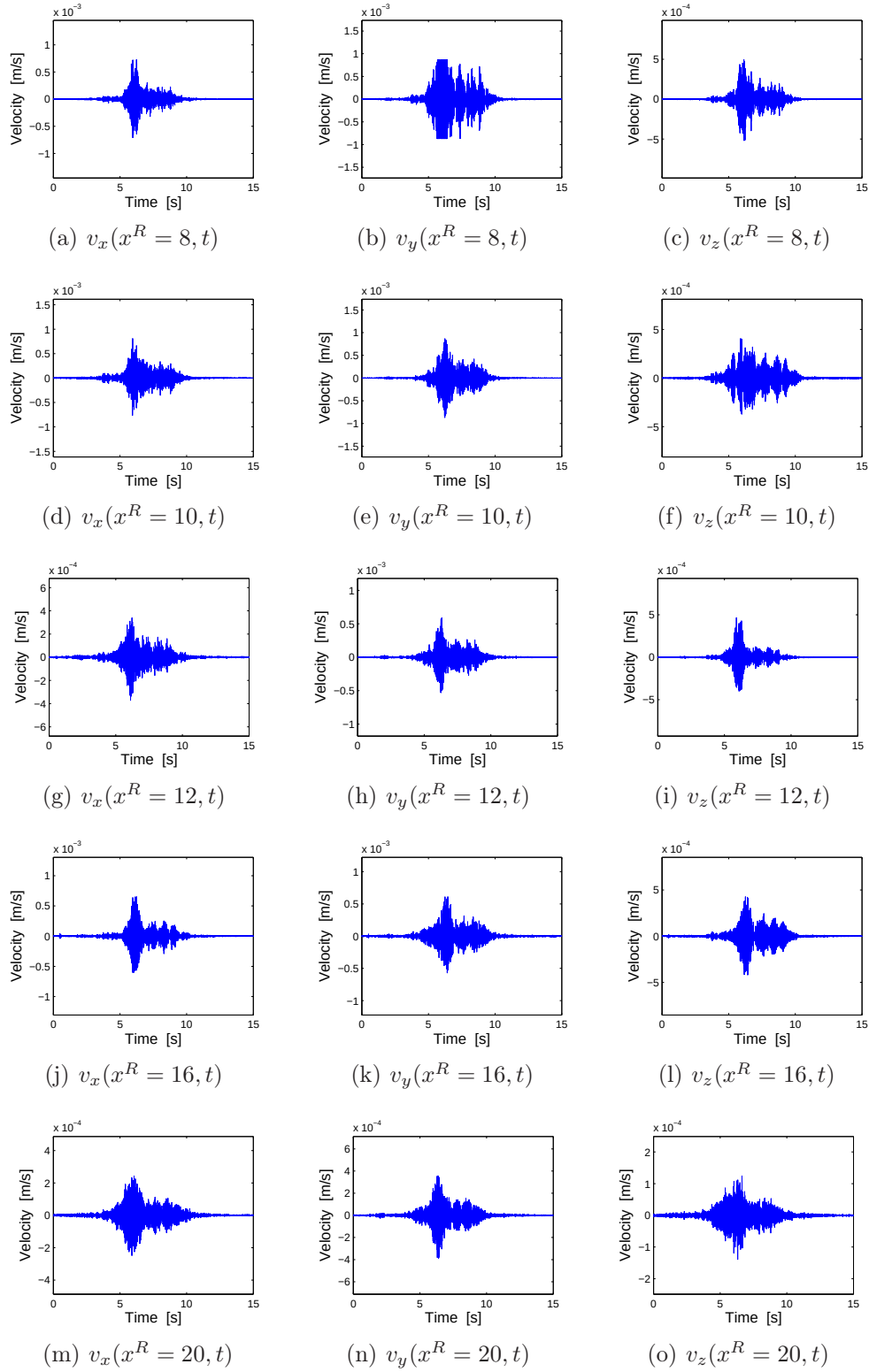


Figure 4.10: Time history of the vertical and horizontal velocities measured in free field during the passage of a M4 railcar at 110 km/h

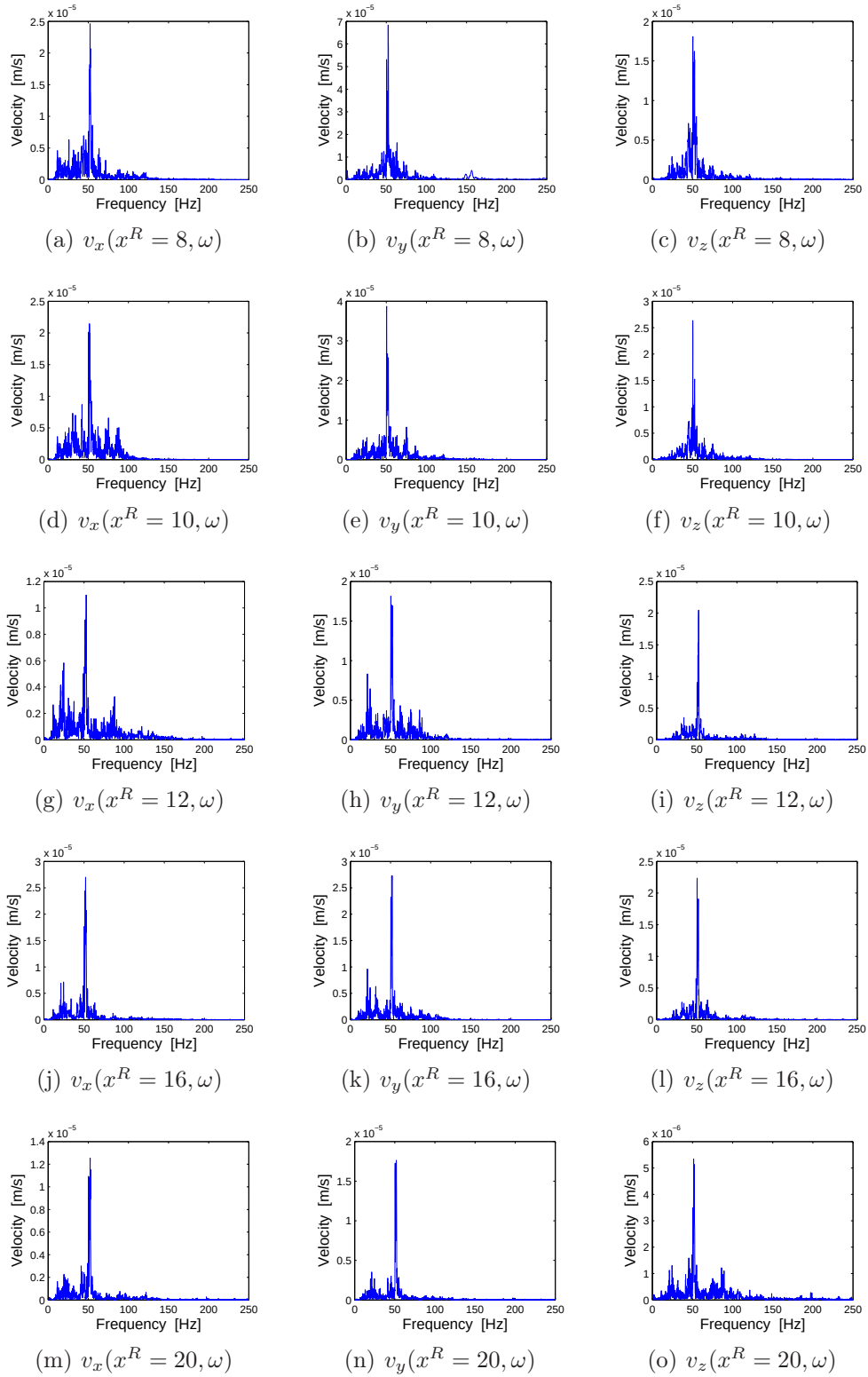


Figure 4.11: Spectral content of the vertical and horizontal velocities measured in free field during the passage of a M4 railcar at 110 km/h

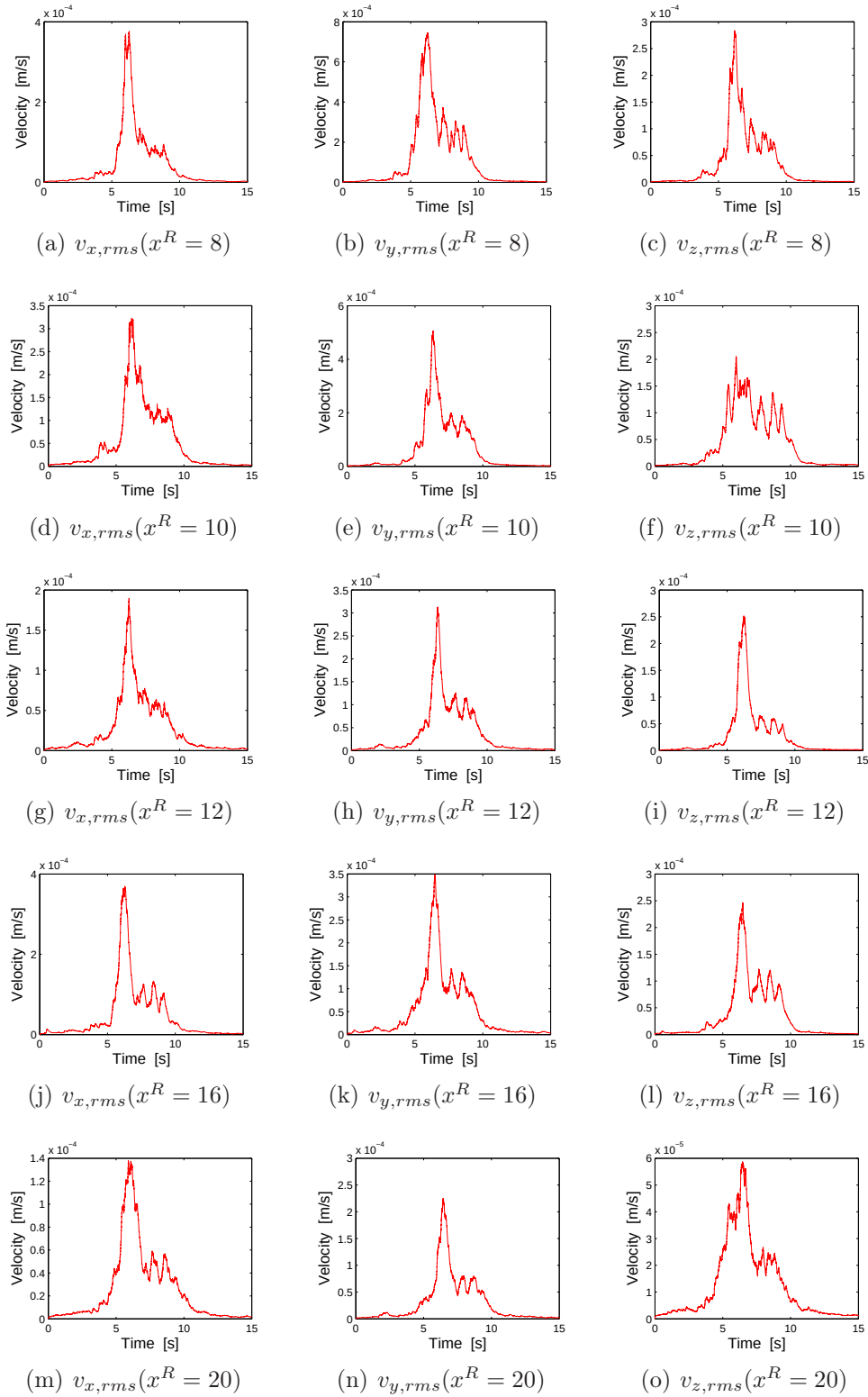


Figure 4.12: Time-average of the vertical and horizontal velocities measured in free field during the passage of a M4 railcar at 110 km/h

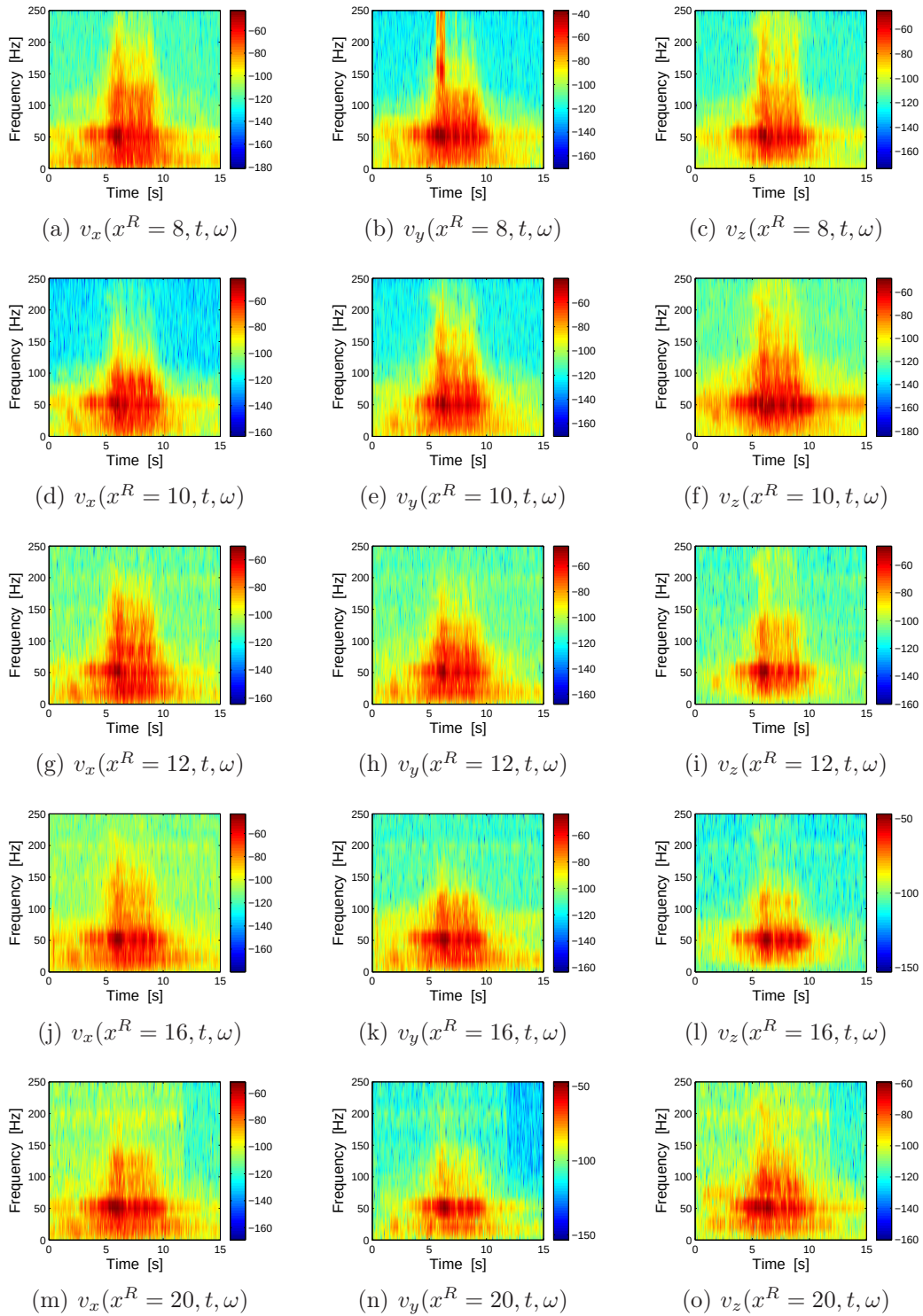


Figure 4.13: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of a M4 railcar at 110 km/h

4.4 AM96 unit at 80 km/h

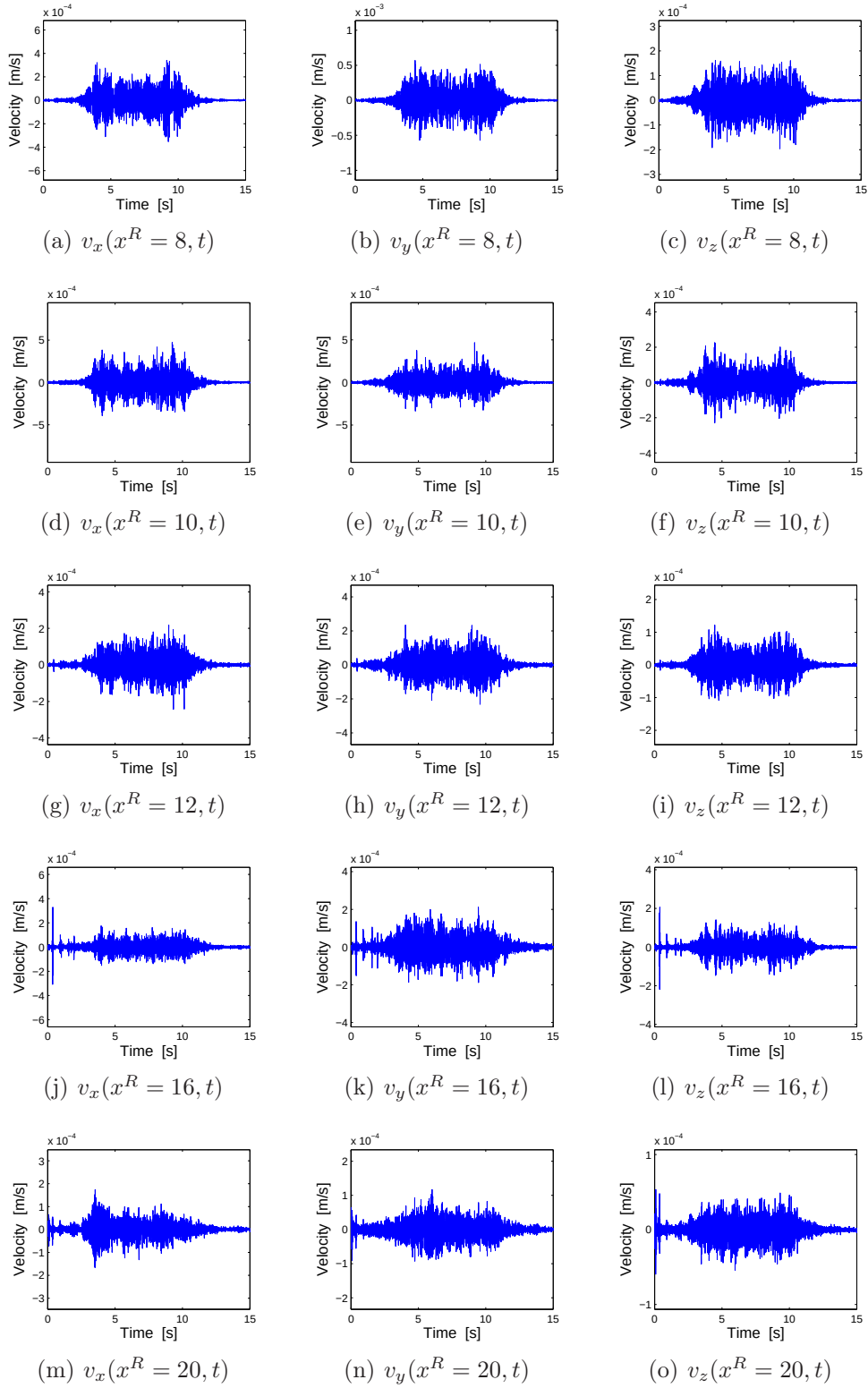


Figure 4.14: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 80 km/h

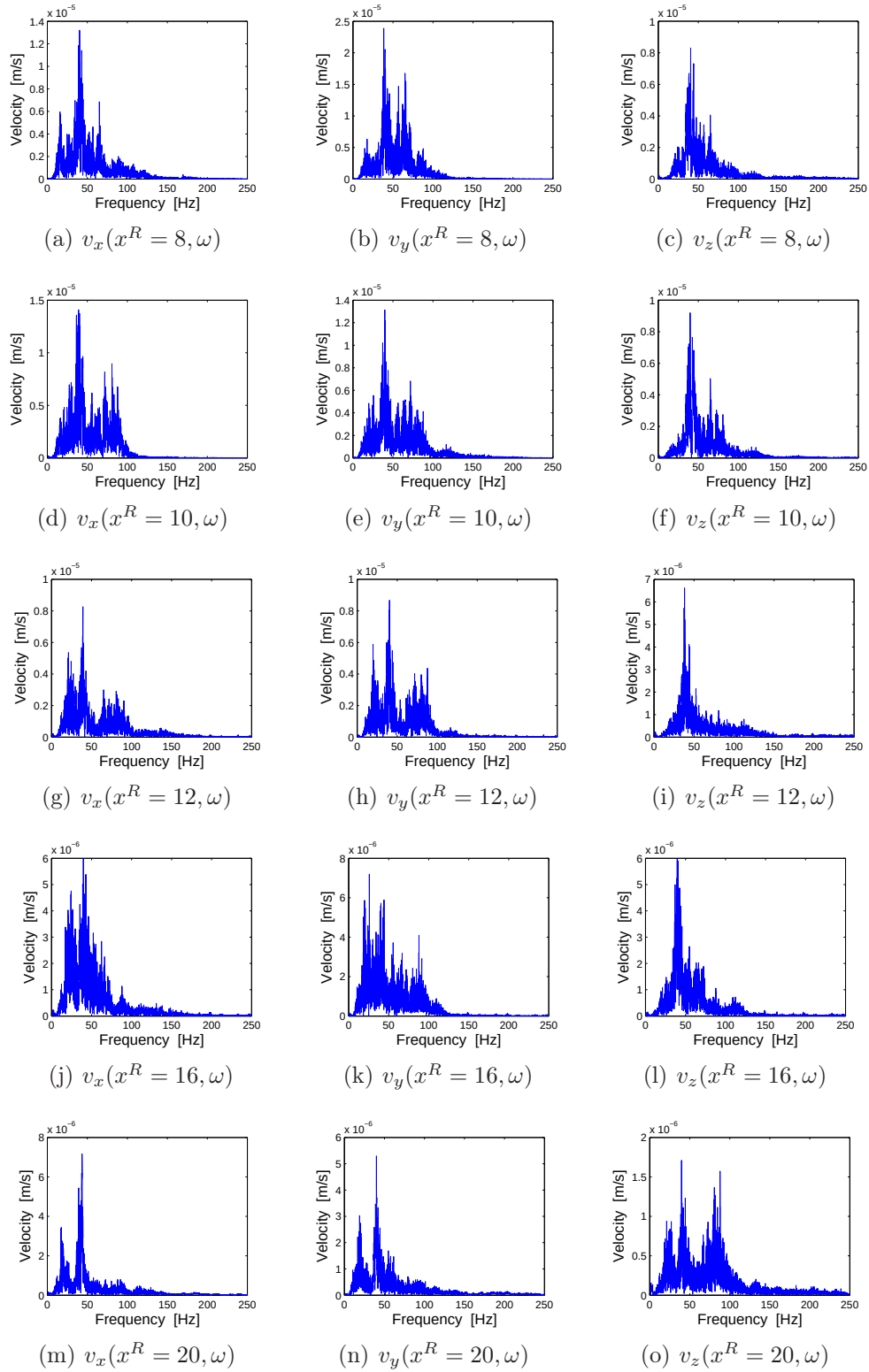


Figure 4.15: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 80 km/h

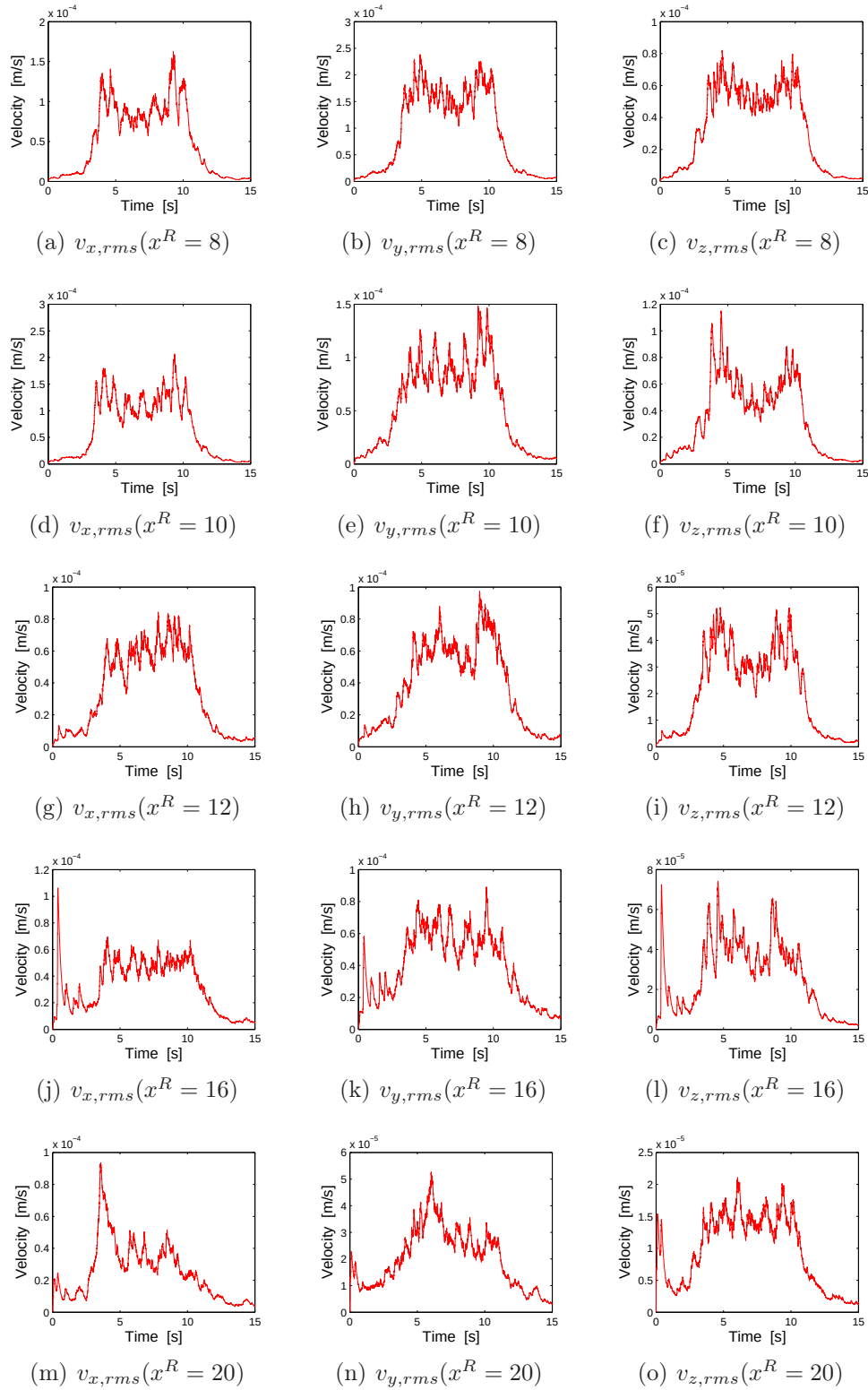


Figure 4.16: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 80 km/h

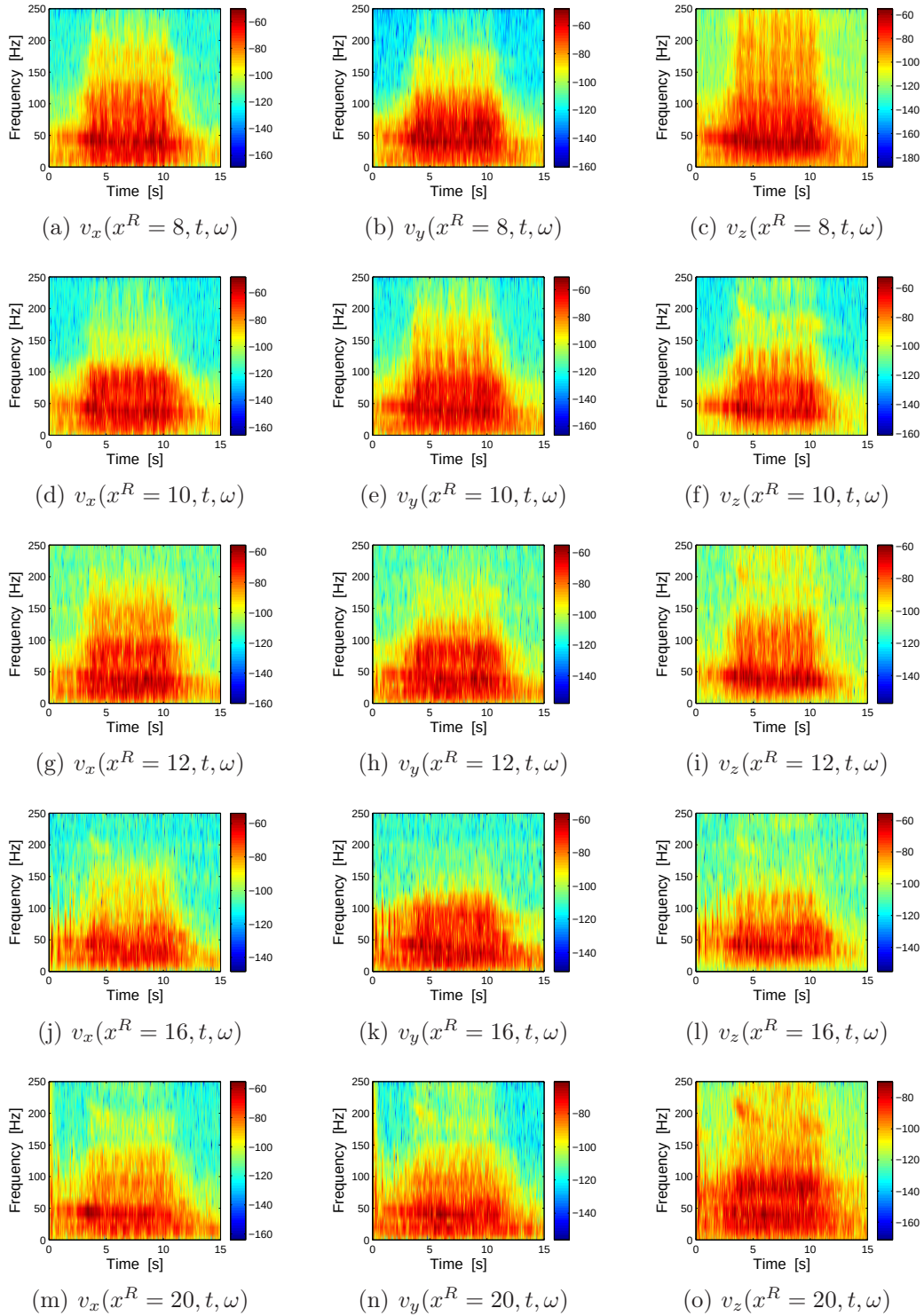


Figure 4.17: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 80 km/h

4.5 AM96 unit at 90 km/h

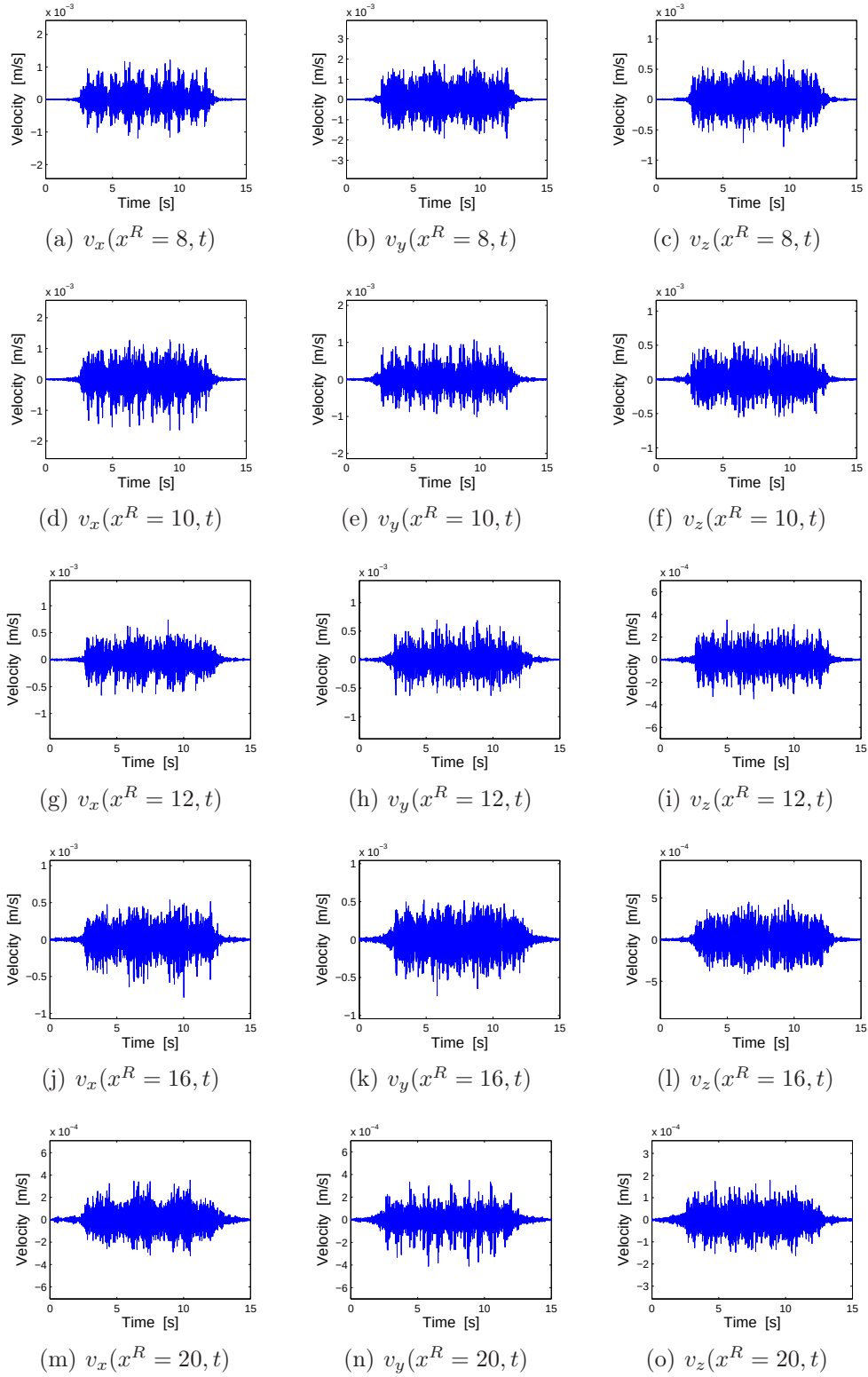


Figure 4.18: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 90 km/h

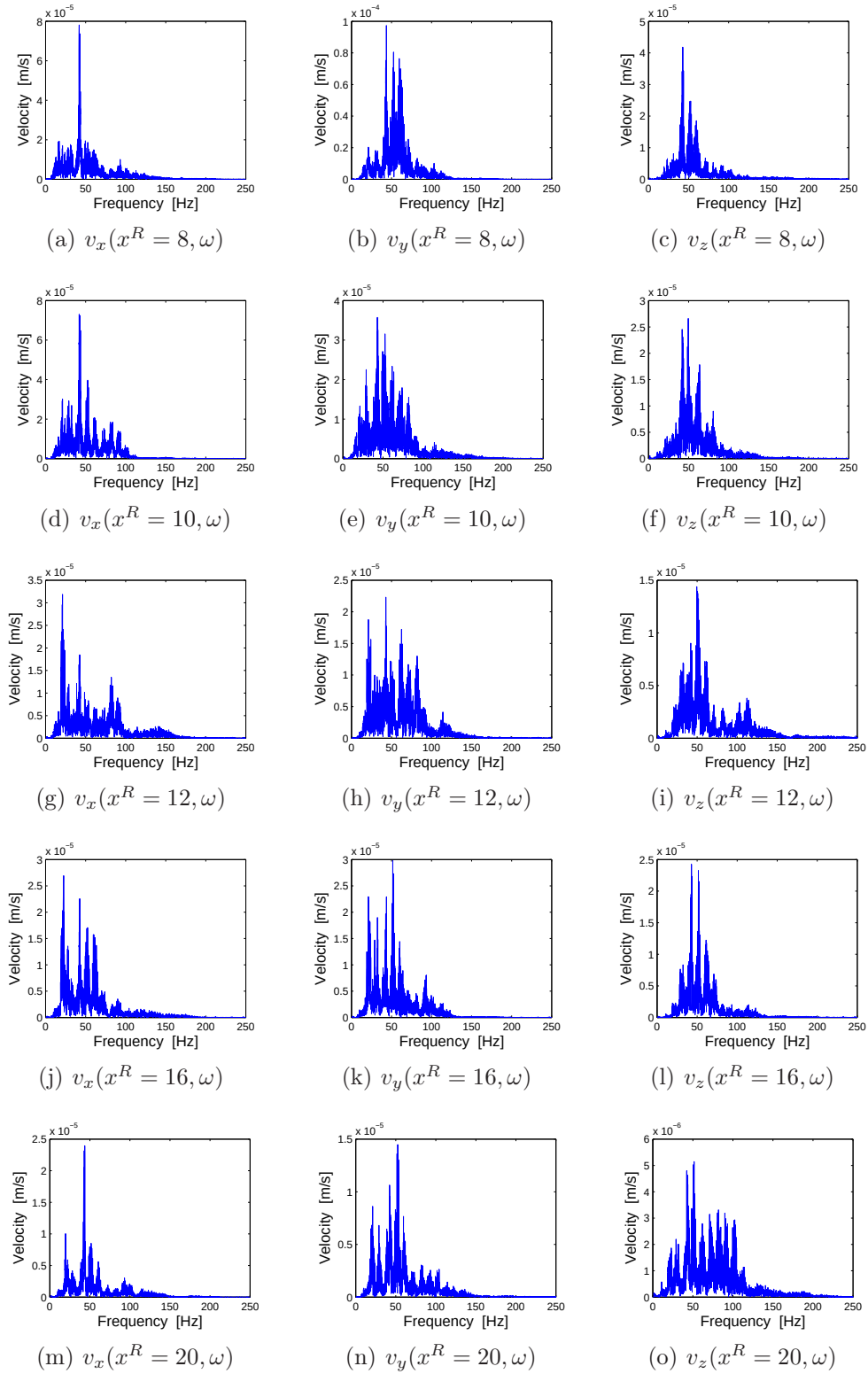


Figure 4.19: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 90 km/h

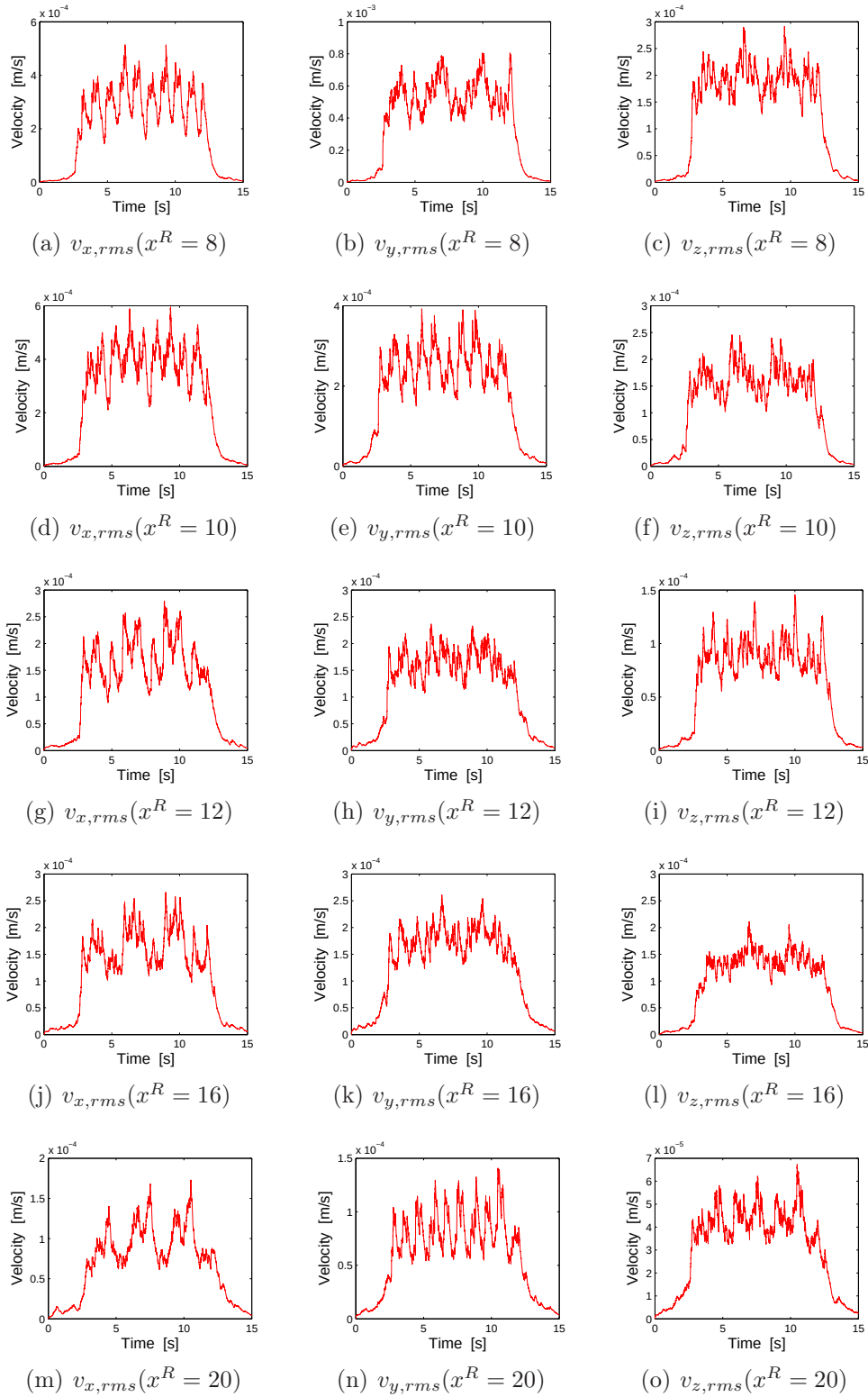


Figure 4.20: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 90 km/h

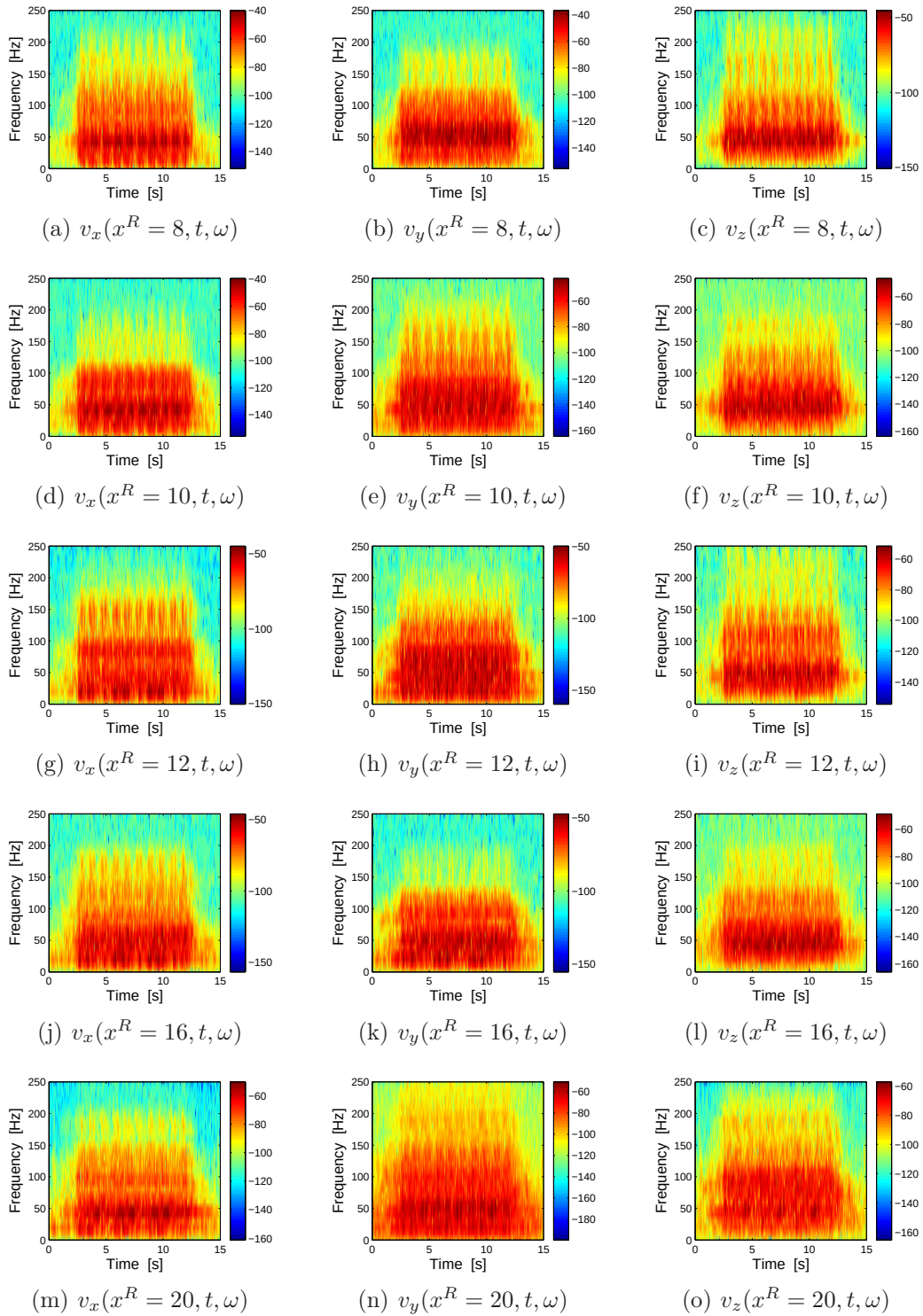


Figure 4.21: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 90 km/h

4.6 AM75 unit at 85 km/h

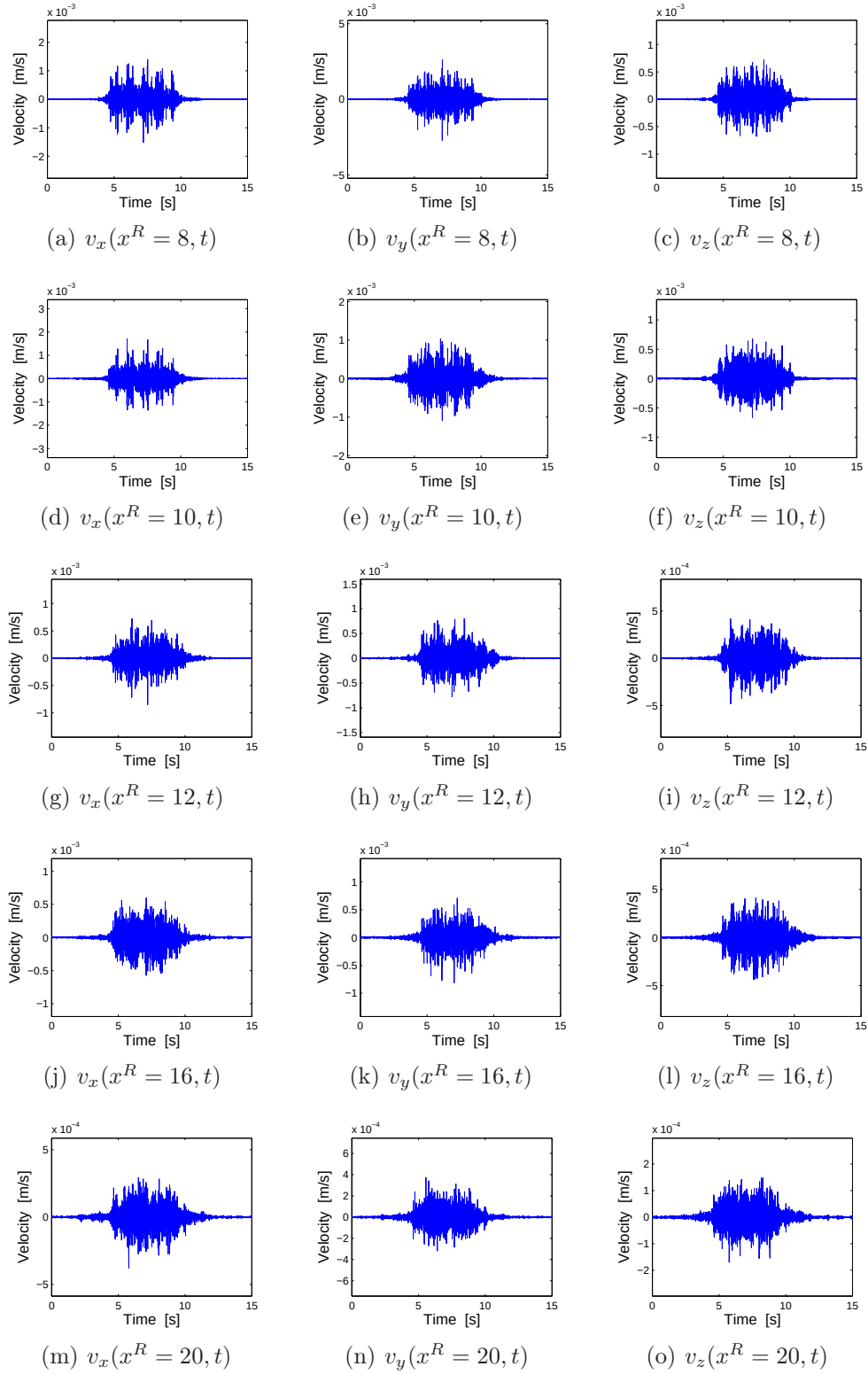


Figure 4.22: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 85 km/h

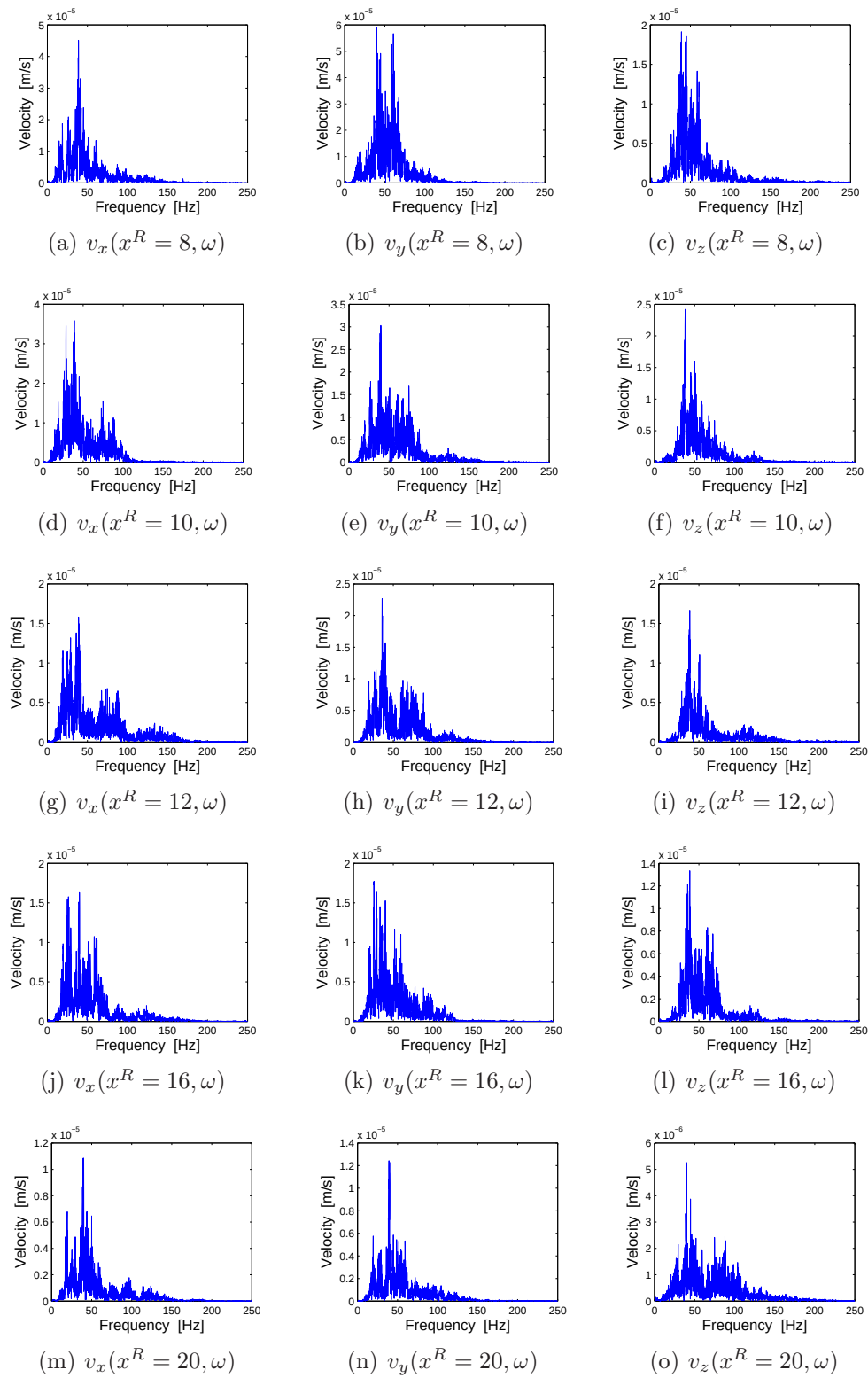


Figure 4.23: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 85 km/h

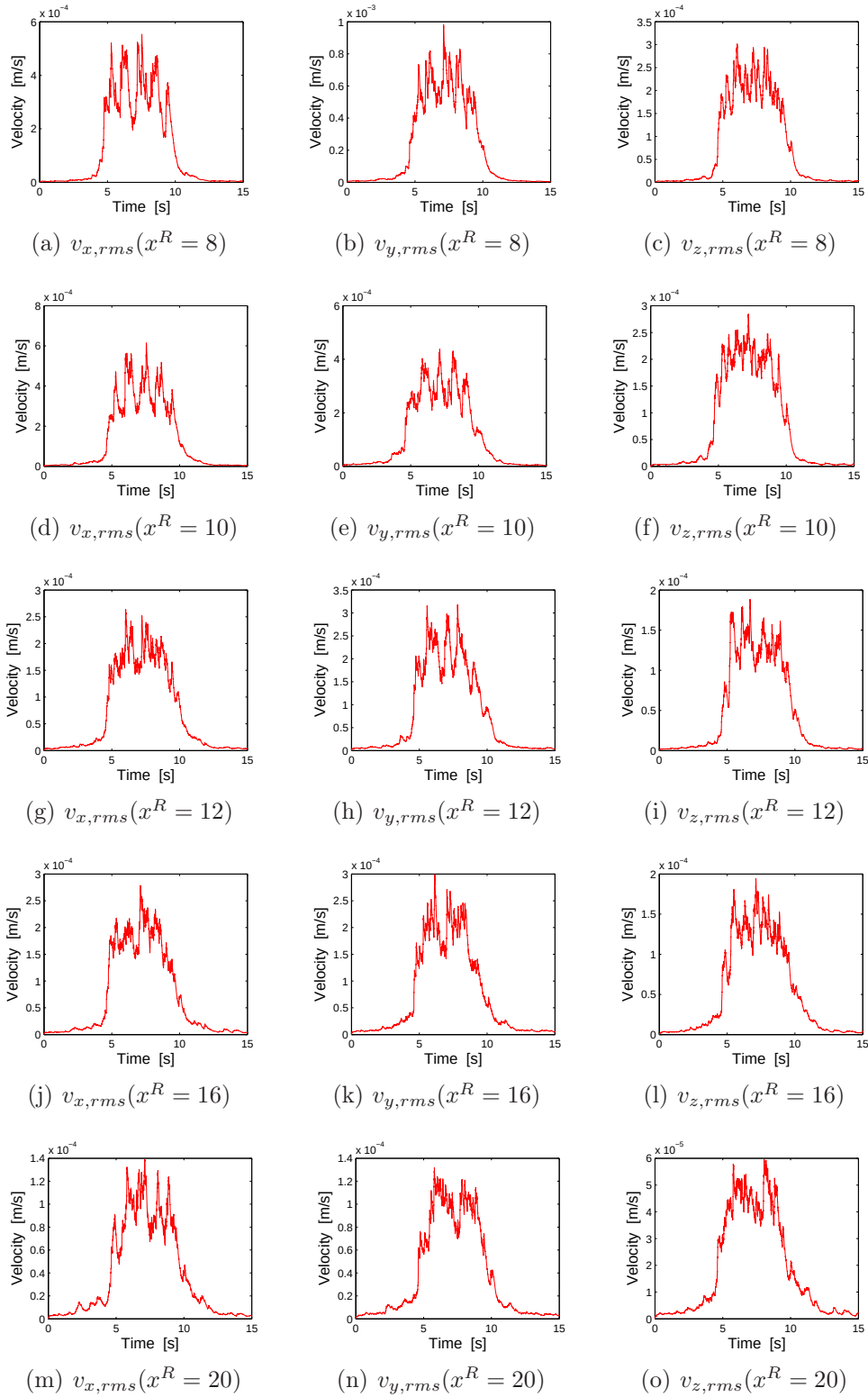


Figure 4.24: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 85 km/h

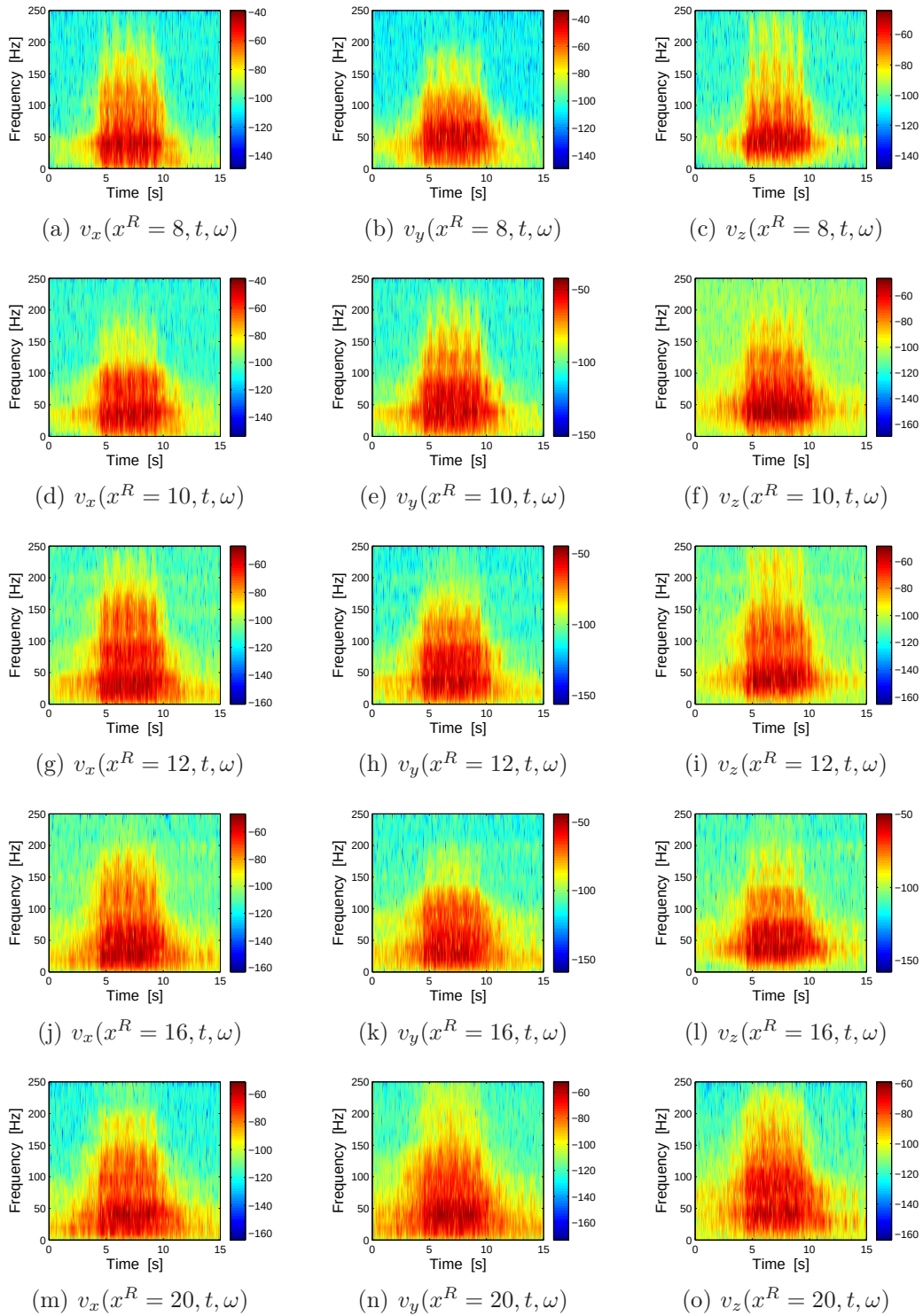


Figure 4.25: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 85 km/h

4.7 AM75 unit at 65 km/h

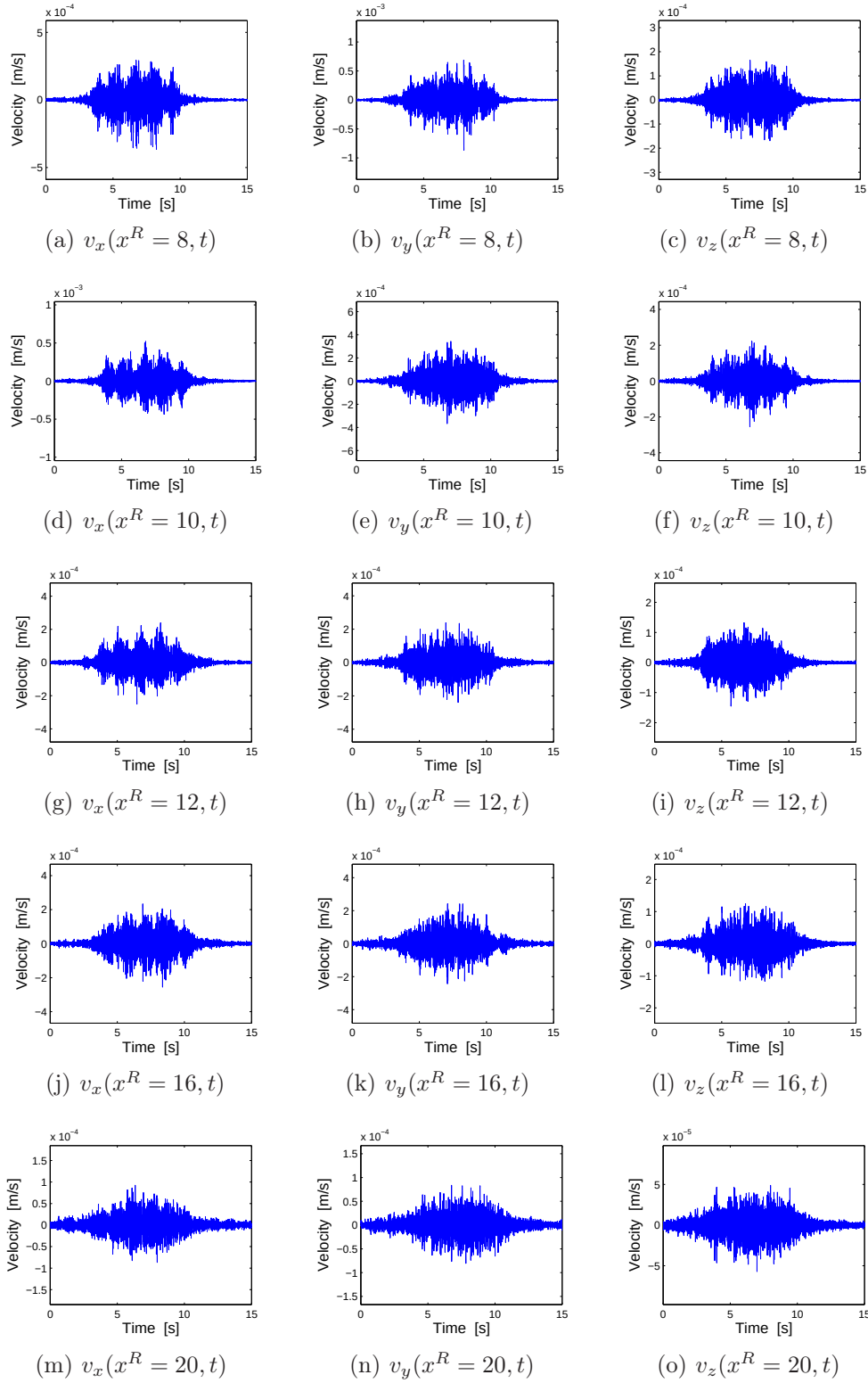


Figure 4.26: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 65 km/h

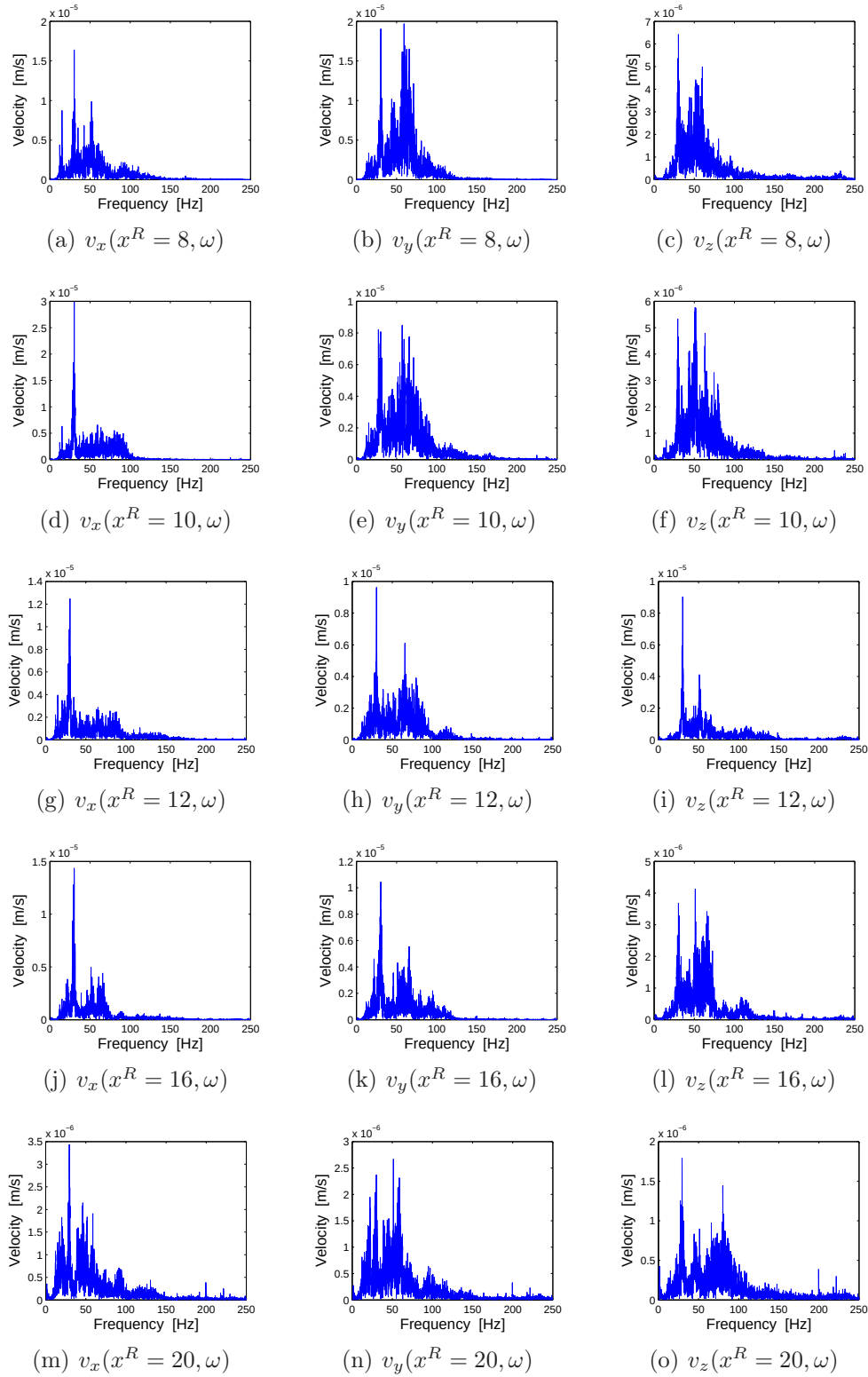


Figure 4.27: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 65 km/h

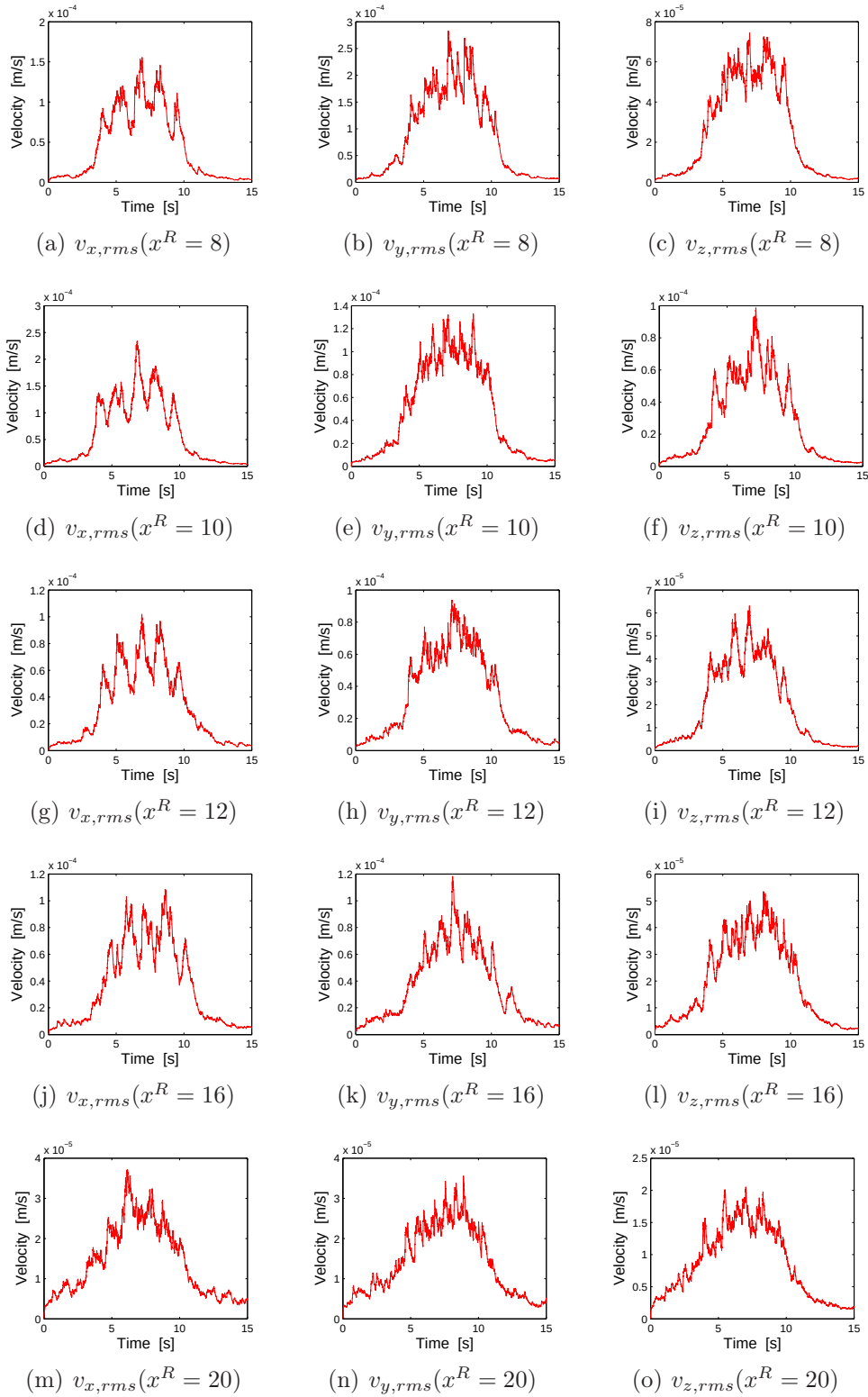


Figure 4.28: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 65 km/h

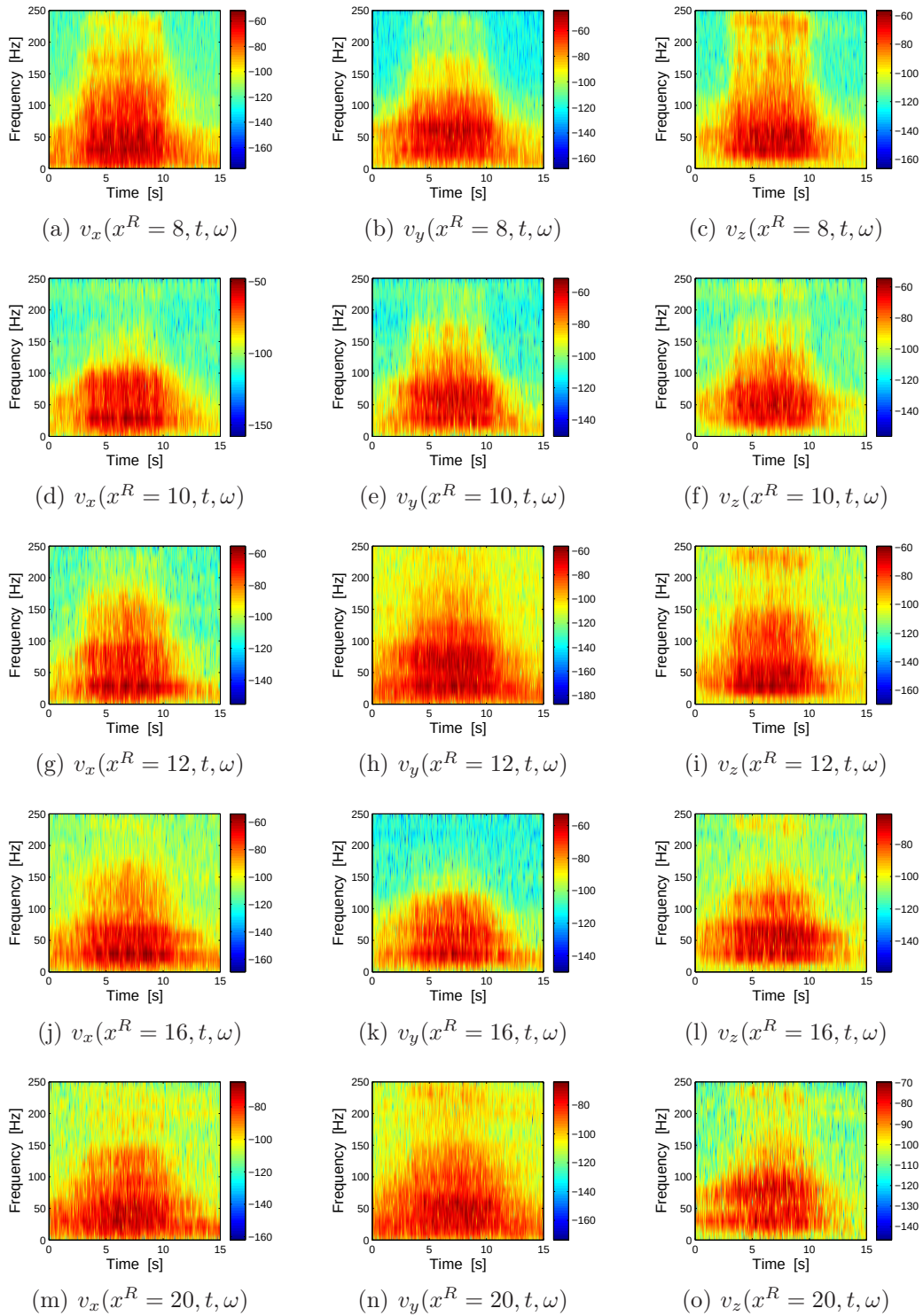


Figure 4.29: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 65 km/h

4.8 AM96 unit at 85 km/h

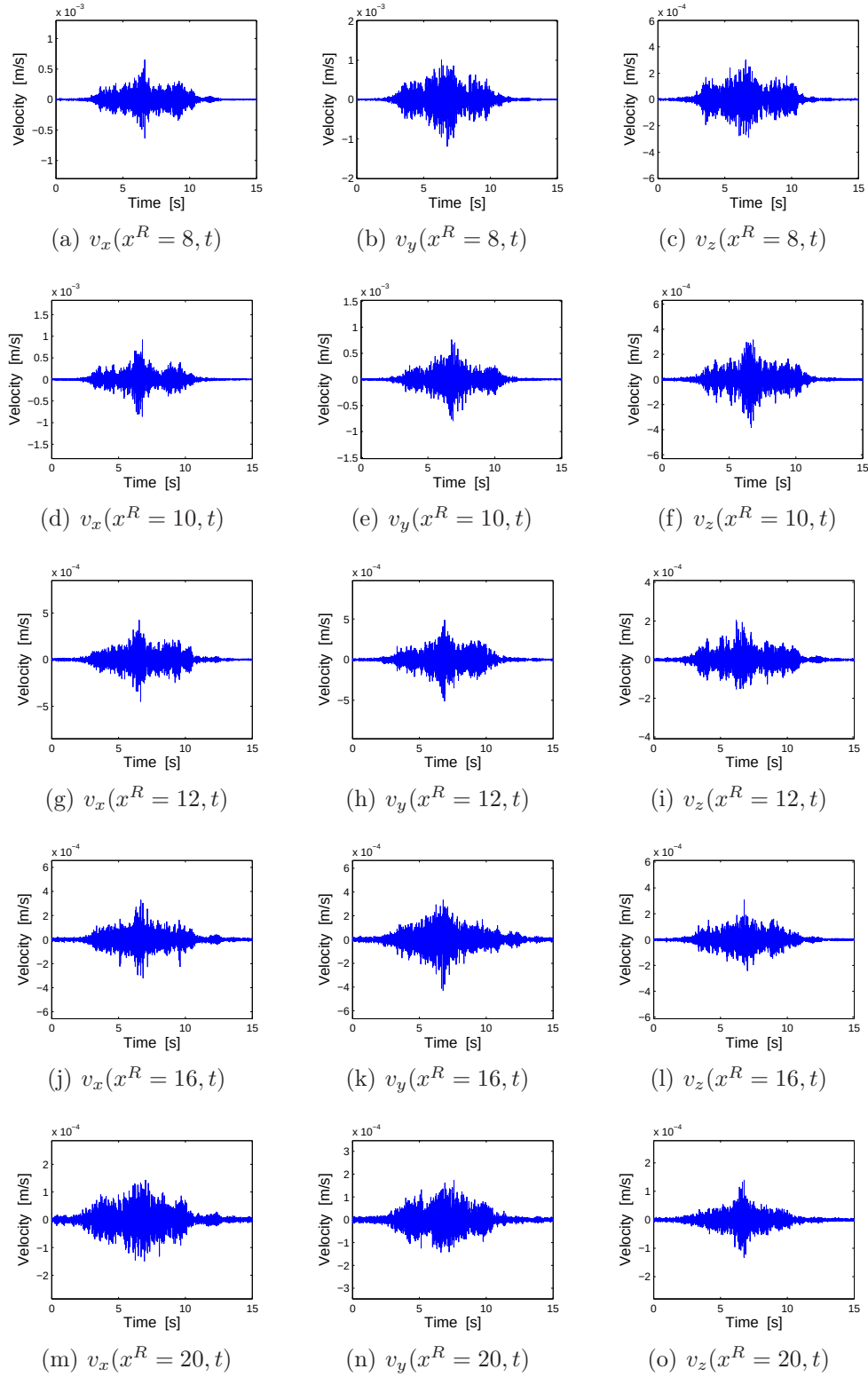


Figure 4.30: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 85 km/h

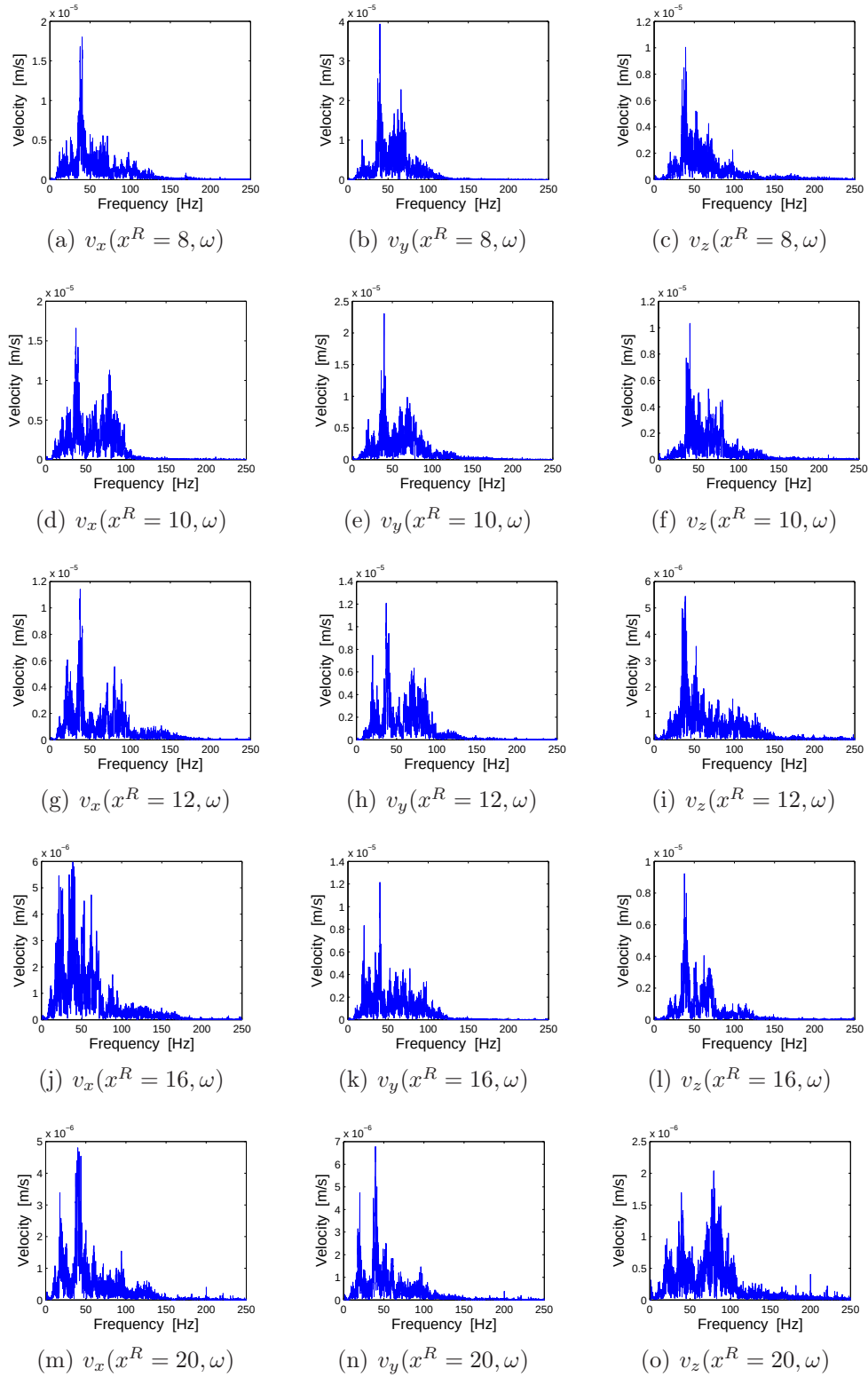


Figure 4.31: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 85 km/h

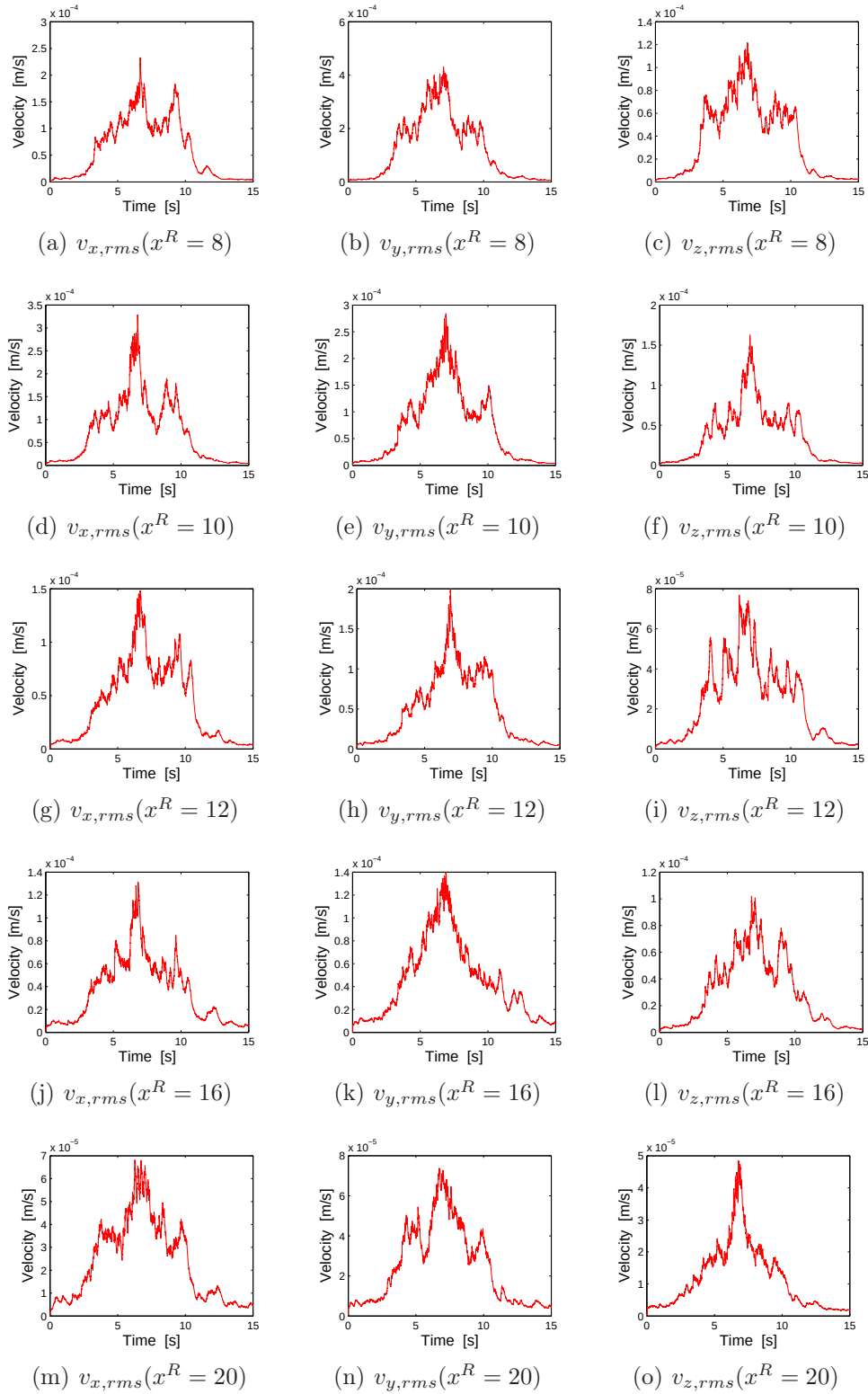


Figure 4.32: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 85 km/h

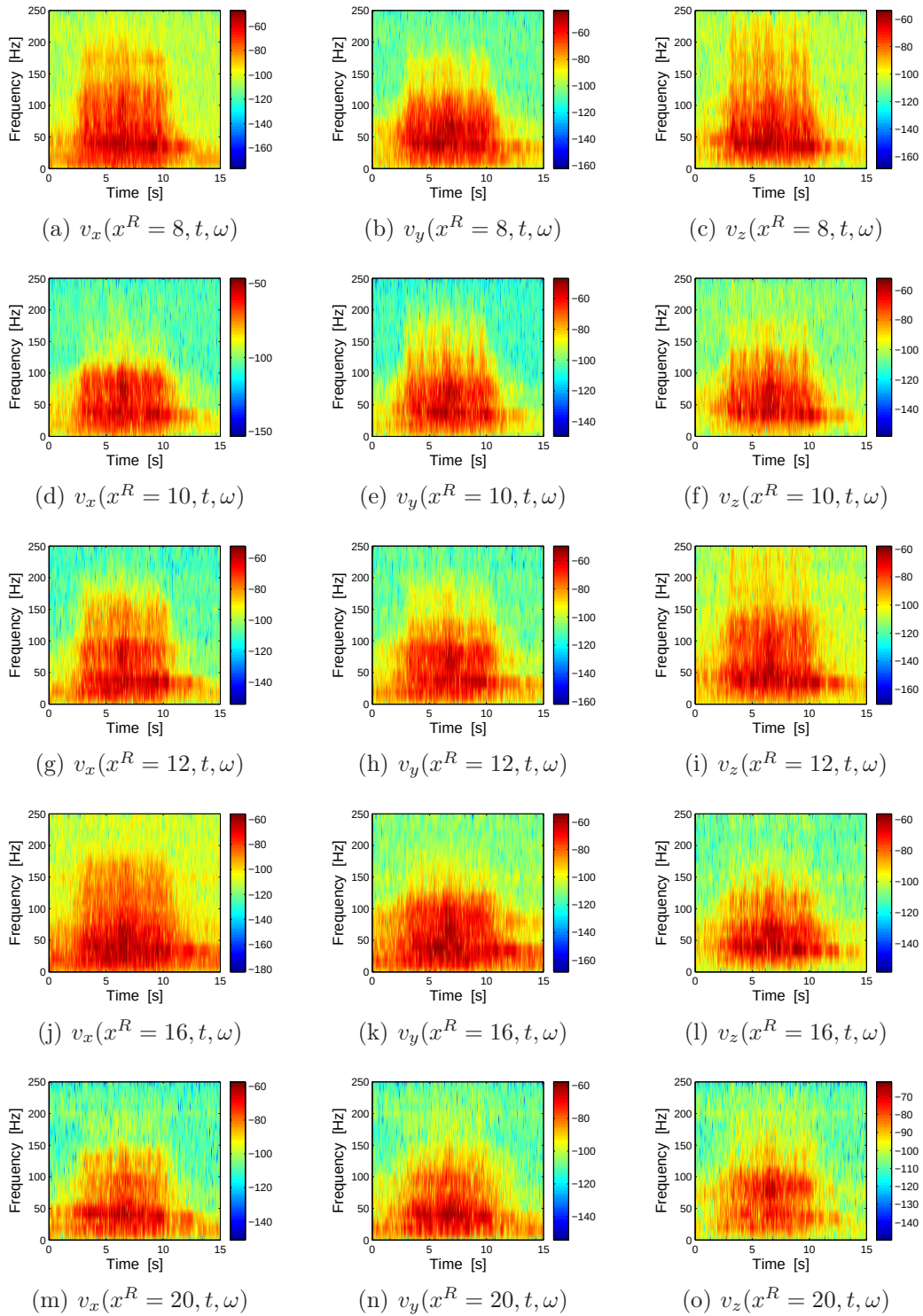


Figure 4.33: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 85 km/h

4.9 AM96 unit at 85 km/h

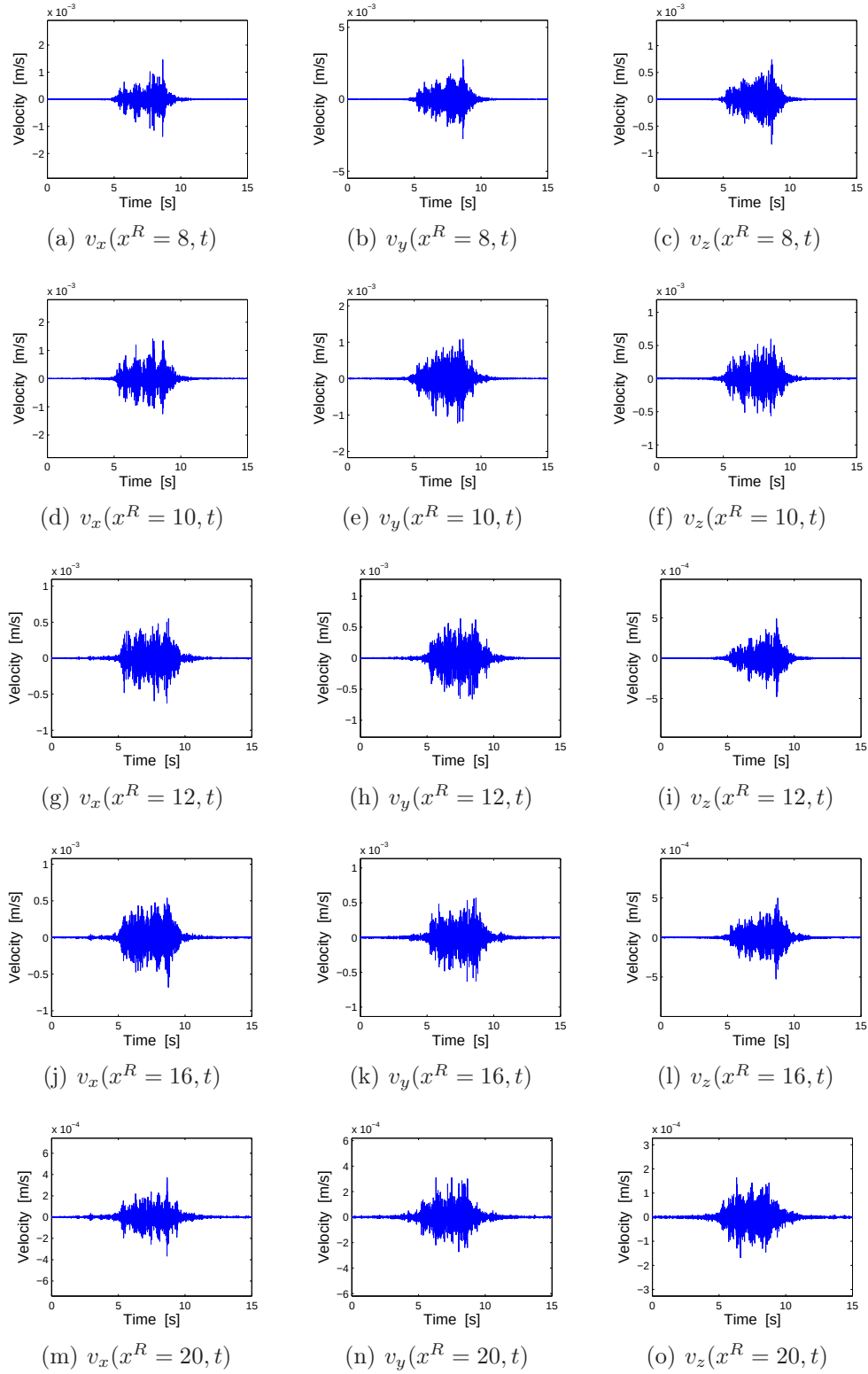


Figure 4.34: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 85 km/h

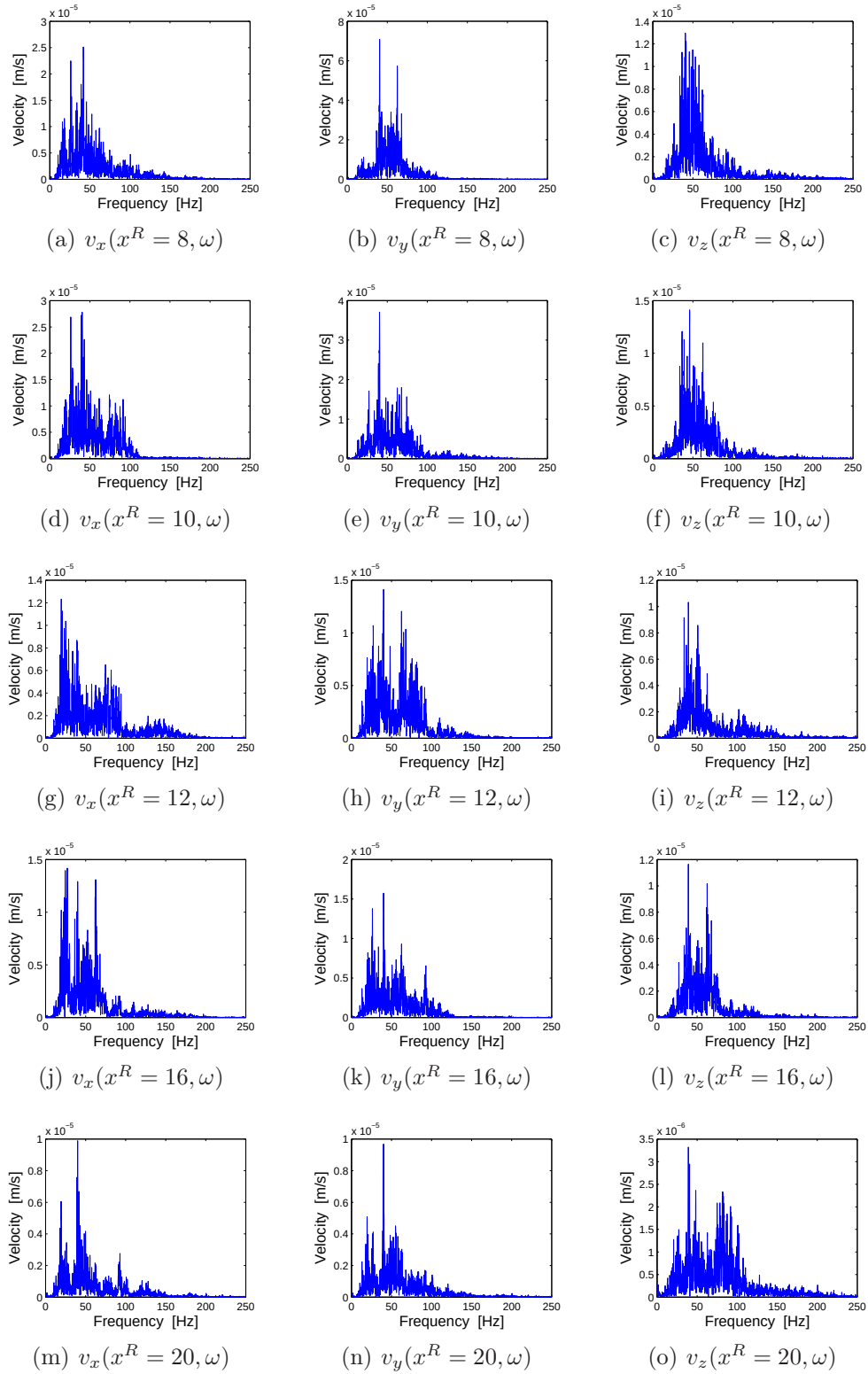


Figure 4.35: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 85 km/h

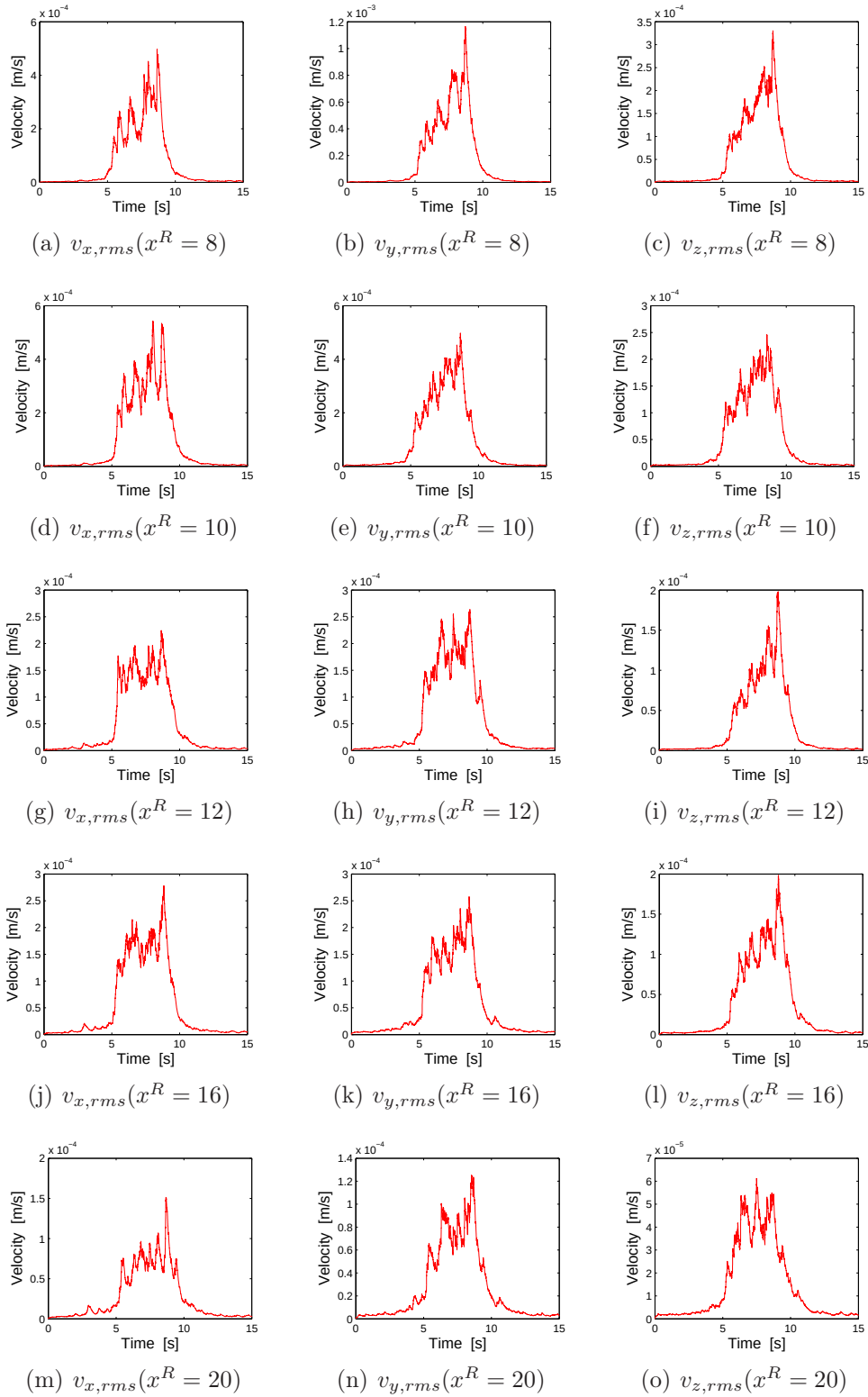


Figure 4.36: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 85 km/h

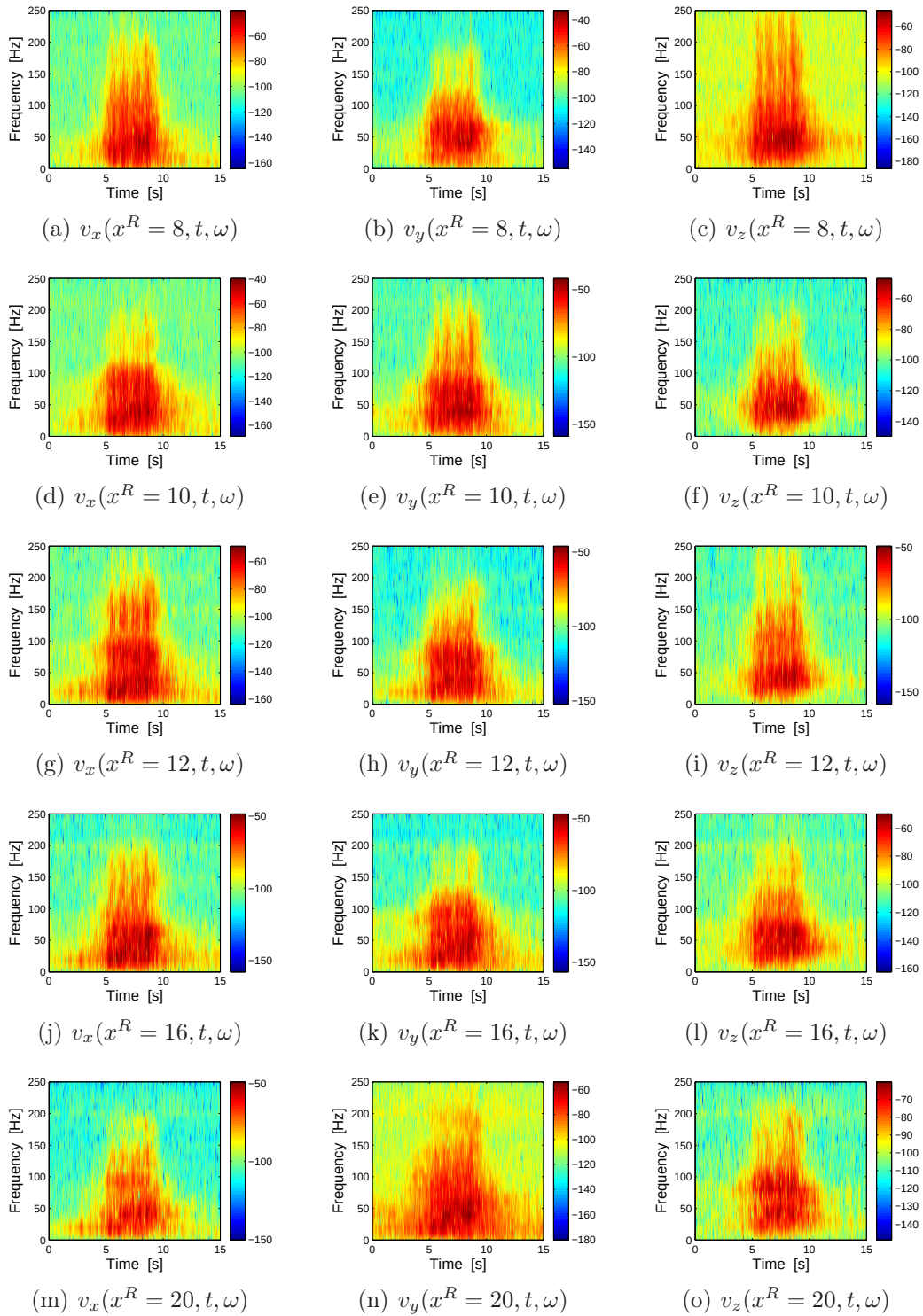


Figure 4.37: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 85 km/h

4.10 AM86 unit at 70 km/h

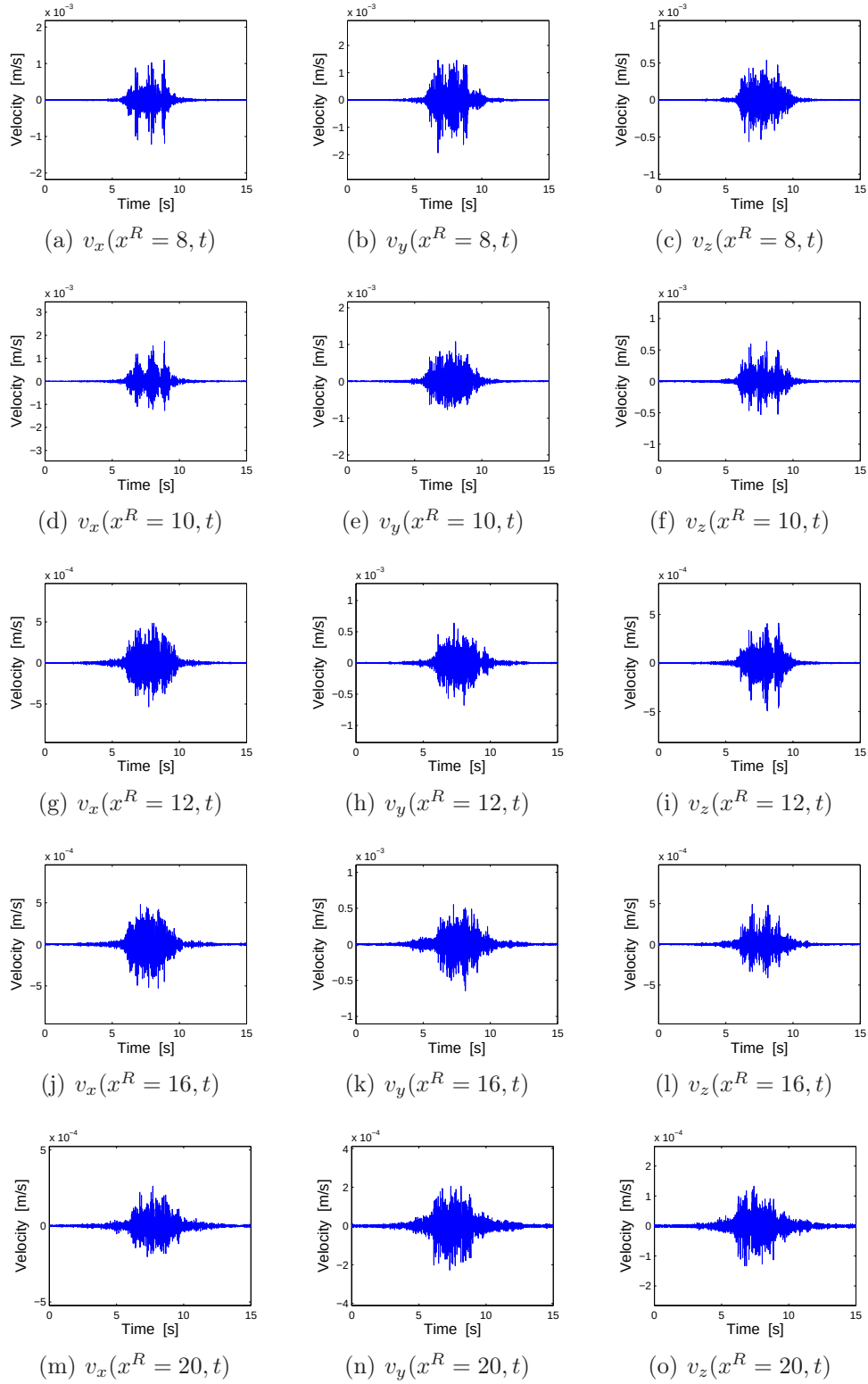


Figure 4.38: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM86 unit at 70 km/h

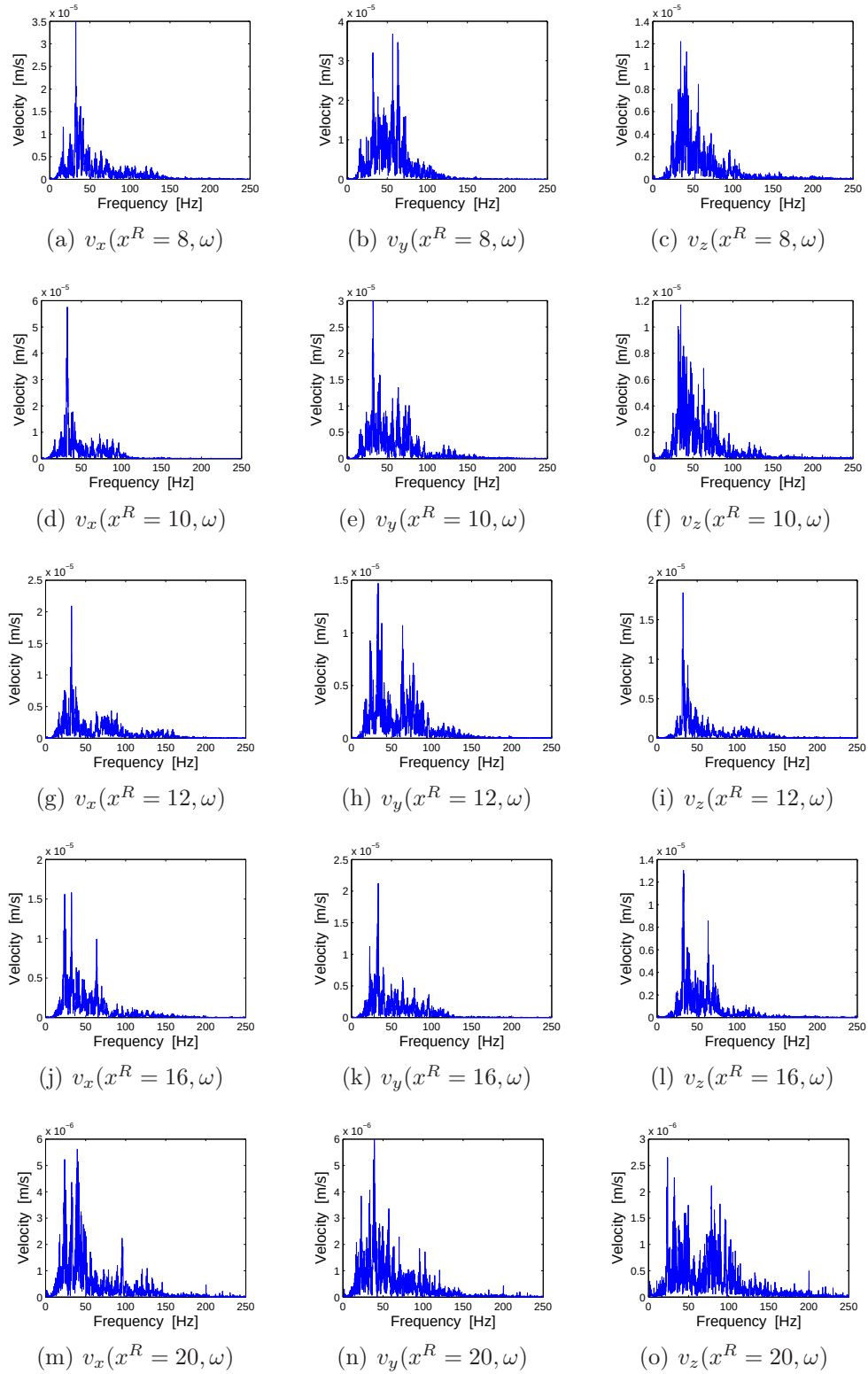


Figure 4.39: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM86 unit at 70 km/h

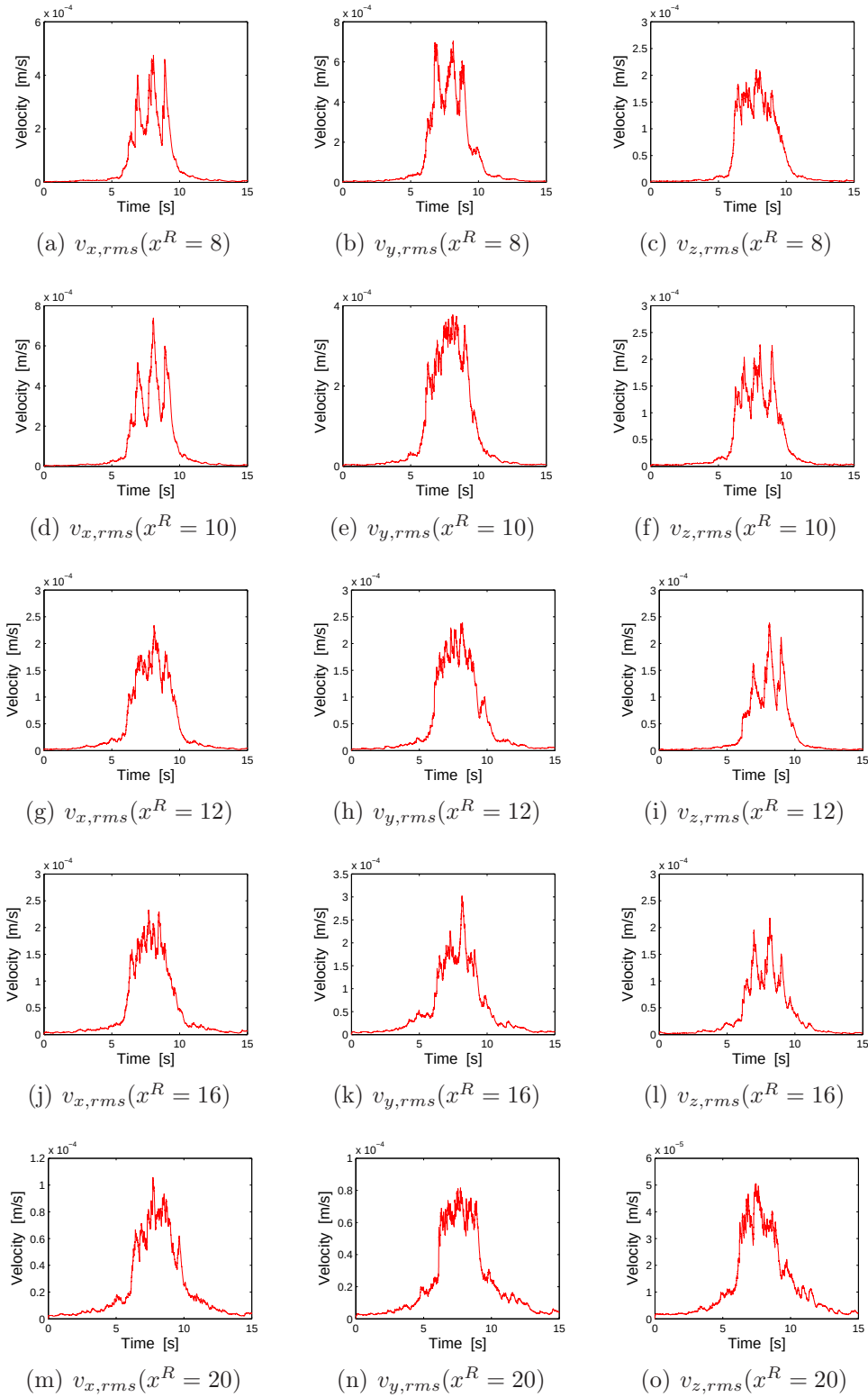


Figure 4.40: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM86 unit at 70 km/h

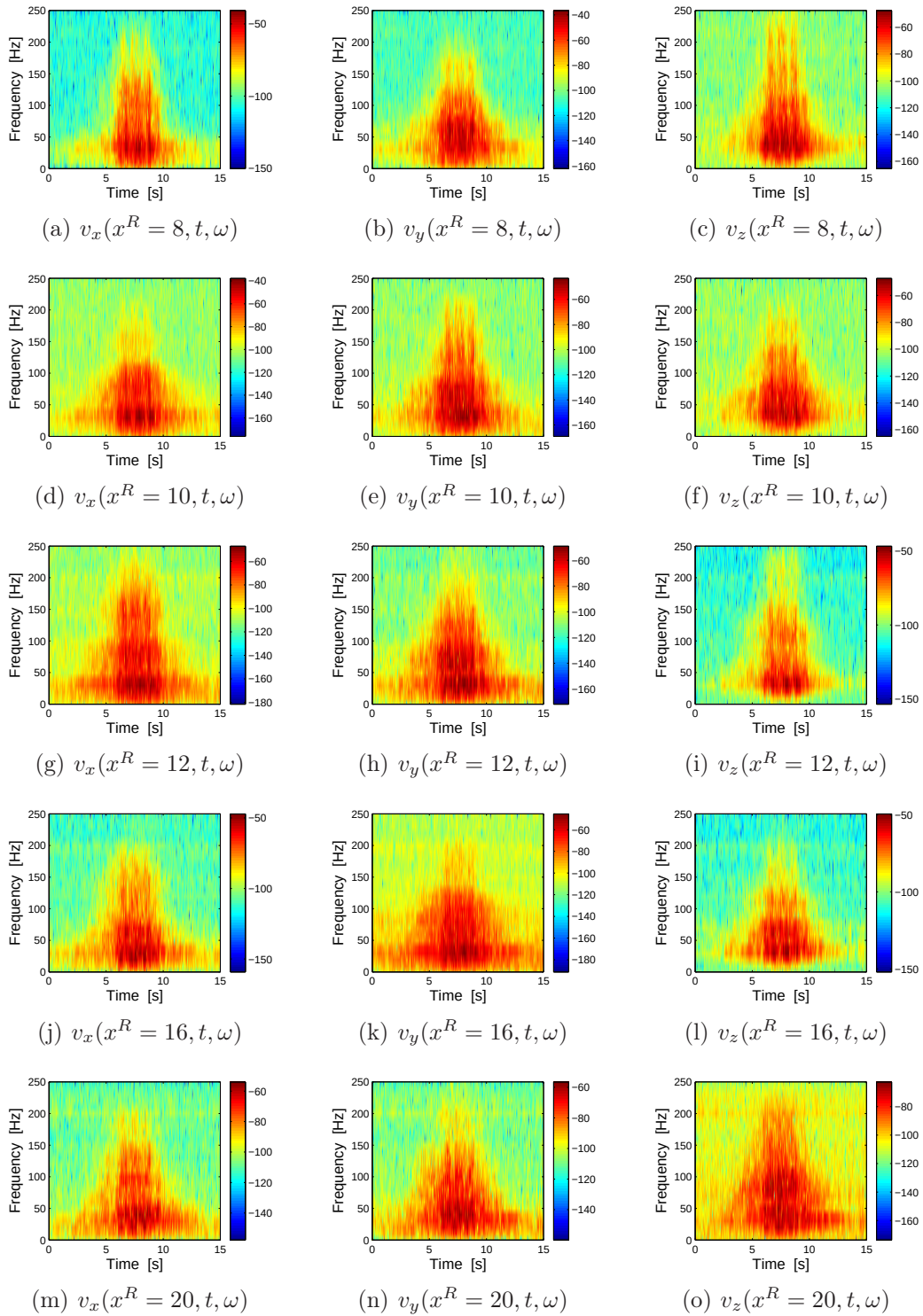


Figure 4.41: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM86 unit at 70 km/h

4.11 HLE27 locomotive at 40 km/h

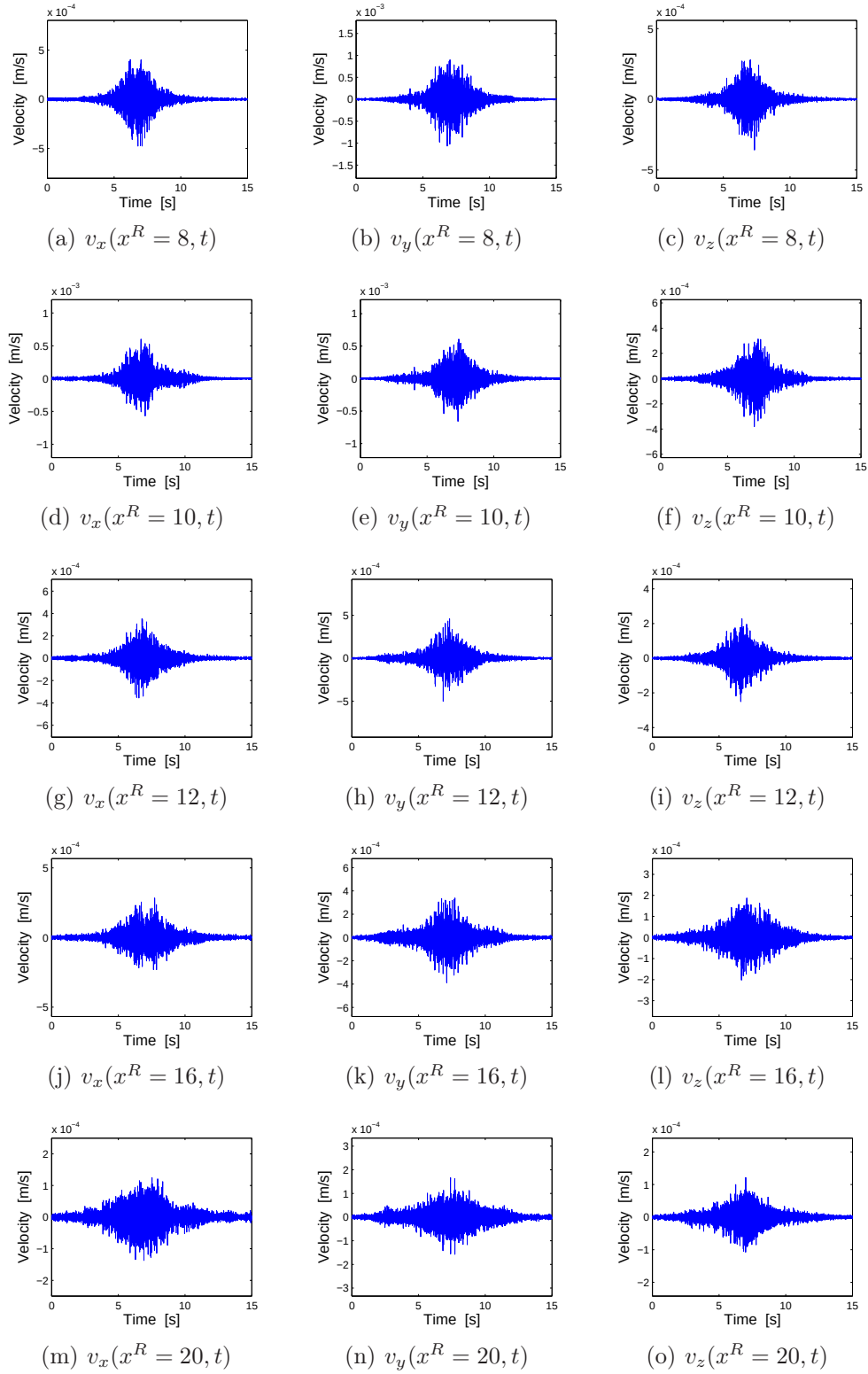


Figure 4.42: Time history of the vertical and horizontal velocities measured in free field during the passage of a HLE27 locomotive at 40 km/h

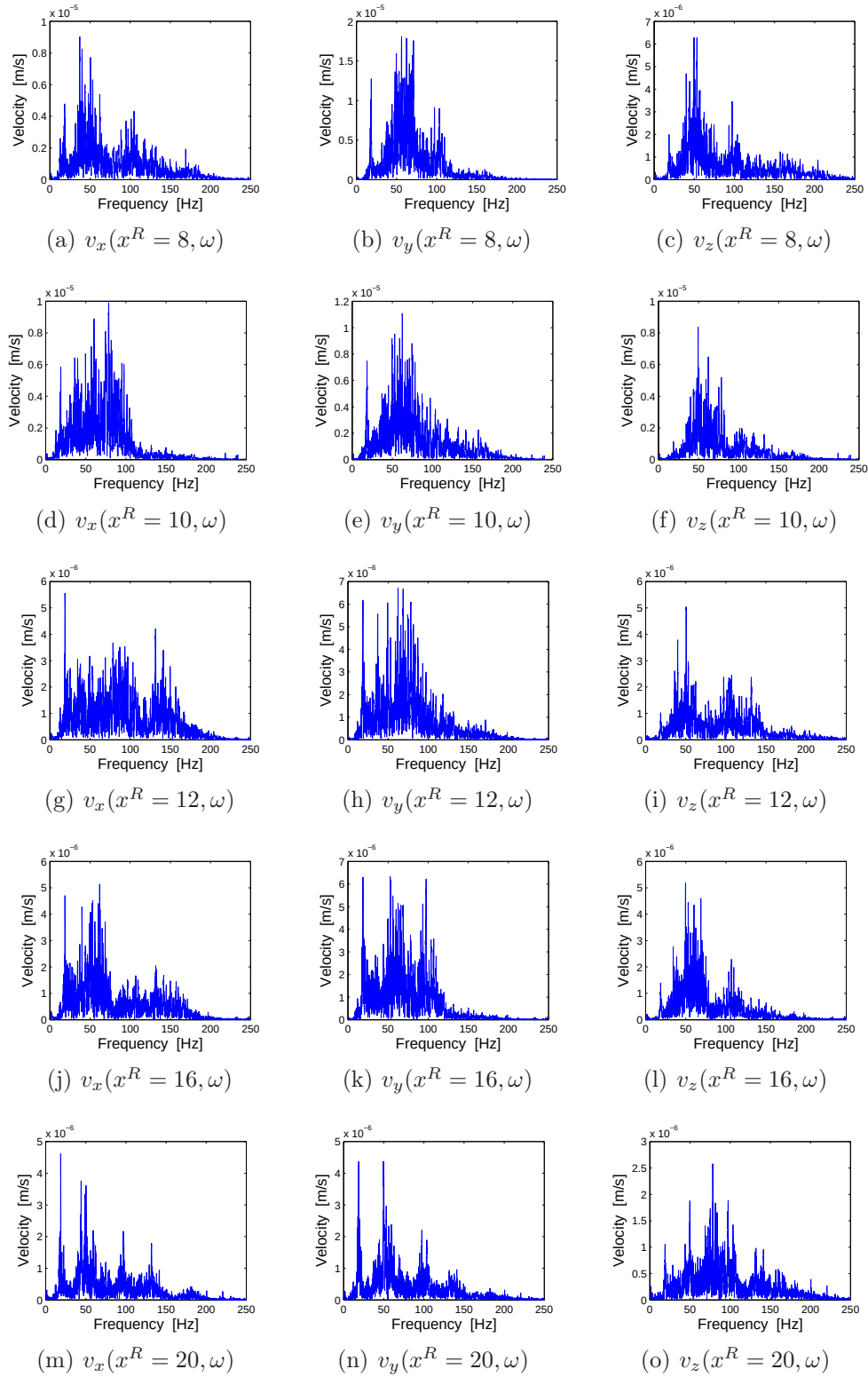


Figure 4.43: Spectral content of the vertical and horizontal velocities measured in free field during the passage of a HLE27 locomotive at 40 km/h

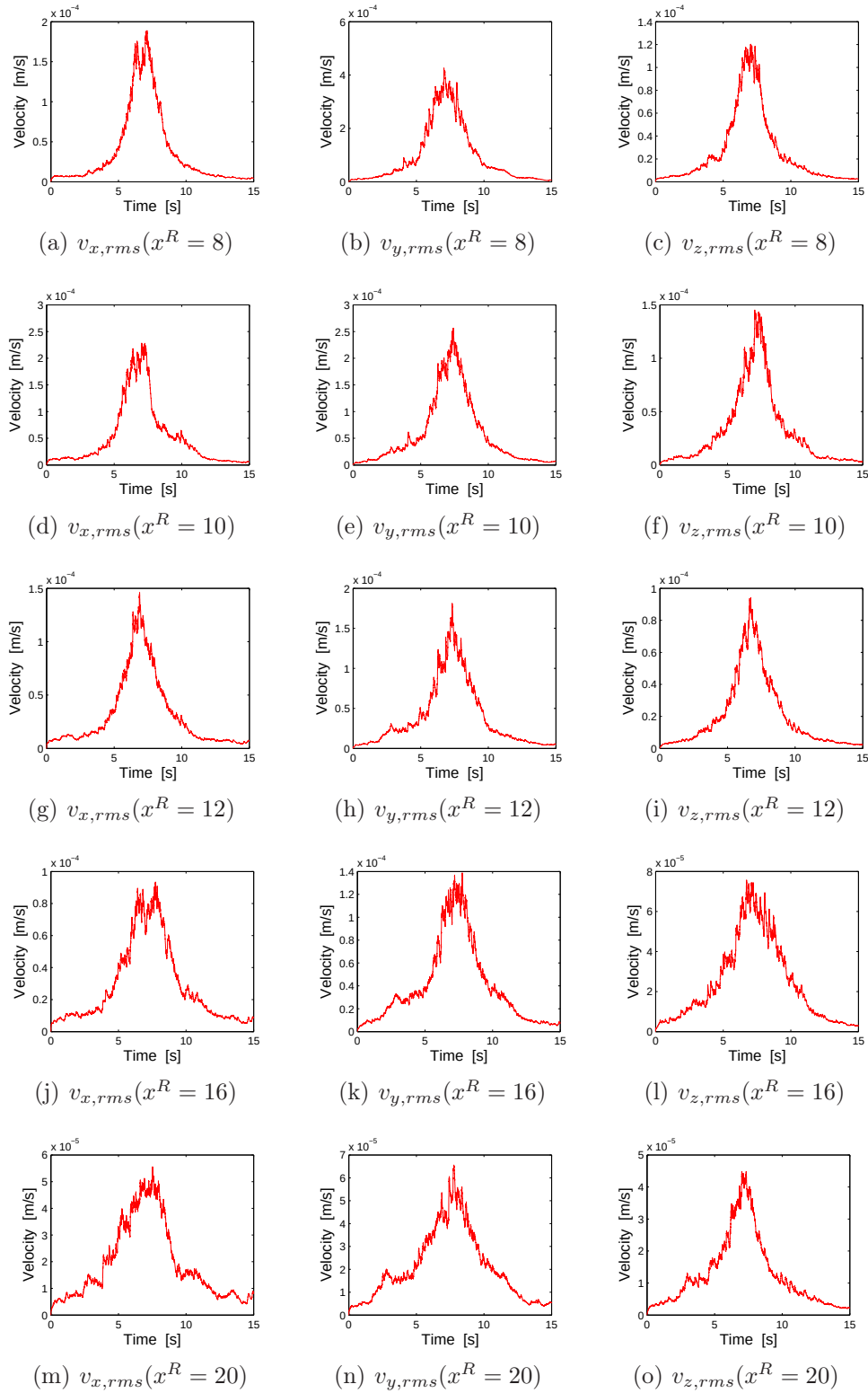


Figure 4.44: Time-average of the vertical and horizontal velocities measured in free field during the passage of a HLE27 locomotive at 40 km/h

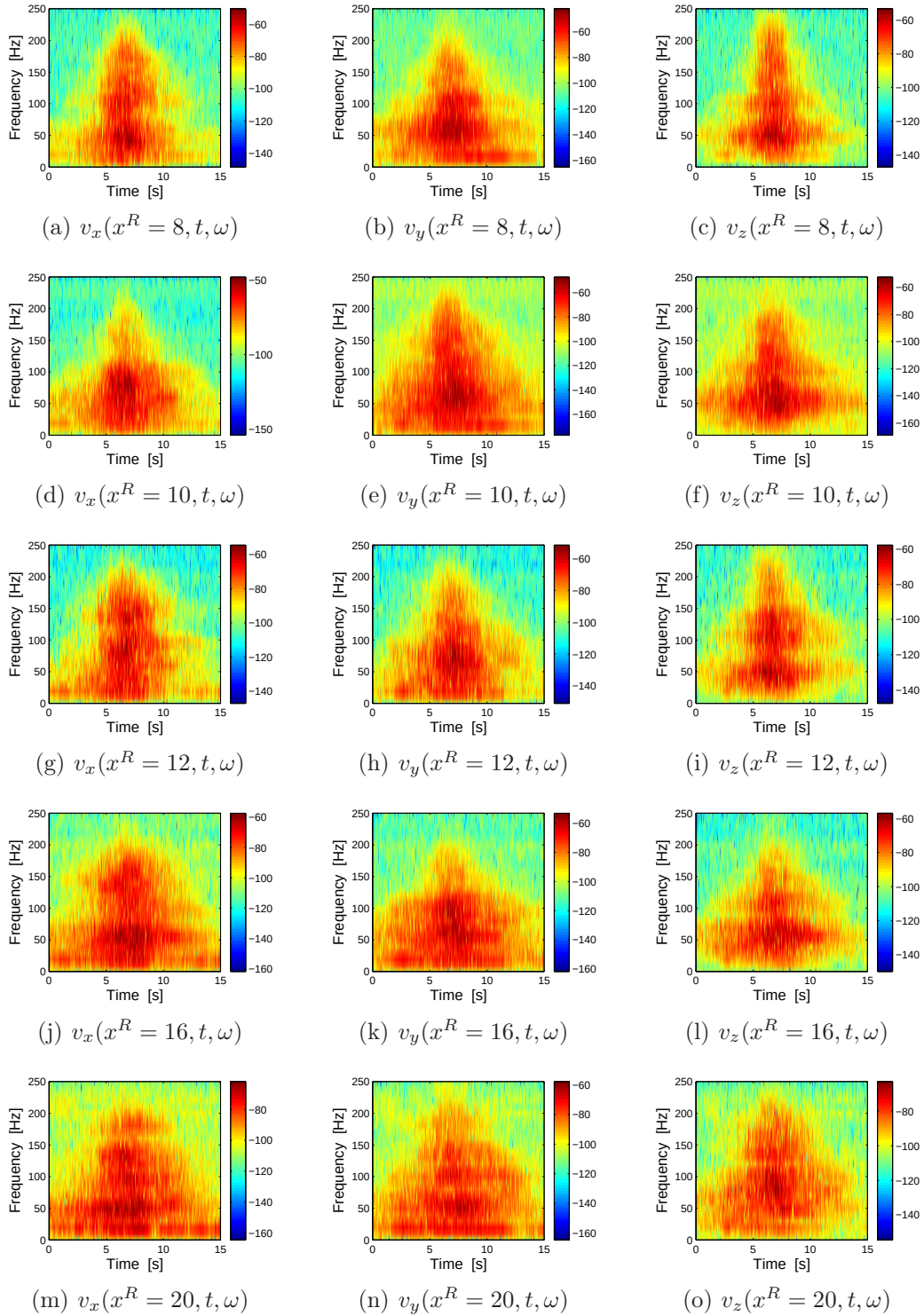


Figure 4.45: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of a HLE27 locomotive at 40 km/h

4.12 AM80 unit at 75 km/h

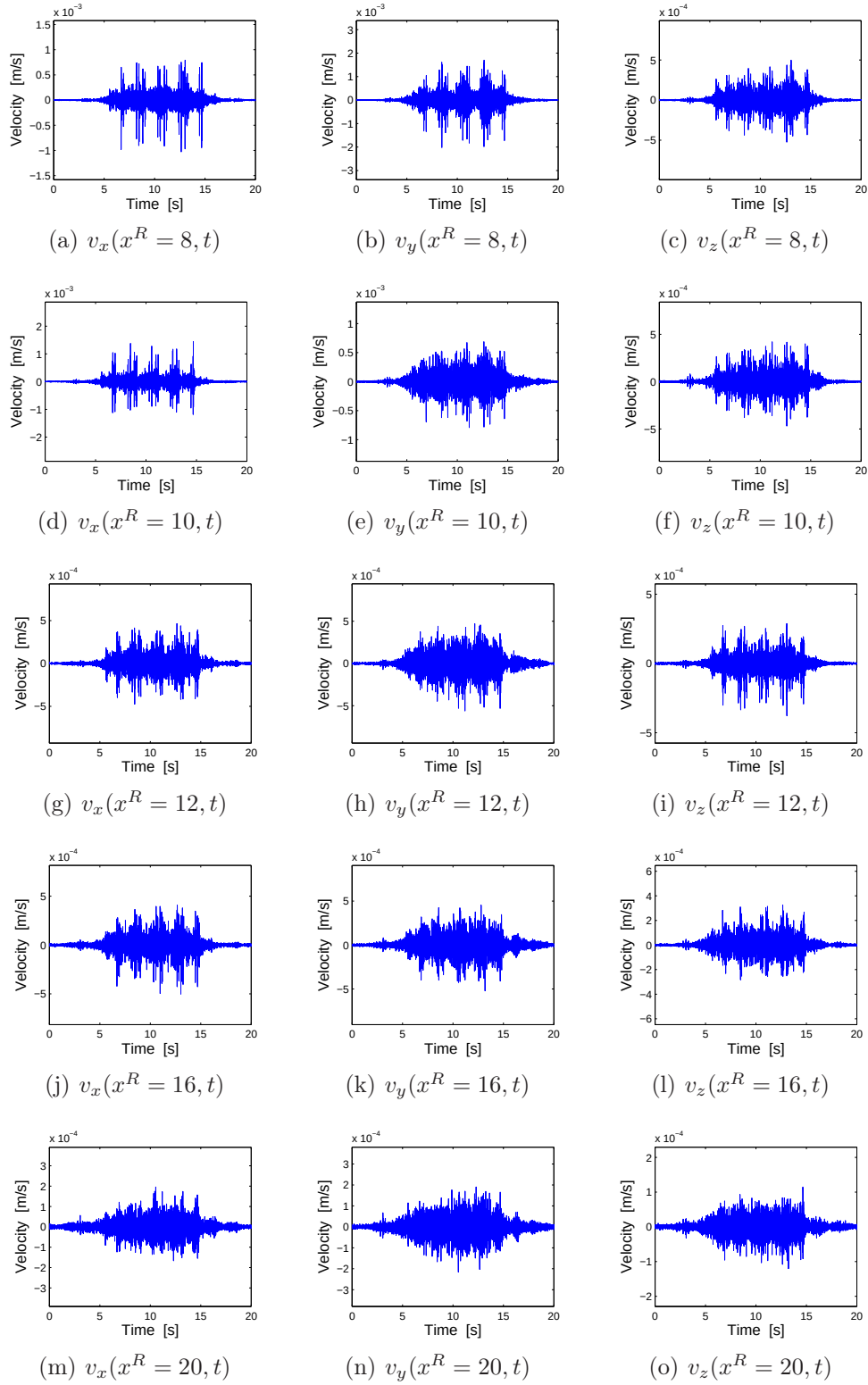


Figure 4.46: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 75 km/h

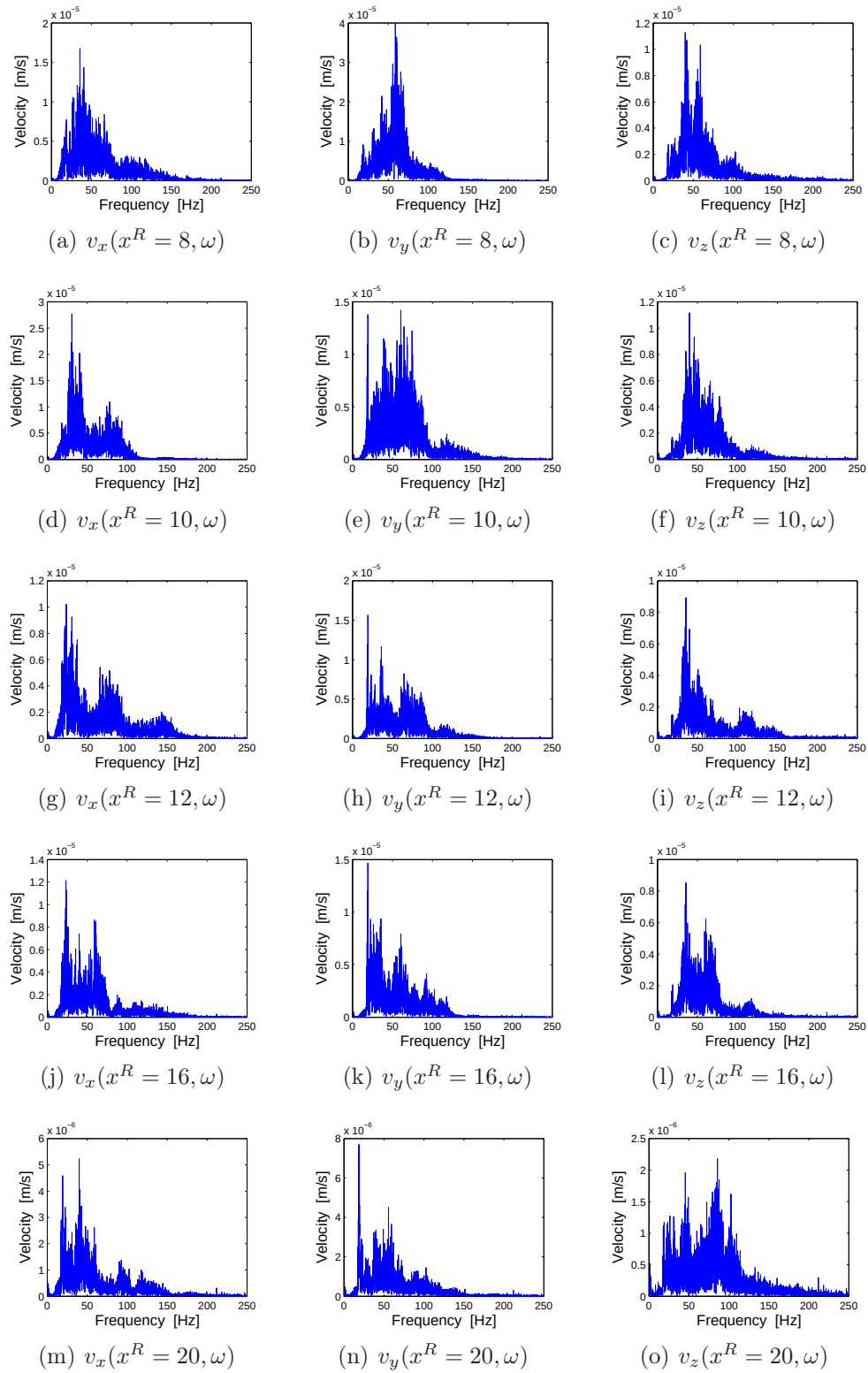


Figure 4.47: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 75 km/h

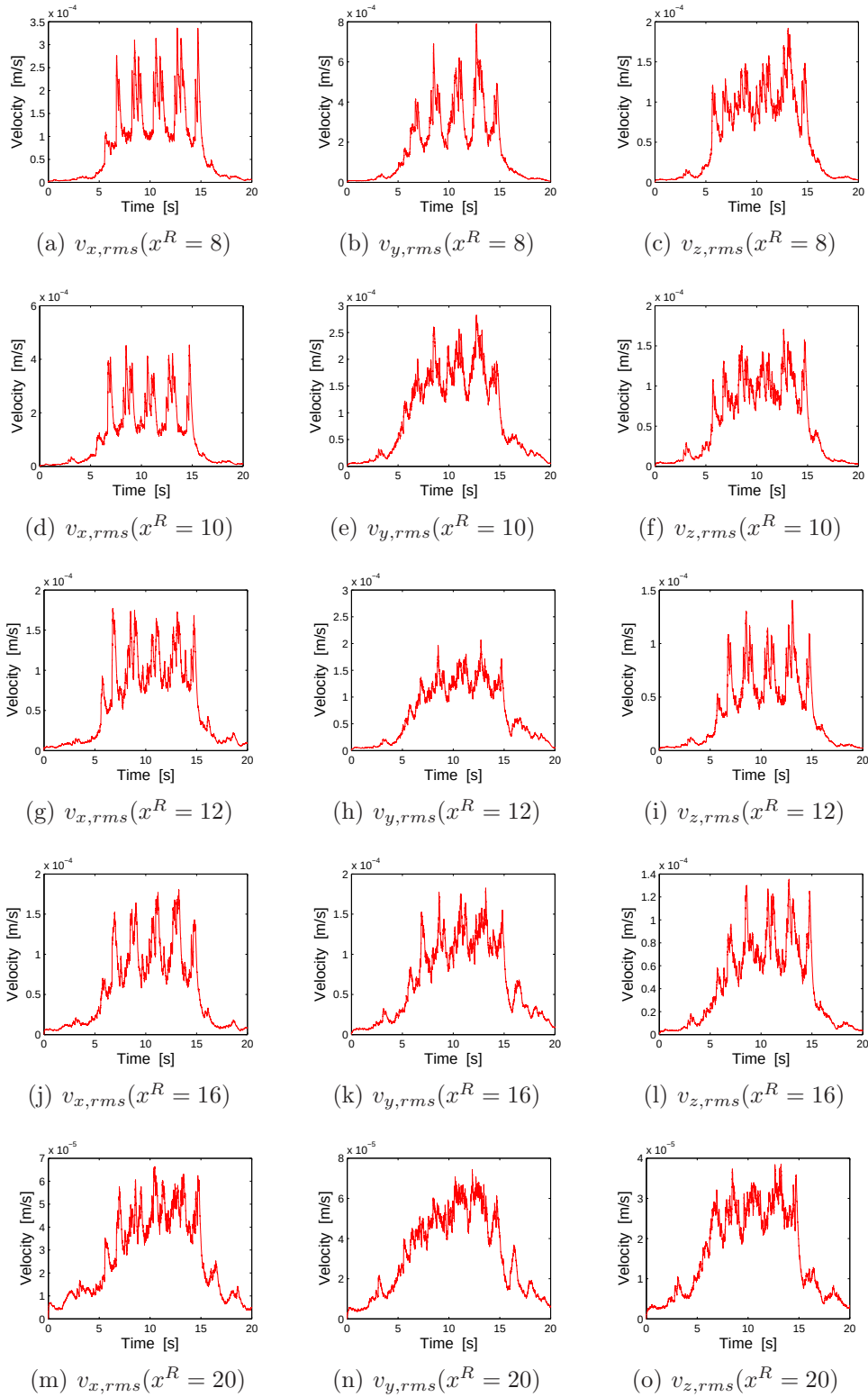


Figure 4.48: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 75 km/h

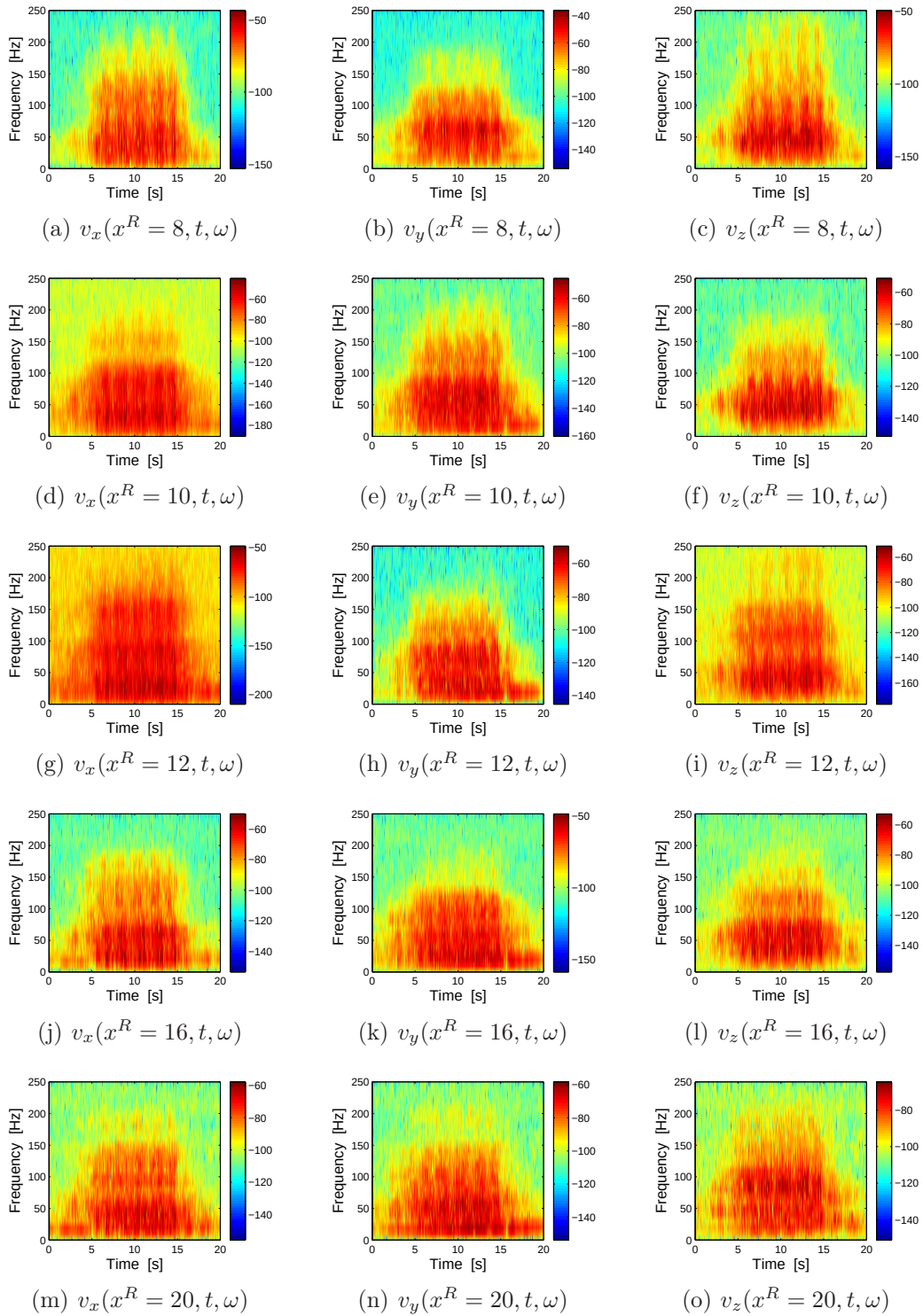


Figure 4.49: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 75 km/h

4.13 AM80 unit at 55 km/h

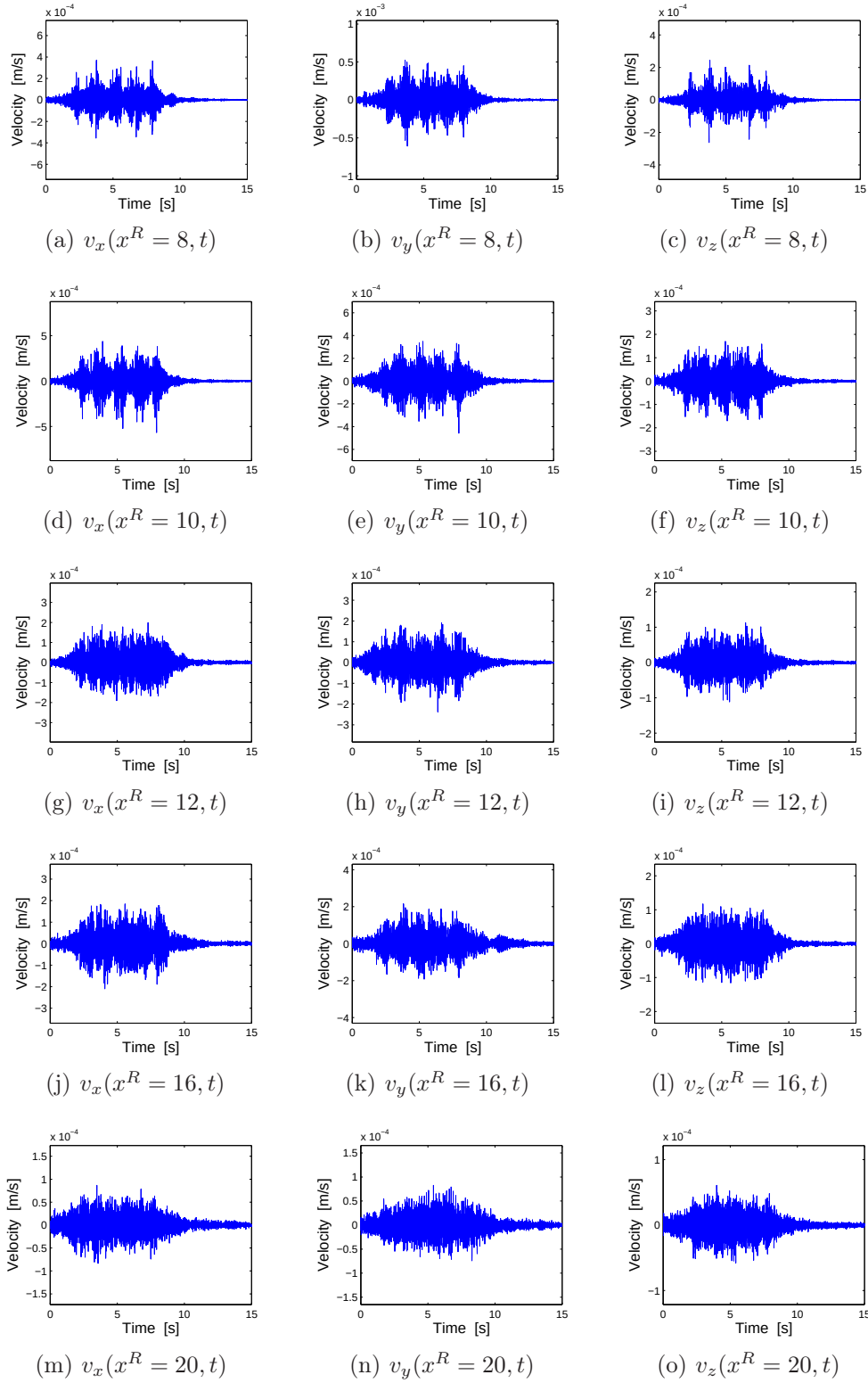


Figure 4.50: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 55 km/h

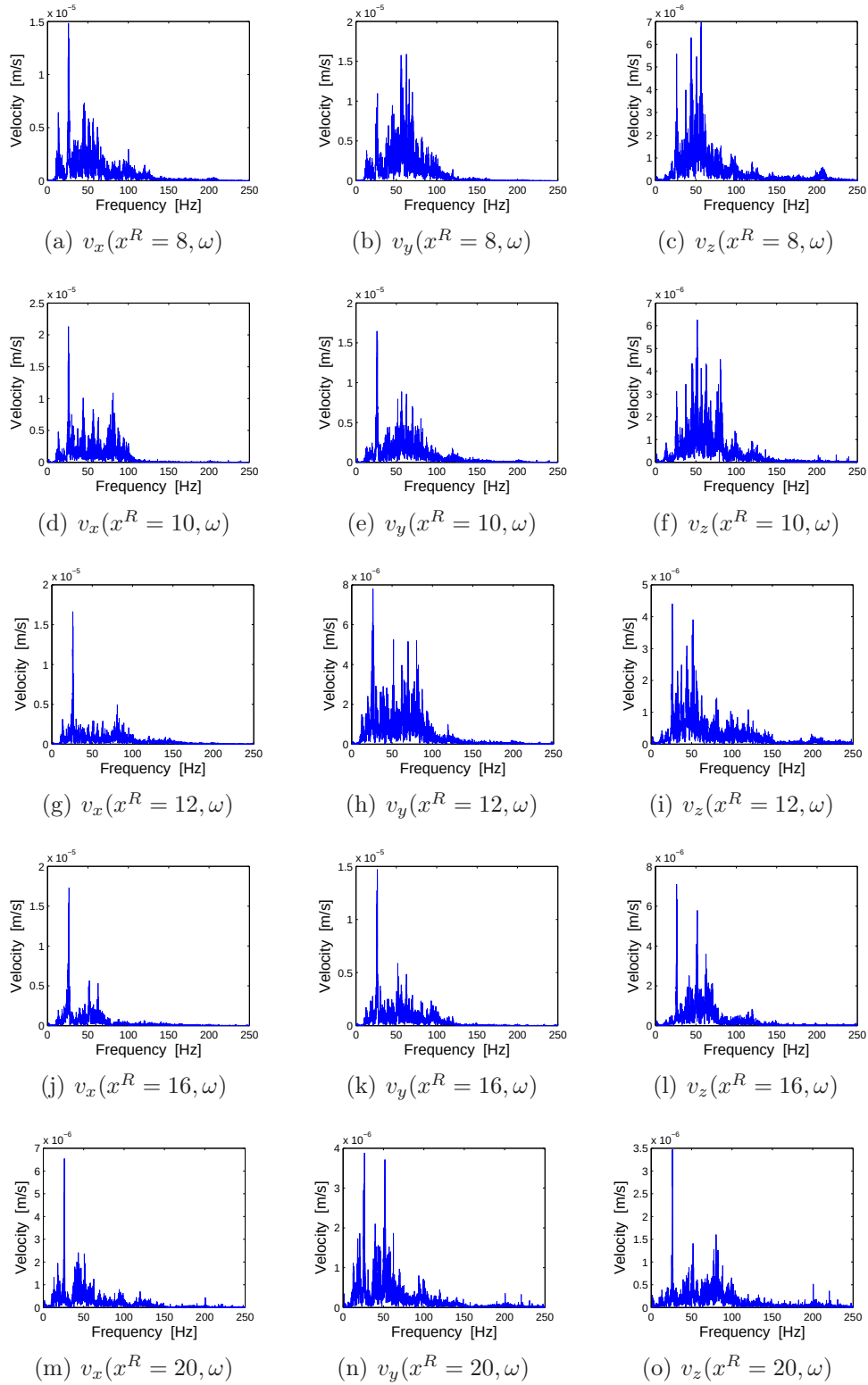


Figure 4.51: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 55 km/h

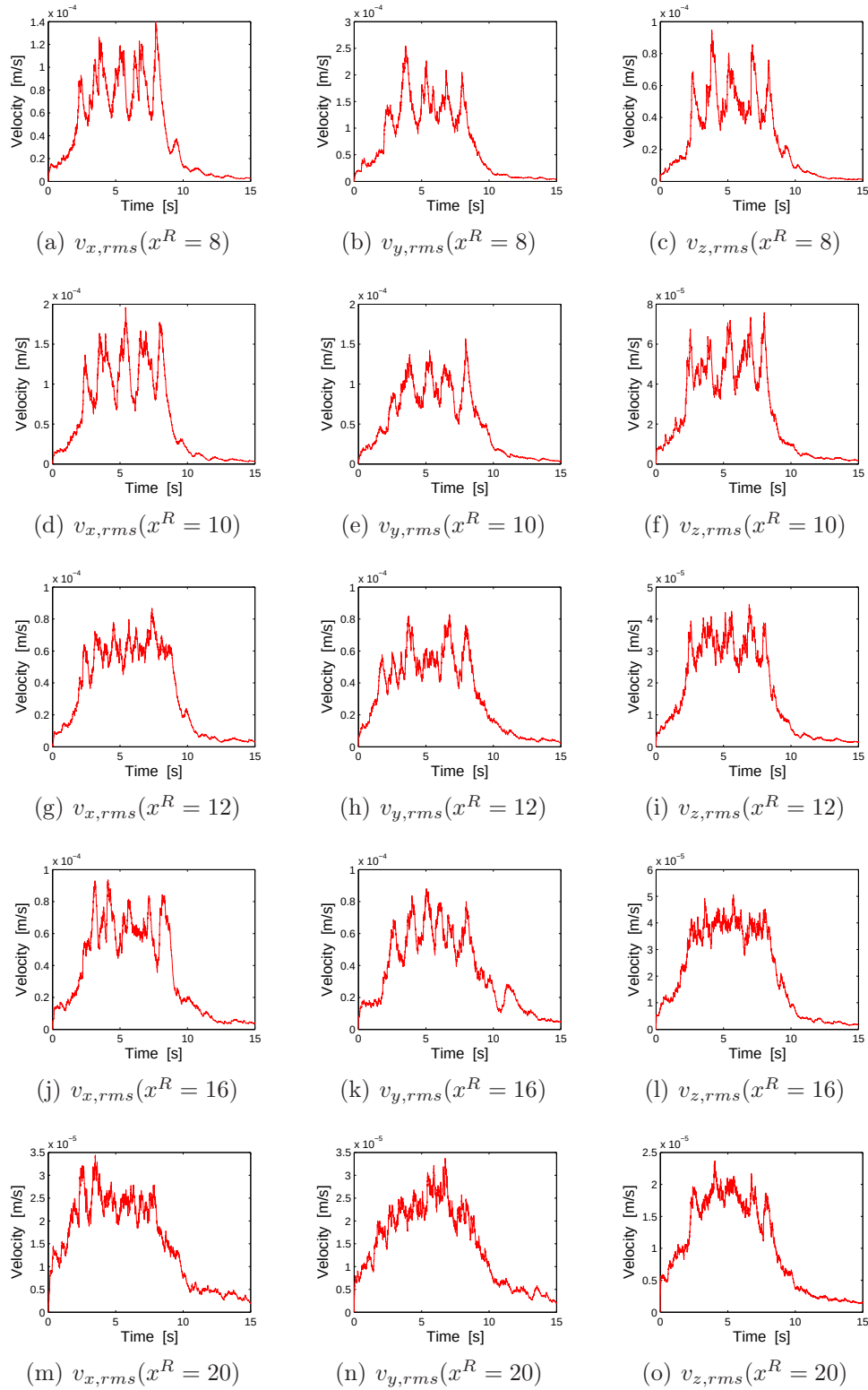


Figure 4.52: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 55 km/h

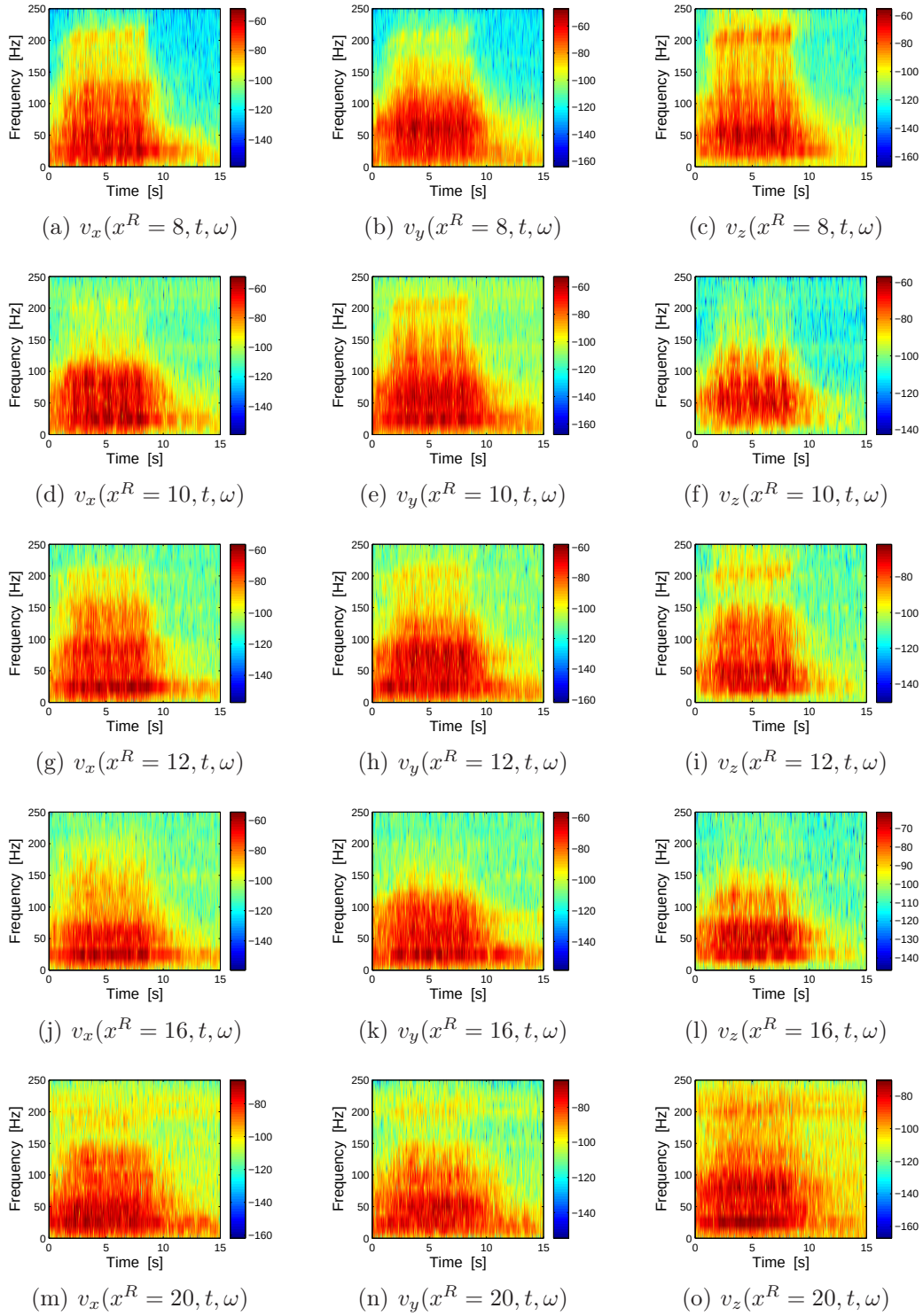


Figure 4.53: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM80 unit at 55 km/h

4.14 AM75 unit at 65 km/h

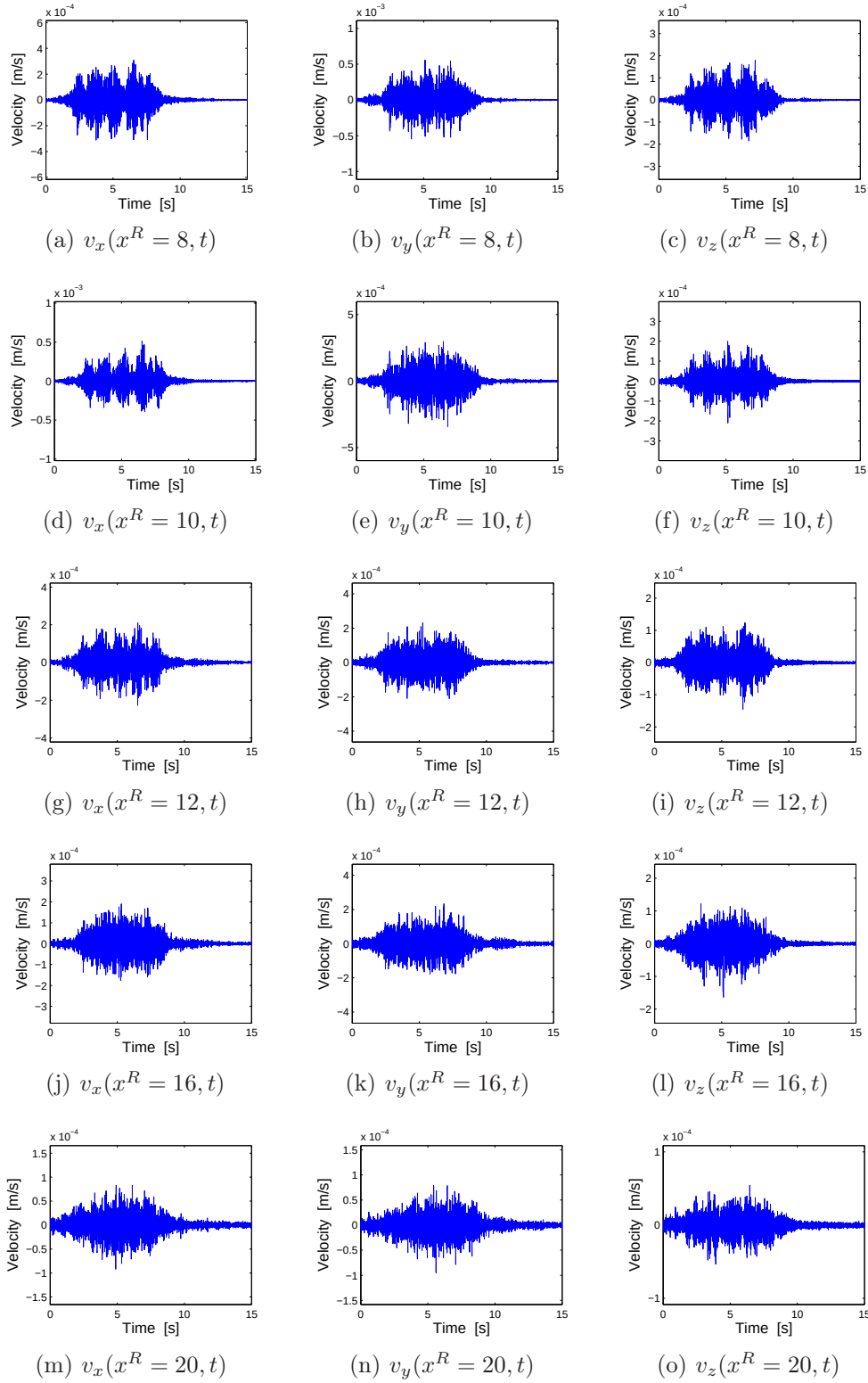


Figure 4.54: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 65 km/h

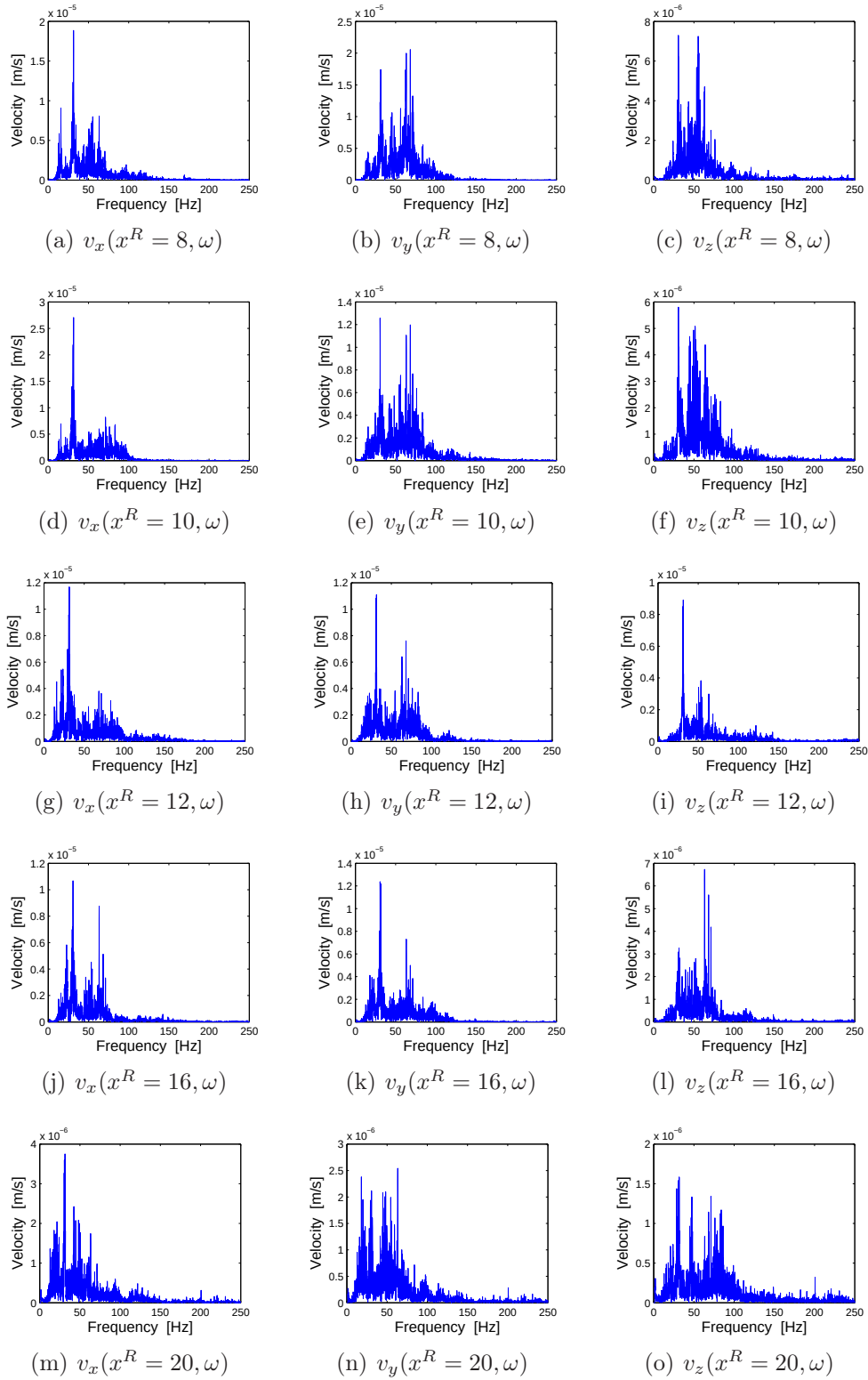


Figure 4.55: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 65 km/h

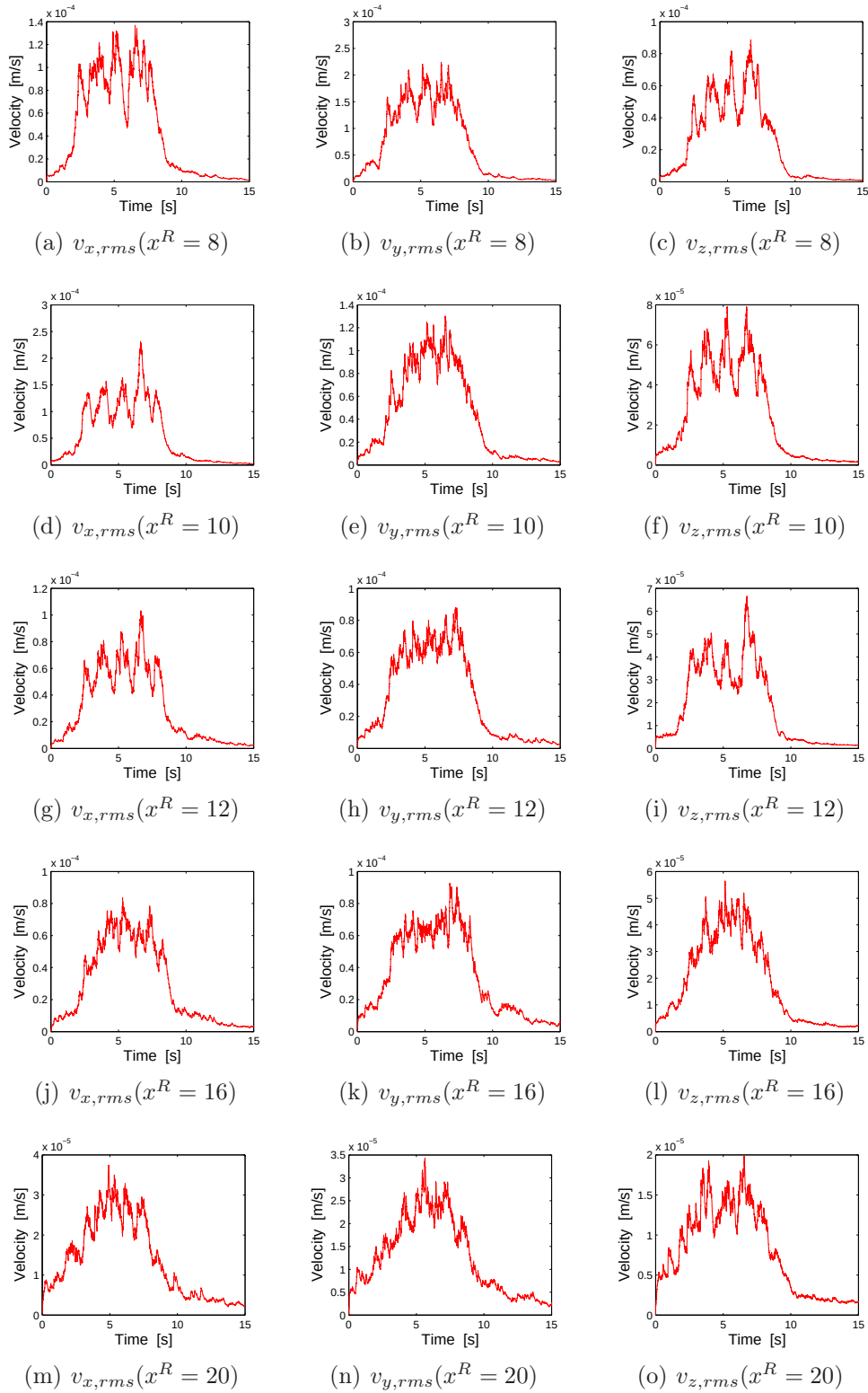


Figure 4.56: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 65 km/h

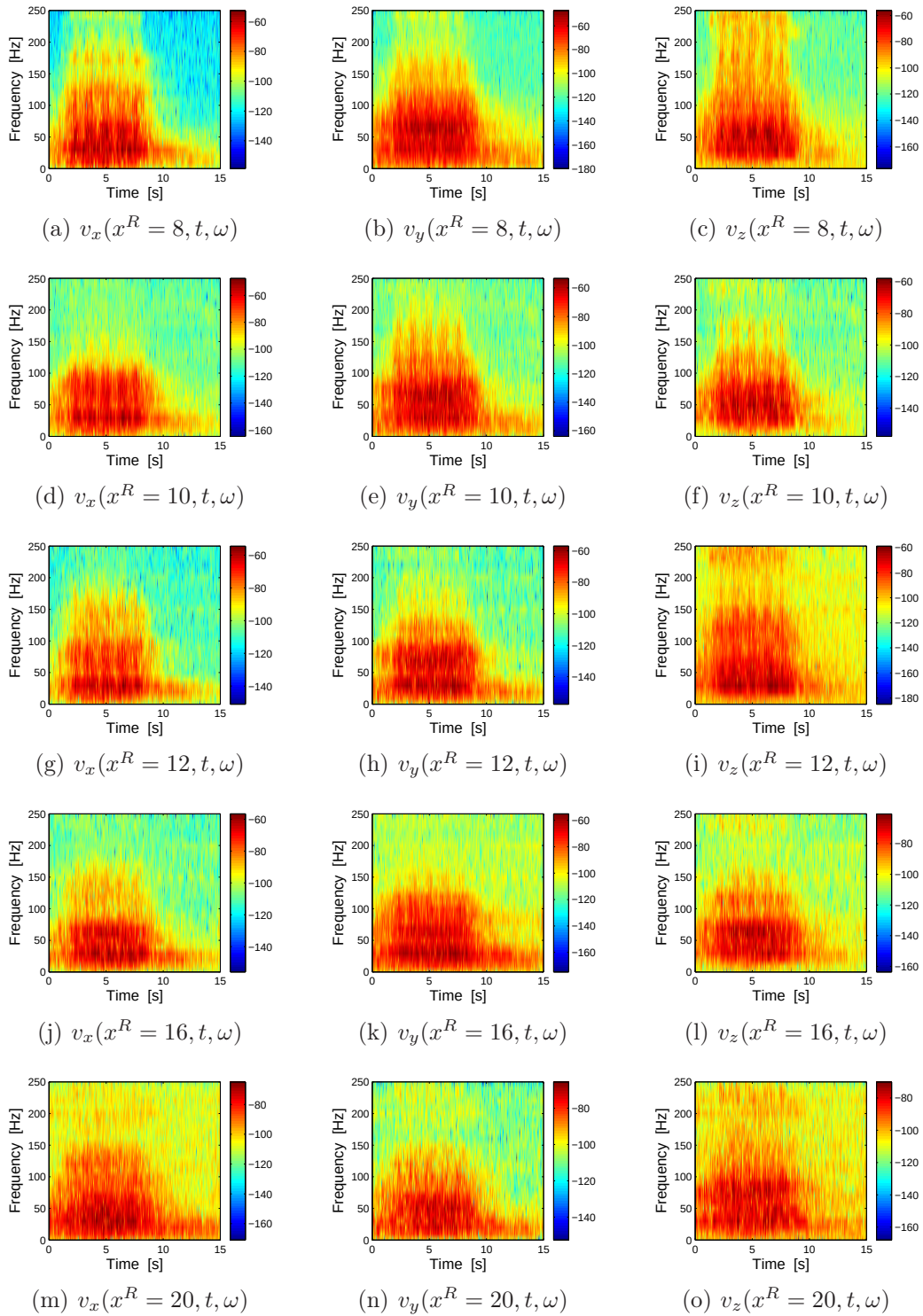


Figure 4.57: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 65 km/h

4.15 AM96 unit at 110 km/h

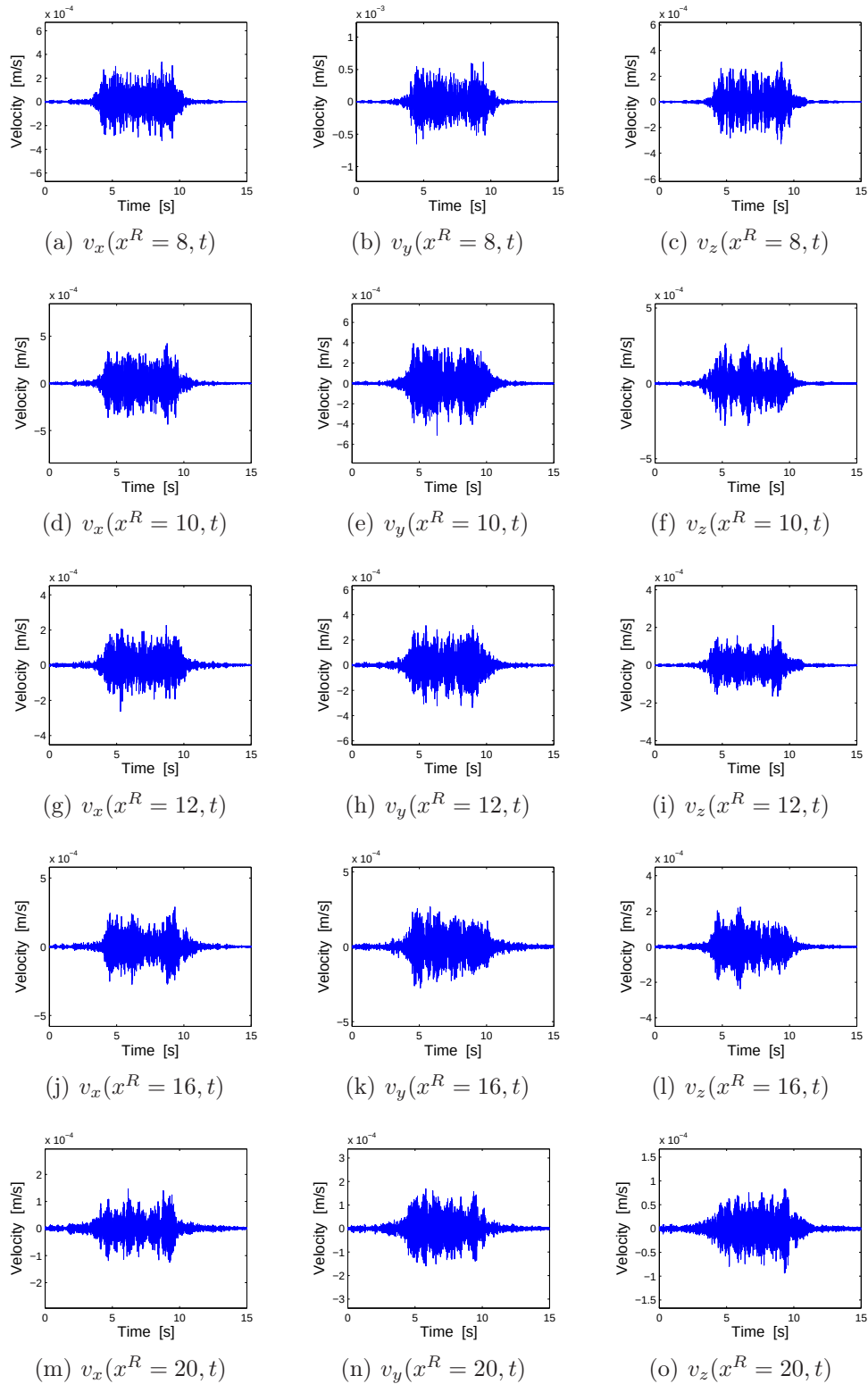


Figure 4.58: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 110 km/h

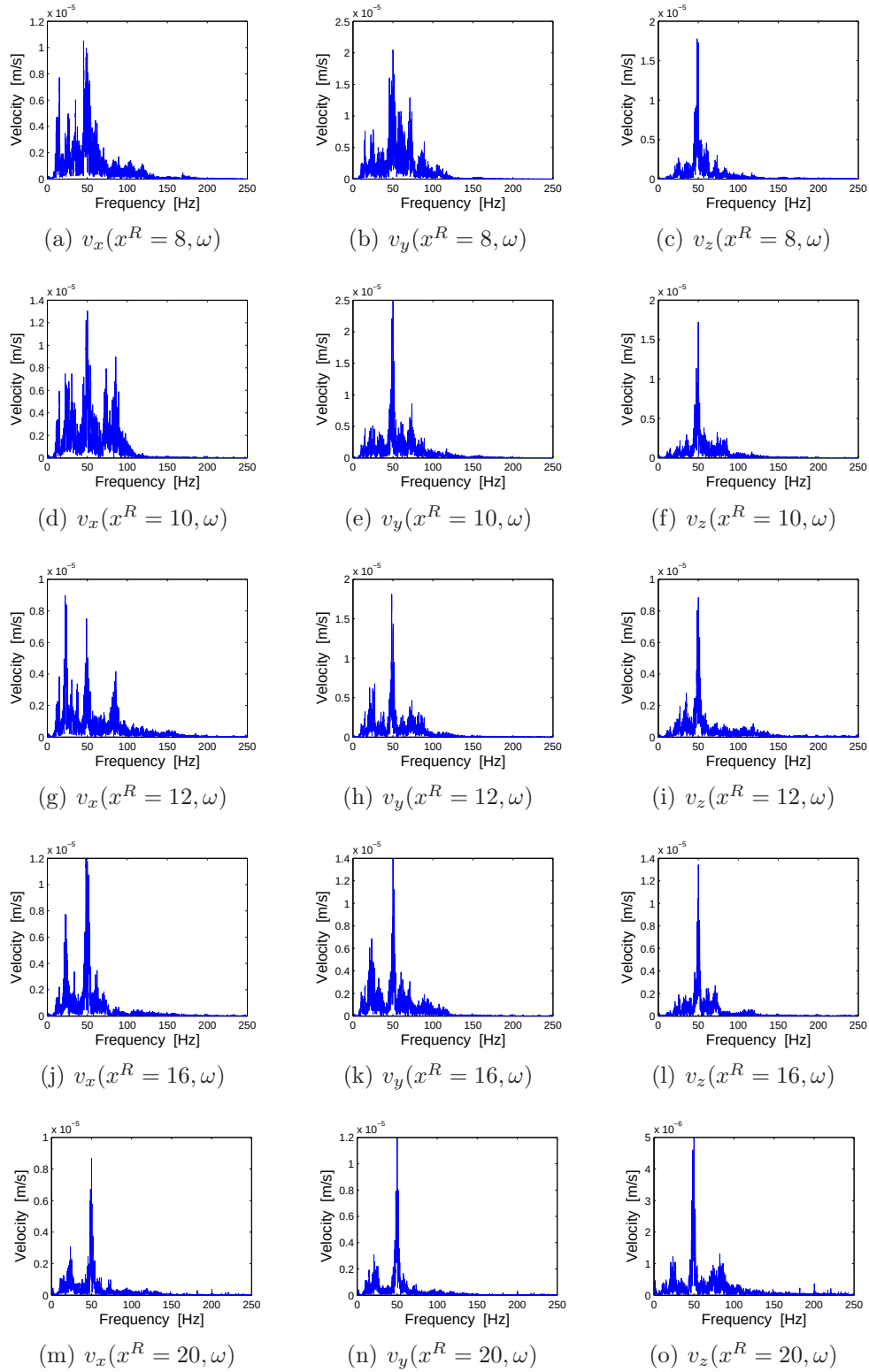


Figure 4.59: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 110 km/h

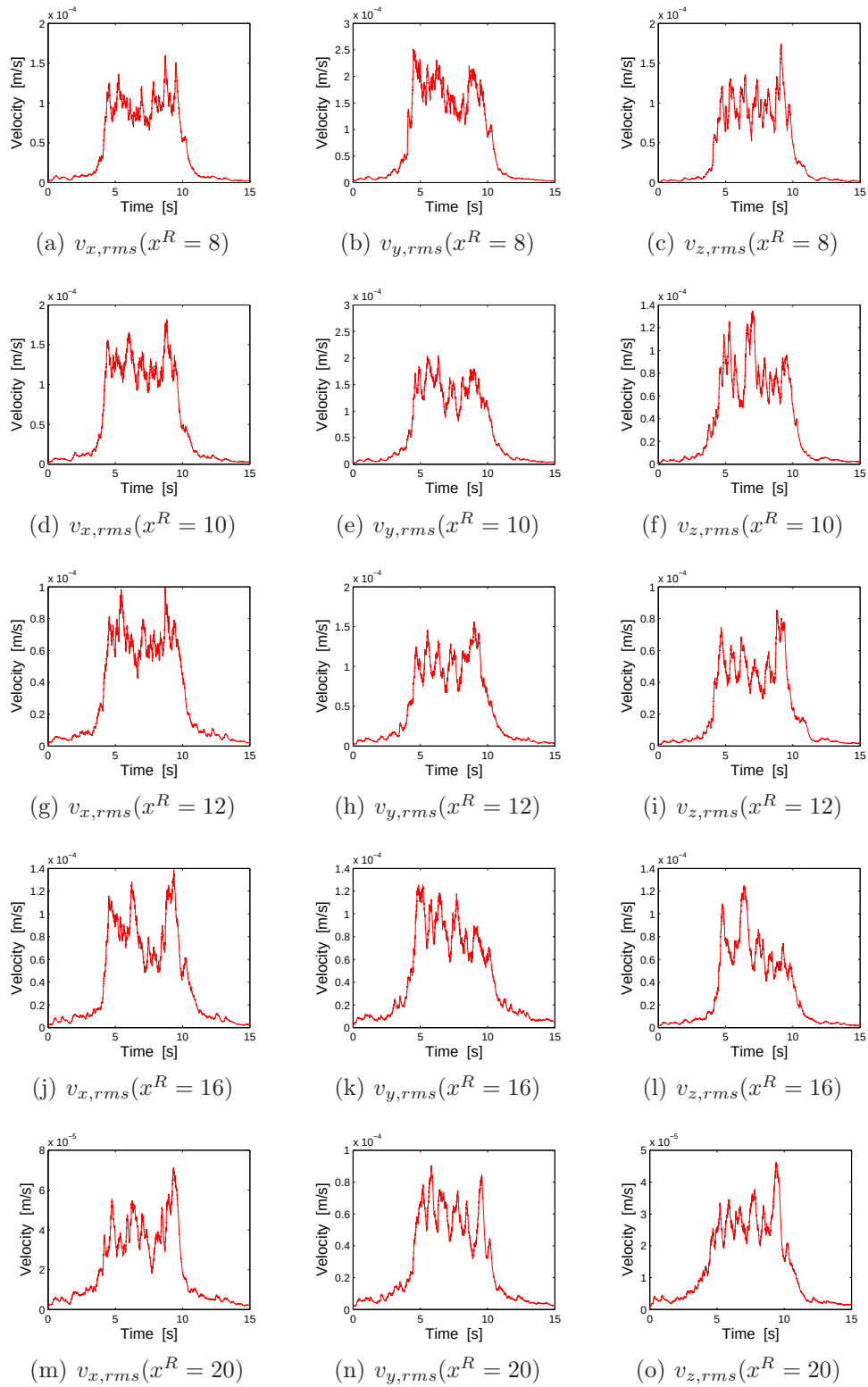


Figure 4.60: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 110 km/h

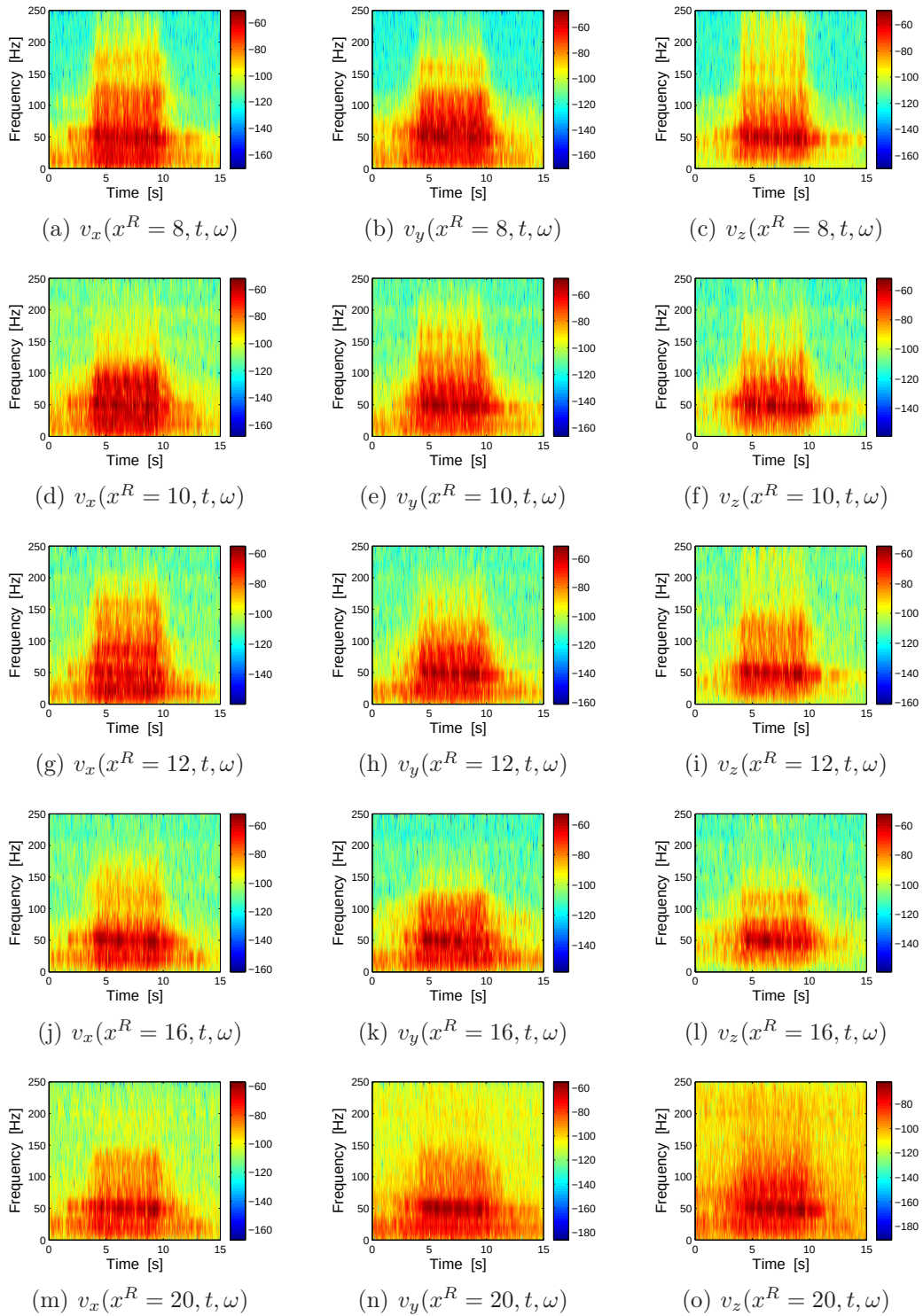


Figure 4.61: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 110 km/h

4.16 AM96 unit at 100 km/h

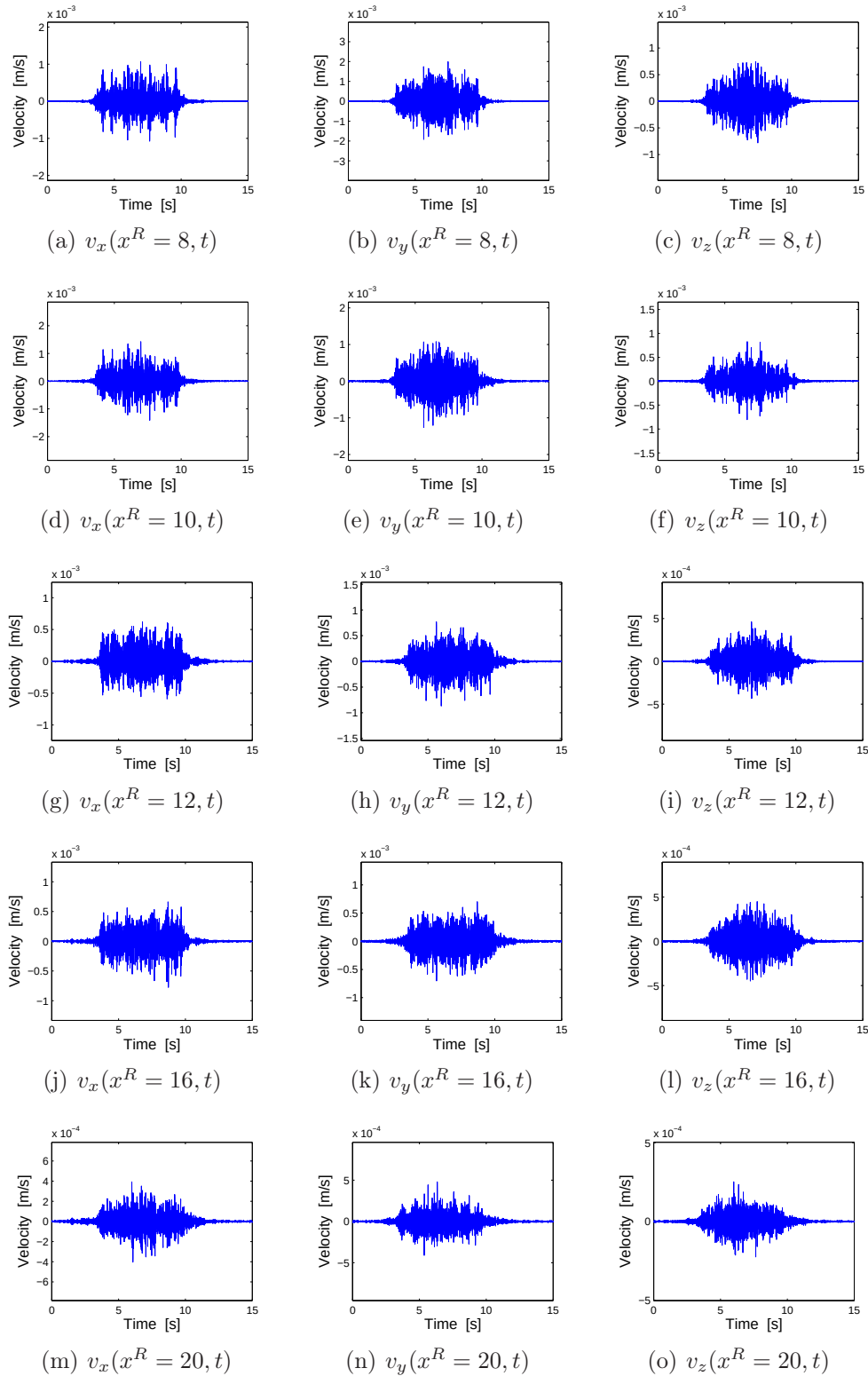


Figure 4.62: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 100 km/h

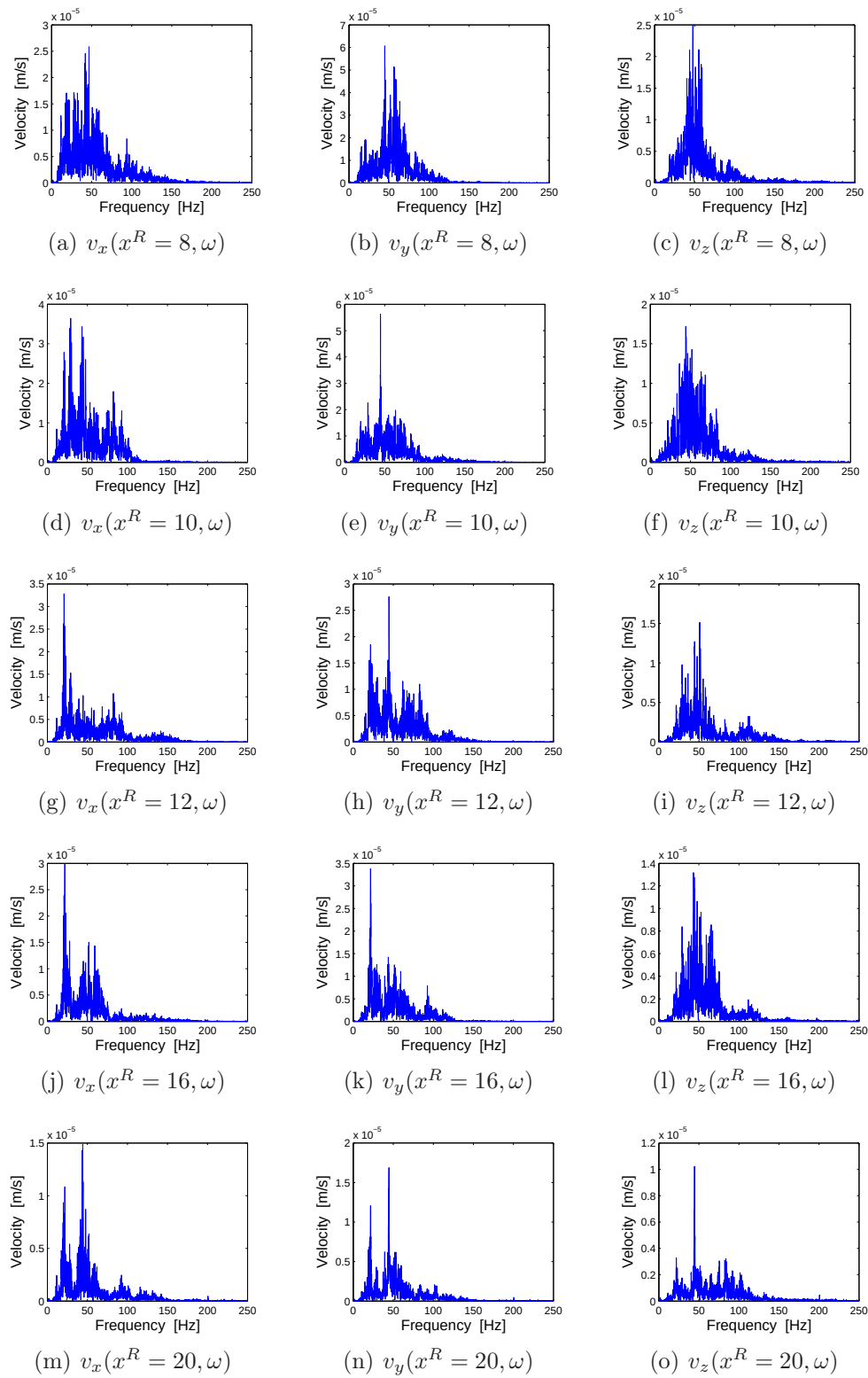


Figure 4.63: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 100 km/h

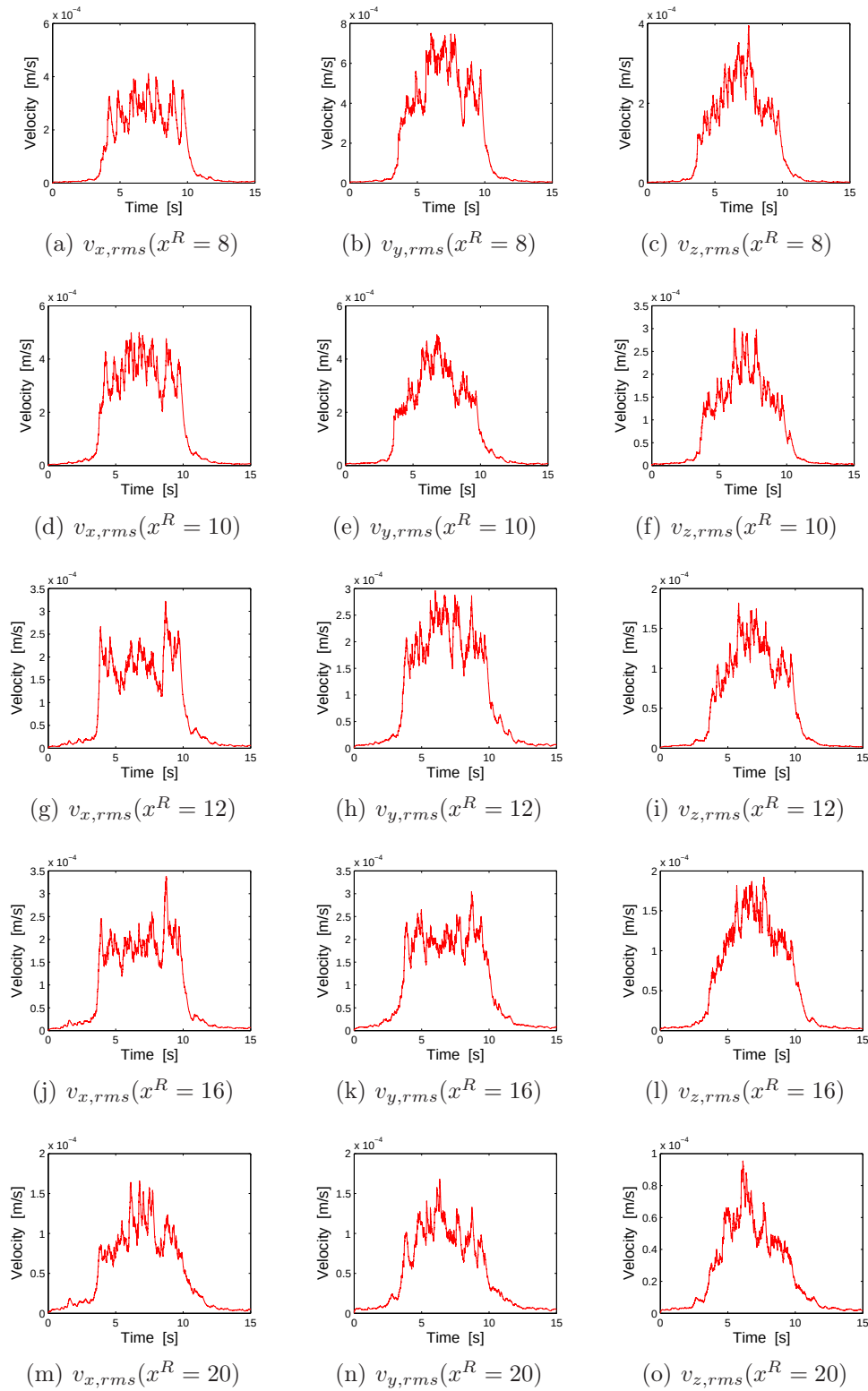


Figure 4.64: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 100 km/h

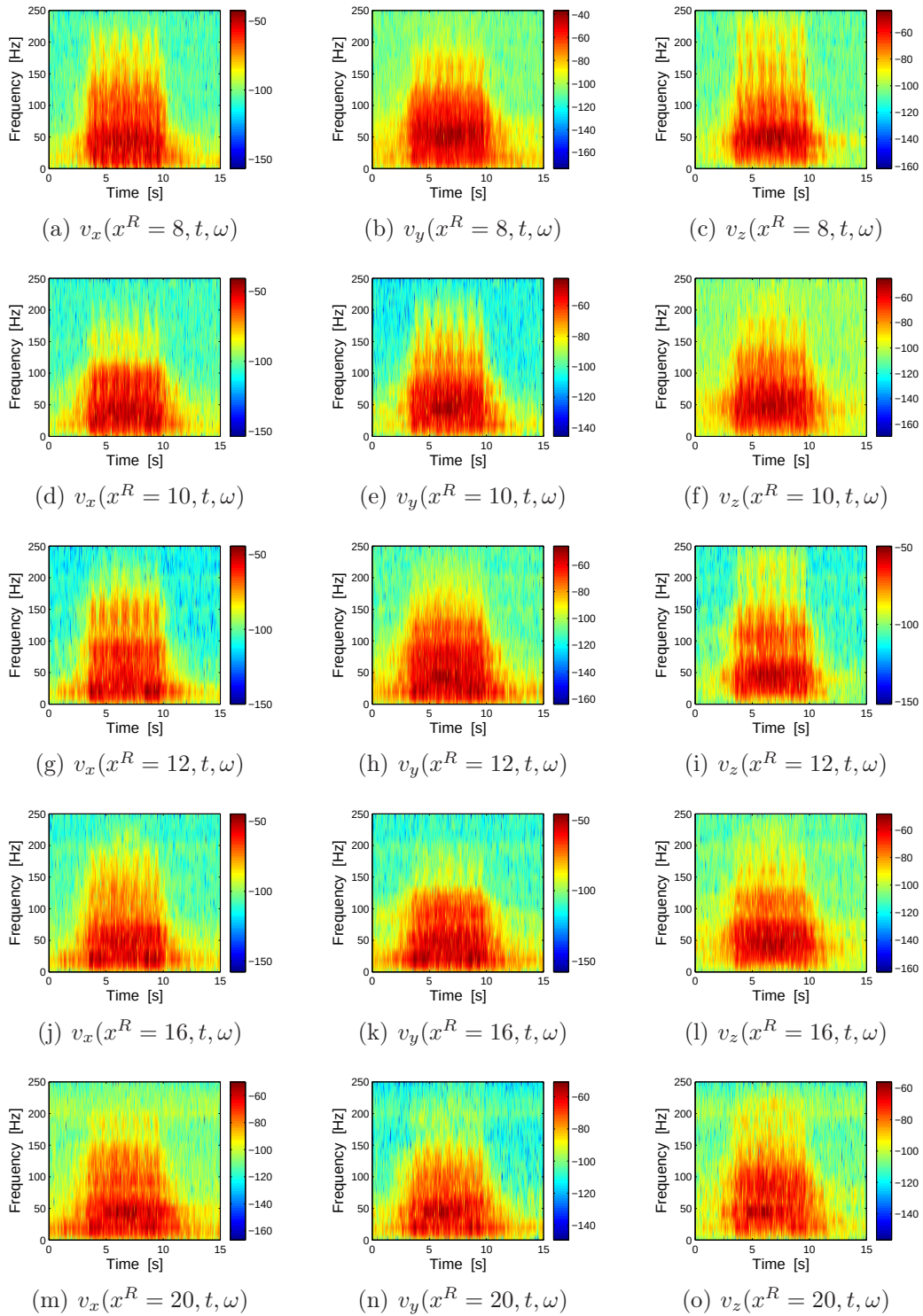


Figure 4.65: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM96 unit at 100 km/h

4.17 AM75 unit at 105 km/h

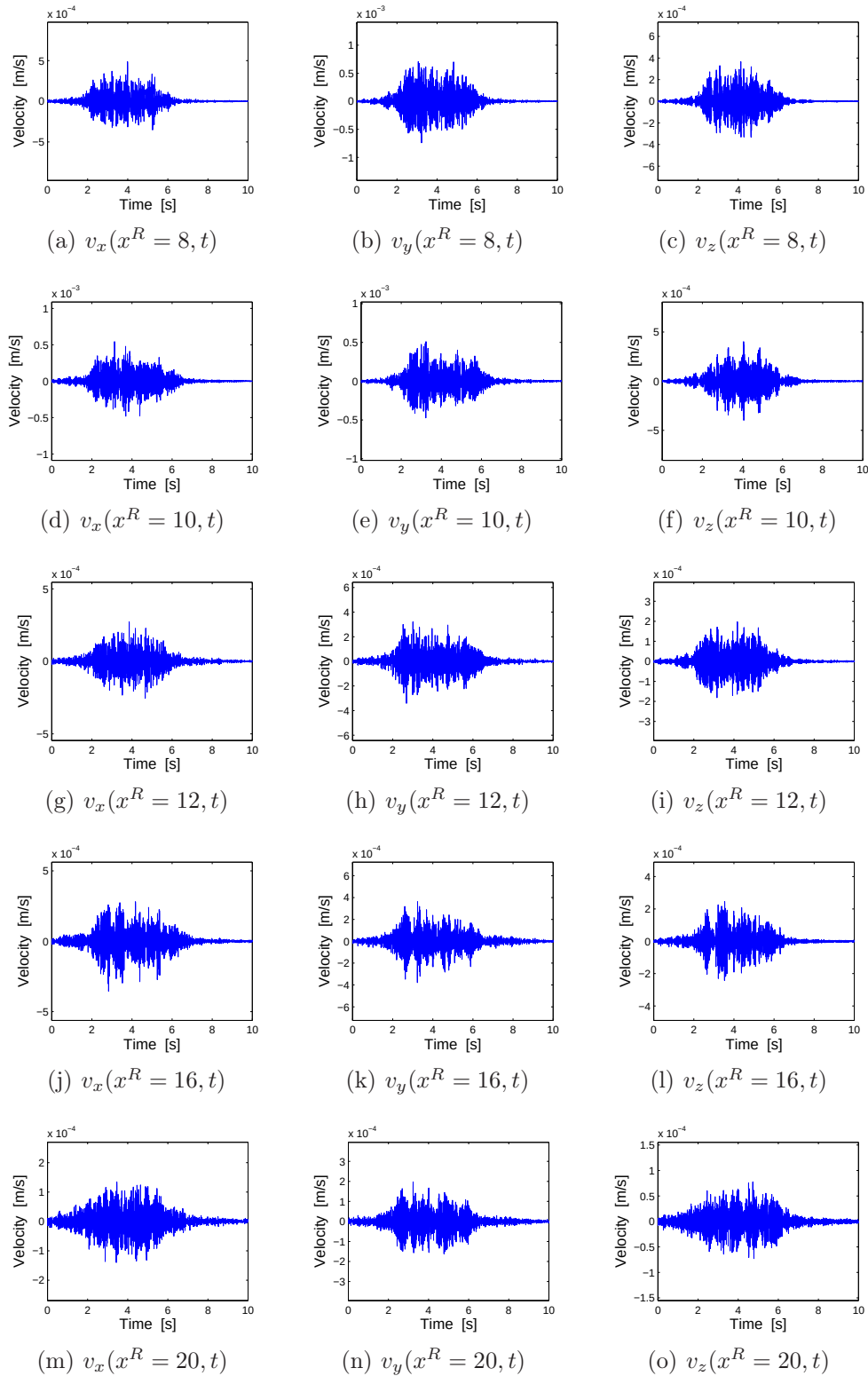


Figure 4.66: Time history of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 105 km/h

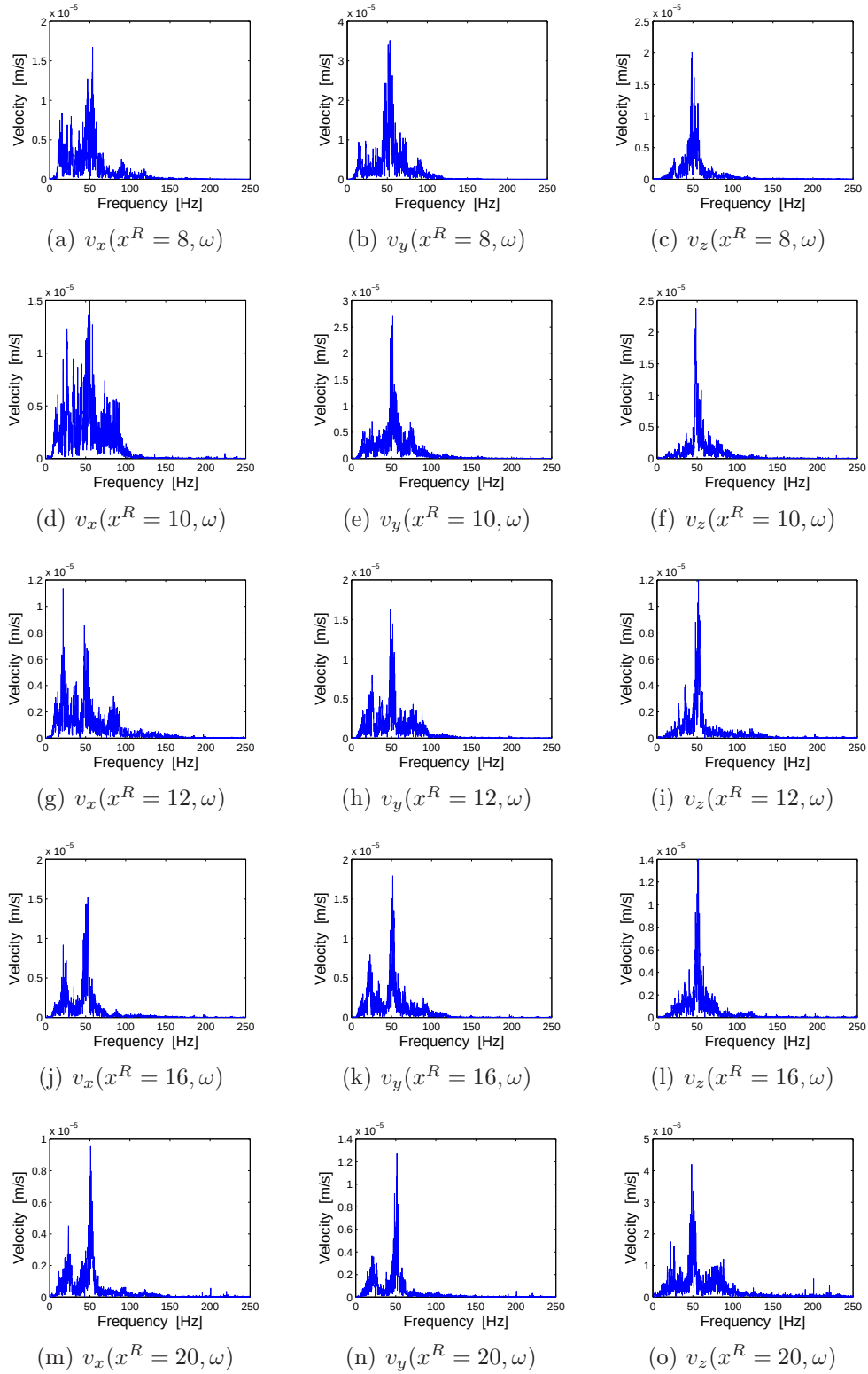


Figure 4.67: Spectral content of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 105 km/h

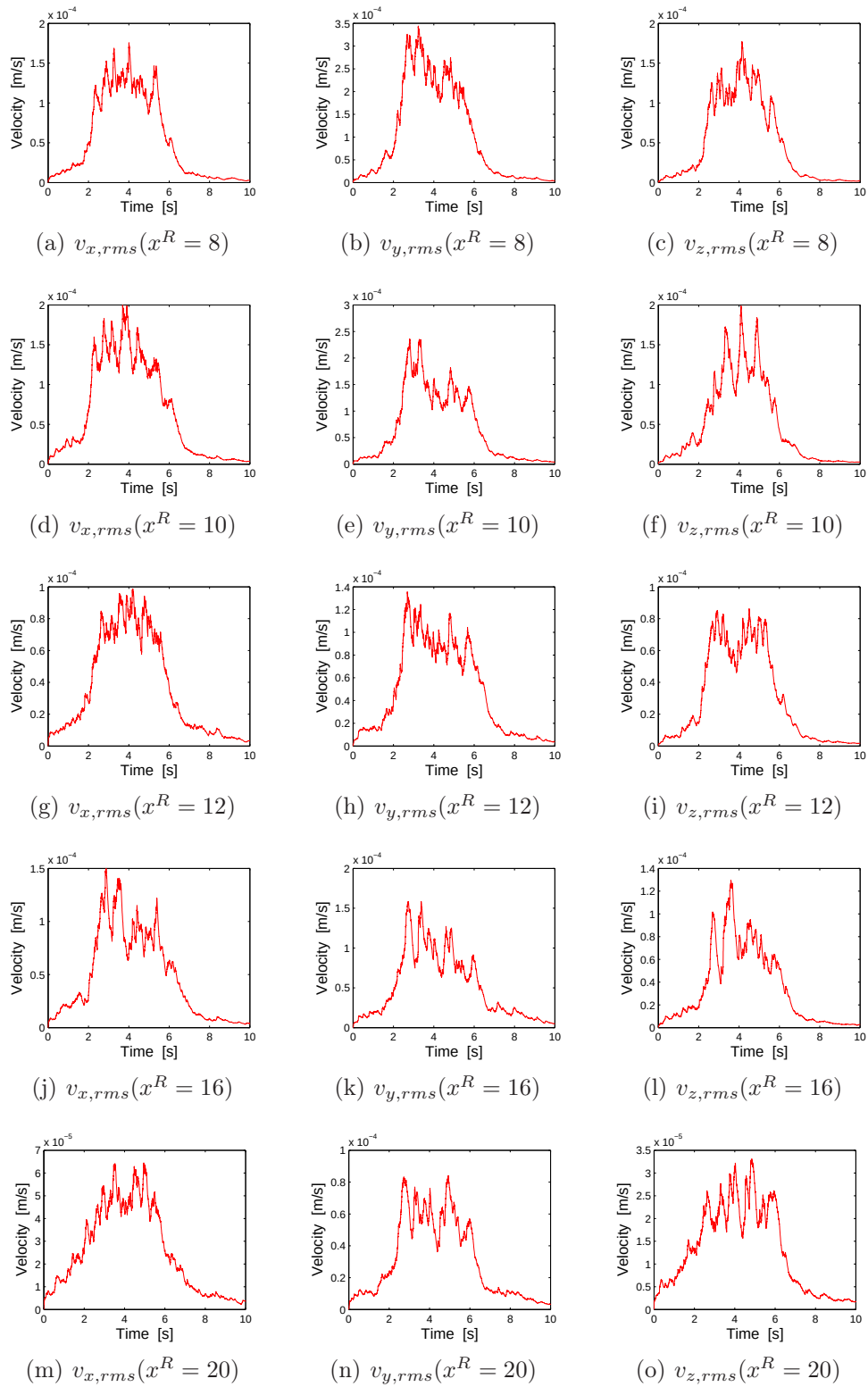


Figure 4.68: Time-average of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 105 km/h

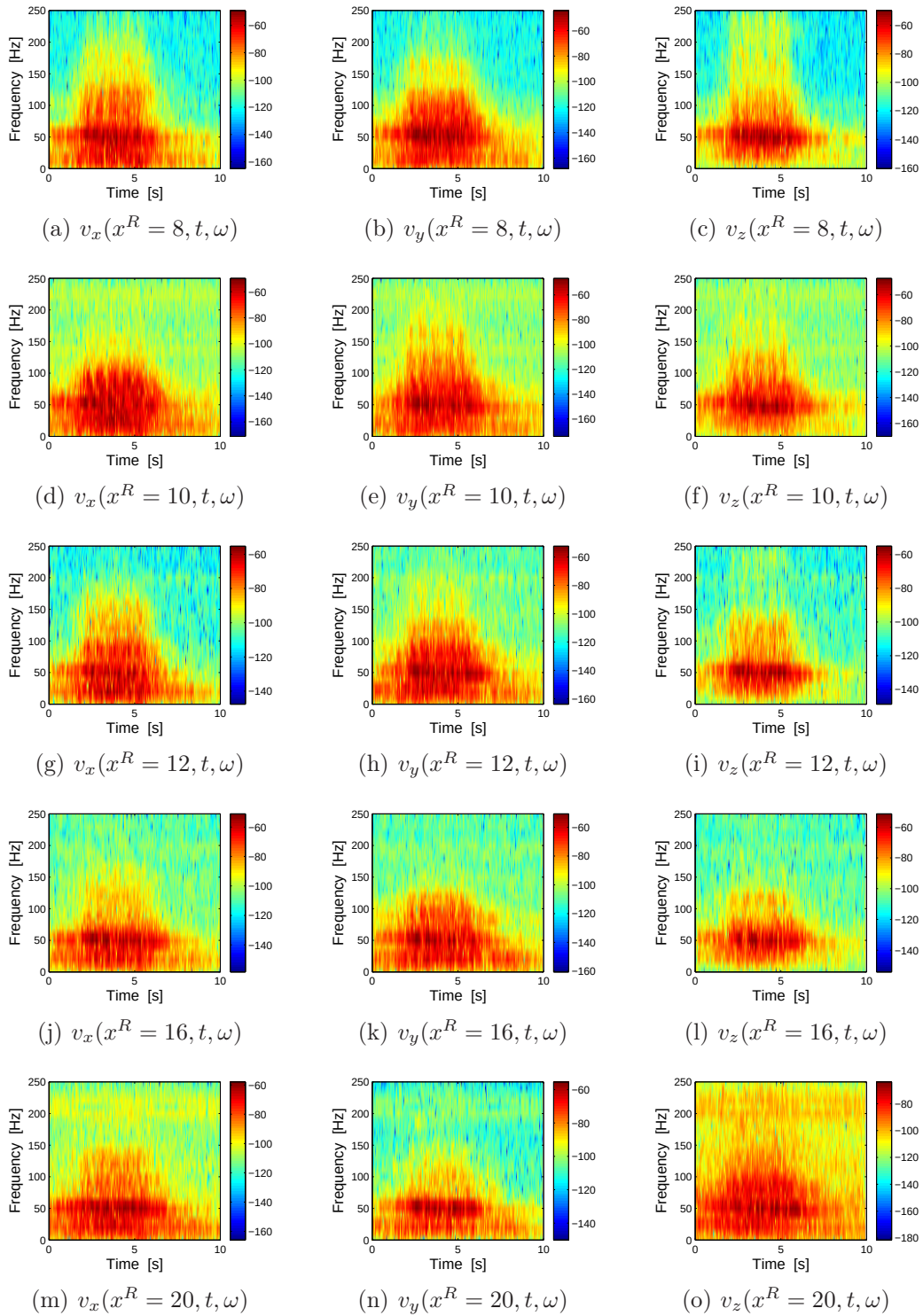


Figure 4.69: Spectrogram of the vertical and horizontal velocities measured in free field during the passage of an AM75 unit at 105 km/h